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GEOLOGY AND ORE DEPOSITS OF THE BONANZA MINING DISTRICT, COLORADO

BY

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WITH A SECTION ON
HISTORY AND PRODUCTION
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CONTENTS

ILLUSTRATIONS

OUTLINE OF THE REPORT

The Bonanza mining district, Saguache County, Colo., lies just within the northeastern edge of the San Juan volcanic region and northwest of the San Luis Valley, of southern Colorado. In the past the district has been one of the smaller producers of lead and silver in Colorado, but in recent years (1925–1929) it has attained somewhat higher rank among the districts of the State by its increased production of lead, copper, and silver.

The area described in this report is about 30 square miles in extent. The topography is rugged, like that of other parts of the San Juan region, but within the mineralized area the dissection of the land is somewhat more intricate than in surrounding regions, owing to the effect of complex block faulting on erosion. The range in altitude is from about 8,500 to a little over 12,000 feet above sea level.

GEOLOGY

General features.—The rocks of the district are principally lavas of Tertiary age, probably Oligocene, which rest upon a basement composed of pre-Cambrian metamorphic rocks and Paleozoic sedimentary rocks. The metamorphic rocks are exposed only in three comparatively small areas within the district; the sedimentary rocks are exposed several miles southeast of the mineralized part of the district as a reentrant in the Tertiary lavas along the lower part of the Kerber Creek Valley.

The pre-Cambrian rocks comprise hornblende-mica gneisses and mica schists intruded by coarse porphyritic granite, aplitic granite, and pegmatite dikes.

About 5,000 feet of Paleozoic strata lie unconformably upon the pre-Cambrian complex. The lower part of the Paleozoic sedimentary section includes limestone and interbedded quartzite and shale of Ordovician, Devonian, and Mississippian age; the upper part consists of a much thicker section of conglomerate, sandstone, shale, and limestone of Pennsylvanian and Permian age. The Ordovician strata have been correlated upon paleontologic and lithologic evidence with the Manitou limestone, the Harding sandstone, and the Fremont limestone of Canon City, Colo. The Devonian and Mississippian limestones have been correlated by their stratigraphic position and lithology with the fossiliferous limestones of these ages in Salida, Monarch, Leadville, and other districts of central Colorado. They contain but few fossils in the vicinity of Kerber Creek. The Pennsylvanian and Permian strata are correlated by their paleontologic and lithologic character with the "Weber" and Maroon formations of other Colorado districts.

The Tertiary effusive rocks of the Bonanza district rest unconformably upon all the older rocks, from pre-Cambrian to Pennsylvanian, and comprise lavas of andesitic, latitic, and rhyolitic composition, with associated breccias and tuffs. Before faulting and erosion in later Tertiary time, there had accumulated a thickness of about 4,000 feet of nearly horizontal lava flows and some local volcanic masses. At present only faulted and tilted remnants of these accumulations are preserved, so that the accurate measurement of sections is difficult. The succession of lavas within the district is shown in the following table:

Section of the Tertiary volcanic formations

Northern part of district	Southern part of district
Brewer Creek latite. (More than 500 feet.)	Brewer Creek latite. (500 to 800 feet?)
Porphyry Peak rhyolite. (Less than 1,000 feet.)	
Squirrel Gulch latite. (300 to 500 feet.)	Squirrel Gulch latite. (About 300 feet.)
Bonanza latite: Upper member. (0 to 400 feet.) Lower member. (300 to 500 feet.)	Hayden Peak latite. (1,000 to 1,500 feet.)
Rawley andesite. (1,000 to 1,800 feet.)	Rawley andesite. (At least 1,000 feet.)

Basement of folded and faulted Paleozoic and pre-Cambrian rocks.

The Tertiary intrusive rocks of the Bonanza district must represent offshoots from a large body of intrusive rock that has not been exposed by erosion. It appears that the movements of this hypothetical deep-seated body or bodies also caused the tilting and intense deformation of the shallow parts of the crust in this district. Many small bodies of molten rock were intruded into the volcanic formations close to the original surface, and these are now exposed by erosion. These intrusive rocks range in composition from monzonite to granite porphyry and include many minor intrusions of quartz latite and rhyolite. The largest of these shallow intrusive bodies is the Eagle Gulch quartz latite porphyry, which forms a band trending northeastward across the middle of the district.

A large number of small intrusions and dikes of rhyolite and quartz latite and a few of monzonite occupy parts of fault fissures and were therefore intruded after or during the faulting of the lavas. In the southern part of the district the late intrusions are represented mainly by a complex about a mile in diameter, presumably representing an old volcanic neck. Within this complex there are irregular intrusions and dikes, as well as bodies of breccia and remnants of the original country rock. The rocks that crop out in this area were decomposed during an epoch of fumarolic and hydrothermal activity that accompanied the period of volcanism. Bordering the central part of this neck are numerous ramifying dikes that cut the andesitic country rock.

Geologic structure and history.—The geologic structure and history of the district naturally fall into two distinct parts, particularly from economic considerations. The main divisions of the structural history are concerned first with those features found in the pre-Tertiary rocks, and second with those features found in the Tertiary volcanic rocks. Data are too fragmentary in the immediate vicinity of the district to permit much discussion of the pre-Cambrian structure and history. The structure in the Tertiary rocks has the greater immediate importance, as most of the ore deposits developed are entirely within Tertiary formations.

Subsequent to the deposition of the Paleozoic sedimentary formations the Bonanza region underwent strong folding and thrust faulting. The systems of folds and faults are older than the volcanic formations and presumably were produced in late Cretaceous or Eocene time. The folds in the Paleozoic sedimentary 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 5,000 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 rocks. 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 period of extensive erosion during Eocene time. Great thicknesses of sedimentary formations must have been destroyed, and there resulted a hilly surface on which were exposed the remnants of the Paleozoic formations and the underlying pre-Cambrian basement. Because of the great extent of this erosion only synclinal bodies of the Paleozoic sedimentary rocks 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.

The Tertiary volcanism, which probably began in Oligocene time, 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 lavas. Presumably the 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 fault blocks, which were thrown downward in successive steps toward a central area of the collapse. The central part of the subsided area appears to be within the eastern part of the region mapped, which probably does not include more than a third of the total area affected by this subsidence. The fault blocks are now 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. A theoretical explanation is advanced contending that partial rotation of the fault blocks occurred as a result of shear faults; these shear faults were in part curved, or combinations of them gave the effect of curved faults, and they were produced as a varying resultant of the gravitative and compressional forces acting on the subsiding crust.

Faulting and fissuring.—The fault systems in different parts of the district have local characteristics, but in only a few places are the underground workings sufficiently large to permit a discriminating study of them.

In actual practice it was found difficult to distinguish readily between fissures produced by notable faulting and those produced by comparatively minor faulting and fracturing. However, systematic observations on large numbers of mineralized fissures lead to the conclusion that most of the veins occupy fault fissures, the displacements of which range from 10 or 20 feet to 500 or 600 feet. The fissures range in dip between 15° and 90°. The average dip of about 300 fissures, systematically recorded from larger underground workings in the northern part of the district, was near 60°, and about 70 per cent of these had dips ranging between 45° and 85°. Most of the faults are normal. In some parts of the district there are high angle reverse faults, which apparently are the result of the shearing of large fault blocks subjected to compression during the subsidence. In accordance with characteristics of the fissures that are of interest in mining operations, they have been divided into those of low-angle and high-angle dips. The fissures or fissured zones with low-angle dips (less than 45°) comprise about 20 to 25 per cent of the group cited above. The walls of the low-angle faults show that they have been subjected to great pressure and friction during faulting. Most of these faults contain a heavy premineral gouge, and their broken walls are likely to present a troublesome problem in mining. Ore bodies lying in such fault fissures are lenticular and not as extensive as those in steeper fissures. In the fissures of high-angle dip (45° to 90°) the premineral gouge is commonly not as thick, and the difficulties of controlling broken ground are obviously much less than along the faults of low-angle dip. Fissure veins of the higher angle of dip have been successfully mined in the district by the shrinkage-stoping method.

The angle of dip of certain faults decreases in depth, but the shallowness of most of the mine workings does not permit sufficient observations to generalize regarding this change. A decrease in dip of 15° within a vertical range of 300 feet is shown by one low-angle fault, but such sharp changes are probably uncommon. The existence of apparent normal faults with dips of only 20° to 30° suggests that these represent parts of curved faults or fault planes that were originally steeper but have been tilted since their formation.

Stresses generated in the walls of some faults during the period of faulting have caused the formation of hanging-wall fractures and parallel fractures. Certain of the hanging-wall fractures are commercially mineralized, but the average grade of ore found in the district does not permit mining or exploring for small fissures of this type.

ORE DEPOSITS

General features.—The division of the district into different belts or zones of metal deposition has been recognized by earlier workers and by the local miners. Only two main divisions, however—into northern and southern parts—appear to be justified on the basis of consistent 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 sulphide content. Some of them show a primary zoning of the metal content, changing from lead-silver or lead-zinc veins near their outcrops to copper-silver or pyritic veins in depth. The mineral zones are in places telescoped within a vertical range of 500 to 1,000 feet, so that complex ores are common. The principal sulphide minerals are 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 district the veins are of types generally assumed to have formed at comparatively low temperatures. Their sulphide content is very low, in many veins not exceeding 2 or 3 per cent. Quartz, rhodochrosite, and fluorite are common gangue minerals, and adularia is found in some veins. The sparse sulphides are commonly pyrite, chalcopyrite, sphalerite, galena, pyrargyrite, proustite, and tennantite. The principal economic value of these veins is in the silver content of the primary sulphide shoots or of the enriched sulphide zones, and to some extent in the manganese oxide content of the completely oxidized veins.

Alteration of wall rock.—In essentially all parts of the district two main stages in the sequence of mineralization can be recognized. The first stage followed closely the development of the faults and fissures. It consisted generally of barren silicification, which converted the lavas near the fissure channels into tough jaspery rocks, made up very largely of fine-grained quartz and to a less extent of chalcedony. Some of the jaspers, particularly those that have replaced andesitic lavas, are red; others are gray or white. Products of the chemical decomposition of the rocks that were deposited together with the early silica comprise hematite, diaspore, alunite, barite, zunyite, rutile, and kaolin minerals. In places the silicified lavas contain much pyrite, but rarely other sulphides. This early stage of rock alteration produced very tough and hard rocks that have caused difficulties in the driving of mine tunnels, certain tunnels having penetrated fissured bodies of rock several hundred feet across that had been completely altered in this manner.

The jaspers are commonly brecciated near strong veins, and the second stage of mineralization, consisting of the vein filling of gangue and metal sulphides, followed the brecciation. In this second stage the principal alteration of the fissure walls was entirely different from that of the first stage and consisted mainly of a micaceous alteration of the rocks. The minerals that were formed in the wall rock are sericite, chlorite, carbonates (mainly calcite), quartz, and pyrite. The intensely altered rock is soft and mechanically weak.

The importance of distinguishing the two types of hydrothermal alteration of the walls is pointed out, as the jasper stage produced no ore and preceded the concentration of metal sulphides in fissures. The silicified rock, however, indicates the presence of a near-by fissure or channel that existed before the formation of ore deposits, and where the jasper has been repeatedly brecciated and cemented by minerals of the second stage there is good evidence that the channel was an active fault fissure.

Because of the nearly complete removal of the elements composing the lavas, with the exception of silica, during the stage of silicification, and by analogy with the chemical activity of modern acid springs and fumaroles, it is concluded that this early stage of wall-rock alteration was accomplished either by fumarolic activity or by acid hot-spring waters. The later stages of wall-rock alteration and vein filling are presumed to have occurred after a decrease in the acidic emanations and to have been the products of alkaline or neutral solutions.

Influence of country rock on ore deposition.—It is concluded that the different country rocks have had no differential influence on the chemical processes affecting ore deposition. The principal effect of the different country rocks 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 premineral gouge which they contain have indirectly affected the processes of ore deposition. As the andesitic lavas fracture the most cleanly and have no flow planes or partings to influence the direction of fracture they were mechanically the most favorable rocks. Intense early silicification of the wall rocks has also favored the later formation of openings that were suitable for ore deposition.

GEOLOGY AND ORE DEPOSITS OF THE BONANZA MINING DISTRICT, COLORADO

By W. S. Burbank

GENERAL FEATURES

GEOGRAPHY

SITUATION OF THE DISTRICT

The Bonanza district covers about 30 to 35 square miles in the extreme northeastern part of the San Juan Mountains of southwestern Colorado. (See fig. 1.) Its name is derived from the town of Bonanza, on Kerber Creek, which is the only settlement in the district. The nearest railroad station reached by road is Villa Grove, about 16 miles southeast of the district, on the Alamosa branch of the Denver & Rio Grande Western Railroad. An aerial tramway connects the Rawley mine, near the center of the district, with Shirley, on the Gunnison branch of the Denver & Rio Grande Western, about 7 miles due north. Both of these branches are narrow-gage lines and connect with the main line of the Denver & Rio Grande Western at Salida, which is about 18 miles in a direct line north-northeast of Bonanza. The distance by road between Bonanza and Salida is about 44 miles by way of Villa Grove and Poncha Pass, at the head of the San Luis Valley.

As it is officially known the term "Bonanza district" refers to the area west of and including the high mountain ridge shown on Plate 1. About 4 square miles east of this ridge and included in the northeastern part of the area mapped is tributary to Alder Creek and is officially known as the Alder Creek district. This separation of districts will be disregarded for the most part in this report.

TOPOGRAPHIC FEATURES

The district lies for the most part on the west slope of the narrow northward-trending range that borders the west edge of the San Luis Valley north of Villa Grove and separates this great valley from the drainage basin of Kerber Creek. This range is not named on the topographic map of the State, but a high peak at its south end is a well-known landmark locally called Hayden Peak. This peak, which has an altitude of 12,124 feet, was one of the triangulation stations employed by F. V. Hayden at the time of his survey of southwestern Colorado in 1874 and 1875. Souh of Hayden Peak the range east of Bonanza is cut through by Kerber Creek, which turns from its southeastward course parallel to the western slope of the range and flows northeastward into the San Luis Valley near Villa Grove. (See pl. 3.) The basin of Kerber Creek is bounded on the west by another northward-trending range, the highest and most prominent summit of which is Antoro Mountain, with an altitude probably exceeding 13,000 feet. This range separates the Kerber Creek drainage area from that of Saguache Creek. At their north ends the Antoro Range and the range extending north from Hayden Peak merge south of Mount Ouray and Marshall Pass. The Continental Divide extends nearly due west from this point, changing from its southeasterly trend in the Sawatch Range, which terminates at Marshall Pass. The two ranges bordering the basin of Kerber Creek, although in line with the southeastward trend of the Sawatch Range, are not structurally a part of it but constitute two independent spurs extending southward from the Continental Divide near Marshall Pass. The crests of the two ranges form essentially a horseshoe closed at the north end, within which lies the drainage basin of Kerber Creek. The map of the Bonanza district (pl. 1) includes only the eastern part of the Kerber Creek drainage area and extends to the crest of the eastern range. (See pl. 4, *A*.) The crest of the western range lies about 1½ to 2 miles west of the area mapped.

The hills and mountains that lie south of Kerber Creek along the western edge of the San Luis Valley and extend to the Saguache River (pl. 4, *B*) are locally known as the Saguache Hills. This name is not applicable to the range east of the Bonanza district, which will be referred to simply as the "eastern range."[1]

The highest summit of the eastern range is a little over 3½ miles north of Hayden Peak and reaches an altitude of 12,137 feet. Between this high point and Hayden Peak there is a fairly continuous ridge with four or five summits rising 100 to 400 feet above

[1] On the maps of the geographic surveys west of the one hundredth meridian (Wheeler's expedition), published in 1874, the mountains bounding the drainage basin of Kerber Creek were called "Kerber Creek Mountains," but this name does not seem to have come into general usage.

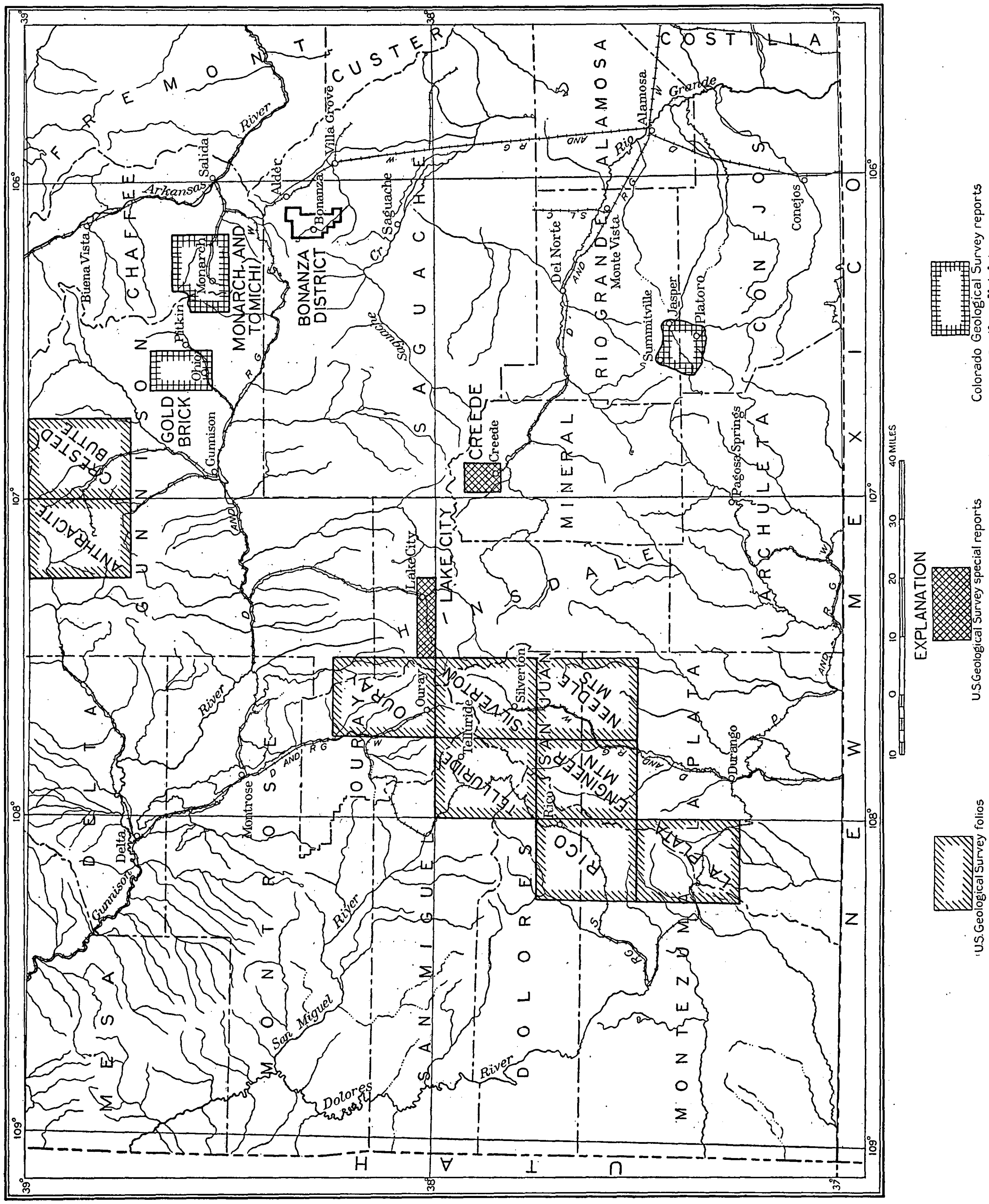

FIGURE 1.—Map of southwestern Colorado, showing location of Bonanza mining district and other districts

the average level. (See pl. 4, *A*.) The lowest saddle in the ridge is at the north base of Elkhorn Peak and has an altitude of 11,400 feet. At the north end of the district the divide between the drainage basins of Kerber and Alder Creeks runs northwestward for several miles, to the northern edge of the area mapped. The two most prominent summits of this ridge are Manitou Mountain, with an altitude of a little over 12,120 feet, and Round Mountain, 12,041 feet. Two prominent peaks known locally as North and South Porphyry Peaks lie at the extreme northwestern edge of the district and reach an altitude of about 11,700 feet. The northern peak lies outside of the area mapped. (See pl. 7, *B*.)

Draining southwestward into Kerber Creek from the main ridge of the eastern mountains are 9 or 10 nearly parallel gulches which range from a mile to about 2½ miles in length. These are separated by a series of sharp spur ridges, which form the main topographic features of the east-central part of the district. The principal gulches from north to south are Bear Gulch, which rises at the base of Round Mountain, Rawley Gulch, Copper Gulch, Elkhorn Gulch, Eagle Gulch, Greenback Gulch, and Express Gulch.

West of Kerber Creek the topographic features are less regular. One of the most prominent is the northward-trending ridge west of the town of Bonanza, which is nearly a mile in width and about 2½ miles in length. It separates the eastern branch of Kerber Creek from the western branch, which is known as Brewer Creek. The highest summit of this ridge has an altitude of 10,363 feet.

The development of the topography of the district has apparently been strongly influenced by the geologic structure and complex faulting in the volcanic formations. Many of the westward slopes are essentially dip slopes on the steeply tilted volcanic flows. The Bonanza latite, one of the most massive and prominent flows in the district, is steeply tilted and repeated many times by faulting, and consequently its outcrops form the most conspicuous minor topographic features in the north-central part of the district. (See pl. 4, *C*.) The nature of the surface upon which the present streams began their erosion can not be determined, but it is probable that erosion was initiated at the time of the intense deformation of the rocks that immediately preceded the period of mineralization. Prior to this deformation a broad domelike elevation probably occupied the site of the Kerber Creek drainage area, and it was broken by this faulting into a rugged and extremely uneven land surface, probably abounding with fault scarps. Subsequent stream erosion was evidently controlled largely by the resulting structural features.

A thick mantle of soil covers many of the slopes and with the usual heavy growth of vegetation makes the tracing of geologic formation boundaries somewhat difficult. Even moderately continuous outcrops of the bedrock are uncommon except on the spur ridges and summits. The covering of soil and débris on the slopes is probably in large part the result of the intense fracturing and alteration to which the lavas of the district have been subjected, as most of the slopes are not steep enough to cause surface slumping of massive volcanic rocks. Only a few small landslide scars are to be seen, although there are very large talus accumulations on some of the slopes bordering the high ridges about Hayden and Elkhorn Peaks, and smaller talus-covered slopes at the heads of Copper and Rawley Gulches.

The topographic effects of mountain glaciation are not pronounced in the Bonanza district. A few small cirquelike features are found on the east and northeast slopes of the range facing the San Luis Valley and indicate the presence of small bodies of ice during the Pleistocene glacial epoch, but only very small marginal deposits are associated with them. The east slope of the western or Antoro Range, however, which is visible from many parts of the district, shows evidence of a moderately heavy glaciation in which several large cirques were formed. Morainal deposits extend eastward into the western part of the area shown on the Bonanza topographic map, a distance of 1 or 2 miles from the range.

CLIMATE AND VEGETATION

Many of the slopes in the northern part of the Bonanza district are heavily wooded with spruce, fir, and pine, and the growths on the north slopes are particularly heavy. (See pls. 4, 6, and 7.) Quaking aspen is also a common tree on the lower slopes and along the stream courses. The higher peaks and summits are above timber, but parts of the high ridges are smooth and grassy and afford some grazing for cattle.

In the southern part of the district the vegetation is more sparse, particularly on the south slopes, although pines are common on many of the higher north slopes. Toward the foothills along the San Luis Valley some species of juniper and piñon become more common.

The ground water in the southern part of the district is relatively deep, and the ore-bearing veins show a much more pronounced and deeper oxidation than in the northern part. Many of the gulches in the southern part are dry or contain flowing water only during wet seasons of the year. In the extreme southern part of the district, as in Manganese Gulch, water can not be obtained, even by deep trenching in the gulches, and shallow mine workings are very dry. The larger tributary creeks in the northern part, such as Brewer Creek, Squirrel Gulch, Rawley Gulch, and Elkhorn Gulch, maintain a flow of water throughout the year.

Precipitation in the district is moderately heavy, and particularly during the summer there are likely to be many rainy or showery days. The winters are not severe, and communication by road is now maintained to Bonanza and the Rawley mine throughout the year. There is a moderately heavy annual snowfall, which may first cover the hills late in November, though some snow may fall in September and October. The early snows do not remain, however, except on the north sides of high, heavily timbered slopes. On the high slopes in protected positions some snowdrifts remain well into the summer. On some of the higher and steeper slopes there are evidences of light snowslides, but at no place is the winter weather severe enough to prevent the operation of mines. The Shawmut mine, at an altitude of 11,800 feet in an unprotected position on the open south slope of Round Mountain, is said to have been operated throughout the winter during the early history of the district.

PREVIOUS GEOLOGIC AND TOPOGRAPHIC WORK IN THE DISTRICT

The earliest geologic and topographic work in the part of Colorado in which the Bonanza district lies was that done by the United States Geological and Geographical Survey of the Territories under F. V. Hayden. That portion of the report of this organization referring to the region about Bonanza was prepared by F. M. Endlich and published in 1875. (See bibliography, p. 5.) The observations in this report are of a very general character. The only other systematic geologic investigation was undertaken during a period of nine weeks in 1912 and 1914 by the State Geological Survey of Colorado and reported in a bulletin by H. B. Patton published in 1916. Patton describes most of the geologic formations included in the present report, but his map does not cover as large an area. He established the general succession and relation of the principal rocks, although in the present report his conclusions are considerably modified as to certain features.

In 1916, after the publication of Patton's report, a small portion of the district adjacent to the town of Bonanza and the larger operating mines was mapped topographically by J. E. Blackburn on a scale of 1,000 feet to the inch. This work was undertaken by the United States Geological Survey in cooperation with the mining companies and the State of Colorado. In 1926, through cooperation between the United States Geological Survey, the State of Colorado, and the Colorado Metal Mining Fund, C. A. Ecklund completed the topographic map of the district used as a base map for this report. This survey covered an area of about 30 square miles.

The surveyed mining claims as shown on Plate 1 were compiled from files of the supervisor of surveys, General Land Office, Denver, to July, 1928, and fitted to the topographic base by the writer. As this fitting required some adjustments the map is not accurate in every detail, although the data were assembled with care.

FIELD WORK AND ACKNOWLEDGMENTS

In 1926 and 1927 the writer made a detailed examination of the geology and mineral deposits in the district, spending in all about 10 months in the field. During this period a reconnaissance plane-table survey was also made of about 15 square miles along Kerber Creek south of the area mapped by Ecklund, for the purpose of determining the structure and thickness of the Paleozoic sedimentary formations that underlie the lavas in parts of the district. A few days during July and November, 1928, and January and June, 1930, were spent in examining some of the new developments in mining.

The writer is indebted to Mr. R. L. Boss for assistance during the field season of 1927, and to Mr. M. G. Barclay for assistance in the office in preparation of some of the illustrations. He wishes especially to acknowledge the cooperation of Mr. M. N. Short, of the United State Geological Survey, in the determinations of ore minerals and in preparation of photomicrographs of ores. Acknowledgments are due to the mining operators of the district for their friendly cooperation, especially to the officials of the Rawley Mines (Inc.) and the St. Louis Smelting & Refining Co. for the use of maps and conveniences of their engineering offices. The thanks of the writer are expressed to many persons in the district for favors and for maps and other information, which will be acknowledged in the proper places in the text. Mr. C. W. Henderson, engineer in charge of the mineral statistics division at the Denver office of the Bureau of Mines, has been of much help in the preparation of this report, especially with regard to matters of production and history and in the cooperation with the mining operators. Messrs. G. F. Loughlin and B. S. Butler, of the United States Geological Survey, under whose general and direct supervision the investigation of this district was made, spent some time in the field with the writer, and their guidance both in the field work and in the preparation of the text of this report is gratefully acknowledged.

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Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, pp. 26, 55, 208, 209, 1926. Contains historical notes on Saguache County and Bonanza district, also yearly production for Saguache County, 1880–1923.

Butler, B. S., Progress Report on Cooperative Geological Survey in Colorado for the Years 1926 and 1927, Colorado Mining Assoc. and U. S. Geol. Survey, Denver, 1928. Includes brief outline of geology and ore deposits of Bonanza district, with remarks on the future of the district.

Butler, B. S., and Burbank, W. S., Relation of Electrode Potentials of Some Elements to Formation of Hypogene Mineral Deposits: Am. Inst. Min. and Met. Eng. Yearbook, 1929, pp. 341–353. Includes brief discussion of mineral succession in Bonanza district and of its bearing on certain chemical hypotheses of ore deposition.

Burbank, W. S., Preliminary Report on the Geology and Ore Deposits of the Bonanza District, Colo.: U. S. Geol. Survey Press Mem. 32801, Aug. 12, 1929. Abstract of some of the main features of economic interest in the present report. Includes an uncolored generalized map of the Bonanza district on scale of 1:24,000.

GENERAL GEOLOGY

PRE-TERTIARY ROCKS

PRE-CAMBRIAN COMPLEX

DISTRIBUTION AND GENERAL CHARACTER

Pre-Cambrian rocks crop out within two areas in the Bonanza district, one large area in the northeastern part of the district along the upper part of Alder Creek (see pl. 1) but only partly within the area mapped, and a second one near the head of Squirrel Gulch, where there are several small exposures. East of the district the pre-Cambrian rocks crop out discontinuously along the western edge of the San Luis Valley, where they are covered in part by Tertiary lavas and in part by the alluvial deposits of the valley. This region has not been explored between the southern area mapped in Plate 3 and the lower part of Alder Creek at the extreme north. Along the lower part of Alder Creek the Tertiary lavas extend to the edge of the San Luis Valley, and the basement on which they lie is not exposed. Three or four miles northeast of Alder Creek, in the Poncha Pass region, lavas lie directly on a pre-Cambrian basement consisting of mica schist, gneiss, granitic rocks, and pegmatite. The pre-Cambrian granite extends southwest from Poncha Pass and up the valley of Silver Creek, probably for several miles. Near Marshall Pass, 6 or 7 miles northwest of the district, erosion has exposed pre-Cambrian rocks directly beneath the lavas. According to available geologic maps the Paleozoic formations are not found here.

The structural relations of the outcrops of pre-Cambrian rocks have been studied in only three places, as shown on Plate 3—at the head of Squirrel Gulch and at the head of Alder Creek, within the district and along Kerber Creek, southeast of the district. The two areas within the district (pl. 1) consist of parts of the basement previously covered but now exposed by erosion of the overlying lavas. Many of the exposed contacts and in greater part the outlines of these two areas are determined by complex block faulting. The southernmost pre-Cambrian mass south of Kerber Creek, shown in Plate 3, is overthrust upon the Paleozoic sedimentary rocks. The area north of it represents an eroded anticline which is flanked by the Paleozoic strata on the northeast and southwest but is overlain directly by Tertiary lavas on the northwest.

The pre-Cambrian of Alder Creek (pl. 1) consists largely of medium-grained aplitic granite which is intrusive into gneisses and schists. A volcanic breccia containing fragments of pre-Cambrian rocks lies unconformably on the aplite and gneiss and is in turn overlain by the andesitic and latitic lavas that form the basal part of the Tertiary volcanic series. At many places, however, the contacts between the pre-Cambrian rocks and the lavas are faults.

The small pre-Cambrian exposures in Squirrel Gulch consist largely of a dark hornblende-mica gneiss with some mica schist and are cut by pegmatite veins. Locally the gneiss in this area is made up in large part of hornblende and mica and might be called a hornblende-mica schist, but this phase grades into banded, more feldspathic varieties typical of the gneiss at Alder Creek. In Squirrel Gulch all the contacts between the pre-Cambrian gneiss and the lavas are faults.

The pre-Cambrian of the area along Kerber Creek southeast of the district is chiefly a pinkish, very coarse grained porphyritic granite with feldspar crystals half an inch or more in length. There are small bodies of mica schist and gneiss, and the whole complex is cut by pegmatite veins and aplite dikes. On the south side of Kerber Creek where gneiss occurs beneath overthrust bodies of Paleozoic rocks, the banding of the gneiss is essentially horizontal, although where seen at other places it stands at a high angle.

At several places in the area mapped on Plate 1 large boulders or fragments of pre-Cambrian rocks similar in character to those exposed in Squirrel Gulch and Alder Creek lie on the eroded surface of the Tertiary lavas. As the position of these fragments can not be explained by the action of glaciers, it follows that they have been torn from the basement along fault planes or carried up by molten rock during the eruption of the lavas and have been separated by erosion from the material in which they were embedded. A large number of fragments were found along the south side of Copper Gulch near the crest of the ridge east of the Cliff tunnel (No. 12, pl. 1). As these fragments occur near the contact between the Rawley andesite and Bonanza latite, it is probable that they lie in a breccia at the base of the latite or were carried to the surface by this flow. Along an altered fault zone between Greenback and Express Gulches just east of the road to Villa Grove there is a narrow discontinuous outcrop of pre-Cambrian hornblende gneiss, presumably forced up along the fault by an intrusion or some force connected with the faulting and volcanic eruptions. Similarly small fragments of the Paleozoic Maroon formation were found along a fault plane near the mouth of Chloride Gulch.

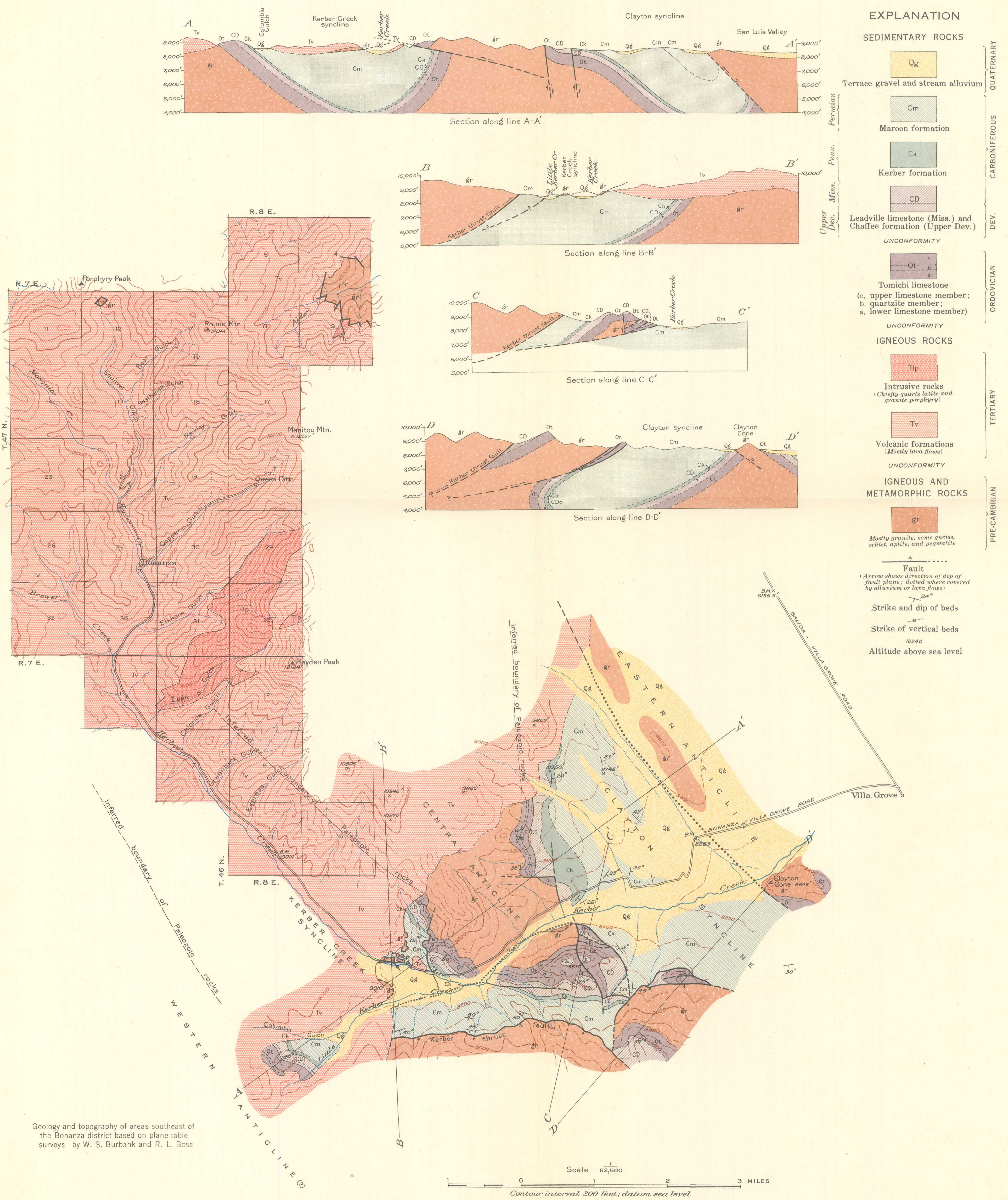
GNEISSES

General and petrographic features.—Hornblende-mica gneiss is a common type of rock on Alder Creek and also forms a large proportion of the pre-Cambrian rock at the head of Squirrel Gulch. It exhibits a wide range in texture and in the proportions of its light and dark minerals. There are gradations between the cleavable or schistose types and the evenly and irregularly banded rocks of typical gneissoid texture, and in composition the range extends from rocks composed largely of hornblende and mica to those in which the feldspathic constituents predominate. The greater part of the feldspathic hornblende-mica rocks found in the pre-Cambrian of this region, however, should be termed gneisses rather than schists.

The more cleavable type of gneiss, a dark almost black rock, consists predominantly, as shown by microscopic study, of blue-green hornblende and biotite, with subordinate amounts of plagioclase (andesine) and a little quartz and orthoclase. Typical accessory minerals present in these rocks are titanite, apatite, and magnetite.

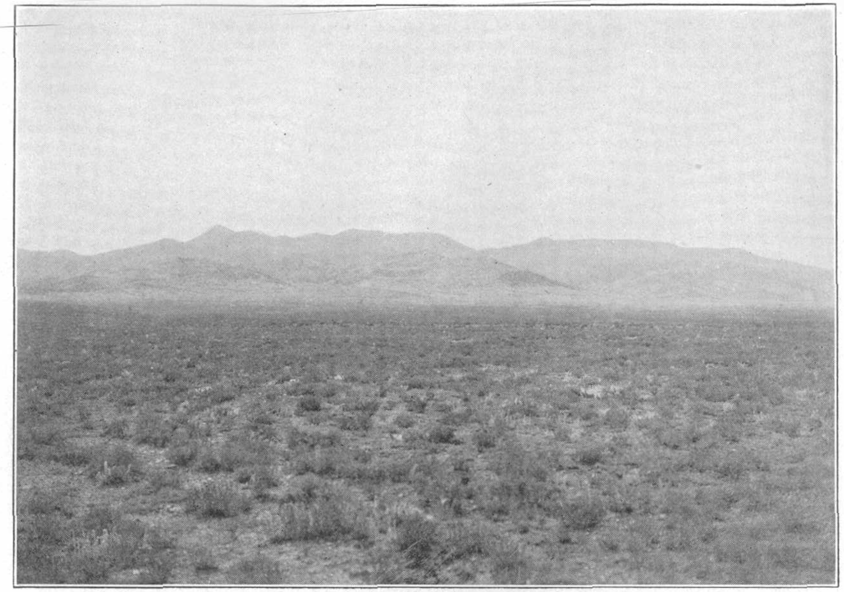
One of the striking types is a finely banded gneiss composed of even alternations of light and dark bands, measuring as little as 1 millimeter in width. The dark bands are seen under the microscope to be composed largely of blue-green hornblende, green biotite, and accessory titanite and magnetite. The light bands are largely plagioclase (oligoclase), with less abundant quartz and orthoclase. The orthoclase usually contains microscopic intergrowths of plagioclase.

The broadly banded and coarser-grained gneisses of Alder Creek may show a predominance of either the light or the dark constituents in parallel bands. The feldspars of the average type of parallel-banded gneiss are largely andesine with minor orthoclase. Pale bluish-green hornblende with subordinate biotite and accessory titanite and magnetite makes up the dark bands. In some lighter-colored gneisses quartz and orthoclase are more common than the plagioclase.



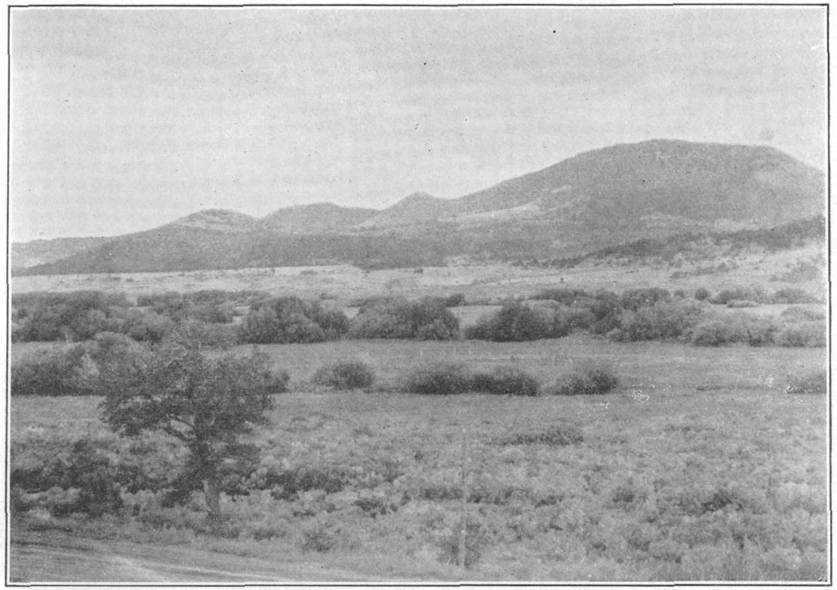
GEOLOGIC RECONNAISSANCE MAP AND SECTIONS OF THE KERBER CREEK REGION, SAGUACHE COUNTY, COLO.

1931



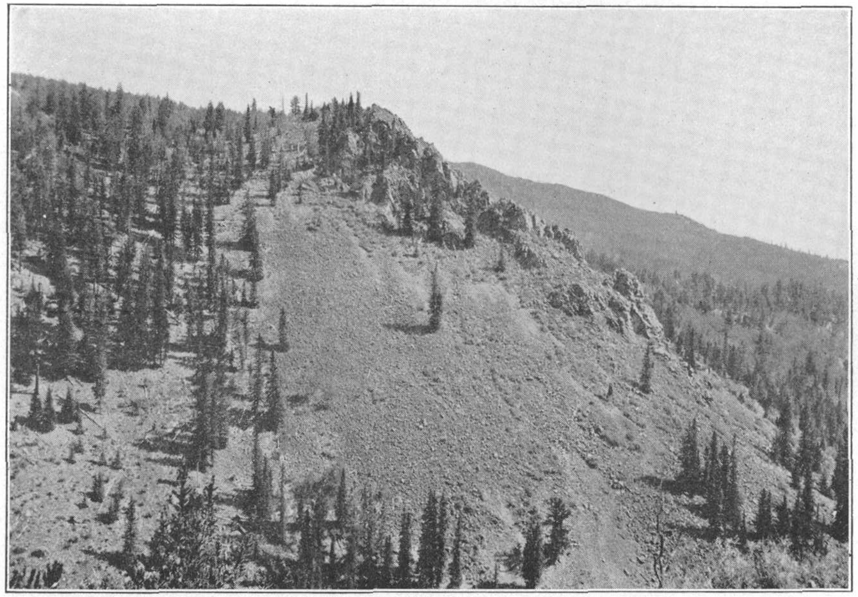
A. THE EASTERN RANGE OF THE BONANZA DISTRICT VIEWED FROM THE EDGE OF THE SAN LUIS VALLEY

Looking northwestward. The conical peak at the left is Hayden Peak, and the high, flat summit at the extreme right of the view is Manitou Mountain.



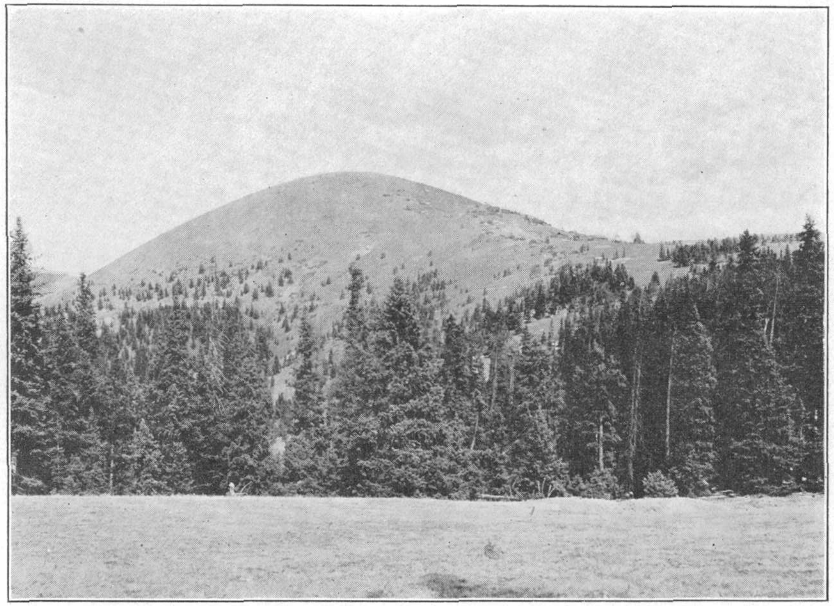
B. VIEW SOUTH ACROSS KERBER CREEK FROM THE BONANZA-VILLA GROVE ROAD TOWARD THE SAGUACHE HILLS

The hills consist of westward-dipping thrust blocks of Paleozoic limestones and pre-Cambrian granite, and the lower, flatter areas are largely underlain by the Maroon formation. (See pl. 3 and text, p. 40.)



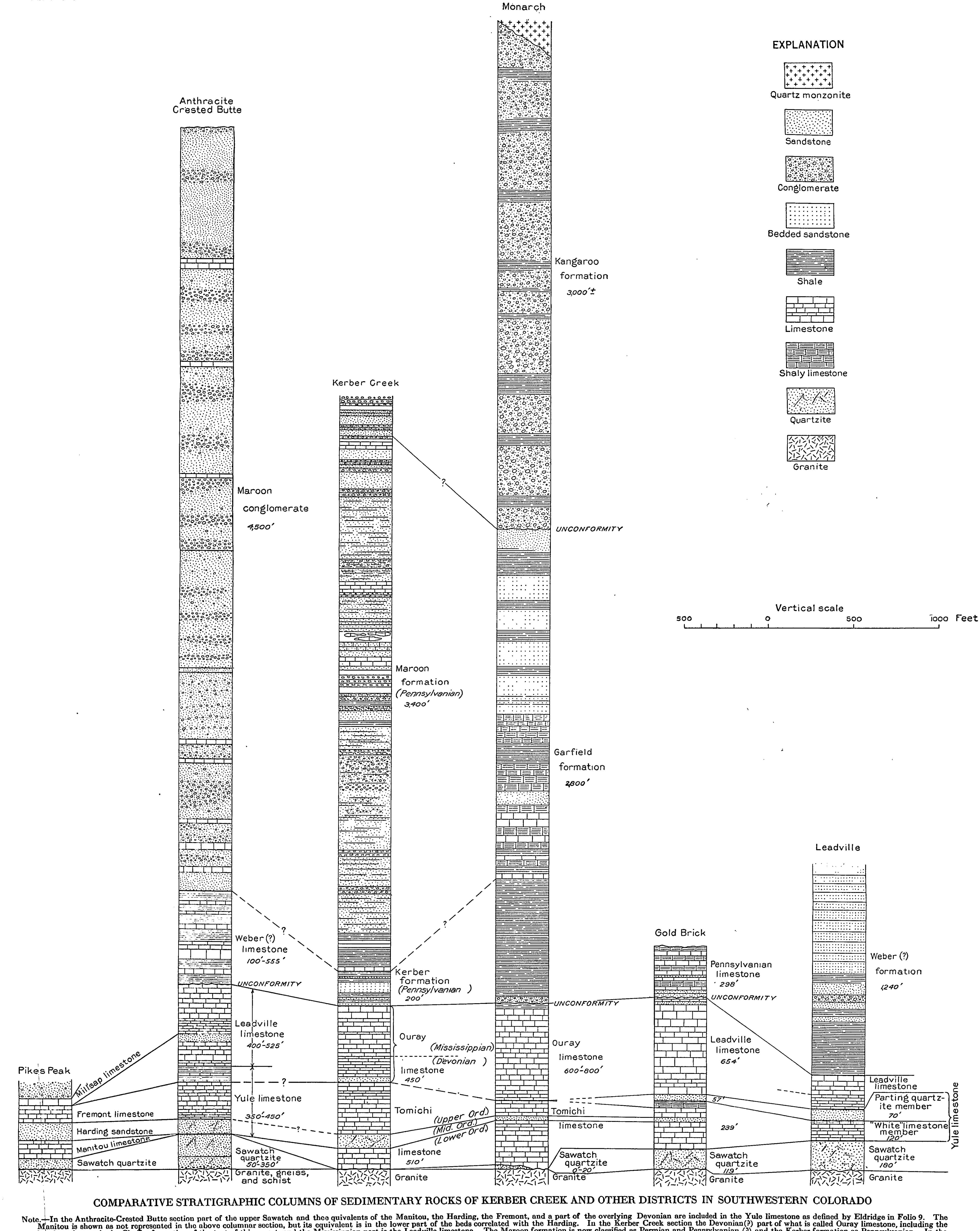
C. A WESTWARD-TILTED FAULT BLOCK OF BONANZA LATITE, ABOVE THE RAWLEY CAMP, SQUIRREL GULCH

Looking southwest. Characteristic of the outcrop of the lava flow and its talus slopes.



D. ROUND MOUNTAIN FROM THE SOUTHWEST

The Shawmut mine in distance on south side of mountain. Typical of barren smooth tops of range and heavily timbered sides of gulches in northern part of district.



COMPARATIVE STRATIGRAPHIC COLUMNS OF SEDIMENTARY ROCKS OF KERBER CREEK AND OTHER DISTRICTS IN SOUTHWESTERN COLORADO

Note.—In the Anthracite-Crested Butte section part of the upper Sawatch and thee quivalents of the Manitou, the Harding, the Fremont, and a part of the overlying Devonian are included in the Yule limestone as defined by Eldridge in Folio 9. The Manitou is shown as not represented in the above columnar section, but its equivalent is in the lower part of the beds correlated with the Harding. In the Kerber Creek section the Devonian(?) part of what is called Ouray limestone, including the basal sandstone, is the Chaffee formation of the text of this report, and the Mississippian part is the Leadville limestone. The Maroon formation is now classified as Permian and Pennsylvanian (?) and the Kerber formation as Pennsylvanian. In the Leadville district the "White" limestone is now considered of Manitou age, while the Parting quartzite member of the Yule limestone and the part of the overlying Leadville limestone up to the dashed line on left of column is included in the Chaffee formation as defined by Kirk (see text). Leadville limestone is now restricted to the beds above the broken dashed line.

The pre-Cambrian exposures are not sufficiently continuous and the hornblende-mica gneisses were not studied in enough detail to throw any light on their origin.

Cross [2] has described a series of hornblendic gneisses near Salida which he was inclined to believe had resulted from the metamorphism of a series of pre-Cambrian lava flows.

Relations to mineralization.—The gneisses of Alder Creek occupy only the northeastern third of the area of pre-Cambrian shown on Plate 1 and form the walls of a few veins of relatively low metal content. The gneiss extends somewhat east of the mapped area, where exploration of mineralized zones has been carried on in a few places, but this region was examined only casually by the writer. It is probable, however, that the more massive types of gneiss would fracture in a manner to permit the existence of open fissures favorable to ore deposition, but the more schistose types would be likely to develop relatively tight shear zones parallel to the foliation.

The apparent lack of any economically important veins within the gneiss, however, may be due not to any inherent properties of the rock but perhaps rather to the depth at which these rocks lay buried beneath the lavas at the period of mineralization or to a decrease in the strength of the mineralization toward the northeast.

Alteration of the gneiss along a few weakly mineralized fissures that were examined consisted in the formation of carbonates, chlorite, and sericite, accompanied by noticeable bleaching. Pyrite and chalcopyrite replace the gneiss to some extent in the immediate vicinity of some fissures. Intense silicification typical of the early stage of alteration in many of the lavas was not observed in the gneisses. At fault contacts between gneiss and Tertiary lavas, as at the head of Squirrel Gulch, the relations of such silicified rock as is seen suggest that the lavas are more susceptible to alteration of this type.

SCHIST

Relatively massive or distinctly schistose rocks composed largely of hornblende and mica are closely associated with the pre-Cambrian feldspathic gneisses. Some of these rocks are dark green or greenish black and are composed essentially of green hornblende and green biotite.

At the head of Squirrel Gulch there are small exposures of quartz-mica schist, composed essentially of muscovite and biotite with some quartz and feldspar. The relation of this rock to the gneiss is not known. Quartz-mica schist is also present in the pre-Cambrian south of the Bonanza district along Kerber Creek.

About half a mile north of Poncha Pass on the road to Salida there are conspicuous outcrops of quartz-mica schists whose character leaves little doubt as to their sedimentary origin. It is not unlikely that the somewhat more micaceous schists in the pre-Cambrian basement near the Bonanza district are of similar origin. The schists within the district are of minor proportion, however, and were not seen in the walls of mineralized fissures.

APLITIC GRANITE

General features.—Bodies of aplitic granite are intrusive into the hornblende-mica gneisses and schists. Granite of this type forms a large part of the bedrock of the western two-thirds of the pre-Cambrian area on Alder Creek but is not differentiated on Plate 1. The granite on Alder Creek is typically pinkish gray and shows under the hand lens crystals of pink orthoclase 2 to 3 millimeters in diameter and grains of grayish plagioclase and quartz 0.5 to 1 millimeter in diameter. In places, however, it is of coarser texture than this. Orthoclase is the most abundant mineral and contains microscopic intergrowths of albite. Plagioclase (albite) and quartz in about equal quantities, with a little accessory magnetite, make up the remainder of the rock.

This granite shows none of the effects of intense recrystallization and metamorphism such as resulted in the production of the gneisses and schists. It is of pre-Tertiary age, as boulders of it are found in the breccias at the base of the lavas near Alder Creek, and, by comparison with small bodies of aplitic granite seen in the pre-Cambrian south of the Bonanza district, it is assumed that this granite belongs to the pre-Cambrian rocks, though possibly of early Cambrian age.

Relation to mineralization.—Only a few mineralized fissures of minor importance were seen in the aplitic granite. The most intense alteration observed in the granite was at its fault contacts with the Tertiary lavas, as on the north side of Alder Gulch (pl. 1), and near its contact with the Tertiary granite porphyry in sec. 9, T. 47 N., R. 8 E., south of Alder Creek. At postmineral fault contacts with the lavas both silicification and sericitization have occurred. The sericitization of the aplitic granite was particularly intense locally and resulted in the formation of a white structureless mass consisting very largely of flaky sericite. The characteristic pink color of the aplitic granite, imparted by the orthoclase, is lost even in only partly sericitized rock, so that the granite that reached certain stages of alteration may be easily confused with the Tertiary granite porphyry occurring south of Alder Creek.

[2] Cross, Whitman, On a series of peculiar schists near Salida, Colo.: Colorado Sci. Soc. Proc., vol. 4, pp. 286–293, 1895.

As the few prospects on mineralized fissures that lie in this rock were either inaccessible or very small, there was no opportunity to study its behavior as a wall rock under conditions of mineralization encountered near ore bodies.

GRANITE

Occurrence and general character.—A coarse porphyritic granite is the typical intrusive rock in the pre-Cambrian area on Kerber Creek southeast of the Bonanza district. The granite has a pinkish-gray color due to the abundance of large crystals of feldspar, presumably microcline, which commonly attain a length of 10 to 20 millimeters. The granite has not been studied petrographically but in general appearance is identical with the coarser-grained granites found in the pre-Cambrian of central and southern Colorado. Granite of this character was not seen outcropping within the pre-Cambrian areas near Squirrel Gulch and Alder Creek. (See pl. 1.) The relation of the much finer-grained aplitic granite of Alder Creek to this coarse granite is not known. The coarse granite is cut by a few dikes of aplite, however, which may be indicative of the relation between the two.

Structural relations.—Bodies of mica schist and gneiss, into which aplitic and pegmatitic bands have been injected, lie within the granite and presumably represent remnants of the older pre-Cambrian rocks intruded by the granite. The oldest known sedimentary rock lying upon the granite is the Ordovician limestone (p. 9), and the unconformable contact is well exposed on the north side of Kerber Creek near the road to Villa Grove. Near the Slane ranch, just east of the point where the old Ute trail to Saguache branches south from the Villa Grove road (pl. 3), small bodies of this granite with a peculiar brecciated structure may be seen lying upon the upturned sedimentary strata of upper Carboniferous (Permian) age, in fault contact. (See pp. 39 and 40.) The fault plane probably dips gently southward at about the slope of the hill. For 10 to 20 feet above the contact the granite is much broken into irregular blocks from a few inches to several feet in diameter. The spaces between the larger blocks are filled with fine breccia and powdered rock composed entirely of the granite itself, with the exception, however, that near the fault contact or sole of the thrust, where the brecciation was most intense, fragments of the underlying sandstones and shales are included in the matrix.

Presumably during the movement of the overriding body of granite intense friction caused the brecciation and rotation of blocks near the contact, and fragments of the underlying strata were either caught between rotating blocks and carried upward or by the pressure on the soft shales beneath were forced upward into openings at the base of the granite. Brecciated structure in the granite, probably of the same origin as that described above, is seen on the east end of the low hill between Kerber and Little Kerber Creeks. (See pl. 3.) Structure of this type is not seen at all fault contacts of the granite, however, as the large steeper thrust fault south of Kerber Creek shows only a few slickensided planes near the contact. (See p. 40.)

PALEOZOIC SEDIMENTARY FORMATIONS

DISTRIBUTION AND GENERAL CHARACTER

As the study of the Paleozoic rocks was merely incidental to the main problems of geology in this investigation, which deal with the volcanic formations within the mineralized part of the Bonanza district, only a preliminary study and correlation of the sedimentary rocks was attempted.

The nearest area to the Bonanza district in which Paleozoic sedimentary formations are found lies about 2 miles to the southeast, where Paleozoic and pre-Cambrian rocks crop out along both sides of Kerber Creek for a distance of 5 to 6 miles. At the western and northern limits of this area the sediments are covered by the Tertiary lavas, and to the east they are covered by the Recent alluvial deposits of the northern part of the San Luis Valley. (See pl. 3.) In the mountains south of Kerber Creek the Paleozoic and pre-Cambrian rocks are known to be present, but the full extent of the areas which they occupy is not known. A small inlier of the Paleozoic rocks about a mile in diameter is exposed by erosion of the Tertiary lavas along the north side of Little Kerber Creek above Columbia Gulch, which branches to the north at a point about 2 miles above the junction of Kerber and Little Kerber Creeks. It is possible that other small exposures of Paleozoic rocks may be present in several of the larger valleys that cut back into the mountains between Kerber Creek and Alder Creek, but nothing definite is known about the geology of that region.

The succession of stratified rocks exposed in the Kerber Creek area ranges from Ordovician to Permian in age and attains a thickness of about 5,000 feet. The Paleozoic rocks and the pre-Cambrian basement were strongly folded and faulted and then partly eroded away before the Tertiary volcanic activity was initiated. Consequently the sedimentary rocks that once covered in great thickness the entire region at the head of the San Luis Valley are now preserved in the Kerber Creek region only in synclinal folds beneath the valley itself or in smaller synclinal bodies beneath the lavas west of the valley. To what extent small bodies may be preserved beneath overthrust pre-Cambrian rocks can not be fully determined, although the discovery of large thrust faults near Kerber Creek has shown these faults to be at least locally effective in protecting small bodies of sedimentary rocks from erosion.

Because of the presence of bodies of granite lying upon and concealing the Permian and Pennsylvanian rocks, the total thickness of the Carboniferous is not known. The entire section that could be measured is shown in Figure 2.

A satisfactory correlation of the entire section with type sections in other parts of Colorado was not obtained, and consequently a tentative division of the local stratigraphy had to be adopted for the purpose of the present report. Five principal formations have been distinguished in the district, partly by means of paleontologic evidence and partly by lithologic character—the Tomichi limestone, of Ordovician age; the Chaffee formation, of Devonian age; the Leadville limestone, of Mississippian age; the Kerber formation, of early Pennsylvanian age; and the Maroon formation, of Pennsylvanian (?) and Permian age.

ORDOVICIAN SEDIMENTARY ROCKS

TOMICHI LIMESTONE

General nature and thickness.—The oldest recognized formation lying directly on the eroded surface of the pre-Cambrian rocks consists of limestone and quartzite beds of known Ordovician age. These are assigned to the Tomichi limestone, as they can be shown to be closely correlative with that formation in the Monarch and Tomichi mining districts. The lower limestone member of the Tomichi limestone nearly everywhere lies directly on the eroded surface of the pre-Cambrian rocks. The Cambrian (Sawatch) quartzite that is found near Canon City and in the northwestern part of the Tomichi district below the Ordovician rocks is not present in the Kerber Creek region, unless very small patches of somewhat feldspathic quartzite that was seen at a few places between the limestone and the pre-Cambrian granite may represent remnants of the Sawatch quartzite. Three lithologic units are recognizable in the Tomichi limestone—a lower limestone, a middle quartzite, and an upper limestone—with a total thickness ranging from 400 to 600 feet.

Lower limestone member.—The thickness of the lower limestone measured at several widely separated localities proved to be not at all uniform, ranging between 90 and 200 feet. Although in some of the thicker sections duplication of the beds by faulting may exist, this variation is very probably due either to inequalities of deposition on the eroded pre-Cambrian surface or to the erosion that produced the unconformity at the base of the middle quartzite member. This variation in thickness also appears to be typical of the lower limestone member of the Ordovician elsewhere, being reported from the Monarch, Tomichi, and Gold Brick districts.[8]

The basal part of the lower limestone member consists of thin-bedded gray crystalline dolomite, containing thin bands and lenses of gray or white chert from 1 to 6 inches in thickness. The surface of the dolomite weathers to a brownish-gray color and granular texture, and the gray chert, which weathers in relief, acquires a dark-brown limonitic stain. Above the base the beds are more massive, being 2 to 4 feet thick, and the chert is less abundant, being found only in irregular masses or nodules a few inches in diameter. All the beds below the middle quartzite appear to be highly dolomitic. A few fossils were found in the lower beds of this member. The common fossils are silicified parts of a cephalopod, *Diphragmoceras?* sp., which occurs at a characteristic horizon with the basal cherty beds. At a somewhat higher horizon a few brachiopods and gastropods have been found. (See table, p. 11.)

Quartzite member.—The quartzite member of the Tomichi limestone has certain lithologic characteristics which, together with the fossil impressions it carries, make it one of the most readily recognized units in the Paleozoic section. The quartzite is uniform in character, and measurements made at several places indicate that its thickness ranges from 60 to 90 feet. Typically it is a very tough gray quartzite, composed of fine to coarse quartz grains cemented with silica. The weathered surface may be stained brown or reddish brown and is in places distinguished by peculiar markings, with or without a stain of limonite, which have proved to be of fossil origin. Some of the beds have a very fine or cherty texture suggesting that of silicified limestone, but all these beds that were examined closely proved to consist of fine sandstone or shaly sandstone completely cemented with secondary silica. Partings parallel to the stratification, from a few inches to 2 feet apart, are well developed in some of the more massive beds. Some coarse pebbly beds and shaly partings were seen near the top of the member on the west side of the prominent mountain south of Kerber Creek. The quartzite is resistant to both mechanical and chemical disintegration, so that it forms prominent outcrops and ledges and is readily distinguished by its lithologic character alone from the sandstones and quartzites in the overlying formations.

Certain beds of the quartzite at some localities are highly fossiliferous and contain impressions and pe-

[8] Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi districts: Colorado Geol. Survey Bull. 4, p. 57, 1913. Crawford, R. D., and Worcester, P. G., Geology and ore deposits of the Gold Brick district: Colorado Geol. Survey Bull. 10, p. 54, 1916.

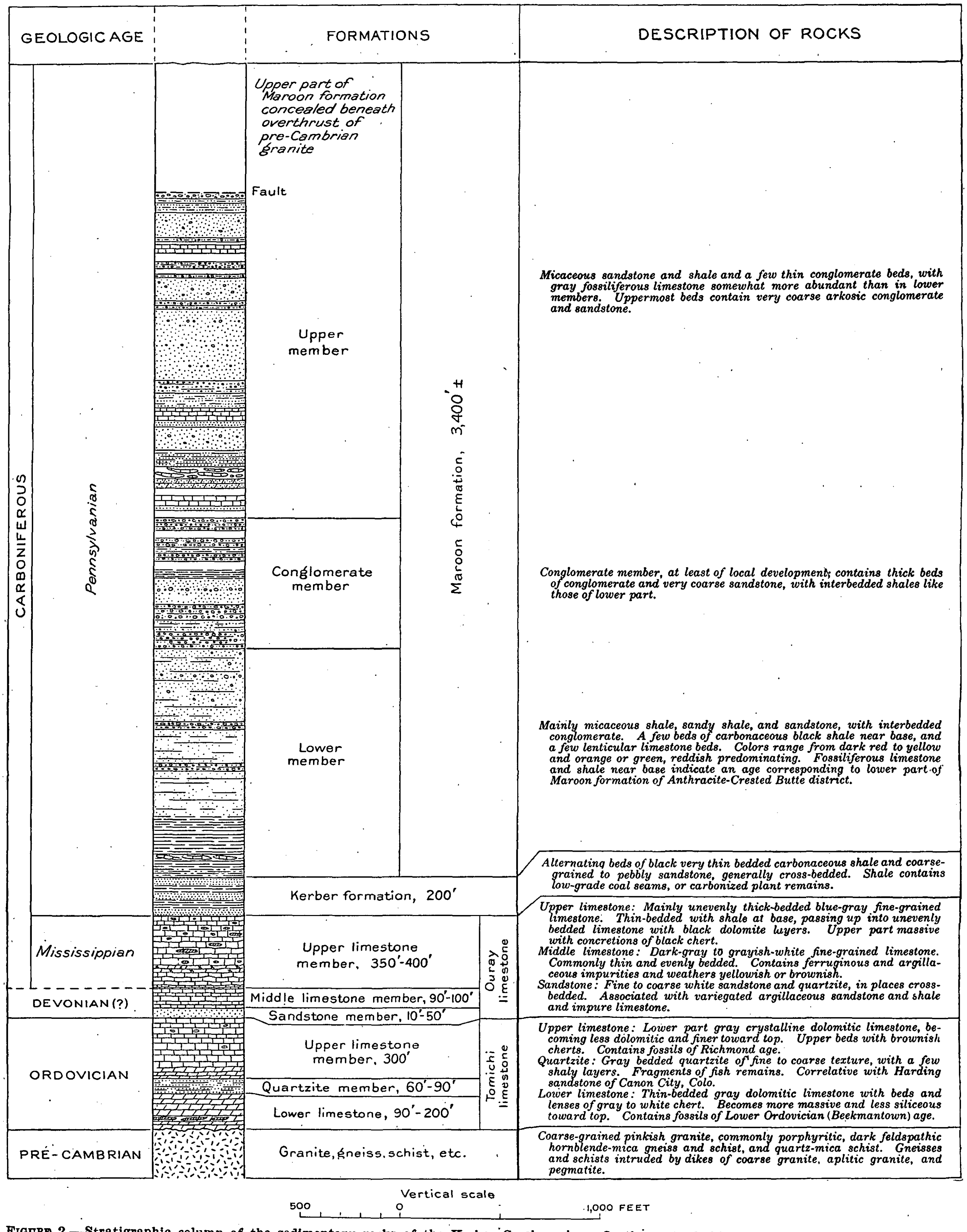


FIGURE 2.—Stratigraphic column of the sedimentary rocks of the Kerber Creek region. In the text of this report the name Ouray limestone has been replaced by Chaffee formation for the lower two members and Leadville limestone for the upper member. The Maroon formation is classified in the text as Pennsylvanian (?) and Permian, and the Kerber formation as Pennsylvanian

culiarly marked casts of small fragments of fish scales, bones, and fucoid markings similar to those which have been found in the Harding sandstone near Canon City. Many of the casts appear to have been originally filled with limonite or other easily soluble material which has been leached away at the outcrop, leaving the quartzite very porous and more or less stained with iron.

Upper limestone member.—The upper limestone member of the Tomichi limestone rests in places upon a somewhat uneven surface of the quartzite member. The thickness of the limestone is about 300 feet, but faulting in several of the sections measured prevents an estimation of any range in thickness that may exist. The upper limestone in its lower 50 or 60 feet is gray to brownish gray, crystalline, and dolomitic and contains abundant but generally poorly preserved fossils. Among the common fossils are *Receptaculites* and corals, which make the horizon easily recognized. Above this lower part the limestone is less dolomitic and fine grained and contains scattered concretions of brownish-black chert. The uppermost beds, which are dark gray, weather to a rough surface marked with irregular pits and seams and contain rather dark chert concretions, but these are much less abundant and smaller than those that characterize the upper part of the Ouray limestone, which is somewhat similar lithologically. In places the top beds are sandy and grade into a thin zone, uncommonly as much as 10 to 15 feet in thickness, of gray dolomite or dolomitic limestone, which is immediately overlain by calcareous sandstone or quartzite. The top of the Tomichi limestone is taken at the base of this prominent sandstone, which is persistent throughout the district. The highest horizon at which Ordovician fossils were found is in the dark-gray limestone immediately below the light-colored dolomitic and sandy beds. In some places, however, a sugary quartzite lies directly on the massive gray limestone.

Fossils collected from the Tomichi limestone near Kerber Creek

	Lower limestone member	Quartzite member	Upper limestone member
Receptaculites sp			×
Sponge	×		
Streptelasma sp			×
Calapoecia sp			×
Lindstromia sp			×
Cystid columnals	×		
Crinoid columnals	×		
Orthoid brachiopod, probably referable to Taffia	×		
Diphragmoceras? sp	×		
Helicotoma sp	×		
Hormotoma sp	×		
Lophospira sp			×
Fish fragments		×	
Fucoids		×	

Age and correlation.—The limestone members of the Tomichi limestone in the Kerber Creek region have yielded fossils sufficient to establish their Ordovician age. According to Edwin Kirk, of the United States Geological Survey, who identified the fossils, the lower limestone "is of Lower Ordovician (Beekmantown) age and correlates with the upper portion of the Manitou limestone and the El Paso limestone of Texas." The fossils collected from the upper limestone "correlate with the upper portion of the Fremont limestone of Canon City, Colo., and are commonly considered of Richmond age." Concerning the peculiar casts of fragmental material from the middle quartzite member Kirk states: "From the fish fragments themselves it is not possible to tell whether this quartzite is of Ordovician or Devonian age. If, however, it occurs between the upper and lower members of the Tomichi limestone it is, of course, of Ordovician age and correlates with the Harding sandstone." As the quartzite lies between the two Ordovician limestones its correlation with the Harding sandstone, of Middle Ordovician age, seems correct. The similar fish fragments in the Harding sandstone of Canon City have been described by Walcott.[4]

The correlation with the Tomichi limestone of the Monarch and Tomichi mining districts is made by the writer on the basis of lithology, the similarity of the faunas, and the position of the fossil horizons. In those districts Crawford [5] distinguishes three members of the Tomichi limestone corresponding in lithology to the three on Kerber Creek, as shown by the correlation suggested on Plate 5. Crawford[6] reports from the lower member of the Tomichi limestone *Helicotoma* sp. and undeterminable cephalopods. Above the quartzite in the lower 50 feet of the upper limestone member were found *Receptaculites oweni*, *Halysites catenulatus*, and small cup corals, which correspond in stratigraphic position with the abundant corals found in the limestone above the quartzite member at Kerber Creek.

The upper member of the Tomichi limestone east of Garfield is described by Crawford[7] as "thick-bedded noncherty gray limestone, dolomitic in upper part, * * * about 100 feet, * * * followed by a few feet of argillaceous limestone and calcareous shale. For the purposes of mapping the shale stratum has been taken as the upper limit of the Ordovician sediments." Regarding the lower part of the overlying Chaffee formation at Monarch Hill, he

[4] Walcott, C. D., Preliminary notes on the discovery of a vertebrate fauna in Silurian (Ordovician) strata: Geol. Soc. America Bull., vol. 3, pp. 153–172, 1892.

[5] Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi districts, Colorado: Colorado Geol. Survey Bull. 4, pp. 56–61, 1913.

[6] Idem, pp. 60, 61.

[7] Idem, pp. 56, 57.

says:[8] "The basal part of the formation, for about 80 feet, is more or less argillaceous or arenaceous."

It seems probable that the change at Monarch and Tomichi from massive gray limestone of known Ordovician age to unfossiliferous shales and impure limestones is represented at Kerber Creek by a corresponding change at the top of the Upper Ordovician limestone, to sandstone and to the overlying argillaceous and dolomitic limestones which are described in more detail in the following paragraphs. Consequently, the base of the prominent sandstone at Kerber Creek is tentatively correlated with the top of the Tomichi limestone east of Garfield as described by Crawford. As he describes no sandstones in the Devonian-Mississippian section at Monarch Hill above the Ordovician, that region probably lay farther from the shore than the Kerber Creek region at the time of deposition of these beds. The tentative correlation of the Tomichi limestone with other sections in southwestern Colorado is shown in Plate 5.

DEVONIAN SEDIMENTARY ROCKS

CHAFFEE FORMATION

Position and thickness.—Lying above the Tomichi limestone and in apparent conformity with it are two lithologic units in the sedimentary series of the Kerber Creek region, which in this report are grouped under the Chaffee formation as defined by Kirk.[9] The Chaffee formation consists of a basal sandstone member 10 to 50 feet thick and an upper limestone member about 90 to 100 feet thick. No definite paleontologic evidence of the age of these two units was obtained, but as they are lithologically similar to the Chaffee formation as defined by Kirk, the age of which is determined by fossil evidence, and lie in the same stratigraphic position, they are assigned to the Devonian.

Sandstone member.—The sandstone member consists of a series of pure or argillaceous and calcareous sandstones and quartzites. Their best development is found on the south slopes of the prominent mountain lying south of Kerber Creek. (See pl. 3.) This series differs considerably from place to place within the area mapped on Kerber Creek, ranging from 10 feet of calcareous or dolomitic sandstone and sandy dolomite to about 50 feet of pure sandstone or quartzite and variegated argillaceous beds and impure limestone. The argillaceous beds in places are mottled with brick-red, purple, or yellowish colors. In their texture the purer quartz sandstones range from fine to coarse sandstone grits. The sandy beds are for the most part rather loosely cemented, differing in this respect from the quartzite member of the Tomichi limestone. However, some true quartzite beds occur at the base of this series near Little Kerber Creek. Part of these basal quartzite beds have a dark blue-green color suggesting the presence of glauconite. Where thinnest the sandstone member of the Chaffee grades toward the base and top into limy sandstone and sandy limestone or dolomite, so that it is difficult to define the boundaries of the member sharply. The gradational beds consist in part of cross-bedded sands that appear to have had an original calcareous cement, which has subsequently become partly or entirely dolomitized. The finer-grained argillaceous sandstones are more evenly and thinner bedded than the coarser sandstones, which are typically cross-bedded.

As here defined the sandstone member of the Chaffee formation is characterized by the predominance of sandstone and quartzite, and its upper boundary is placed at the top of the transition to the impure or dolomitic limestone.

Limestone member.—The limestone member of the Chaffee formation is separated both from the underlying sandstone and from the overlying Leadville limestone by a conformable series of gradational beds, but the transition at the base is gradual, whereas that at the top is more abrupt. The basal beds in some localities consist of pinkish limestone and dolomitic limestone of a granular or sandy texture. The thickness of the member ranges from 90 to 100 feet. The entire thickness is rarely well exposed, but in its typical development the member consists of dark-gray to grayish-white even-textured limestone, ranging from sublithographic to fine granular in texture and containing siliceous and argillaceous impurities. Oolitic texture is of local development. Much of the member is evenly thin bedded, but it becomes thick bedded locally. It characteristically weathers at the outcrop to yellowish-white or yellowish-brown fragments and small chips that have a soft, smooth surface resembling that of buckskin. Freshly broken surfaces, however, are dark brownish or blue-gray. This characteristic of the weathering is perhaps due to an accumulation of the argillaceous impurities and of iron oxide on the weathered surface. Where there are open weathered slopes underlain by this limestone their yellowish color serves to distinguish this horizon even at a distance.

MISSISSIPPIAN SEDIMENTARY ROCKS

LEADVILLE LIMESTONE

Thickness and stratigraphy.—The name Leadville is here applied, as restricted by Kirk, to alternations of massive, unevenly bedded, and thin-bedded fine

[8] Crawford, R. D., op. cit., p. 62.

[9] Kirk, Edwin, The Devonian of Colorado: Am. Jour. Sci., 5th ser., vol. 22, pp. 222–240, 1931.

blue-gray limestone ranging from 350 to 400 feet in thickness. The basal 10 or 15 feet consists of shale or shaly limestone in beds from a quarter of an inch to 2 or 3 inches in thickness. Above these beds the limestone abruptly becomes very massive and unevenly bedded, with warped or curved bedding planes from 1 to 3 feet apart, soft in texture, of a blue-gray color, and usually free from chert. These massive beds of pure limestone continue upward for 20 to 30 feet and then pass into thinner-bedded limestone. About 80 to 100 feet above the base in practically all the sections examined is a coarsely crystalline black dolomite containing black chert. Above the black dolomite the limestone again becomes massive and unevenly bedded but carries abundant concretions and lenses of black chert, the concretions reaching 7 or 8 inches in diameter. These chert concretions are typical of the upper part of the Leadville limestone and distinguish it from the lower part, which is comparatively free from chert. The uppermost beds of the limestone are rarely well exposed but consist of medium or thin bedded soft blue limestone containing black chert, with perhaps some concealed shaly layers. The change to the basal sandstone grit of the overlying Kerber formation is abrupt.

With the exception of one fish tooth no fossils were found in this member, although they were searched for carefully at a number of localities.

Age.—The beds assigned to the Leadville limestone in the Kerber Creek region are regarded as of Mississippian age. This assignment, however, is based solely upon their lithologic correlation and their stratigraphic position compared with other Devonian and Mississippian sections in Colorado.

PENNSYLVANIAN SEDIMENTARY ROCKS

KERBER FORMATION

Thickness and stratigraphy.—The beds here named Kerber formation, from exposures along Kerber Creek, consist of a series of coarse-grained sandstones or grits and carbonaceous shales, which overlie the Leadville limestone and extend upward to the base of the lowest red micaceous sediments or sandy shales. So defined, the Kerber formation is about 200 feet thick and includes nearly all the beds below a certain fossiliferous zone which corresponds in age to the basal part of the Maroon formation as defined by Eldridge.[10] (See p. 14.) The formation possesses certain characteristics which make it easily recognized as a lithologic unit.

The Kerber formation at several localities within the limited area in which it was studied comprises a basal sandstone and overlying alternations of nearly pure quartz sandstone and black carbonaceous shale. A typical section is shown on page 14. The sandstones are coarse grained to pebbly, and the quartz that forms their principal or sole constituent, occurs in angular to subangular grains as much as 6 or 8 millimeters (one-fourth inch) in diameter. The sandstones are predominantly white to gray but not uncommonly are reddish or yellowish as a result of iron stain. They are generally cross-bedded but on a much larger scale than the sandstones at the base of the Chaffee formation. A characteristic feature at all localities where the formation could be studied was the essential absence of white mica (muscovite), a mineral which is very abundant in all the sandstones and sandy shales of the overlying Maroon formation.

The shales of the Kerber formation contain considerable carbonaceous matter and impure coal showing plant impressions, but no beds are sufficiently free from incombustible material to be used for coal, and attempts to mine them at several places have been unsuccessful.

The beds immediately overlying the upper sandstone of the Kerber formation are typically reddish-brown micaceous shaly sandstones or sandy shales, and have been arbitrarily included in the overlying basal member of the Maroon formation.

Age.—No fossils were found in the Kerber formation other than the plant remains in the carbonaceous shales, which have not been studied, so that for the present the geologic age of these beds can only be inferred from the age of the beds above and below them. The underlying Leadville limestone is considered to be of early Mississippian age,[11] and although there is no angular unconformity at the base of the Kerber formation, the abrupt change in lithology and the absence of transitional beds indicate a stratigraphic break at this horizon. As will appear from the evidence of the age of the overlying Maroon formation, the Kerber formation corresponds in stratigraphic position and possibly in age to the so-called Weber limestone of the Anthracite-Crested Butte district and hence is probably of Pennsylvanian age. It is not intended, however, to correlate the Kerber with the so-called Weber(?) formation, "Weber grits," or "Weber shales" of other districts in Colorado, as there appears to have been little uniformity in the application of this name.

PENNSYLVANIAN (?) AND PERMIAN SEDIMENTARY ROCKS

MAROON FORMATION

Thickness and stratigraphy.—The sedimentary beds included in the Maroon formation in the Kerber

[10] Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), 1894.

[11] Girty, G. H., The Carboniferous formations and faunas of Colorado: U. S. Geol. Survey Prof. Paper 16, pp. 217–231, 1903.

Creek area include the strata from the base of the lowest red or maroon micaceous sandstone or shale to the highest exposed bed found within the area mapped on Plate 1. The only section measured included a stratigraphic thickness of about 3,400 feet, but the presence of overthrust bodies of pre-Cambrian rocks and other formations and of minor faults adjacent to major thrust planes prevents an accurate estimate of the maximum exposed thickness of this formation, which may greatly exceed 3,400 feet.

To assist in defining the base of the Maroon formation as mapped, the general character of the section immediately overlying the top of the Kerber formation is shown in the following section:

Stratigraphic section of Maroon and Kerber formations

	Feet
Maroon formation:	
Covered.	
Gray shale.	
Soft gray fossiliferous limestones in beds and lenses interbedded with gray shale	10–15
Black or gray shale, red near base	30
Greenish shaly micaceous sandstone	10–15
Red sandy micaceous shale	20
Kerber formation:	
Coarse cross-bedded sandstone, consisting almost wholly of subangular quartz grains, with essentially no white mica	35
Black carbonaceous shale	20–30
Coarse to medium sandstone, cross-bedded in places, consisting mostly of quartz	30–50
Black carbonaceous shale	10–20
Coarse to medium sandstone, in places prominently cross-bedded	70–75
Mississippian limestone.	

The general character of the higher beds in the Maroon formation can be seen from Figure 2. The lower 1,100 or 1,200 feet consists largely of dark-red and green sediments containing a relatively greater proportion of sandy shale or shale, but with many interbedded sandstones and conglomerates and a few black shales, particularly near the base. The color of the rocks covers a considerable range from dark red to yellow, orange, or green, but the red color predominates. Mica is a conspicuous constituent of nearly all the beds and serves to distinguish the Maroon formation from grits included in the Kerber formation in this region.

From about 1,200 to 1,900 feet stratigraphically above the base the formation is characterized by thick beds of conglomerate and coarse-grained sandstone which form prominent escarpments or low hills and ridges. The general character of the strata interbedded with these conglomerates is similar to that of the sandstones and shales in the lower part of the formation.

Above the conglomerate division, shale and gray fossiliferous limestone are more abundant, and toward the top of the exposed section coarse arkosic conglomerates containing red feldspar and mica are conspicuous. The upper conglomerate beds contain large pebbles and boulders as much as 8 inches in diameter and include rounded pebbles of limestone and sandstone similar to those found in the lower part of this formation, which suggest the presence of an unconformity within the upper part of the formation.

Age.—Collections of fossils were made at two horizons near the base of this formation. The soft gray limestone mentioned in the section shown in the preceding column contained the following species:

Echinocrinus sp.	Pustula nebraskensis.
Derbya crassa.	Composita subtilita.
Productus cora.	Schizostoma catilloides.
Rhombopora lepidodendroides.	Chonetes mesolobus var. decipiens.
Rhipidomella carbonaria.	
Chonetes granulifer.	

G. H. Girty, of the Geological Survey, who identified the fossils, says:

The collections are clearly of Pennsylvanian age and appear to have had their source in the lower part of the Maroon formation as defined in the Anthracite-Crested Butte folio. At least the small faunas collected are in closer agreement with that than with the fauna of the Weber limestone as recorded.

Another collection at a horizon near the base of the Maroon formation but undetermined in relation to the horizon of the collection above mentioned contained the fauna listed below.

Bed 10

Myalina?, n. sp.	Pseudomonotis kansasensis?

Bed 8

Astartella concentrica.	Phillipsia sangamonensis?

Bed 7

Crinoid fragments.	Productus morrowensis var.
Lingulidiscina sp.	Productus cora.
Schizophoria texana.	Composita subtilita.
Derbya crassa?	Acanthopecten carboniferus?
Chonetes levis.	Bucanopsis? sp.

Bed 6 (lowest)

Schizophoria texana.

These beds cover a stratigraphic thickness of about 15 to 20 feet. According to Mr. Girty the collections may safely be interpreted as early Pennsylvanian.

The age of the upper part of the Maroon formation is not known, although limestones near the middle of the section contain *Chaetetes milleporaceus*, commonly regarded as a characteristic Pennsylvanian coral. It is believed, however, that the upper several hundred feet of the beds included in the stratigraphic column (fig. 2) are of Permian age, as suggested by the change in lithologic character and the inclusion of pebbles of the older Carboniferous rocks. David White,[12] on the evidence of fossil plants collected by him in the Maroon formation at several localities, assigns the entire for-

[12] Unpublished report.

mation to the Permian series. It is the opinion of J. B. Reeside, jr.,[13] that the Cutler and Rico formations, both of which are classified as Permian, are represented in the Maroon formation. In this report, therefore, the Maroon is classified as Permian and Pennsylvanian (?).

TERTIARY IGNEOUS ROCKS

THE VOLCANIC SUCCESSION

Tertiary volcanic formations cover nearly all of the surface of the Bonanza district. They comprise for the most part a series of lava flows and associated tuffs and breccias, which are in part of local origin and probably in part from volcanic centers beyond the immediate vicinity of the district. These effusive rocks have been invaded by several bodies of porphyry of latitic and granitic composition and locally are cut by many dikes of rhyolite, quartz latite, and monzonite. The lavas range in composition from augite andesite to rhyolite but include a great proportion of rocks of intermediate composition such as latitic andesite, latite, and quartz latite. A few local or thin accumulations of tuff, breccia, or agglomerate are found. The earliest flows and associated breccias rest upon a basement composed largely of pre-Cambrian gneisses, schists, and granitic rocks; and in the southeastern part of the district and possibly east of it the basement includes some folded and faulted Paleozoic sedimentary rocks. The unconformity at the base of the Tertiary lavas represents a long erosion interval in early Tertiary time. The topographic character of the old surface upon which the lavas were poured out is entirely undetermined within the district, but several miles to the southeast, near Kerber Creek, where erosion has exposed the base of the lavas, there is some indication that the relief of the land in early Tertiary time was at least 500 feet.

The earliest flows, constituting the Rawley andesite, were widespread and probably covered the hilly erosion surface of the pre-Tertiary formations completely. The next younger flows make up the Bonanza latite, a characteristic unit in the volcanic series by which many of the present structural features can be determined. Its distribution and comparatively small thickness show that these lavas flowed onto an approximately level surface of the underlying andesite. The sources of the andesite and latite flows have not been determined. Above the horizon of the Bonanza latite the lava succession is more complicated, consisting of several thick local accumulations of rhyolitic and latitic lavas and associated tuffs and breccias. In addition to these local accumulations there are also widespread lava flows of nearly the same age but probably having a more distant origin. These are predominantly of latitic composition. They partly surround and are partly interbedded with some of the more local volcanic bodies. When the flows had reached a total thickness of nearly a mile another eruption of andesitic lavas occurred, followed by more latites. These later lavas are now found on the slopes and tops of the mountains west of the district, and as no remnants of them have been found within the district, it is not known if they ever extended completely across the region.

After or during the accumulation of the earlier series of volcanic rocks the crust was invaded and weakened by molten magma that may have been the source of some of the local effusive rocks. The rocks near the surface were deformed, and part of them subsided onto the underlying molten rock, so that they were broken into many tilted fault blocks. At the time of faulting dikes were intruded into the rocks in some areas.

The remnants of the volcanic series that have been preserved from erosion within the area mapped represent a thickness of approximately 4,000 feet, but without more detailed surveys of the surrounding regions it can not be determined whether this thickness actually represents the total volcanic accumulations of the area. The correlation of this volcanic sequence with the divisions of the volcanic series of the San Juan Mountains is not established, but according to Larsen[14] probably all or at least most of the flows of this district are of the pre-Potosi age. The age of the earliest volcanic eruptions of the San Juan Mountains and the relation of the Potosi volcanic series (Miocene) to these lavas suggest that their period of eruption may have been in the Oligocene.[15]

Although there is no evidence of long erosion intervals between the successive eruptions, the sequences in different parts of the district are not the same, and the thickness of individual formations differs from place to place. These differences are perhaps largely due to the overlapping of formations and to the accumulation of some volcanic material about local vents, rather than to extensive erosion. Some differences are also very likely only apparent, being due to the practical difficulties of obtaining accurate measurement in faulted and tilted volcanic formations. Many of the fault blocks into which the rocks were broken are small in comparison with the thickness of individual formations, so that few places afford favorable conditions for measuring thicknesses as great as 500 to 1,000 feet.

The following table shows the divisions of the volcanic flows that have been used in mapping. The

[13] Unpublished report.

[14] Larsen, E. S., personal communication.

[15] Based on personal discussion with Doctor Larsen.

oldest formation is at the bottom of the list, but the table does not include the younger intrusive rocks, which will be discussed in a following section. The thicknesses stated are approximate.

Section of Tertiary volcanic formations in the Bonanza district

	Feet
Andesite (flows, only small part of series within the district)	300
Brewer Creek latite (flows)	500
Porphyry Peak rhyolite (local(?) flows, tuffs, and agglomerates; some intrusives)	1,000
Squirrel Gulch latite (flows)	300–500
Hayden Peak latite (local flows, tuffs, and breccias; probably some intrusives). Believed to be in part contemporaneous with Bonanza latite and in part younger	1,000–1,500
Bonanza latite (mostly flows, some tuff and breccia in upper part)	500–1,000
Rawley andesite (mostly thin flows, with some latites and breccia)	1,000–2,000

ley mine, comprises most of the rocks outcropping in the northeastern, east-central, and extreme southern parts of the district. It consists of a thick series of flows and breccia beds, which range in composition between augite andesite and latite. The thickness of the individual flows ranges from 10 or 15 feet to over 100 feet. Commonly the latite members of the series form the thicker flows, and many of the flows less than 50 feet thick are augite andesites.

The crest of the high eastern range of the district between Elkhorn Peak and Round Mountain is composed wholly of these lavas. Because of the prevailing westward dip of the flows in this region, successively higher beds of the andesite crop out westward from this range to the locality where the overlying latites and rhyolites conceal the andesite in the northwest and west. The individual lava beds on the western slope of this range are not exposed, however, in

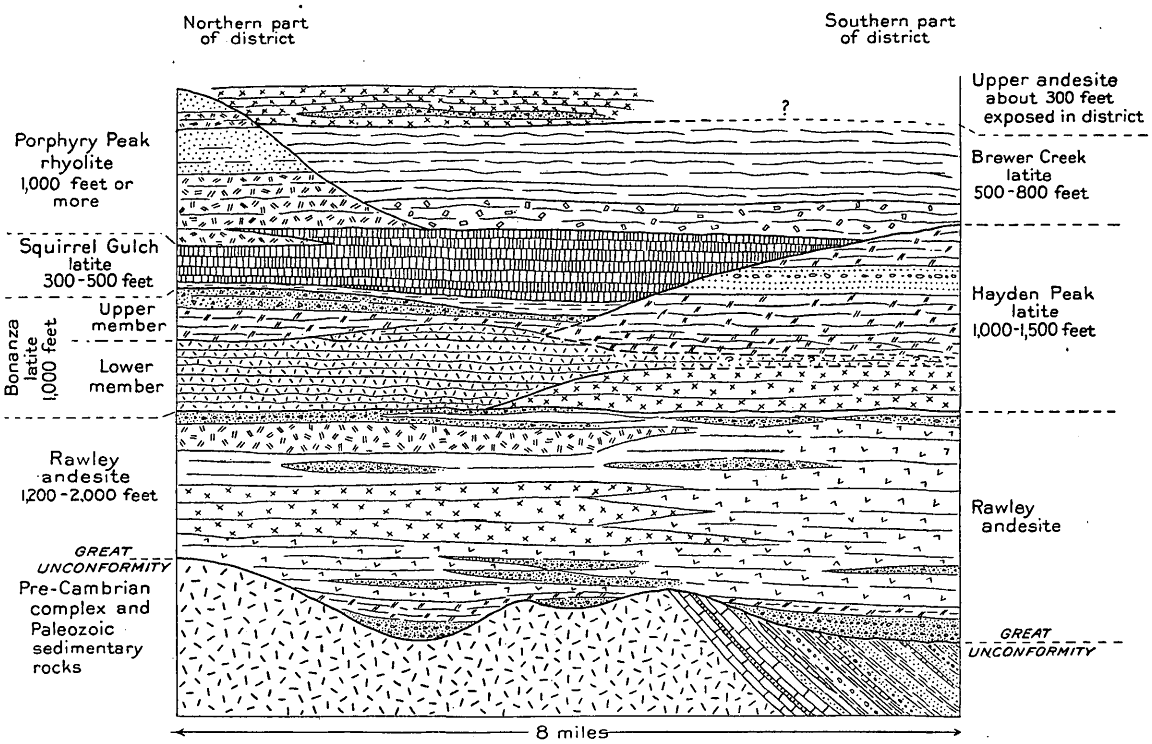


FIGURE 3.—Columnar section of the Tertiary lavas of the Bonanza district

As many of the lavas came from different sources and as their periods of eruption overlapped, a simple tabular arrangement of the formations does not express the relative age satisfactorily. For this reason the comparative age of the formations in so far as they could be interpreted is shown in a columnar diagram. (See fig. 3.)

VOLCANIC FLOWS

RAWLEY ANDESITE

DISTRIBUTION AND GENERAL CHARACTER

The Rawley andesite, named from its typical occurrence on the slopes of Rawley Gulch and in the Raw-

the order in which they were originally erupted, but the flows are tilted and repeated many times by step faults. The present outcrops thus afford only a jumbled section of the original series. Toward the west, where the outcropping rocks consist chiefly of lavas younger than the Rawley andesite, small areas of fault blocks of the underlying andesite crop out in the valleys and at places even on the ridges. The largest exposure of andesite in the western part of the district lies between the forks of Kerber and Brewer Creeks and is bounded mostly by faults.

The east slope of the eastern range lies mostly outside of the area mapped but at the north consists largely of the Rawley andesite. The base of the andesite is exposed near Alder Creek but is not known to be exposed elsewhere in the district. On the north side of Alder Creek, where this series rests upon the pre-Cambrian rocks, breccia beds usually form the base.

The small outcrops of pre-Cambrian rock near the head of Squirrel Gulch are fault blocks that have been thrust upward into fault contact with the andesite. These fault blocks may, however, indicate the position of a hill or high area of the original basement, as otherwise the displacements of the bounding faults would exceed 1,000 feet. If so, the andesite may be thinner here than elsewhere in the district.

In the southern part of the district the andesite is found south of the Hayden Peak latite, and the intrusive Eagle Gulch latite. Its exposures are practically continuous on both sides of Kerber Creek for several miles southeast of the area mapped. The andesite rests upon the pre-Cambrian rocks and the Paleozoic sedimentary formations near Kerber Creek within the area shown on Plate 3. Basal breccias found in this area contain fragments of pre-Cambrian rocks and of the Paleozoic rocks. The lower flows are mica andesite or latite, but their exact composition has not been determined.

SEQUENCE OF FLOWS

Although several lithologic divisions were made in the Rawley andesite in the northern part of the district, based upon the sequence of flows within this formation, corresponding divisions could not be recognized in the southern part of the district. It was found that only doubtful correlation could be made, even across the eastern range, between beds in the Rawley Gulch region and those in the Alder Creek region. The making of such correlations in the district is much handicapped by the intricate faulting and lack of continuous exposures, but it must also be concluded that many of the individual flows were never continuous over these areas or that the appearance of the consolidated lava is different at different places. The lack of sharp distinctions between different flows is typical of the augite andesites, especially of the finer-grained types. Within an area as small as the Bonanza district many of the andesite flows may have had a common source, and their periods of eruption presumably followed one another so closely that there was little opportunity for differences to develop in the composition of the lavas. However, at several periods in the sequence of flows were erupted latites and lavas that are intermediate in composition between andesite and latite and differ markedly in composition and texture from the more basic lavas. At least three latites of distinctive character are recognizable in the northern part of the district. One of these is found at the very base of the series and is exposed near Alder Creek and perhaps represented by lavas at the base on Kerber Creek south of the district. A second one crops out on the high ridges on both sides of the upper end of Rawley Gulch. This horizon is also recognizable at the east end of the Rawley drainage tunnel, beneath the surface. The horizon of these lavas is believed to be about midway in the series. The uppermost latite lavas are a conspicuous series of flows near the top of the Rawley andesite, which crop out on the western slope of the range between Copper Gulch and Round Mountain. Typical exposures are found above the old Stemwinder prospect, below the Superior mine, on the high ridge east of the Whale mine, and in the vicinity of the Antoro shaft. Because of the closeness of this horizon to the top of the andesite the latite is exposed at many places in the northern part of the district, both at the surface and in underground workings, as in the Rawley drainage tunnel and in deep levels of the Cocomongo mine. Between these several horizons of latite the lavas consist of augite or augite-mica andesites, all of very similar types, and thin local beds of breccia or agglomerate. The uppermost latites are overlain by andesite breccias and at places by thin augite andesite flows. At many places the Bonanza latite, which overlies the Rawley andesite, lies upon a partly oxidized breccia bed.

In the southern part of the district the upper part of the andesite series contains many mica andesites or latitic andesites of types that are rather uncommon among the lavas farther north. The middle and upper latite horizons were not recognized in individual flows. Although it is possible that the mica andesites or latites of the south represent the upper latite horizon, it is perhaps more likely that such divisions in the sequence of lavas are of only local significance. The vagueness of these correlations from place to place thus did not permit subdivision of the lavas of the Rawley andesite into smaller units.

THICKNESS

Only the approximate thickness of the Rawley andesite can be determined, because of several variable and unknown factors that must be used to calculate it. One of the variable factors is the relief of the surface upon which the andesites accumulated. This relief can not be determined for the Bonanza district, because exposures of the base of the andesite within the district are relatively few and because none of the mine workings in the north-central and southern parts of the district penetrate the andesite deep enough to reach the pre-Cambrian rocks. A relief of about 500 feet in the surface of the basement was observed southeast of the district, but the relief in different places may of course be much greater or less than this.

Other factors that differ from place to place and are in part unknown are the present attitude of the formation as a whole and the displacement of faults which lie entirely within this formation. Both of these factors are difficult to estimate quantitatively. The direction of dip of individual flows can be determined at many places, but as the beds are commonly steeply tilted in local zones, dips based upon random observations of contacts are not trustworthy as indications of the attitude of the formation as a whole. Furthermore, the exposures are not sufficiently good to permit large numbers of observations of this type to be made. The attitudes that have been assumed in constructing the cross sections within areas of Rawley andesite are based upon partial mapping of the outcrops of certain key beds, such as the latites mentioned above.

The most favorable area for estimating the thickness of the andesite is near Alder Creek, where both the base and the top of the series are exposed on the slopes. Because of faults intervening between the outcrops of the base and top the estimate here also depends upon an interpretation of the structure. (See section A–A′, pl. 3.) The minimum possible estimate is 1,000 to 1,200 feet, and only by assuming very large displacements along some of the fault zones can the thickness be placed at more than 1,500 feet. The pre-Cambrian of this area possibly represents a high region of the old pre-volcanic surface, so that these thicknesses may perhaps be less than the average for the formation.

Where the pre-Cambrian rocks are exposed in Squirrel Gulch, in the northwestern part of the district, they are in fault contact with andesite and with lavas higher in the volcanic series. The presence of these upthrust blocks in contact with lavas younger than the andesite suggests that another high area of the basement lies beneath this region, but other interpretations of the structure are possible. (See pp. 47–50.)

In the vicinity of Rawley Gulch the deep shaft of the Rawley mine permits the estimation of another minimum thickness of this formation. As the crest of the range between Alder Creek and the Kerber Creek drainage area corresponds closely to the structural crest of a faulted arch or dome, the thickness of the formation can not be determined by simply adding the depth of the deepest mine working to the relief of the high range above. The Rawley shaft has penetrated the andesite to a depth of about 1,100 feet below the surface. As the beds in this portion of the arch are tilted possibly as much as 30° or 40° from the horizontal, the stratigraphic thickness is somewhat less than the depth of the shaft. The lavas cut by the Rawley drainage tunnel near the bottom of the shaft (pl. 25) represent the middle latite horizon in the andesite. This horizon is believed to be about midway in the series but is more likely nearer the base than the top. The thickness of lavas below the middle latite probably is not less than 500 feet but may, of course, be greater, depending upon the unevenness of the basement at this locality.

The minimum thickness of the andesite in Rawley Gulch on this rough basis is from 1,600 to 2,000 feet. A regional thickening of the formation southwestward from Alder Creek is a possibility that can not be denied with any evidence at hand, so that the actual thickness may be much greater than this minimum estimate.

In the southern part of the district there are few data on which to determine thickness other than a minimum represented by the depth of explorations and the relief of the surface. None of the mine shafts penetrate to the base of the andesite, and the deepest shafts are not more than several hundred feet deep. A thickness of at least 800 to 1,000 feet is indicated, but the total thickness is certainly greater than this.

PETROGRAPHY

Augite-biotite andesite.—The most abundant and typical lava of the Rawley andesite is augite-biotite andesite. It presents a considerable range of texture but nearly all the unaltered lava is characterized by a dark-colored, dense groundmass. In texture it ranges from fine-grained nonporphyritic or very finely porphyritic types to conspicuously porphyritic rocks in which the phenocrysts attain a length of 6 or 8 millimeters. The conspicuous phenocrysts are plagioclase and have a wide range in their shape and proportion in the different lavas. Augite and mica phenocrysts are mostly small and are commonly altered and inconspicuous. Amygdaloidal lavas are not uncommon, but they differ much in the shape and prominence of the amygdules, which rarely reach a diameter of half an inch. Some beds are amygdular throughout, although many more contain only thin zones of finely amygdular or vesicular material at their top. The oxidation of the thin, highly vesicular beds is commonly pronounced, giving them a purple or reddish-brown color. The color of the unaltered lavas ranges from nearly black to greenish gray or rarely reddish brown, but the altered lavas are much bleached or green, according to the relative abundance of sericite, chlorite, and calcite.

Microscopic examination shows that the feldspar phenocrysts in typical lavas are labradorite (An_{55} to An_{63}) from 2 to 6 millimeters in length. In some lavas these crystals are long and lath shaped; in others they are of stouter outline and occur singly or in clusters. Several generations of feldspars are present in some lavas, where one generation is intermediate in size between the larger ones and the feldspars of the groundmass. Augite is not abundant in any of the lavas examined and in many is represented only by its alteration products, calcite, chlorite, and magnetite. It occurs in small prismatic crystals 1 to 2 millimeters in diameter or in aggregates of smaller grains, and also in very small scattered grains and prisms in the groundmass. A few biotite flakes, 1 to 2 millimeters in diameter, are mostly altered to chlorite or serpentine or to pseudomorphic aggregates of chlorite, quartz, calcite, and rutile. In a few of the lavas examined there was a little brown hornblende associated with augite or in small isolated crystals. The groundmass exhibits textures ranging from the more typical andesitic, having slender plagioclase crystals in a glassy base, to the holocrystalline. In the intermediate types the groundmass is essentially of submicroscopic texture, so that the nature of the minerals composing it is obscured by alteration products. The plagioclase of the groundmass is mostly andesine. Magnetite is fairly abundant in large grains and in very small ones scattered through the groundmass. Apatite is an accessory mineral. Calcite and chlorite are practically everywhere present as alteration products, and sericite is more or less common, depending on the nearness of the rock to fissured and hydrothermally altered ground.

The amygdules present in some lavas are composed of chlorite, calcite, chalcedony, and in part of hematite. In the red highly vesicular portions hematite is scattered throughout the rock, probably as an alteration product of escaping gases or of air in contact with the hot lava.

Augite andesite.—Typical augite andesites are probably not as common as the augite-biotite andesites, but several lavas that were examined microscopically belong to this group. These are of finely porphyritic texture and of dark-gray or reddish-brown color. The phenocrysts are abundant, are from 1 to 3 millimeters in length, and consist of about equal amounts of labradorite (An_{65}) and greenish augite. The augite is perfectly fresh and either forms prismatic crystals 1 to 2 millimeters in length or occurs in aggregates of many smaller grains which occupy areas several millimeters in diameter. The groundmass has a typical andesitic texture, consisting of a glassy base clouded with magnetite or hematite and containing very small, slender plagioclase microlites with random orientation. Magnetite and apatite are accessory minerals, and chlorite, epidote, and calcite are secondary.

Biotite andesite or latite.—In the southern part of the district the upper part of the Rawley andesite contains many dark mica-bearing lavas. The texture and mineral composition of these lavas suggest that they are latites rather than andesites, and at least they are of intermediate composition. They are conspicuously porphyritic, containing phenocrysts of both feldspar and biotite.

The feldspar in typical lavas has the composition of andesine (about An_{40}) and occurs in slender or broken crystals 2 to 6 millimeters in length. The biotite is in conspicuous flakes 2 to 5 millimeters in diameter and under the microscope is seen to be partly altered to chlorite, epidote, and rutile. Fresh biotite is pleochroic from brownish yellow to deep brown and contains hematite and lines of opaque grains parallel to the cleavage.

These lavas contain a few aggregates of calcite, deep-green chlorite, and magnetite which have the outline of augite crystals. The groundmass is clouded, of brownish tint, and contains patches that are of submicroscopic texture, but it is largely crystalline. Quartz, orthoclase, and plagioclase can be recognized, but much of the mineral intergrowth is too fine or clouded with alteration products for estimation of the relative amounts of minerals. Magnetite, hematite, and apatite are accessory minerals in the groundmass. Scattered alteration products consist of calcite, epidote, and sericite.

Latite.—The first few thin flows near the base of the Rawley andesite on Alder Creek are latites, which differ markedly in appearance from the typical andesites of the series. They are dark gray, greenish, or reddish brown and exhibit a prominent flow texture. They contain small phenocrysts of feldspar, 2 to 4 millimeters in length, and a few smaller inconspicuous flakes of biotite. Microscopic examination of one flow from the north side of Alder Creek shows the feldspar crystals to have the composition of andesine (An_{35-40}). Brownish biotite is the only ferromagnesian mineral present and occurs in small flakes. Magnetite in small grains is scattered throughout the groundmass, and apatite is a less common accessory mineral. The groundmass, which is in greater volume than the phenocrysts, is composed largely of devitrified glass showing brownish flow lines. The present mineral composition of this base can not be determined with accuracy, because of the abundance of alteration products such as chlorite, sericite, and epidote. The index of refraction of most of the crystalline material composing the groundmass is slightly greater than that of Canada balsam. A little quartz can be recognized. These lavas are believed to be latites from their similarity in mineral composition and texture to the typical latites of the region, but this classification is made without the support of a chemical analysis.

The middle part of the Rawley andesite in the northern part of the district is characterized by a second prominent series of latitic lavas, which crop out high on the west slope of the range between Rawley Gulch and Alder Creek. These lavas dip westward and are exposed again beneath the surface in the Rawley drainage tunnel just west of the Rawley vein. (See pl. 25.) The best exposures at the surface are found on the top of the high ridge about midway between the Gladstone shaft and the Antoro shaft. Several of the lava beds of this series are massive, forming prominent outcrops with talus slopes. These lavas are light greenish-gray to dark-gray porphyritic rocks, some beds of which are amygdaloidal or vesicular throughout and others only slightly so near the top. The feldspar phenocrysts are commonly large, ranging from 5 to 8 millimeters in length, and are rather sparingly developed. In some of the lavas there is also a second generation of feldspar phenocrysts that are more abundant but only 1 to 2 millimeters in length. Even without the aid of a hand lens the groundmass is seen to be distinctly coarser in grain than that of any of the typical andesites. The rocks weather to greenish gray and rusty brown, and some of the large feldspar crystals weather out, producing a pitted surface. Microscopic study of these lavas shows that some of them are considerably altered. In the least altered lavas the phenocrysts are plagioclase, having the composition of sodic labradorite (An_{50-55}). The ferromagnesian minerals comprise augite, hornblende, and altered biotite. Augite occurs very sparingly in grains 1 to 2 millimeters in length and in minute grains scattered through the groundmass. A brown hornblende forms rims on some of the altered augite. Biotite is entirely altered to chlorite, calcite, and rutile. The groundmass is a granular intergrowth of plagioclase, orthoclase, and quartz of about 0.2 millimeter grain in some lavas. The plagioclase forms the principal constituent of the groundmass and occurs in short prismatic grains ranging in composition from andesine to sodic oligoclase. Orthoclase occurs in irregular grains bordering the plagioclase prisms and in small crystals of quadratic outline within quartz. The quartz is somewhat more abundant than orthoclase, forming nearly 10 per cent of the volume of the groundmass. The groundmass contains abundant grains of magnetite and scattered grains and flakes of brown hornblende and chlorite. Apatite is a less common accessory mineral. In advanced states of hydrothermal alteration the plagioclase crystals are converted to sericite and calcite, the alteration attacking the centers of the larger phenocrysts first. Most of the amygdules are composed of chlorite and calcite. The composition of these lavas has not been determined by chemical analysis, but from their mineral composition it is clear that they are comparatively high in sodium and potassium and are presumably calcic quartz latites.

At a horizon near the top of the Rawley andesite latites are prominent on the slopes east and above the Whale mine, forming there a conspicuous talus of large angular blocks. A similar talus slope of these lavas occurs above the Stemwinder property. As seen at this locality and on the crest of the main ridge east of the Whale the member appears to consist of at least two or three individual flows. This bed is also found on the west slope of Manitou Mountain in the vicinity of the Antoro shaft. These lavas are conspicuously porphyritic, with abundant plagioclase crystals tending to a somewhat square outline and 2 to 6 millimeters in size. The groundmass is greenish gray to dark gray and exceedingly fine. Both in the fineness of the groundmass and in the abundance of the phenocrysts these lavas are contrasted with those of the latite just described. Altered biotite and greenish aggregates representing altered augite may be recognized on close inspection. Microscopic examination of these lavas shows that the plagioclase crystals are sodic labradorite (An_{50}) and that the groundmass is a fine intergrowth of small plagioclase laths, orthoclase, and quartz. The plagioclase in the groundmass is more sodic than that of the phenocrysts, consisting partly of andesine-oligoclase, and is mostly mantled with orthoclase. A little hornblende can be recognized with the microscope and is associated with the augite.

CHEMICAL COMPOSITION

The following analyses of three specimens, one collected by Patton[16] and two collected by the writer, show at least partly the range in composition of lavas of the Rawley andesite. It will be noted that the potash is comparatively high in all the analyses. The high potash in analysis 1 may be partly accounted for by the fact that the rock was an altered one containing sericite. The high percentage of carbon dioxide also indicates alteration. As Patton states that the rock contains "rather sparingly developed augite" it is probably not representative of the more basic types of augite andesite described above but is of the intermediate type. Analysis 2 represents an augite-biotite andesite containing only small amounts of augite and biotite, with phenocrysts of calcic labradorite in a partly glassy groundmass. There is microscopic evidence of weak propylitic alteration, also shown by the amount of carbon dioxide. The lava should perhaps be more strictly called latite. Analysis 3 is the highest in silica and lowest in lime compared to the potash and soda and represents the uppermost latite horizon, near the top of the Rawley andesite. Orthoclase and quartz are both visible in the groundmass of this lava, and biotite is the most abundant ferromagnesian mineral. The rock is prac-

[16] Patton, H. B., Geology and ore deposits of the Bonanza district, Saguache County, Colo.: Colorado Geol. Survey Bull. 9, p. 54, 1916.

tically fresh except for a very little calcite associated with the augite grains.

Analyses of lavas from the Rawley andesite

	1	2	3		1	2	3
SiO_2	54.23	57.62	59.66	CO_2	2.13	1.06	0.10
Al_2O_3	18.82	15.84	16.09	P_2O_5	.16	.44	.35
Fe_2O_3	1.69	3.05	2.57	SO_3	Tr.	.05	------
FeO	4.06	3.90	3.53	Cl	Tr.	Not det.	------
MgO	2.25	2.14	2.29	F	------	Not det.	------
CaO	6.62	4.81	4.48	S	Tr.	Not det.	------
Na_2O	3.91	3.07	3.08	MnO	.17	.15	------
K_2O	3.08	4.95	4.92	BaO	------	.04	------
H_2O-	.08	.24	.25				
H_2O+	1.51	1.39	1.84		100.14	100.05	100.16
TiO_2	1.43	1.30	1.00				
ZrO_2	Tr.	Not det.	Not det.				

1. Augite andesite from point 3,900 feet southwest of the summit of Round Mountain. Phenocrysts of labradorite and rather sparingly developed augite. The groundmass shows plagioclase and secondary minerals, chlorite, calcite, and sericite. Collected by H. B. Patton, Colorado Geol. Survey Bull. 9, p. 54, 1915. Analysts, George Rohwer and E. Y. Titus.
2. Augite-biotite andesite (latite) from ridge just below Superior mine. Analyst, J. G. Fairchild.
3. Biotite-augite latite from ridge near Superior mine. Analyst, J. G. Fairchild.

RELATION TO MINERAL DEPOSITS

The Rawley andesite forms the country rock of many of the most productive veins of the district. Where unaltered it possesses characteristics, described above, by which it can ordinarily be easily distinguished from the other rocks of the district. Where it is encountered in the walls of drifts that follow veins or faults, however, intense alteration is likely to obscure many of its typical features. Near feebly mineralized fissures or at some distance from strong veins a chloritic alteration is the one usually found, in which the rock is partly replaced by calcite and chlorite with a little sericite and some pyrite. Such altered rock is mostly of a dark-green color and is somewhat softened, though comparatively tough. When broken by mining operations it may show many joints coated with films of chlorite and calcite. These joints form planes of weakness along which the rock readily parts and slumps into the drifts or stopes. Mining experience in the district has shown that, owing to this altered condition of the walls, the vein material must be mined without breaking too far into the adjacent wall; otherwise the wall will gradually cave and dilute the ore as it is drawn from the stope. In some parts of the ore bodies the silicification of the walls close to the vein, mentioned in the next paragraph, may protect one or both walls from caving unless the silicified zone is narrow and is broken down with the vein filling.

The more intense alteration in the immediate walls of the larger veins consists of two main types—one in which the andesite is entirely replaced by silica and one in which it is largely replaced by an association of sericite, quartz, calcite, and pyrite. The silicified andesite is called jasper and is an exceedingly hard, resistant rock. It is commonly tinged with red or of dark-red color and in places contains many crystals of pyrite scattered through it. Such rock is present in parts of one or both walls of the Rawley and many other veins in the district. It is also found less closely associated with mineral deposits and in other types of lavas than andesite. Where the wall rocks are completely silicified it may not be possible near the vein to determine the original character of the rock, as its texture is largely or completely lost. Under conditions encountered in parts of the Cocomongo mine, for example, it is difficult to distinguish between silicified andesite and silicified Bonanza latite. However, the red color of silicified rock is probably more typical of the andesites than of the latites and rhyolites.

The other type of intense alteration close to the veins in the district is commonly called sericitization. It consisted of the replacement of the andesite by different proportions of finely divided sericite, calcite, quartz, and chlorite. Where the proportion of sericite is large the andesite is converted into a soft greenish-gray or white rock, between which and the darker chloritized rock there are all gradations. The original appearance of the andesite is largely lost, but at certain stages of the alteration the outlines of the larger feldspar crystals may still be seen. Under such conditions some of the conspicuously porphyritic andesites may be confused with the dikes of light-colored intrusive porphyries that occupy some of the mineralized fissures. Although the presence of a porphyry dike between the fissure walls is probably rightly considered a rather unfavorable condition because of choking of the fissure, the highly sericitized andesite is typical of the more productive veins and is an indication of the passage and chemical action of sulphide-bearing solutions. The relation of the different types of alteration to the formation of ore is discussed in more detail in following pages.

Bleaching of the andesite at the surface is also noticeable along the outcrops of veins or faults. Alterations of the sericitic and chloritic type in conjunction with the fracturing weaken the andesite so that it does not crop out. Silicified andesite, however, stands up in ridgelike outcrops or as prominent masses, and bodies of such resistant rock serve to indicate the position of fissured zones.

BONANZA LATITE

DISTRIBUTION AND STRATIGRAPHIC RELATIONS

The Bonanza latite was first so called by Patton,[17] who applied the name to the latite flows, possessing a

[17] Patton, H. B., op. cit., pp. 29–37.

prominent flow texture and containing inclusions of andesite, which overlie the andesites and underlie flows of hornblende-biotite latite. Patton's detailed description of the Bonanza latite applies strictly, however, only to the lower flow or series of flows of this formation. The name as here applied includes all the lavas that lie stratigraphically between the Rawley andesite and the Squirrel Gulch latite (the hornblende-biotite latite of Patton). Because of the different characteristics of the flows of the lower and upper parts of this formation, the Bonanza latite is divided in this report into a lower latite member and an upper rhyolitic member. As there is a significant change in the physical nature of the rock between the upper and lower members, which has a pronounced effect on fissure formation, these members have been mapped separately over parts of the region where they are both present and distinguishable.

The Bonanza latite is widely distributed in the central and northeastern parts of the district and extends south along Kerber Creek 7 or 8 miles below the town of Bonanza. In the northern part of the district the outcrops of flows of this group form the more conspicuous features of the local topography. (See pls. 4, *C*, and 7, *A*, *B*.)

The contact between the Rawley andesite and the massive lower flows of the Bonanza latite is well marked by the sharply defined differences in appearance of the lavas. Because of repetition by step faulting the exposures of this contact are found over a greater area than would be expected from the steep angle at which the lavas are tilted. The highest altitude which the Bonanza latite reaches in the district is on the crest of Round Mountain, the upper several hundred feet of which is composed of these flows. It also covers many of the tops and northern slopes of the ridges north of Alder Creek. In the Kerber Creek drainage area it crops out on all the spur ridges that separate the streams, from Bear Gulch to Elkhorn Gulch, and extends considerably west of Kerber Creek throughout this stretch. On the south side of Elkhorn Gulch for about a mile east of Kerber Creek the Bonanza latite flanks the intrusive Eagle Gulch latite on the north, but on much of the south side of this intrusive it is entirely missing in its characteristic development. West of Kerber Creek, however, it retains its characteristic features and can be traced for several miles south of the Eagle Gulch latite, but it lies west of the area mapped. The southernmost exposure west of Kerber Creek shown at the edge of the map is opposite the mouth of Greenback Gulch.

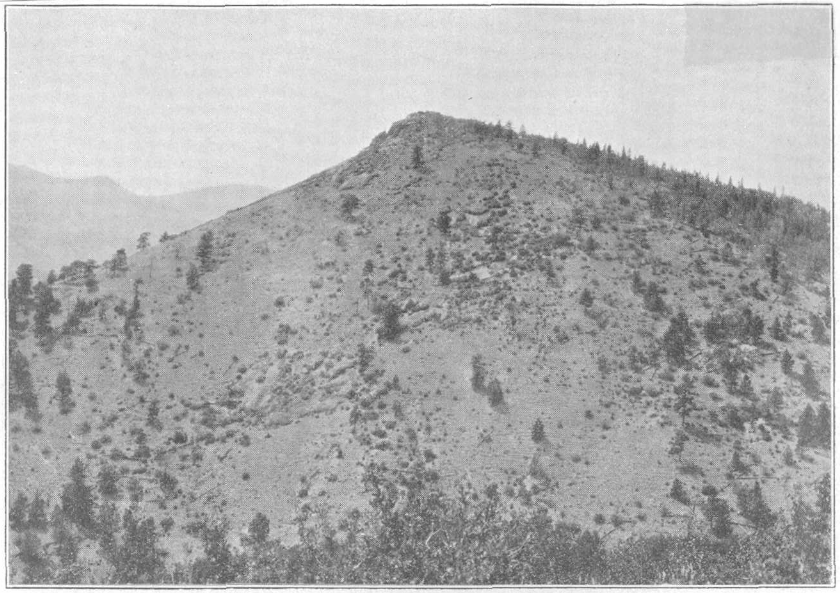
Although lying stratigraphically above the Rawley andesite, the Bonanza latite has been completely eroded from the top of the range between Round Mountain and Elkhorn Peak, owing to the arching of the formations over this region. That it once extended completely across this range seems to be certain, inasmuch as its base is found at an altitude of about 12,000 feet on Round Mountain, where it lies practically horizontal and forms the crest of the arch. The stratigraphic position of the Bonanza latite above the Rawley andesite and beneath the Squirrel Gulch latite, a sequence which was first recognized by Patton,[18] is entirely clear from the exposures in the northern part of the district. The Bonanza latite is also intruded by the Eagle Gulch latite and associated dikes, but its age relation to the Hayden Peak latite is obscured by the facts that it is not found in its characteristic development in the region covered by that formation and that the typical latites of the Hayden Peak region are also absent in areas in which the Bonanza latite is characteristically developed. At the southern base of Hayden Peak and on the ridges north of the peak there are a few thin flows of mica latite containing abundant inclusions and somewhat resembling the Bonanza latite in appearance. If these thin flows represent a great thinning of the Bonanza latite, this formation is older than the quartz latites and tuffs of Hayden Peak but younger than some of the latites that flank the northeast end of the Eagle Gulch latite at Elkhorn Peak. This suggests the possibility that the local Hayden Peak eruptions had begun and some flows had accumulated before the period of more widespread flows that formed the Bonanza latite and that the Hayden Peak eruptions continued for some time afterward.

The source of the Bonanza latite is not known, and it is perhaps not unlikely that the lower and upper members as defined had entirely different sources. In some respects the upper member, because of its rhyolitic composition and light color, more nearly resembles some of the more latitic rhyolites of the Porphyry Peak eruptions than it does the lower member. The two members are, however, difficult to distinguish where much altered.

THICKNESS

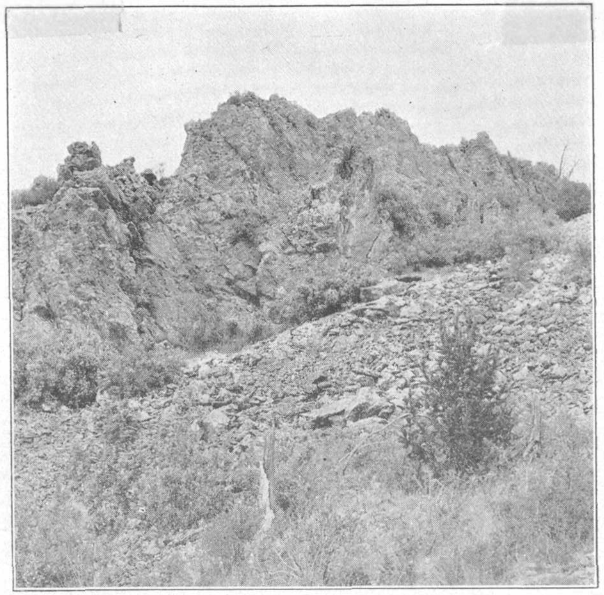
The total thickness of the Bonanza latite is not constant throughout the district, nor are both members everywhere present. The thickest development of this series seems to be on the ridge between Copper and Elkhorn Gulches, where the upper member, if present, has not been differentiated. An accurate estimate of the thickness could not be made in this area, as the faulting is more complicated than can be shown on the map. The thickness can not be less than 500 feet,

[18] Patton, H. B., op. cit., p. 60.



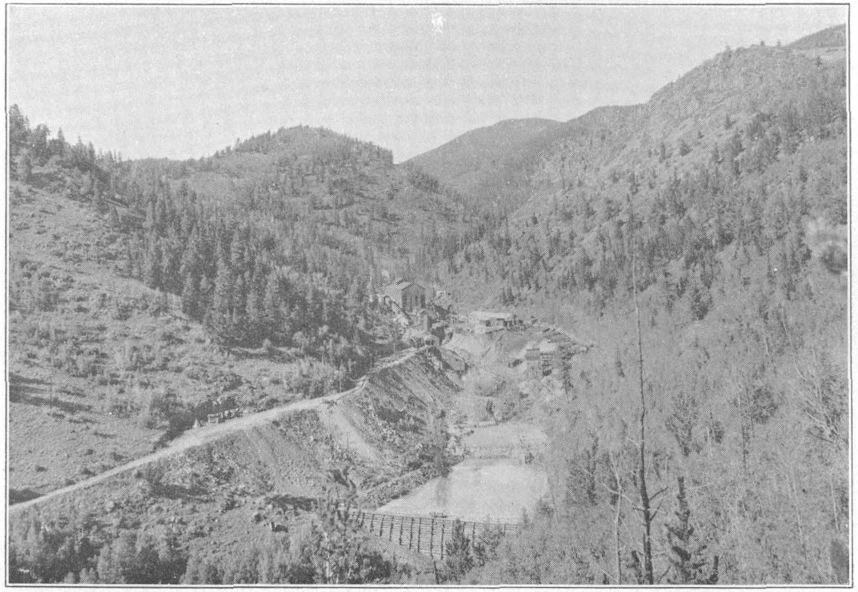
A. CONICAL HILL JUST EAST OF KERBER CREEK BETWEEN GREENBACK AND CHLORIDE GULCHES

Viewed from the southeast. This hill is composed largely of the altered rocks of the Greenback Gulch volcanic neck and is capped by a large mass of silicified rock formed by solfataric action.



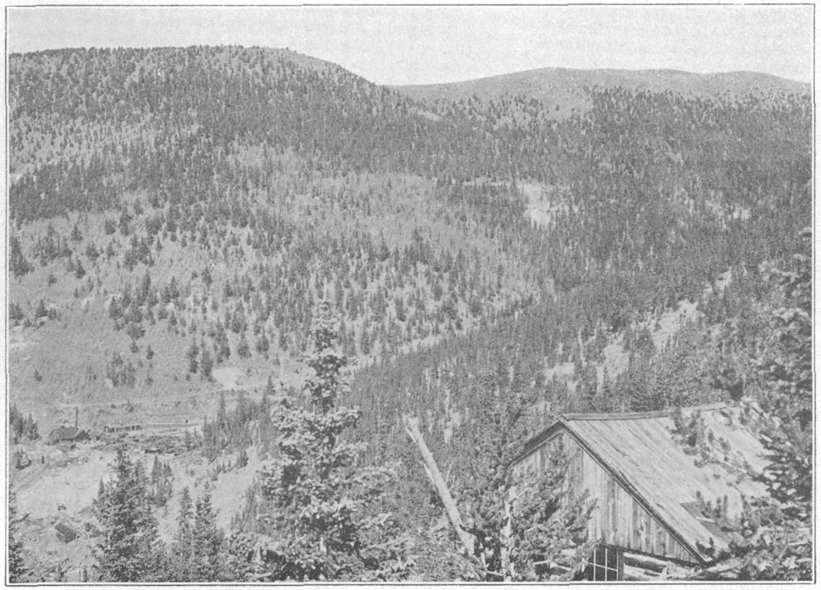
B. CLOSE VIEW OF ONE OF THE SILICIFIED ROCK MASSES FORMING A SHARP RIDGE ON THE SOUTH SIDE OF GREENBACK GULCH

Plate 10, *A*, *B*, shows the nature of part of the rock forming this ridge.



C. VIEW LOOKING NORTH UP SQUIRREL GULCH

Shows Rawley mill at portal of Rawley drainage tunnel. All the ridges in view are formed of westward-tilted Bonanza latite, repeated by faulting.



D. VIEW FROM POINT NEAR HANOVER MINE LOOKING NORTH ACROSS RAWLEY GULCH

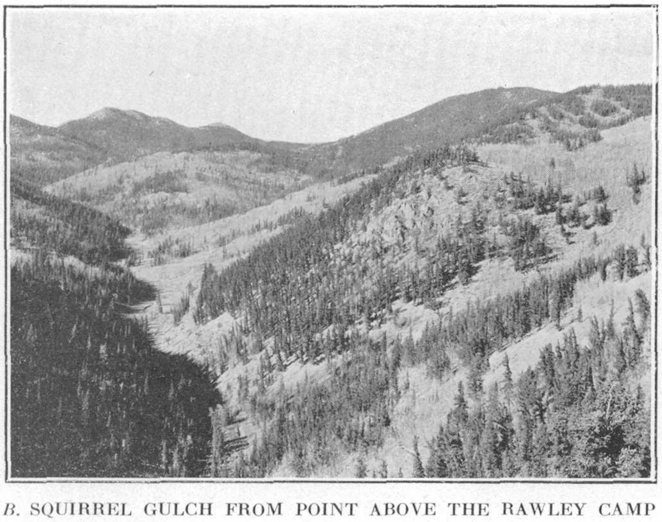
The portal of the Rawley 300 level adit is in the bottom of the gulch. Halfway up the slope on the extreme left is the portal of the Antoro tunnel and in the central part the dumps of the Michigan tunnels.

A. DETAIL OF OUTCROP OF STEEPLY TILTED BONANZA LATITE SHOWN IN *B*

The sheeted structure parallels the flow lines, although several of the shearing planes cut across this structure at a small angle.

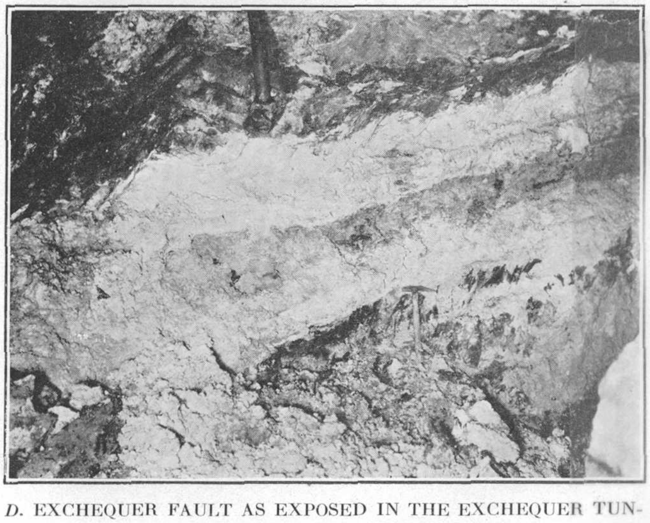
C. PARTLY ALTERED BONANZA LATITE, COCOMONGO MINE

Differential alteration has accentuated the flow structure.



B. SQUIRREL GULCH FROM POINT ABOVE THE RAWLEY CAMP

An outcrop of a tilted fault block of Bonanza latite is seen at the right center. The high peaks near the head of the gulch consist of the Porphyry Peak rhyolite.



D. EXCHEQUER FAULT AS EXPOSED IN THE EXCHEQUER TUNNEL, KERBER CREEK

The view is taken along the strike of the fault and shows the low angle of easterly dip. White material filling the fault fissure is sericitized gouge.

however, and may be several hundred feet more than that.

Throughout the district the lower member ranges approximately from 300 to 500 feet and the upper member, where present, from a knife-edge to 400 feet. The total thickness of the two members certainly does not exceed 1,000 feet at any place in the district.

PETROGRAPHY

Lower member.—The lower member of the Bonanza latite forms many massive outcrops and talus slopes in the district; a typical one occurs near the Rawley camp on Squirrel Gulch. Near the base and upper portions of the bed the flow structure is generally developed to the greatest degree, but the middle part is in many places rather massive. A parting or cleaving is developed in much of the rock parallel to the flow lines, causing it to break into platy blocks. The surface of the rock weathers to a brown or brownish gray, bringing out the flow lines very distinctly, so that the curvature of these lines around included fragments may be readily seen. On freshly broken surfaces of the rock the flow structure is as a rule hardly noticeable, and the contrast between included fragments and the mass of the rock so well shown on slightly altered or weathered surfaces is largely lost.

The normal facies of the Bonanza latite are greenish-gray to blackish-gray rocks. The groundmass is greenish to nearly black and very fine grained, or partly glassy and contains abundant phenocrysts of plagioclase and orthoclase from 0.5 millimeter to 2 millimeters in length. When cleaved parallel to the flow lines, surfaces of the rock show abundant green to brown plates of biotite 2 to 3 millimeters in diameter, with hexagonal or more irregular outline. Some of the darker rocks are andesitic in habit but may generally be readily distinguished from the andesites by the abundance of these mica flakes. One of the most characteristic features of the rock, which readily serves to distinguish it where well developed, is the presence of angular inclusions of latite and andesite. These inclusions vary in abundance. Those of latite are irregular in distribution and may occur in any part of this flow or the overlying flows, but the andesite inclusions appear to be confined to the lower parts of the Bonanza latite and near its base may be very abundant and as much as 6 inches or 1 foot in diameter. In the Cocomongo mine, where the contact between the Bonanza latite and the breccia bed of the Rawley andesite is exposed, the relation between the included andesite fragments and the base of the flow is readily seen. Near the base the penetration of the breccia by the fluid latite and the lifting up of the breccia fragments into the overlying flow are well shown. At the very base large fragments of the andesite breccia are caught up into the latite, but at 20 to 30 feet above the base in a crosscut the fragments are small and less abundant. Small andesite fragments may have readily been carried to the upper parts of the flow, but abundant large andesite fragments are characteristic of its basal portion. The angular latite fragments that are also abundant in the flow at some localities may have been derived from brecciation of cooled portions of the flow or from brecciation of bodies of latite prior to extrusion upon the surface. That the latter explanation is true for at least some of the inclusions is supported by the occurrence of fragments of pre-Cambrian rocks in the latite at a few places and by the occurrence of latite inclusions near the contacts of some intrusive bodies of latite of similar character to the Bonanza latite. The molten latite lava probably possessed some physical characteristics of fluidity or viscosity that enabled it to readily pry away and carry off fragments of brecciated rock with which it came into contact. The fairly uniform size of many of the inclusions in certain parts of the flow was apparently governed by the carrying and lifting power of the fluid lava, as seems to have been demonstrated by the occurrence in the Cocomongo mine.

Microscopic study of the Bonanza latite shows the greater part of the feldspar crystals to be andesine (An_{45-50}), orthoclase being present in less abundance. Quartz occurs locally as rounded crystals but is only rarely noticeable in specimens. The biotite is generally altered to chlorite, calcite, and magnetite, and in more altered rocks the plagioclase feldspar is changed to albite. The groundmass is partly glassy or submicroscopic in some rocks and contains plagioclase, orthoclase, and quartz. Quartz is so abundant in the groundmass of some of the specimens that the rocks can be called quartz latites. Whether the average composition is that of quartz latite is not known, but microscopic study of several specimens indicates a composition intermediate between that of quartz latite and that of normal latite.

Analysis of Bonanza latite [19]

[Analysts, George Rohwer and E. Y. Titus. Phenocrysts of orthoclase, plagioclase, and biotite. Constituents of groundmass not recognizable except magnetite. Secondary sericite and calcite]

SiO_2	58.04	K_2O	4.17	SO_3	None.
Al_2O_3	17.89	H_2O-	.09	Cl	0.02
Fe_2O_3	2.17	H_2O+	1.70	S	None.
FeO	2.41	TiO_2	.49	MnO	.12
MgO	1.55	ZrO_2	.12		
CaO	4.54	CO_2	3.35		100.46
Na_2O	3.37	P_2O_5	.43		

Upper member.—The upper member of the Bonanza latite at the Cocomongo mine can be described only in a general way, because it does not generally form prominent outcrops like the lower member but

[19] Patton, H. B., The geology and ore deposits of the Bonanza district, Colo.: Colorado Geol. Survey Bull. 9, p. 44, 1916.

breaks up readily on weathering, forming a fine soil. The most favorable exposures of it occur on the ridge between Bear Gulch and Squirrel Gulch and west of Squirrel Gulch, where it overlies the lower latite member, but even here the outcrops are not prominent, and weathered fragments on the surface are of most value for recognizing the rocks. Weathered fragments are generally gray to nearly white or pinkish white, and many of them are extremely porous and pitted, owing to the formation of lens-shaped cavities an inch or two long, arranged roughly parallel to the flow lines. So far as known inclusions are not common in the upper member, although they are found at some localities. The lavas are porphyritic with small feldspar phenocrysts, biotite appearing to be less common and in much smaller flakes than in the lower member and in general completely altered. Individual flows are not distinguishable, although near the upper part of the member the presence of several different flows is indicated by variations of texture and the occurrence of breccia beds or tuffs of local distribution.

Microscopically the upper member is clearly distinguished from the lower latite. Orthoclase phenocrysts are much more abundant than plagioclase and are usually only from 0.5 to 3 millimeters in length. They are clear and glassy except that they may be partly altered to sericite along cracks. The plagioclase is andesine and nearly always cloudy. A few quartz crystals, either cracked or with rounded outlines, are usually present. Biotite occurs in very small flakes and where fresh is strongly pleochroic from dark brown to yellowish; but it is nearly everywhere altered to a colorless mica. The groundmass contains quartz arranged in streaks parallel to the flow lines. Some evidence of an original spherulitic texture is seen in some sections. The rock is probably nearer rhyolite than quartz latite in composition, but its chemical composition has not been determined.

RELATION TO ORE DEPOSITS

The Bonanza latite is next to the Rawley andesite in importance as the country rock of ore bodies in the district. The largest deposit so far developed in it is in the lower member at the Cocomongo mine, on Kerber Creek. The lower member of the Bonanza latite consists of one or several massive beds which fracture under certain conditions, so that the fissures formed in this rock compare favorably with those in the Rawley andesite. Although the lower flows possess a distinct parting parallel to the flow planes, such partings are usually best developed at the top and base of the flows, the center being more massive. Where a bed is tilted to an angle of 50° or more these closely spaced partings tend to interfere with the formation of simple fractures and fissures, unless the fissure plane is at an oblique angle to the strike of the beds. Faults striking parallel to the partings form tight shear zones rather than fissures. Many such shear zones in steeply tilted latite may be seen along the upper part of Squirrel Gulch, where the fault blocks strike essentially north and are tilted to angles of 40° to 80°. Although alteration of the sericite and carbonate type with the formation of minor amounts of quartz and sulphides has occurred along some of the north-south fissures in this region, none of them have yielded economically important quantities of ore. Several of the larger well-mineralized fault fissures in this formation along Kerber Creek cut the latite obliquely to the strike—the Cocomongo at an angle of about 40°, the Bonanza vein at angles of 50° to 80°, and the Memphis and Baltimore veins nearly at right angles.

The upper rhyolite member of the Bonanza latite, on the other hand, is a soft cleavable rock which is distinctly unfavorable to simple fissuring. No large veins were seen in this member, and so far as known there has been essentially no production from veins in it. This may be due partly to the fact that it lies mainly outside of and flanks the main zones of ore deposition. However, it crops out on the slopes west of Kerber Creek near the town of Bonanza, where there is considerable fissuring and strong alteration, but little ore has been discovered in it near the surface. The mechanical influence of rocks on fissure veins has been observed at other places in the San Juan Mountains—for example, the unfavorable effect of the rhyolite of the Potosi volcanic veins on strong fissures in the underlying andesites of the Telluride district. (See p. 92.)

Alteration near ore deposits in the Bonanza latite is similar mineralogically to that in the Rawley andesite. There is, however, some difference in the appearance of altered andesite and altered latite. Silicification, sericitization, and chloritization are all common in latite near ore. Silicified latite usually contains less red ferric oxide than andesite, but this distinction is not always reliable, as some silicified andesite is comparatively light colored. Most of the silicified latite is of gray, greenish, or white color and may have partly retained the original flow texture. Like silicified andesite, it is a very hard rock and difficult to drill. In some places silicification has worked outward from parting planes in the latite. Where replaced by sericite, chlorite, and calcite, the latite is bleached and softened, forming a very weak wall rock. Alteration of this type is well illustrated in the Cocomongo mine, where the altered Bonanza latite is of a greenish color, the feldspars are altered to a mass of sericite, the groundmass is partly replaced by calcite, sericite, chlorite, and pyrite, and the biotite is altered to white mica and rutile. This rock has little strength, and in parts of the mine where this alteration predominated over silicification the walls of open workings will not stand unsupported for any great length of time.

SQUIRREL GULCH LATITE

GENERAL CHARACTER AND DISTRIBUTION

The Squirrel Gulch latite is characterized by massive flows of hornblende-biotite latite, which are most prominently developed in the upper part of Squirrel Gulch and on north-south ridges west of Kerber Creek in sec. 23, T. 47 N., R. 7 E. Beds of this lava form rather prominent outcrops weathering to a yellowish-brown surface on which the slender black hornblende crystals are conspicuous. Where the flow is interbedded with more easily weathered latites it stands above the surface, forming a ridgelike outcrop. The direction of the columnar jointing where well developed serves to give the approximate dip of the flows where they are tilted, as the hexagonal columns stand nearly perpendicular to the surface of the flows.

At the very base of the Squirrel Gulch latite in the northern part of the district there occurs a thin dark-gray to nearly black flow of latite of similar appearance to the glassy portion of the normal latite, but it lacks the columnar jointing and has a flow structure parallel to its top and base. This bed is not more than 15 or 20 feet thick and is not everywhere present. In the central and southern parts of the district this basal bed is absent, and west of Kerber Creek below Brewer Creek latites corresponding to this series exhibit characteristics somewhat similar to those of the overlying Brewer Creek latites. The hornblende is less prominent or absent, and large mica flakes are more conspicuous. Here the division between the Squirrel Gulch latite and the Brewer Creek latite is difficult to make and is based largely on the more glassy, dense, and dark-colored groundmass of the Squirrel Gulch flows, in contrast to the typical reddish Brewer Creek latite.

North of the west branch of Kerber Creek in sec. 14, T. 47 N., R. 7 E., the Squirrel Gulch latites are overlain by the white rhyolitic lavas of the Porphyry Peak rhyolite, but just south of the creek the rhyolites wedge out and the Squirrel Gulch latite is directly overlain by the Brewer Creek latite. These stratigraphic relations are shown diagrammatically in Figure 3. In the northern part of the district hornblende latites are interbedded in places with the Porphyry Peak rhyolite, but the details of the relation between the two formations are much confused by faulting.

The Squirrel Gulch latite in the Bonanza district is confined so far as is known to a narrow zone in the western part of the area mapped on Plate 1, extending from the east side of Porphyry Peak, near the head of Squirrel Gulch, southward to the Eagle Gulch latite near Kerber Creek. Within this zone of exposures the flows everywhere dip west at angles ranging from nearly horizontal to as much as 60°.

The Squirrel Gulch latite is found along Little Kerber Creek above Columbia Gulch, several miles south of the district, and may possibly be more or less continuous between that locality and the exposures within the area mapped, but the outcrops have not been traced.

The thicker individual flows of the Squirrel Gulch latite probably exceed 100 feet in thickness and may attain 200 feet on the ridge west of Squirrel Gulch. The formation ranges between 300 and 500 feet in total thickness and hence consists of only a few flows, but the exact number at any place was not determined.

No ore deposits are known to occur within this formation, but it is altered and bleached where it is intersected by faults and fissures. The absence of ore deposits within it is probably due to its position in the western part of the district, outside of the area of strongest mineralization.

PETROGRAPHY

The typical hornblende-biotite latite has been described by Patton,[19a] who also gave a chemical analysis (shown in the accompanying table) supporting its classification as a latite. The rock is glassy, has a black color, and is generally characterized by a pronounced vertical columnar jointing perpendicular to the top and bottom surfaces of the flow and similar to that occurring in basaltic rocks. The columns are commonly 5 or 6 inches in diameter and are generally five or six sided. The rock is porphyritic, with plagioclase, hornblende, and biotite phenocrysts. The feldspar and hornblende crystals are conspicuous and may be as much as 10 millimeters in length. The hornblende occurs in long, slender prisms with well-developed cleavage. Biotite is less prominent but can be recognized in shiny brownish-black flakes from 1 to 4 millimeters in diameter. The groundmass is dense and black and has an irregular fracture and a somewhat greasy appearance.

Analysis of hornblende-biotite latite (Squirrel Gulch latite)[20]

[Analysts, George Rohwer and E. Y. Titus. Phenocrysts of labradorite, hornblende and biotite; hyalopilitic groundmass with plagioclase microlites and magnetite]

SiO_2	58.10	K_2O	3.88	SO_3	0.3
Al_2O_3	18.72	H_2O-	.92	Cl	.01
Fe_2O_3	2.01	H_2O+	1.99	S	None.
FeO	2.64	TiO_2	.90	MnO	.10
MgO	1.12	ZrO_2	Trace.		
CaO	5.37	CO_2	.81		99.99
Na_2O	3.09	P_2O_5	.06		

[19a] Patton, H. B., Geology and ore deposits of the Bonanza district: Colorado Geol. Survey Bull. 9, pp. 40–42, 44, 1916.

[20] Idem, p. 44.

Microscopic study of a specimen collected from the ridge west of Kerber Creek in sec. 23, T. 47 N., R. 7 E., shows the lava to be perfectly fresh, with phenocrysts of labradorite, brown hornblende, biotite, and a pale-greenish augite, named in the order of abundance. The pale-green augite is not recognizable in the hand specimen. The groundmass is a brownish glass with abundant narrow plagioclase laths, which in some specimens exhibit a flow structure, an arrangement typical of certain varieties of trachytic lavas.

Where exposed on the knoll between the branches of Brewer Creek in sec. 35, T. 47 N., R. 7 E., both hornblende and biotite are present in the latite, but the hornblende is much less conspicuous. The lava forming the crest of the knoll is bluish gray and contains abundant plagioclase phenocrysts 5 to 10 millimeters in diameter and prominent mica flakes 4 or 5 millimeters in diameter. The rock weathers to a rusty-brown color and breaks into large angular or platy blocks from a few inches to several feet in diameter. Here the columnar jointing is on relatively gigantic proportions, as the columns are 5 to 6 feet in diameter and also possess a parting parallel to the dip of the flow. This exposure is fairly typical of the latite in the southern part of the district.

PORPHYRY PEAK RHYOLITE

GENERAL CHARACTER AND STRATIGRAPHIC RELATIONS

The Porphyry Peak rhyolite, named from its typical exposures on the slopes of Porphyry Peak (pls. 2 and 6, *B*), is found only in the northwestern part of the district. This formation consists of a complex series of rhyolite flows and interbedded tuffs and probably includes some intrusive rhyolite. The structural relations and sequence of flows in the formation is much complicated by faulting and local tilting and has not been determined. In places the lower flows dip as much as 50°, and there is little uniformity in their strike. The base of the formation is well exposed on the conical mountain near the east line of sec. 14, T. 47 N., R. 7 E. Here the lower lavas consist of thin whitish rhyolite flows having a flow texture and containing numerous lenticular gas cavities. They overlie the Squirrel Gulch latite and dip 30°–40° W. The lower individual flows are comparatively thin, some of them appearing to be less than 100 feet in thickness. These lower flows can be traced southward to a point near the west branch of Kerber Creek, a little south of the south line of sec. 14, where the rhyolites wedge out, so that the overlying Brewer Creek latite lies directly upon the Squirrel Gulch latite.

The upper part of the Porphyry Peak rhyolite is best exposed on the slopes of Porphyry Peak and on the large flat-topped mountain to the south. Tuffs, breccias, and rhyolite pitchstones occur here interbedded with the normal grayish-white rhyolite lavas. The rhyolite on East Porphyry Peak, which lies just north of the area mapped, splits into thin slabs, and the flow lines are much contorted. The rocks of this formation extend north and west of Porphyry Peak beyond the limits of the map and probably into the valley of Silver Creek, but the boundaries of the formation are not known. It is presumed, however, to be a local accumulation about some concealed rhyolite neck, such as the one near Greenback Gulch but probably of larger size. The evidence of intense solfataric alteration in places on the large flat-topped mountain south of Porphyry Peak is an indication of some subjacent fissures or vents within this series.

Because of the complicated structural relations of the rocks the total thickness of rhyolite is not known, but at least 1,000 feet is exposed within the Bonanza district.

PETROGRAPHY

Rhyolite.—The petrography of the Porphyry Peak rhyolite has been described in some detail by Patton,[21] who gives the chemical analysis reproduced below.

The lower part of the formation where it overlies the Squirrel Gulch latite on the ridges west of Squirrel Gulch consists of lavas having a pronounced flow structure with small crystals of glassy orthoclase (1 to 4 millimeters) and prominent flakes of brownish-black biotite (1 to 2 millimeters) in a gray, grayish-white, or brownish-gray groundmass. Quartz does not occur as a phenocryst in these lower flows, but quartz and orthoclase are the major constituents of the groundmass. Some of these lower flows contain a few phenocrysts of oligoclase-andesine. Small lenticular flat gas cavities are present in some of the beds. These basal flows are more latitic in composition than the upper flows of the series but should nevertheless be classified as rhyolites.

The upper part of the Porphyry Peak formation is best exposed on East and West Porphyry Peaks, at and beyond the northern edge of the area shown on the map. The rhyolites exposed here are light gray to nearly white, and on East Porphyry Peak they have a very pronounced flow structure. The rhyolite splits in very thin slabs a foot or more in diameter. The dips and strikes of the flow planes are not constant but curve in an irregular manner.

Microscopic examination shows that the upper members of this formation are typical rhyolites. Both quartz and clear glassy orthoclase (sanidine) occur as phenocrysts, usually not over 1 to 2 millimeters in

[21] Patton, H. B., op. cit., pp. 23–27.

length, but locally the orthoclase may reach 4 millimeters. Quartz is less common than orthoclase in the flows. Biotite occurs in small fresh flakes with a strong pleochroism from yellowish to dark brown. Plagioclase is entirely lacking as phenocrysts in the upper members, but it may be present in some of the indeterminable intergrowths in the groundmass.

The groundmass of the lavas ranges in texture from granular quartz-orthoclase intergrowths of a poikilitic nature to spherulitic intergrowths and perlitic obsidian. Quartz and orthoclase are the only recognizable constituents of the groundmass, except that a little tridymite was noted in one flow. The quartz in the groundmass may be partly concentrated in lenslike streaks parallel to the flow lines. The borders of these streaks are intergrown with prismatic crystals of orthoclase which lie irregularly distributed in the quartz. In other lavas the quartz and orthoclase occur in radial spherulitic intergrowths, in which the orthoclase forms thin radiating prisms. Some of the spherulitic structures are so small that the nature of the minerals forming them can not be determined.

The chemical analysis given by Patton represents a rhyolite from the ridge running southwest from the summit of East Porphyry Peak and is reproduced in the accompanying table. According to Patton this rock has a strong flow structure and contains phenocrysts of sanidine, also a very few small biotite crystals but no quartz phenocrysts.

Analysis of a rhyolite flow from the Porphyry Peak rhyolite[22]

[Analysts, George Rohwer and E. Y. Titus]

SiO_2	71.57	K_2O	5.56	MnO	Trace.
Al_2O_3	16.84	H_2O-	.28	Cl	Trace.
Fe_2O_3	.63	H_2O+	1.06	SO_3	None.
FeO	.07	TiO_2	.34	S	None.
MgO	.29	ZrO_2	.05		
CaO	.31	CO_2	Trace.		100.05
Na_2O	3.05	P_2O_5	None.		

Rhyolite obsidian.—Greenish, yellowish, brown, and nearly black rhyolite obsidians are found among the rocks of the Porphyry Peak rhyolite. Some of the brown obsidian appears to be in the form of thin intrusive bodies or dikes along the southeast base of Porphyry Peak. Other varieties, such as the greenish obsidians, occur either as portions of larger flows or at their surfaces. Black obsidian containing spherulites is found as a flow on the ridges south of Porphyry Peak, and occurs probably in about the middle part of the series.

These rocks have not been studied petrographically in much detail, but a few sections made show the presence of a few small orthoclase crystals and less common plagioclase and biotite. The texture of the brown obsidian is somewhat perlitic. There are all gradations between the obsidians and the crystalline groundmass of some of the rhyolites.

Rhyolite tuff.—Rhyolite tuffs are found on Porphyry Peak and on the ridge north of it, beyond the area mapped. The tuffs are white or gray and contain fragments of rhyolite lava, obsidian, and fragmental crystals of orthoclase and quartz. Some of the quartz is in rounded grains. The fragments are cemented with quartz, opal, and fine amorphous material.

[22] Patton, H. B., op. cit., p. 25.

ALTERATION AND MINERALIZATION

Although no deposits of ore of commercial importance have been found in the rhyolite, many parts of the rhyolite series are intensely fissured and altered. The most common alteration was of a solfataric nature, in which the rhyolite was completely altered to granular quartz and alunite. This alteration was the most intense on the road to Mears and Silver Creek, on the west slope of the large flat-topped mountain near the center of sec. 11, T. 47 N., R. 7 E. At this locality the rhyolite is completely silicified over areas 1,000 feet or more in extent. Although the structural relations were not worked out in detail, it is fairly certain that some of the rhyolite on these slopes is of intrusive origin. The alteration was probably related to some fissure or neck through which rhyolite lavas were extruded.

At the east base of Porphyry Peak the contact between the rhyolite and the older lavas is faulted, and bodies of intrusive rhyolite and breccia along the contact are silicified. At many other places where there is fault contact between the rhyolites and other lavas bodies of gray or white silicified rocks are found, but the only vein material seen was barren quartz, with a little pyrite and limonite.

On the east slope of the mountain in the western part of section 12 there is a strong northeastward-trending fault within the rhyolite. The fault is poorly exposed, but springs emerge along some parts of the fault line and deposit limonite.

HAYDEN PEAK LATITE

GENERAL CHARACTER AND STRATIGRAPHIC RELATIONS

The Hayden Peak latite consists of two overlapping series of flows, largely of local origin, occurring in their greatest development in the southeastern part of the district between Hayden Peak and Elkhorn Peak. As the lavas of this series have been greatly eroded, with the exception of the remnants near Hayden Peak, their original extent, thickness, and source can not be determined. The Hayden Peak latite is younger than the Rawley andesite and lies directly upon it near the southwest base of Hayden Peak. Two divisions of the Hayden Peak formation can be recognized—an older one with its thickest development on the ridges just south of Elkhorn Peak and a younger one with its greatest development on Hayden Peak. The older latites thin abruptly southward and underlie the younger latite beds on the south and west sides of Hayden Peak. The older series of lavas consists of dark-colored porphyritic rocks of latitic composition, some of which resemble andesites, and contains interbedded flows with inclusions of porphyritic latite. Because many of the flows in this series are entirely different from those of any other formation in the district, the series is believed to be composed largely of flows from some local volcanic vents. The younger series of flows, which have their principal exposures on the slopes of Hayden Peak, are light-colored fine-textured latite and quartz latites with interbedded bodies of latitic tuff and breccia. The abrupt changes in stratigraphy found within this series further suggest accumulation about some local volcanic vent or the occurrence of faulting and erosion during their eruption. Several thin flows resembling the Bonanza latite, but not all typical of it, lie between the lower and upper series and suggest the possible correlation of this middle horizon with the Bonanza latite, but because of the entirely different nature of the associated lavas and the lack of definite correlation, it was considered preferable to map the entire series as a local formation. The Hayden Peak latite has therefore been made to include a greater thickness of beds than was originally assigned to it by Patton,[23] who mapped the lower members of this formation as andesite and Bonanza latite.

The Eagle Gulch latite is intruded beneath the lower flows on Elkhorn Peak, and they are consequently sharply tilted toward the southeast. The flows on Hayden Peak are also tilted southward with dips ranging from 30° to 45°. The relations of the Hayden Peak latite to the Eagle Gulch latite and the Rawley andesite, with which it is in contact, are further complicated by faulting. Local fault blocks of latite of the Hayden Peak formation are found within the andesite for several miles south and west of Hayden Peak. The lavas doubtless extend east and southeast of Hayden Peak and Elkhorn Peak for some distance beyond the region mapped.

The greatest thickness of the lower series of lavas is exposed on the west slope of the high peak lying south of Elkhorn Peak. They extend from their lower contact to about the 11,700-foot contour on the west slope of this peak, where they are overlain by a series of lighter-colored latites corresponding to some of the lower latites on Hayden Peak. At this position the lower latites appear to be from 500 to 800 feet thick. On Hayden Peak the upper latites may be divided into three members—a lower series of latite flows several hundred feet thick, a middle tuff member which is apparently a lenticular body with a maximum thickness of several hundred feet, and an upper series of quartz latite flows occupying the crest of Hayden Peak at least 500 feet thick. As the flows of this formation overlap and change in thickness, the total or average thickness of the formation is difficult to estimate. Doubtless a considerable thickness of flows has been eroded from above the highest lavas on the crest of Hayden Peak. The thickness of the flows remaining in this region is probably not less than 1,500 feet.

[23] Patton, H. B., op. cit., pp. 38–40, pl. 1.

PETROGRAPHY

The lower latites of the ridge south of Elkhorn Peak are greenish-gray to brown or reddish-brown rocks having conspicuous phenocrysts of greenish-white feldspar from 1 to 5 millimeters in size. Most of them contain only a few small specks of altered biotite. The groundmass of the rocks is usually dense or felsitic and in some flows shows a weakly developed flow banding. There are a few greenish-gray flows exhibiting a well-developed flow structure and containing inclusions of other rocks. They are similar to some flows underlying the latite on Hayden Peak and are similar in texture to the Bonanza latite.

Microscopic examination shows the lower flows to consist of true latites, quartz latites, and calcic andesitic latites. The true latites contain phenocrysts of andesine or oligoclase but usually none of orthoclase. Biotite is invariably present but commonly altered to muscovite and epidote. The groundmass is submicroscopic or fine grained and consists of an intergrowth of sodic plagioclase, orthoclase, and quartz. The rocks are very much altered, presumably because of their position above the intrusive Eagle Gulch latite, and they contain secondary epidote, chlorite, quartz, and calcite. Some lavas contain hematite in the groundmass and have a reddish-brown color.

The quartz latite contains abundant clear phenocrysts of orthoclase, many of which are broken and fragmental. Plagioclase phenocrysts are less common and are usually andesine. The groundmass consists largely of orthoclase and quartz with some plagioclase. Biotite is largely altered to white mica. Sericite and calcite are common alteration products.

The more calcic latites have phenocrysts of labradorite (An_{55}). The groundmass is brown and very fine or submicroscopic in texture; it contains some orthoclase but only a small amount of quartz. The biotite is usually altered to epidote and muscovite. Magnetite and apatite are common as accessory minerals.

Some of the lavas contain much secondary epidote, chlorite, and quartz.

The latites on Hayden Peak and in the down-faulted blocks along Chloride and Greenback Gulches are typically fine-grained, inconspicuously porphyritic rocks of gray, blue-gray, or brownish-gray color. Phenocrysts of both orthoclase and plagioclase are numerous but are rarely larger than 1 or 2 millimeters. In some of the rocks the orthoclase has a slightly pinkish color. Biotite occurs in small rounded flakes or rectangular plates 0.5 to rarely 1 or 2 millimeters in length. The groundmass is fine or dense and usually structureless but shows a flow banding at a few localities. A platy fracture is developed in the quartz latite on the crest of Hayden Peak, but the fracture planes strike and dip in various directions and apparently bear no constant relation to the attitude of the flow. On Hayden Peak the lavas form talus slopes with some rock flows or landslide masses.

Microscopic examination of the flows at the base of Hayden Peak shows that they contain orthoclase and altered plagioclase, usually near albite in composition. Epidote, sericite, and calcite are common as alteration products of the feldspars. The biotite is as a rule partly or entirely altered to chlorite. The groundmass is very fine grained and clouded, so that the determination of its constituents is difficult. It contains only a little quartz and appears to consist largely of sodic plagioclase and orthoclase. Magnetite and apatite are accessory minerals.

The lava on the crest of Hayden Peak, as seen under the microscope, proves to be less altered and to contain phenocrysts of orthoclase and andesine ($An_{40\pm}$). The plagioclase is slightly zonal and is usually mantled with oligoclase-andesine. Some of the orthoclase has a mottled appearance, due to intergrowth with sodic plagioclase. The groundmass contains abundant quartz, nearly 25 per cent in some specimens, intimately intergrown with orthoclase and forming irregular poikilitic patches. Some sodic plagioclase is present. Magnetite, apatite, and hematite are accessory minerals. This lava on the crest of Hayden Peak is clearly a quartz latite and is nearer to rhyolite in composition than the other latites.

The latitic tuff occurring on the west slope of Hayden Peak and the north slopes of North Hayden Peak is a bluish-gray, yellowish, or nearly white rock. In places it is rather fine, with uniform angular fragments 0.5 to 5 millimeters in diameter, but with less common larger fragments measuring several inches. The fine fragments contain no feldspars, but the larger ones are porphyritic and are similar in texture and composition to the flow rocks. Coarse agglomeratic beds occur here and there.

RELATION TO ORE DEPOSITS

Ore deposits of importance have not been discovered within the lavas of the Hayden Peak formation, yet they are cut by many veins and altered fissure zones. Many of the veins seen in this formation consist mostly of barren quartz, with some manganese oxides, probably derived from the oxidation of rhodochrosite. The lack of strong mineralization within the latite on Hayden Peak is probably due to the high position of this formation in the lava series and its distance from the center of mineralization rather than to any unfavorable characteristics of the rock itself. Evidence of both silicification and sericitization of the latite is to be seen where the rock is fissured. The lavas are also epidotized near contacts with the intrusive Eagle Gulch latite.

BREWER CREEK LATITE

DISTRIBUTION AND STRATIGRAPHIC RELATIONS

The Brewer Creek latite is named from its typical exposures north of Brewer Creek and westward along its course. Within the mapped area it is confined to a belt along the western edge of the district, extending from a point near Mosquito Creek at the north southward along the west side of Brewer and Kerber Creeks to the vicinity of the Eagle Gulch latite. The latite crops out intermittently for several miles along Brewer Creek west of the area mapped, its exposures alternating with those of the overlying andesite probably because of complex step faulting like that within the district. As far north as the west branch of Kerber Creek in sec. 14, T. 47 N., R. 7 E., the Brewer Creek latite lies directly on the lavas of the Squirrel Gulch latite, but farther north it lies upon the Porphyry Peak rhyolite. It is overlain on Brewer Creek by a series of andesite flows similar to those of the Rawley andesite but of later age. In section 35, south of Brewer Creek, there is a series of gray or white rhyolitic lavas and tuffs of undetermined relations. These lavas are provisionally mapped with the Brewer Creek latite, although they probably either represent a local body of rhyolite or are fault blocks of some rhyolitic lavas of different age. Nearly everywhere within the district the Brewer Creek latite is tilted westerly at angles ranging from a few degrees to 40°, and its outcrops are repeated by step faulting.

The Brewer Creek latite appears to extend considerably south of the area shown on the Bonanza map, at least as far as Little Kerber Creek. On this creek, about 2 miles up from its junction with Kerber Creek, lavas resembling the Brewer Creek latite in general appearance overlie glassy hornblende latites with prominent columnar jointing. This occurrence agrees with its stratigraphic position on Brewer Creek, where it overlies hornblende-biotite latites (Squirrel Gulch latite).

The thickness of this formation is probably at least 500 feet, though tilting and complex faulting prevent more than an approximate determination.

PETROGRAPHY

The typical Brewer Creek latite is a porphyritic quartz-mica latite, usually of purplish-gray or brownish-gray color but in places of a darker brick-red, and on the whole gives the impression of being much oxidized and altered. The series of flows of which it consists differ in the development of flow structure, but in some flows the structure is fairly pronounced. A distinct platy jointing is the only prominent manifestation of the flow planes, and this may be evenly developed with an inch or two to several feet between the joint planes.

Large outcrops of the more massive portions of the flows weather to rounded boulders as much as several feet in diameter. The lavas in the upper part of the series always appear porous, owing to the presence of small cavities. The rock is stained with limonite in or adjacent to many of these cavities. In some places a flow structure may be developed in the groundmass and is emphasized by the numerous small lenticular cavities parallel to the flow planes, but this structure is not typical.

The lava contains abundant large phenocrysts of plagioclase, which is usually andesine but in some of the basal flows is andesine-labradorite and strongly zoned. The plagioclase crystals range in size from 2 to 12 millimeters, but most of them are between 5 and 7 millimeters. Large phenocrysts of orthoclase are relatively uncommon. Quartz is also rare in small round glassy grains 2 to 3 millimeters in diameter. Brownish-black biotite 1 to 3 millimeters in diameter is everywhere present, but in the brown flows is usually altered to yellowish-brown mica and iron oxides. The groundmass is clouded and contains andesine or other sodic plagioclase, some orthoclase, and a little quartz. In the upper flows tridymite is usually present and occurs as hexagonal crystals or platy crystals with a wedgelike twinning. It probably occurs to some extent in the clouded groundmass and is found in or adjacent to gas cavities. The texture of the groundmass is trachytic to andesitic. Some of the basal flows below the junction of Brewer and Kerber Creeks contain a colorless augite in amounts about equal to the biotite, but they contain no tridymite and appear to be more calcic latites. In the southern part of the district these platy mica latites at the base of the series are somewhat less oxidized in appearance than the upper Brewer Creek flows and for this reason are difficult to differentiate from the upper flows of the Squirrel Gulch latite. They are intermediate in character but were placed in the Brewer Creek formation because of their slight but distinct oxidation and the absence of a black fine-grained or glassy groundmass such as characterizes all the flows grouped under the Squirrel Gulch formation. They appear to indicate a gradual change in the character of flows passing from the Squirrel Gulch series of lavas to those of the Brewer Creek and hence suggest the lack of any great time interval separating the two formations.

MINERALIZATION

No commercial deposits of ore have been discovered within the lavas of the Brewer Creek latite, but, like the other rocks of the district, they have been subjected to hydrothermal alteration along the course of faults and fissures. Both silicification and bleaching of the latite have occurred in the fissure walls. The apparent absence of large veins in the formation is presumably caused by its occurrence in an unfavorable position rather than by unfavorable features of the lavas themselves.

YOUNGER ANDESITE OF BREWER CREEK

South of the north branch of Brewer Creek, in the southwest corner of sec. 23, T. 47 N., R. 7 E., there is a small exposure of andesites that are in fault contact with the Brewer Creek latite. They are also found along the main branch of Brewer Creek just west of the limit of the area mapped. They crop out intermittently in fault contact with the Brewer Creek latite along Brewer Creek for a distance of about 2 miles, to the base of the range lying west of Bonanza. In the cirque at the head of Brewer Creek these andesites are overlain by light-colored latites.

The andesitic lavas are very similar in texture and composition to the lavas of the Rawley andesite, but conspicuously porphyritic types are somewhat more abundant than in that formation. Some of the lavas contain phenocrysts of both plagioclase and mica. Amygdaloidal augite andesites are also found. These lavas have not been studied in detail, as they lie for the most part west of the Bonanza district. Although there is a slight possibility that they may be of the same age as the Rawley andesite, this would require a very abrupt westward thinning of the lavas lying between the Rawley andesite and the Brewer Creek latite. Pending further study of the structure and lava flows west of the district these andesites must be considered to represent an eruption of lavas separate from the Rawley andesite and to overlie the Brewer Creek latite.

INTRUSIVE ROCKS

EAGLE GULCH LATITE

GENERAL CHARACTER AND DISTRIBUTION

A gray porphyritic quartz latite, which will be referred to in this report as the Eagle Gulch latite, a name assigned by Patton,[24] crops out in a band extending from a point near Kerber Creek at the mouth of Eagle Gulch to the head of Elkhorn Gulch. Small outcrops of a grayish-white porphyritic rock of similar character are found west of Kerber Creek along the edge of the area mapped, in line with the trend of the main body. The Eagle Gulch latite probably does not extend much west of Kerber Creek but appears to extend northeast of Elkhorn Peak for a mile or so, where it forms a large barren domelike mountain, but the outcrops on this mountain were not examined. The eastern limit of the outcrop of the latite is not known.

Although the Eagle Gulch latite exhibits certain uniform characteristics, its texture has a considerable range in detail, suggesting that the rock may not be a simple intrusion but rather a multiple intrusion of several facies. No uniformity in the distribution of the rocks of different appearance could be detected. Within the body and extending out into the surrounding formations there are a number of dikes, a few of which are shown on Plate 1. These dikes, though more strikingly porphyritic than the main mass of the porphyry, are of similar composition and petrographic character, and their only occurrence in the district is in or adjacent to the Eagle Gulch latite. A few small veins of pegmatite about a foot in width cut the porphyry on the slopes facing Elkhorn Gulch.

RELATION TO OTHER FORMATIONS

Although Patton[25] interpreted the Eagle Gulch latite as an effusive lava, he pointed out that it is in an uncertain stratigraphic position. It is found in contact with all the volcanic formations of the district except the Porphyry Peak rhyolite and possibly the Brewer Creek latite. Many of these contacts are rectilinear, however, and in part they are definitely fault contacts, although in places some contacts suggest that the latite may have been intruded along preexisting faults. The most definite evidence of the intrusive character of the latite, aside from its crosscutting relations, consists of the presence of porphyry and pegmatite dikes in the latite, changes in grain or texture at the contact, and the formation of epidote in rocks near the contacts. East of Elkhorn Gulch, in the northeast corner of sec. 31, T. 47 N., R. 8 E., epidotization has occurred both in andesite and in the Eagle Gulch latite near the contact. Farther northeast, nearer the head of Elkhorn Gulch, a flow-banded breccia is exposed at one place between the Eagle Gulch latite and the andesite. The breccia contains fragments of latite and a few of andesite, and the flow lines parallel the contact of the latite and are nearly vertical. The relative positions of the rocks may be interpreted to illustrate the formation of an intrusive breccia at the contact of the porphyry, but the gradation of the breccia into normal latite porphyry is obscured by talus and soil. The contact of the latite with the andesite in the saddle north of Elkhorn Peak is clearly fissured or is a fault contact, inasmuch as strong hydrothermal alteration and the formation of some vein material have occurred along it. Southwest of Elkhorn Peak a platy parting has been developed in the south contact of the latite and suggests that the latite dips beneath the overlying lavas in the form of a laccolithic intrusion. The steep southeastward tilting of the Hayden Peak latite flows also favors the possibility of a wedgelike penetration of the Eagle Gulch latite beneath the lavas on the south flank. The contacts of the latite along the lower parts of both Elkhorn and Eagle Gulches are so obscured on the talus-covered slopes that their exact nature can not be determined. The contact along the lower part of Eagle Gulch, however, is clearly displaced by a number of northwest-southeast breaks. It could not be determined whether all these displacements were formed after the intrusion of the latite or part of them were in existence before, but fissuring along some of them has occurred since intrusion. Mineralized fissures such as the Eagle fissure are also to be found within the latite, and some definite faulting within the intrusive body has been recognized at other places along Eagle Gulch.

The very much faulted and fissured condition of the rocks with which the Eagle Gulch latite is in contact, in conjunction with the scarcity of dikes of this rock along these fault lines, indicates that a considerable part of the faulting took place after the intrusion of the latite. On the other hand, porphyry dikes that are of similar character and are closely associated with the latite can be traced out into the surrounding formations. One such dike that cuts across the western contact above Elkhorn Gulch has been mapped. The dike is also displaced by still later faults. A single dike of nearly the same color as the Eagle Gulch latite cuts the latites of Hayden Peak about 2,000 feet east of the Oregon tunnel. On the lower slopes of the mountain this dike is about 50 feet wide and is of the same texture as the Eagle Gulch latite, but 500 feet or so higher on the slope the dike is narrow and exhibits a pronounced fluidal texture. The shape and general structural relations of the

[24] Patton, H. B., op. cit., pp. 37–38.
[25] Idem, p. 60.

latite indicate that it was intruded along a major fracture in the crust, possibly at the intersection of differentially tilted crustal blocks. The northern contact appears to be the steeper, particularly along the upper part of Elkhorn Gulch, and the abutting formations do not exhibit the regular tilting away from its edge that is shown by the lavas on the south side.

The rhyolite intrusives associated with the volcanic neck at Greenback Gulch are of later age than the Eagle Gulch latite. One or two dikes of this rhyolite cut the latite near Kerber Creek.

PETROGRAPHY

Normal porphyritic quartz latite.—The Eagle Gulch latite is typically a gray or greenish-gray porphyritic quartz latite with abundant but somewhat inconspicuous feldspar phenocrysts ranging from 3 to 8 millimeters in length. Biotite occurs in altered greenish flakes 2 to 3 millimeters in diameter. Rarely a few quartz grains are seen. The groundmass is nearly everywhere crystalline. In the coarser phases the larger grains in the groundmass may be 0.5 millimeter in size, but in the finer ones the grains can hardly be distinguished. No flow structure is present in the rock, although it may have a platy parting parallel to some of its contacts. Typical exposures, however, owing to the abundant joints in the rock form angular blocky talus fragments from several inches to a foot or more in size.

The orthoclase phenocrysts are usually somewhat less abundant than plagioclase and range in size in different rocks from 2 to 8 millimeters. The orthoclase is of a somewhat sodic character and in some phases contains lamellae or ragged patches of albite distributed throughout the crystals. Such crystals of orthoclase have under crossed nicols a mottled appearance characteristic of microperthite. In some rocks the orthoclase is mantled with an orthoclase-plagioclase intergrowth. The most basic plagioclase noted was oligoclase, although Patton [26] reports finding labradorite in one specimen. In most of the rocks examined the plagioclase is dusty or sericitized and consists entirely of albite. The cloudiness and sodic character of much of the plagioclase may be due to some alteration attending the crystallization of the magma. The phenomenon is too widespread to be the result of some outside agency. The brown biotite is as a rule partly altered to chlorite. The groundmass is a granular intergrowth of orthoclase, sodic plagioclase, and quartz. Orthoclase is the most abundant constituent, and it may be intimately intergrown with albite, as in some of the phenocrysts. Magnetite, apatite, zircon, and probably monazite occur as accessory minerals, partly of late introduction. Sericite, epidote, calcite, and chlorite are common secondary minerals.

Porphyry dikes and pegmatite.—In some of the porphyry dikes associated with the Eagle Gulch latite orthoclase in large pink phenocrysts as much as 15 millimeters long may be the most common feldspar. Oligoclase is less abundant. A mottled appearance of the orthoclase, due to minute lamellae of plagioclase, is also evident in some of the porphyries. This feature is not seen in any of the other volcanic formations in the district and appears to support the hypothesis of a common origin for the Eagle Gulch latite and its associated dikes. In one dike the plagioclase was determined to be andesine. The dikes and the large porphyry mass are similar in other petrographic details.

The pegmatites found in the Eagle Gulch latite on the slope south of Elkhorn Gulch are composed mainly of quartz and orthoclase, of which either may predominate. They occur as narrow dikes along joint planes in the porphyry or as small round pipes a few inches in diameter which have evidently replaced the porphyry adjacent to intersecting joints.

CHEMICAL COMPOSITION

A chemical analysis of the Eagle Gulch latite is given in the accompanying table. It shows that the rock is rather higher in silica than the average quartz latite and approaches the composition of some sodic granites.

Analysis of Eagle Gulch latite [27]

[George Rohwer and E. Y. Titus, analysts]

SiO_2	67.16	K_2O	5.78	SO_3	0.03
Al_2O_3	16.03	H_2O-	.11	Cl	None.
Fe_2O_3	1.67	H_2O+	.64	S	None.
FeO	1.38	TiO_2	.56	MnO	.12
MgO	.77	ZrO_2	None.		
CaO	1.62	CO_2	.06		100.21
Na_2O	4.23	P_2O_5	.05		

ALTERATION AND MINERALIZATION

The results of several types of alteration are distinguishable within and adjacent to the Eagle Gulch latite. Certain minor alteration products are widely distributed in the latite and near its contacts and are consequently believed to have been formed by "mineralizers" that were perhaps derived from the body of the intrusive mass during its crystallization. The most typical results of the interaction of these mineralizers with the partly or completely crystallized rock were the albitization of the plagioclase and the production of secondary epidote. Sericite, magnetite, chlorite, calcite, and apatite are also produced by alteration of this type.

The later alteration associated with fissuring and the formation of ore deposits was similar in most re-

[26] Patton, H. B., op. cit., p. 38.

[27] Patton, H. B., op. cit., p. 44.

spects to that occurring elsewhere throughout the Bonanza district. The most intense kinds consisted of silicification, sericitization, and pyritization. Silicification of the Eagle Gulch latite in the wall of the Eagle vein has been mentioned by those familiar with the mine. Other alterations adjacent to the fissures resulted in a softening of the latite similar to that noted in the Bonanza latite. The secondary minerals formed were sericite, chlorite, calcite, pyrite, and some quartz. Secondary orthoclase was seen in one section of altered Eagle Gulch latite from the wall of a fissure.

So far as known, all the veins found within the Eagle Gulch latite are low-sulphide manganese-bearing veins, typified by the Eagle and Oregon veins. Mineralization of this type was not confined to the Eagle Gulch latite, however, but occurred throughout the southern part of the district and so is believed to have borne no particular genetic relation to the intrusion of the Eagle Gulch latite, but to have been related to a much deeper and larger body of igneous rock of later age.

GRANITE PORPHYRY

DISTRIBUTION AND PETROGRAPHIC CHARACTER

About half a mile south of Alder Creek, near the center of sec. 9, T. 47 N., R. 8 E., there is a small intrusive body of granite porphyry lying at the contact between the pre-Cambrian aplitic granite and the lavas of the Rawley andesite. The character and structural relations of this intrusive body and the alteration of the adjoining rock show that it belongs to the Tertiary igneous rocks and not to the pre-Cambrian complex. The volcanic rocks, the pre-Cambrian granite, and the porphyry itself are intensely sericitized near its contacts.

The rock is typically a light to medium gray rock speckled with scattered black flakes of biotite. The porphyritic texture is not pronounced, because of the granularity and color of the groundmass. The feldspar phenocrysts form a large proportion of the rock and range from 2 to 6 millimeters in size. The biotite flakes are from 1 to 2 or 3 millimeters in diameter.

Microscopic examination shows the feldspar phenocrysts to be largely orthoclase exhibiting a microperthitic texture. The plagioclase comprises sodic oligoclase and albite and is about one-fifth as abundant as the orthoclase. The quartz does not occur as phenocrysts but in the groundmass. It is graphically intergrown with the orthoclase and forms about 30 per cent of the rock. The biotite is pleochroic from greenish brown to pale yellowish and is perfectly fresh. Accessory minerals are deep-yellow titanite, magnetite, apatite, and zircon. The rock is a biotite granite porphyry with a micrographic groundmass.

ALTERATION ASSOCIATED WITH THE PORPHYRY

Near the contacts of the porphyry the volcanic rocks are intensely bleached and locally are altered to a somewhat soft massive rock in which there is little or no evidence of the original texture. The altered rock is nearly white and is composed of glistening flakes of sericite. The conversion to sericite is practically complete at some places. Similar bleached rocks are found on the high ridge south of the porphyry body and in the volcanic rocks west of it represented by the stippled zones shown on Plate 1. As some of these altered rocks lie half a mile or more from the outcrop of the granite porphyry, they would appear to indicate that the exposed area of the granite porphyry represents only a small part of a much larger concealed body. This alteration presumably resulted from relatively volatile constituents expelled from the granite during its consolidation.

DIORITE AND MONZONITE DIKES

A series of massive coarse-grained dark-gray or greenish-gray rocks occur as dikes in a number of places throughout the district. (See pl. 1.) They are more common in the southern part of the district, where they occupy fault fissures like the quartz latite dikes. One fissure on the north side of Greenback Gulch (shown on pl. 1) contains both a monzonitic dike and a latite dike. The age of the monzonite dikes relative to the light-colored latite dikes was not determined, but they are probably nearly if not quite contemporaneous. A body of hornblende-augite monzonite occurs on the north side of Rawley Gulch about a mile above Kerber Creek. It is irregular in outcrop and was probably intruded into openings produced during the faulting of the volcanic rocks. Its outcrop terminates abruptly, and it is only a few hundred feet in length.

Although the dikes vary in the character and amounts of dark minerals, orthoclase, and quartz, which they contain, they are all of very similar appearance and range in composition from diorites, containing only small amounts of orthoclase and quartz, to monzonites or perhaps quartz monzonites. Some of the monzonitic dikes in the southern part of the district contain considerable brown mica. The grains of the minerals composing the dikes are commonly from 2 to 4 millimeters in diameter, and the texture is typically granitoid and not porphyritic.

The monzonite body of Rawley Gulch contains andesine (An_{40}) and a nearly equal amount of orthoclase. The orthoclase occurs in large plates inclosing smaller crystals of andesine poikilitically. A small amount of quartz lies interstitially to the orthoclase and plagioclase. Colorless augite and bluish-green hornblende are present in about equal amounts. The hornblende is largely altered to chlorite, and the augite is partly altered to calcite. Only a little biotite is present. Magnetite, apatite, and zircon are accessory minerals.

The dike that crops out on the ridge between Chloride and Greenback Gulches at the eastern edge of the district is dioritic in composition. The plagioclase is about andesine ($An_{40}\pm$) in composition but has borders of somewhat more sodic plagioclase. A little orthoclase and quartz occur together interstitial to the plagioclase. Some chlorite is pseudomorphic after hornblende, but the rock originally contained only a little biotite. Magnetite and apatite are the common accessory minerals. Secondary calcite, chlorite, titanite, and a little sericite are present.

INTRUSIVE BODIES OF RHYOLITE AND LATITE

STRUCTURAL FEATURES AND DISTRIBUTION

Many of the faults and fissures of the district contain dikes of porphyritic rocks, most of which have a prominent fluidal or flow texture. This texture is in general much more striking in these small intrusive bodies than in any of the lava flows in the district. The flow lines are very closely spaced and bend around feldspars or inclusions in the rocks, and near the edges of irregular-shaped bodies the main direction of the flow lines almost everywhere parallels the contacts, even though they change abruptly in direction. Intrusions are found in some of the larger vein fissures, as in the Rawley fissure. Many of the narrower dikes are intensely altered where they occupy fractures along which later fissuring occurred and mineralizing solutions have circulated. So far as known, all the dikes in the district are of premineral age.

In the northern part of the district the dikes are small with a few exceptions, such as the porphyry dike of the Rawley fissure and a few wide dikes exposed at the surface and shown on Plate 1. Some of these dikes are mere narrow stringers and discontinuous sheets from a few inches to a foot or so in width, which have been forced into irregular openings in the fissures, presumably by faulting movement of the walls during intrusion. Such narrow bodies are usually very white, largely owing to alteration, and show a very pronounced fluidal structure. In the larger dikes the flow structure may be lacking except along their contacts. The longest known exposure of a dike in the northern part of the district can be traced for about 2,500 feet on the high ridge south of the upper end of Rawley Gulch. This dike is of latitic composition, with phenocrysts of quartz and feldspar, and is in places slightly vesicular. The smaller dikes in the north do not warrant detailed description, and many of them have not been represented on the map. Fragments of rhyolite or quartz latite are of common occurrence in the surface débris of some of the hill slopes, but the source of many of them is concealed. Some dikes that are exposed in underground workings either do not crop out or are concealed at the surface. The "bird's-eye" porphyry dike of the Rawley vein is about 20 feet in width in places and lies alongside the vein on the 12th level, but it leaves the main fissure at some unknown position above this level and is again encountered in a footwall branch vein on the 700-foot level. (See pl. 26.) The dike has not been recognized on the surface, however, and may possibly end underground. A latite porphyry dike 20 feet or more in width is also cut by the Wheel of Fortune tunnel on the east side of Kerber Creek near the upper end of the town of Bonanza. The largest intrusion of rhyolitic or latitic composition in the northern part of the district crops out at the end of the ridge that extends northwestward from Round Mountain. This intrusive body has an eastward-dipping flow structure that parallels the contacts near the top of the ridge. The peculiar lenslike shape of this intrusion, together with the apparently almost vertical attitude of its lower part, suggests that the lava came up along steep fissures and spread laterally on flatter fractures.

The relative periods of intrusion of the different dikes in the north are not known, as intersections of them have not been seen. Presumably they were all intruded shortly after or during the faulting of the formation. The presence of the small dikelike stringers of intrusive latite along some fissures suggests that intrusion occurred in part during faulting, as the stringers appear to have been too narrow and viscous to have entered such openings in quiescent rocks by their own pressure, particularly as they undoubtedly came from molten bodies at great depth.

In the southern part of the district dikes and other small intrusions of irregular shape are very common. Many of these, however, are associated with a central area of intrusive activity near Greenback Gulch. In certain areas adjacent to this center scarcely a fault or even a small fissure is entirely free from some intrusive material.

GREENBACK GULCH VOLCANIC NECK

Centering about the lower part of Greenback Gulch is a large necklike intrusive complex of oval outline that may be likened to a large-scale intrusion breccia. The central part of the complex is composed of intrusive bodies and ramifying dikes of rhyolite, enormous blocks of the andesite country rock, and bodies of altered breccia of indeterminable origin. The chaotic distribution of the different rocks in this central part and the intense hydrothermal alteration to which they have been subjected made it necessary to generalize the geologic mapping and to represent a large part of this complex by a single pattern on Plate 1. There is little doubt that the complex represents a volcanic neck or pipe. The vertical attitude and great number of the dikes and fissures and the intense hydrothermal alteration suggest that part of the lava, volatile constituents, and hot mineralized waters that made their way through this broken zone reached the surface. Extending half a mile or more on nearly all sides of the central part are many branching and discontinuous dikes, the patterns of which suggest that the lavas were broken by some centralized force into large blocks that were only partly supported. Gravitative adjustments of the blocks caused the temporary existence of open spaces into which molten lava was intruded. The intrusive lava is mostly of rhyolitic composition, but dikes and bodies of both monzonitic and latitic character are also present.

Nearly all the intrusive bodies appear to be of the same age, and few of them cross one another. Further fissuring has followed the solidification of the intrusions, but none of the dikes seem to be greatly displaced by later faulting. The intrusive bodies within the central part of the neck are of different shapes, consisting of parallel and compound dikes, radiating dikes, and larger intrusive masses of irregular shape. The mapping of the separate bodies was impracticable because of local alteration and inadequate exposures of the contacts. The dikes are mostly rhyolite or perhaps in part quartz latite, but many of them have been more or less silicified and otherwise altered so that their original composition is indeterminable. They are nearly all characterized by prominent flow texture, and some of the rhyolite dikes, particularly on the north side of Express Gulch below the Express mine, certain spherulitic structures. A few of the larger intrusive masses are porphyritic and lack the flow texture of the narrow bodies. One such body occurs on the south side of Express Gulch below the Express mine. The spaces between many of the dikes and the other intrusions are occupied either by large fissured masses of andesite and latite lava that are comparatively little altered or by bodies of breccia that are so completely altered that the material of which they were formed is largely indeterminable. Some of the breccia is seen to have contained fragments of andesite, but the matrix is completely altered. Good exposures of this breccia are to be found on the hill between Express and Greenback Gulches facing Kerber Creek. On this same slope there are also a few large blocks of hornblende gneiss. The outcrops of gneiss are discontinuous and appear to be restricted to a fissure zone, but whether this pre-Cambrian rock was carried upward from below by an intrusion or by explosive force could not be determined. Fissures near the mouth of Chloride Gulch also contain fragments of red and green sandstone that, to judge from their lithologic character, must have been derived from the Permian and Pennsylvanian sedimentary beds. Material of this nature suggests the presence of breccia dikes within this neck, but good exposures of such dikes were not found.

PETROGRAPHIC FEATURES

These late dikes show great variation in texture and details of composition. No attempt will be made here to record all the petrographic details, some of which are unusual but of more scientific than general interest. A general description of the appearance and composition of the dikes will be sufficient to assist in identifying them in the field. They range in color from white to greenish, brownish, or bluish gray, but the lighter-colored dikes are by far the more common. Many of them exhibit a prominent fluidal structure, and some of these at their outcrops split into sheets not more than a quarter of an inch thick. Most of the dikes are porphyritic, but the phenocrysts are rarely larger than a quarter of an inch, although the Rawley Dike contains phenocrysts more than half an inch in length. The feldspar phenocrysts are rather sparingly developed, and plagioclase appears to be everywhere more abundant than orthoclase. Quartz is rare as a phenocryst but is found abundantly as small rounded crystals in some of the dikes of the northern part of the district. Biotite is the only common dark mineral, but it is usually altered. Most of the rocks have a felsitic groundmass, generally much altered, and a few have partly glassy bases that are still incompletely devitrified. A few rare varieties exhibit a granular groundmass thickly crowded with spherulitic growth of feldspar, chalcedony, and a little quartz.

Because of their alteration it is difficult to determine the original composition of some of the dikes, but the great majority of them appear to be quartz latites and rhyolites.

In the more typical quartz latites and least altered dikes the plagioclase is oligoclase or albite and is rarely as basic as andesine. In most of the sections studied the plagioclase is dusty albite. Orthoclase is sparingly developed as a phenocryst but is invariably present in the groundmass. In a few of the dikes studied orthoclase phenocrysts are more abundant than plagioclase. The biotite is brown where fresh but is usually altered to chlorite or white mica. The groundmass is commonly an intergrowth of orthoclase, sodic plagioclase, and quartz. The quartz occurs either in fine intergrowths or in small areas and lenticular streaks.

In the rhyolitic dikes large spherulitic growths of quartz, chalcedony, and feldspar are common. The spherulites range in size from small ones less than an eighth of an inch in diameter to ones as large as a man's head. These large spherulitic bodies are particularly abundant in some of the dikes bordering the lower part of Express Gulch.

ALTERATION OF THE DIKES

Nearly all the dikes occupy fault fissures, along many of which renewal of movement has occurred after intrusion, so that the dikes have been attacked by the later mineralizing solutions which circulated in the fissures. The formation of sericite and quartz and of epidote, chlorite, and calcite is characteristic of the alteration to which the dikes have been subjected. Kaolin, diaspore, and alunite are other secondary minerals that have replaced the dike rocks locally in areas of solfataric alteration.

In the northern part of the district silicification and sericitization were common types of alteration. The porphyry dike of the Rawley fissure is strongly sericitized and consequently much softened. Dikes occupying fissures that are not strongly mineralized have been commonly subject to silicification.

In the southern part of the district, in the area of altered rock adjoining Chloride, Greenback, and Express Gulches, intense solfataric alteration of the dikes has been a characteristic phenomenon. It was accompanied by the formation of kaolin, diaspore, and other rarer minerals such as zunyite. Sericitization and pyritization also followed silicification in some places. The silicification of large spherulites in some of these dikes has produced hollow spheroidal masses that contain linings of terminated quartz crystals and consequently resemble geodes.

As a result of renewed movement along fissures occupied by dikes, crushing and shearing of dikes along their surfaces occurred in places. This favored further attack on the dike material by mineralizing solutions, and thick layers of gouge were formed. Dikes within mineralized fissures are therefore likely to have had an unfavorable effect on ore deposition. This is noticeable alongside the porphyry dike of the Rawley mine. Usually barren quartz and lean pyritic ore are found near the dikes, probably because of the greater ease with which these higher-temperature facies of the mineralization were able to penetrate choked portions of fissured zones.

MINOR INTRUSIVE ROCKS

MICA ANDESITE DIKE

A single dike of mica andesite occurs in the northern part of the district, extending from the junction of Squirrel and Sosthenes Gulches southwestward 4,000 or 5,000 feet to the vicinity of Mahoney's sawmill on Kerber Creek. The dike cuts the Bonanza latite and the Rawley andesite and to all appearances was intruded into these formations before faulting took place. The very complicated nature of the displacement from one fault block to another brings out forcibly the intense deformation of the rocks, which is not so readily apparent to a casual observer. The dike at its widest part measures nearly 100 feet. It may possibly extend in either or both directions beyond the length mapped, but the writer was unable to find further segments. A microscopic examination of one thin section shows it to be essentially andesitic in composition. The dike is dark colored and fine grained, resembling some of the andesite flows of the district except for the presence of many small altered biotite flakes. It contains scattered plagioclase phenocrysts 3 to 5 millimeters in length and many smaller ones, measuring less than 1 millimeter, all of which are labradorite. The groundmass is fine textured and is composed of small plagioclase crystals with random orientation, magnetite grains, and chlorite. Nearly all of the original brown biotite is altered to chlorite, and calcite and sericite are other alteration products in the rock.

LAMPROPHYRE

On the 400-foot level of the Cocomongo mine near its north end (pl. 23) there is a small body of dark mica-bearing rock, probably a dike intruded into one of the fault fissures. The comparative abundance of mica in this rock, together with the absence of feldspar phenocrysts and its peculiar texture, suggests that it belongs to the lamprophyre group. Microscopic examination shows that the feldspar of the rock is probably sodic plagioclase and orthoclase, but its exact nature is obscured by abundant secondary calcite. Many of the long tabular feldspars show only Carlsbad twinning and are grouped in sheaflike forms. Brown biotite is the only phenocryst and occurs in scattered groups of larger flakes and as small ones throughout the rock, but it is largely altered to chlorite. Magnetite and apatite are common accessory minerals, and a little quartz is found in the rock. No other rock of this character has been noted in the district.

TRIDYMITE LATITE

Several small bodies of a brownish rock with scattered phenocrysts of feldspar and mica occur near the contact of the Brewer Creek latite with the younger andesite, in the western part of sec. 23, T. 47 N., R. 7 E. The shapes of these bodies suggest that they are intruded along fault lines, but their structural relations could not be exactly determined, and they may possibly be faulted segments of a flow lying near the top of the Brewer Creek latite.

Microscopic study shows that the scattered phenocrysts, 1 to 3 millimeters in length, are largely glassy orthoclase, but a few consist of andesine. There is a little fresh biotite, pleochroic from dark reddish brown to yellowish. The groundmass of the rock is a very fine aggregate composed chiefly of orthoclase with a subtrachytic orientation. The groundmass contains lenslike and rounded areas of tridymite somewhat drawn out by the flow of the rock. Some inclusions of a darker similar rock in the latite contain larger areas of tridymite. No quartz could be detected. Magnetite, hematite, and rutile are accessory minerals.

QUATERNARY DEPOSITS

The Quaternary deposits of the Bonanza district comprise glacial moraines and water-laid gravel, sand, silt, and clay. Only the larger deposits are shown on Plate 1, as time did not permit an exhaustive study of the unconsolidated formations. The morainal deposits do not cover the bedrock very deeply at most places and are confined entirely to a narrow strip of the western edge of the district.

Morainal débris was evidently deposited along the outer edge of ice sheets extending eastward from the Antoro Range, west of the district. There is some indication that at least two epochs of glaciation are represented by these deposits, although more detailed study is required to differentiate and map them. Thin deposits of early morainic material on the ridges north and south of Brewer Creek extend to an altitude of a little over 10,000 feet. There is much glacial débris and many erratic boulders, whose source is evidently the crest of the Antoro Range. The alinement of part of these deposits indicates that the ice front had a north-south direction at times. Many large and small blocks of stagnant ice partly surrounded by morainal débris also appear to have rested on the eastward-facing slopes in the western part of secs. 26 and 35, T. 47 N., R. 7 E. The thin deposits of erratic material found on the crests of the ridges show evidence of long weathering, as only the most resistant boulders appear to remain.

The later moraines are confined to the sides of eastward-draining gulches but are more prominent west of the district than within it. They do not reach as high an altitude in the western part of the district as the earlier deposits and are distinguished by the fact that the material composing them is less weathered than that of the early deposits found on the tops of the ridges.

Outwash gravel deposited in the earliest stage of glaciation has been largely removed by interglacial or postglacial erosion, and the only evidences of such material noted in the district were scattered boulders that extend possibly to a level 100 feet above the present bottom of Kerber Creek along the east side below Brewer Creek. Between the junction of Kerber Creek and Copper Gulch, near the town of Bonanza, there is also evidence of an early terrace deposit at about the same height above the creek.

Near Simmons Gulch and along parts of Brewer Creek there are remnants of a higher, partly dissected gravel terrace which evidently filled the valley of Kerber Creek to a higher level than the present gravel bottoms. Near the mouth of Simmons Gulch and on the east side of Kerber Creek they extend from 40 to 60 feet above the present bed of Kerber Creek. The base of a large alluvial cone consisting of gravel and silt with some clay and corresponding to this terrace lies west of the area shown on the topographic map at Simmons Gulch and extends toward the Antoro Range. The small gulches are intrenched 20 to 30 feet in this deposit. Remnants of silt deposits evidently corresponding in age to these older beds are found along some of the smaller tributary gulches. Terraces formed during the glacial epoch may possibly be the result of several stages of deposition, but their levels have not been correlated. Some of the black silt deposits into which the present gulches are partly cut contain many pieces of sticks and peaty material.

The modern gravel along the stream bottoms contains on the whole fairly well rounded pebbles, although the low degree of sorting indicates deposition during torrential stages of the streams. Along the lower parts of Kerber Creek sand and silt are more common. So far as known there are no placer deposits in any of the alluvial material.

GEOLOGIC STRUCTURE

GENERAL FEATURES

The area covered by the two geologic maps (pls. 1 and 3) is part of a region that marks the boundary between the strongly folded and faulted rocks of the Sangre de Cristo Range on the east and the volcanic rocks of the San Juan field on the west. These great geologic units of southern Colorado are separated by the San Luis Valley, but as the valley is filled with late Tertiary sediments and with recent alluvial deposits from the erosion of the two bordering areas, the details of its structural relations are not known. Siebenthal[28] has suggested that the San Luis Valley is a great syncline. He says:

> Correlated with the uplift of the range [Sangre de Cristo] was a depression of the valley, apparently either by a synclinal fold or by a great fault along the west border of the range, or probably by a combination of the two. The details of the time and the stages of this sequence of events must wait for final solution until the geology of the east and west ranges is more intimately known.

[28] Siebenthal, C. E., Geology and water resources of the San Luis Valley, Colorado: U. S. Geol. Survey Water-Supply Paper 240, pp. 34–37, 50–54, 1910.

So far as is known no formations older than Miocene have been recognized among the Tertiary deposits in the valley.

From a study of the complex structure in the pre-Tertiary sedimentary rocks in the Kerber Creek region, west of Villa Grove, and from an examination of the western front of the Sangre de Cristo Range in the vicinity of the Orient iron mine and at Valley View Springs, it is evident that the portion of the San Luis Valley north of the vicinity of Mineral Hot Springs does not have a simple synclinal structure. In the vicinity of Orient the Ordovician and Carboniferous sedimentary rocks overlie the pre-Cambrian rocks and dip steeply eastward beneath the west slope of the Sangre de Cristo Range. West of this locality, on the opposite side of the valley, in the Kerber Creek region, the Paleozoic formations are involved with the pre-Cambrian in a series of northwestward-striking folds essentially parallel to the trend of the Sangre de Cristo Range in this latitude, and upon these folds are superimposed a series of major thrust faults striking east to southeast and dipping south to southwest. Thus, so far as can be seen from these relations, the valley may be either anticlinal or synclinal, but in all probability its structure is complex and, as suggested by Siebenthal, was most likely determined by both faulting and folding. The final determination of the structure still awaits more detailed knowledge of that of the bordering regions, and the above statements are offered merely to provide a geologic setting for the discussion of the structural problems that arise in the region about the Bonanza district.

West of the main part of the San Luis Valley the Tertiary volcanic rocks reach to its edge and thus obscure the structure in the pre-Tertiary basement. However, west of the small northern extension of the valley, along the eastern edge of what is locally called the Saguache Hills, there is exposed a narrow bordering fringe of the pre-Tertiary rocks, which extend back into the volcanic formations as reentrant areas exposed by the erosion of eastward-flowing streams. These areas in which the basement rocks are exposed lie east and south of the strongly mineralized area in the volcanic rocks of the Bonanza district. About 12 miles northwest of Bonanza and east of Sargents, along Indian Creek, there are some further exposures of Paleozoic sediments. Due north and northeast of the Bonanza district, in the Marshall Pass and Poncha Pass regions, the volcanic rocks rest directly on the pre-Cambrian.

The small geologic map (pl. 3) shows a part of the reentrant area along Kerber Creek and serves to indicate some features of the complex structure of the basement on which the lavas of the Bonanza district lie. Several other small areas of pre-Cambrian are exposed along some of the streams flowing into the San Luis Valley east of the Bonanza district, and on Alder Creek one tract partly within the area covered by the Bonanza topographic map contains pre-Cambrian rocks but so far as known no sediments.

The main purpose for including a study of the pre-Tertiary basement in the work on the Bonanza district was to determine the age and thickness of such limestones as might have been favorable to replacement by ore-bearing solutions and to determine whether the structure of the basement would permit inferences as to the position of these limestones beneath the volcanic formations in the mineralized areas that lie north and west of the fringe of exposed pre-Tertiary rocks.

The structure in the pre-Cambrian and Paleozoic rocks and the later Tertiary deformation in the volcanic rocks present two problems that so far as the writer is able to determine are unrelated, and in the following discussion these problems will be dealt with separately.

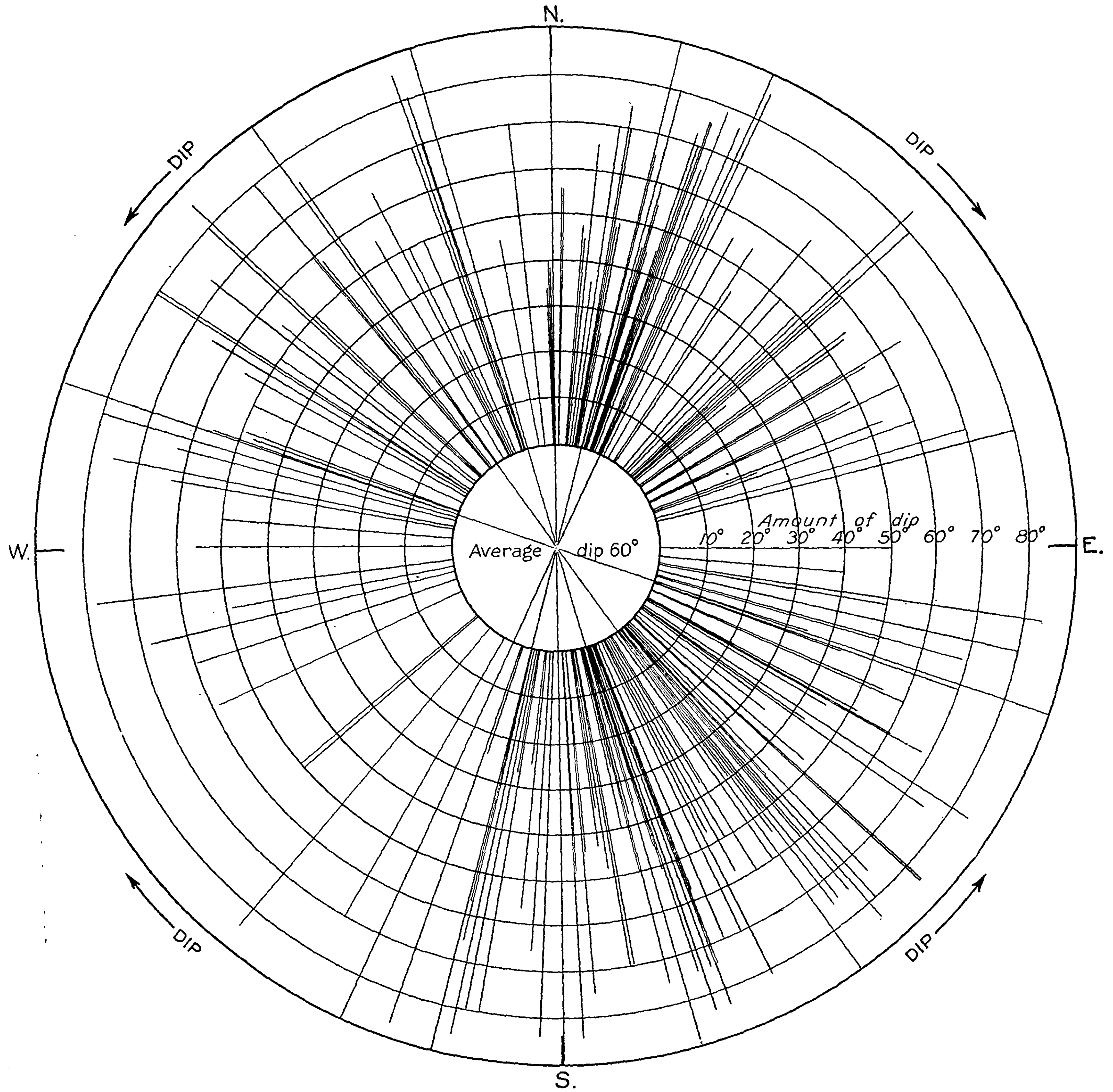
STRUCTURE OF THE PRE-TERTIARY ROCKS

STRUCTURAL RELATIONS OF THE PRE-CAMBRIAN COMPLEX AND PALEOZOIC SEDIMENTARY FORMATIONS IN THE KERBER CREEK REGION

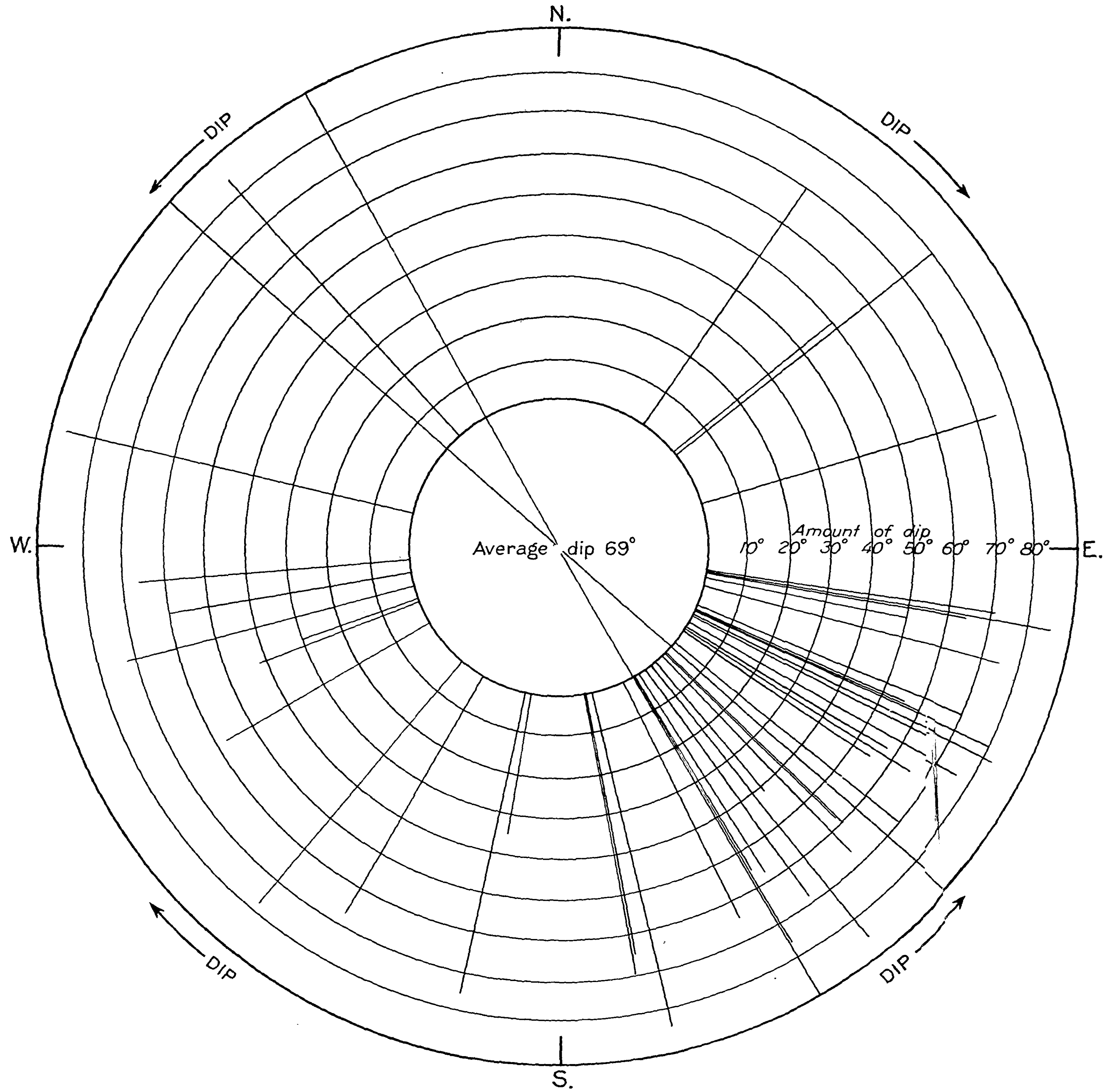
GENERAL FEATURES

In the Kerber Creek region the pre-Cambrian complex is overlain by Paleozoic sedimentary formations (p. 8), which range in age from Ordovician to Permian and of which a maximum thickness of about 5,000 feet is exposed within the area shown on the geologic map. The pre-Cambrian and sedimentary rocks are both involved in a series of folds and thrust faults. As a result of the erosion which had cut deeply into these formations before they were covered by the Tertiary lavas, the Paleozoic sediments are preserved mostly in synclinal areas and in bodies protected by the overthrusting of more resistant rocks. Just how influential a factor the major thrust faults have been in the preservation of the sediments in this area can not be settled until more extensive mapping is done, but it is rather significant that scattered outliers of pre-Cambrian granite occur in one of the synclinal areas of the Maroon formation and that the thrusting has been of sufficient magnitude to affect the normal strike and dip of the formations over a large part of the area studied. A few dikes and perhaps some porphyry sheets are associated with the sediments, but all of those seen are small.

It is probable that the pre-Cambrian and Paleozoic rocks exposed along Kerber Creek were involved to some extent in the intense Tertiary deformation that had its maximum development in the central part of the Bonanza district, but in the short time devoted to the study of this area it was not possible to differenti-



A



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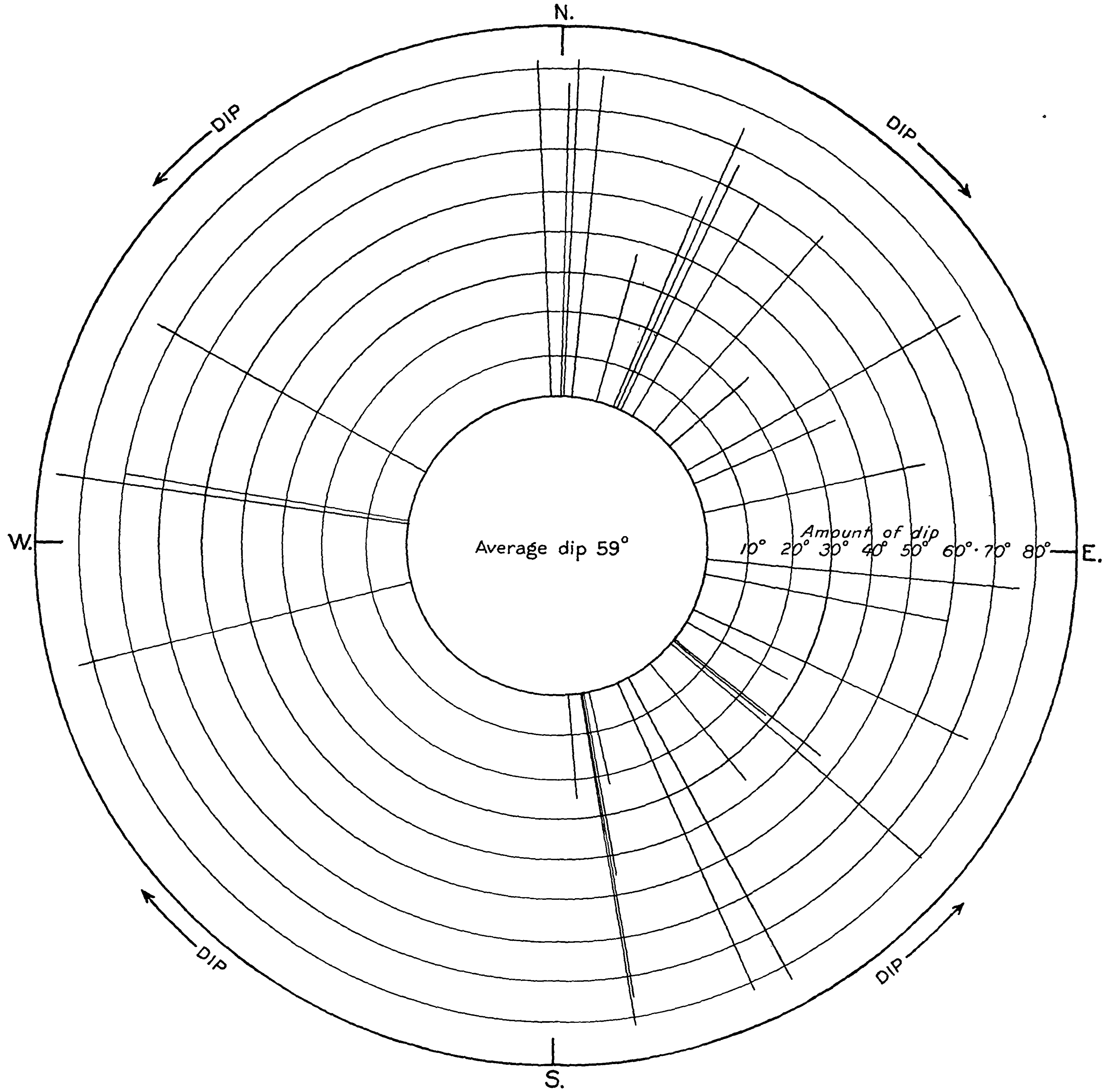


C

A. STRIKES AND DIPS OF FAULTS AND FISSURES FROM UNDERGROUND WORKINGS IN THE NORTHERN PART OF THE DISTRICT
B. STRIKES AND DIPS OF FAULTS AND FISSURES FROM UNDERGROUND WORKINGS IN THE SOUTHERN PART OF THE DISTRICT
C. STRIKES AND DIPS OF THE PRINCIPAL VEINS IN THE DISTRICT

Fissures dipping northeast or southeast are plotted in the east quadrants of the circles and those dipping southwest or northwest in the west quadrants. The amount of dip is indicated by the relative length of the lines. Only vertical fissures are extended through the center of the circles. The plots therefore show the prevailing directions of dip as well as strike.

ate completely the effects of pre-Tertiary and Tertiary faulting.

The main structural features of the pre-Tertiary rocks appear to have been developed by deformations at two independent times. The first deformation produced unsymmetrical anticlines and synclines of north-northwest trend, broken by overthrusts parallel to their strikes. The second deformation developed a group of large overthrusts of general east-west trend which have overriden the earlier folds obliquely, thrusting the older formations northward and locally distorting the folded structure of the first stage.

FOLDING AND ASSOCIATED FAULTING

The most evident features of the northerly folds are two main synclines with an intervening central anticline. There is, however, an eastern anticline, only partly shown on the map, and some suggestion of a western anticline near Little Kerber Creek.

The eastern anticline, the pre-Cambrian core of which is exposed in Clayton Cone, extends north of Kerber Creek in a direction about N. 36° W. and finally disappears under the lavas about 4 miles north of the creek. The syncline to the west of this, comprising the broad area of Maroon formation, will be referred to as the Clayton syncline. The pre-Cambrian core of the central anticline is exposed in the area north of the southward bow in Kerber Creek. West of the central anticline but largely concealed by the volcanic flows and cut off to the south by the Kerber thrust is the western synclinal area, which will be called the Kerber Creek syncline. The western anticline is only suggested by the eastward dip of the sedimentary beds between Columbia Gulch and Little Kerber Creek and except for this eastern limb is entirely covered by the volcanic flows to the west. The strike of the formations here is about N. 35° W., which appears to be the more normal undisturbed regional trend. An anticlinal arch very probably exists to the west, however.

Both the eastern anticline and the central anticline appear to be plunging to the south, although the rate of this plunge appears to have been locally much steepened by the effects of thrust faulting. At the south end of the eastern anticline, less than a mile southeast of Clayton Cone, the crest of the pre-Cambrian core plunges under the Paleozoic sediments, which here dip southward rather more abruptly than would be expected from the normal pitch of the anticline. The sediments within a short distance are covered by the recent alluvial deposits, which obscure the cause of this abrupt change in their dip.

The central anticline is clearly asymmetrical, the eastern limb dipping from 25° to about 35° and the western limb from 50° to 90°. The western limb is overthrust along a nearly horizontal fault plane, the Tomichi limestone at the northern extension of the thrust lying on the lower Maroon, while at the south near the Kerber Creek Road the lowest Maroon beds and Kerber formation lie upon the upper Maroon. The horizontal westward movement on this overthrust is approximately 2,000 feet, and it can be traced north of the edge of the Kerber Creek Valley for about 4,000 feet, at this point dying out or becoming lost in the pre-Cambrian granite. (See section A–A′, pl. 3.)

The structure of the northern part of the eastern anticline can only be inferred, as the pre-Cambrian core is the only part exposed north of Kerber Creek. The Clayton syncline narrows northward, the Kerber formation on the west limb holding a north to slightly northwest strike. North of Kerber Creek, in the central part of the syncline, the middle Maroon beds dip about 40° E. beneath the pre-Cambrian granite. Unless the dip of the beds on the east side of the syncline is nearly vertical there is not sufficient width for the 3,000 feet of sediments that should be concealed under the wash between this outcrop of the Maroon beds and the granite to the east. As inferred from these exposures and by analogy with the asymmetrical overthrust character of the central anticline, it appears that the pre-Cambrian core of the eastern anticline is also thrust over its western limb, the thrust playing out southward and hinging or pivoting on a point near Clayton Cone. The interpretation of the structure of the eastern anticline and the Clayton syncline is shown in section A–A′, Plate 3.

KERBER THRUST FAULTS

Besides the overthrust faulting genetically associated with the development of the folds, thrust faults of later age and of much greater magnitude are represented by a group of faults in the southern part of the mapped area. There are also a number of outliers of pre-Cambrian granite bounded by faults with circular outcrop and resting upon the upper Maroon beds above the junction of Kerber and Little Kerber Creeks. The trend of the thrust planes is roughly east, and the general dip of the thrust planes is southward, ranging from a few degrees to perhaps as high as 50°. These overthrusts are oblique to the overthrust folds in strike and dip. Three main lobes of the Kerber thrust group were discovered in mapping the area, but they have not all been completely mapped. The western lobe, which is also the southernmost of the group, is south of and parallels the lower course of Little Kerber Creek. Its western extension is concealed beneath younger volcanic rocks. South of Kerber Creek it curves from an easterly to a southeasterly course, which has been traced for a mile or more. What was thought to be the eastward extension of this lobe was found about 3½ miles south of Clayton Cone. There it strikes about S. 70°–80° E. and continues in this direction to the edge of the San Luis Valley, northwest of Mineral Hot Springs, where it is covered by the Recent alluvial deposits. If it crosses the valley it has not been recognized on the west slope of the Sangre de Cristo Range in line with its strike. There is a possibility that it may turn southward and lie buried under the late Tertiary and alluvial deposits of the valley. If so, the cause of the local deflection of this thrusting movement is at present unknown. The total exposed length of this lobe, including its eastward extension, is about 6 miles. Throughout its length the coarse-grained pre-Cambrian granite forms the upper block, and the upper or middle part of the Maroon formation strikes approximately parallel to the outcrop of the thrust plane and dips from 40° to 55° beneath the granite.

The central lobe is composed of the large mountain that lies south of the bend of Kerber Creek. The top of this mountain is a prominent topographic feature and reaches an altitude of about 9,530 feet. The northwest slope is composed of pre-Cambrian granite, which is overlain on the western ridge of the mountain by the Tomichi limestone in its normal position but dipping south, out of alinement with its normal westerly dip north of Kerber Creek. The northeast slope of the mountain is composed of a confusing succession and repetition of the Paleozoic limestones and quartzites which appear to lie nearly horizontal or dip gently to the south. The structure of this part of the lobe could not be deciphered in the time allotted to the mapping of this area.

The eastern lobe of the thrust comprises the high ridge that extends southward from Kerber Creek along the eastern front of the Saguache Hills and faces the San Luis Valley. (See pl. 4, *B*.) The fault bounding this block was not traced eastward to the end of its exposure. Its western or southwestern termination appears to pass beneath the western lobe of the series. At the north-central part of this eastern lobe there is a minor block of the Paleozoic limestones lying between the granite of the upper block and the westward-dipping Maroon beds of the underlying block.

Where the force of the overriding block of the Kerber thrust has impinged against the south ends of the central anticline and the Kerber Creek syncline, the direction of strike of the sedimentary formations has been turned sharply from its regional trend of N. 35°–40° W. to nearly due west, parallel to the thrust plane. The southward-dipping block of sediments on the northeast side of the central lobe evidently represents what prior to the thrusting was a portion of the western limb of the central anticline. This block has been thrust northeastward and over the Maroon formation, which crops out around its northeast side and dips about 12° to 15° beneath it. At the northeast edge of the block the lower limestones and quartzites are repeated many times by a series of minor thrusts, which evidently branch upward from the main thrust plane. This same repetition of the lower formations is also shown at the north end of the eastern lobe of the Kerber thrust. These small blocks probably represent portions of the eastern limb of the central anticline, this anticline having been overturned toward the east and its pre-Cambrian core thrust partly over the eastern limb. The effect of the Kerber thrust has been to produce secondary folding and bedding-plane faults in advance of and under the overriding block.

Another structural feature associated with the northern central lobe of the thrust is a transverse fault or "flaw" striking about N. 15° W., the bounding blocks of which seem to have undergone differential deformation and movement, although the exact nature and amount of this difference were not determined. The northeast slope of the mountain across which the fault passes is characterized by a jumbled series of fault blocks in which the Ordovician beds and possibly part of the Carboniferous limestones are repeated many times. It is apparent, however, from the distribution of the pre-Cambrian and faulted Paleozoic rocks that the transverse fault is associated with the thrust faulting and probably does not extend much deeper than the base of the major thrust planes. The interpretation of its relation to the thrusting is shown in section C–C′, Plate 3.

The small isolated remnants or outliers of a fault plane found near the junction of Kerber and Little Kerber Creeks present some characteristics unlike those of the thrust planes just described, and are believed to represent an independent thrust fault. All the fault planes in the three lobes described are relatively inconspicuous but are generally characterized by slickensided fragments along their outcrops and by slickensides indicating bedding-plane thrusts in the Maroon formation in advance of the main thrusts. The formations nearly everywhere strike and dip approximately parallel to the main thrust planes, even where these undergo sharp changes in strike. The outlying thrust, on the other hand, is characterized by a fault breccia from 20 to 30 feet in thickness above the sole or base of the thrust, while the strike and dip of the Maroon formation underlying the fault vary widely from those of the fault plane. The brecciation in the pre-Cambrian granite is very striking, and the movement and friction on the sole of the thrust have ground the granite blocks together and incorporated fragments of the Maroon beds into the breccia at least 3 to 5 feet above the base of the fault. The outliers north of Kerber Creek indicate a nearly east-west strike and a southerly dip of about 15° to 25°; the strike and dip of the fault in the block exposed between Little Kerber and Kerber Creeks are not determinable, although the fault plane appears to lie nearly horizontal. The fault breccia here is also very pronounced and probably of even greater thickness than north of the creek. It is believed that this fault plane represents an older and perhaps more shallow break than those of the three southern lobes, the pre-Cambrian granite having ridden northward over the central portion of the Kerber Creek syncline along a nearly horizontal fault plane. The southern part of this fault plane was later thrust upward by the advance of the southern blocks and the northern part was perhaps slightly folded or warped. The supposed relations of the faults are shown in section B–B′, Plate 3.

The geologic map indicates that the large area of the Maroon formation south of Kerber and Little Kerber Creeks and north of the western lobe of the Kerber thrust has a strike of N. 60° W. to N. 70° E. and dips 45° to 60° S. beneath the thrust plane. North of Kerber Creek, however, the Maroon beds forming the western limb of the central anticline have a more nearly normal northwest strike and very high westward dips, from 70° to 90°. In order to account for this change in strike and for the repetition of the beds in the upper part of the Maroon formation, which appear to be present both north and south of the creek, it seems necessary to infer another fault approximately in the position of Little Kerber Creek. There is no actual evidence of its presence in the field other than the structural features just mentioned, however, as the structure in the valleys of the creeks is completely hidden by alluvial deposits. This hypothetical fault is indicated on the map and in section B–B′, Plate 3, by a broken line with question marks.

Another interpretation of these small outlying thrust blocks also appears possible, if it is inferred that a second transverse fault of north-south strike had existed near the western termination of the southern lobe. The small outliers would then represent remnants of a body of granite which moved northward over a nearly horizontal fault plane, being bounded on the east by the nearly vertical transverse fault. The northward continuation of such a fault should appear somewhere on the slopes north of Kerber Creek unless it had been entirely eroded with the overthrust block. However, no evidence was seen that a transverse fault existed here.

INDIAN CREEK EXPOSURES

In the valley of Indian Creek, which lies about 12 miles northwest of Bonanza and a little east of Sargents (see fig. 1), there is an exposure of the Paleozoic sedimentary rocks which, though hardly permitting any inferences to be drawn regarding their connection with those east and south of Bonanza, offers some additional evidence of the regional trend of the folding in this part of Colorado. B. S. Butler, of the United States Geological Survey, called the writer's attention to this area and supplied the data on which this description is based.

The sedimentary rocks appear from under the Tertiary lavas about one-third of a mile above the mouth of Indian Creek where it joins Marshall Creek. Where they first appear only the lower series of limestones is present, and as the pre-Cambrian is not exposed the thickness of the limestones could not be determined. The general strike of the limestones is N. 30° to 40° W., with a dip of about 10° SW. Farther up the stream the dip reverses, the beds being tilted gently to the northeast, and the overlying sandstones and grits of the Kerber and Maroon appear about 3 miles from the mouth of the creek.

CONCLUSIONS

In all probability the northwestward-striking folds in the pre-Tertiary rocks are related in origin to the early Tertiary folding of the Rocky Mountains in Colorado. The folding is clearly post-Carboniferous and prevolcanic, but further than this it can not be placed. The east-west thrust faults are somewhat but perhaps not much younger and appear to be genetically unrelated to the anticlinal folding and its associated overthrusts, but they are also prevolcanic. These major thrusts may be tentatively correlated with the thrust faulting observed in other parts of the Colorado Rockies, which Lovering[29] has recently shown to be in the Williams Range section post-Lance and probably Wasatch in age.

BEARING OF THE STRUCTURE ON MINERALIZATION IN SEDIMENTARY ROCKS BENEATH THE LAVAS

Although so far as known there has been no mineralization of commercial importance in the sedimentary rocks exposed near Kerber Creek, replaceable rock that extended beneath the lavas within the mineralized area of the Bonanza district would offer some possibility of containing bodies of ore. The first consideration, however, in such a conjecture is the possibility of one or the other of the large synclines extending uninterruptedly beneath the district. The northwesterly trend of the Kerber Creek syncline agrees closely with the N. 30°–40° W. trend of the sedimentary rocks exposed along Indian Creek east of Sargents. The mineralized part of the Bonanza district lies partly between these two widely separated exposures. If the Kerber Creek syncline were projected northwestward beneath the lavas of the Bonanza district its

[29] Lovering, T. S., Williams thrust fault [abstract]: Geol. Soc. America Bull., vol. 39, pp. 173–174, 1928.

trough would be alined closely with the lower part of Kerber Creek. (See pl. 3.) In the volcanic neck at Chloride Gulch (p. 35) fragments of pre-Cambrian gneiss and sandstones of the Maroon formation were found along fissures. Although the fragments of sandstone were few they offer some corroborative evidence that the Kerber Creek syncline may extend northwestward along Kerber Creek at least as far north as Chloride Gulch. It is singular, however, that although some rather large blocks of pre-Cambrian gneiss were found within the volcanic complex only small fragments of sedimentary rocks were discovered. However, as the alteration was very intense in this vicinity, the original nature of many of the fragmental rocks that compose parts of the complex has been completely destroyed.

The presence of these several large thrust faults near Kerber Creek, whatever their relation may be to the general structure of the pre-Tertiary rocks, undoubtedly signifies the presence of some major shear in the crust which may extend beneath the lavas in a westerly or northwesterly direction. Additional thrust planes may even lie completely covered beneath the lavas of the Bonanza district. Thus, while the northwestward-trending folds along Kerber Creek agree rather closely in trend with the sedimentary exposures on Indian Creek, the assumption that the direction of the folds continues undisturbed beneath the Bonanza district is hardly warranted in view of the existence of these large thrust faults. On the whole, perhaps the evidence supports the extension of the Kerber Creek syncline as far northwestward as has been indicated on Plate 3. It should be clearly understood, however, that the position of the boundaries indicated is entirely hypothetical, as the syncline may widen or narrow northwestward.

The Clayton syncline, to judge by the nearly north-south trend of its western limb where it disappears beneath the lavas, seems to be narrowing abruptly toward the north. It also seems possible that the eastern limb has been overridden by the granite along the thrust fault that is presumed to form its eastern boundary. The trend of the eastern anticline is alined approximately with the exposure of the pre-Cambrian basement on Alder Creek. The evidence thus suggests a northward narrowing of the Clayton syncline as indicated on the map, although the eastern edge of the syncline may lie partly beneath overthrust pre-Cambrian granite.

The Kerber Creek syncline accordingly appears to be the most favorably situated and to have the trend that would carry replaceable beds beneath the mineralized areas. The southern part of the district, however, is the least strongly mineralized, and the probable character of mineralization, if any, at a depth of 1,000 to 2,000 feet beneath the surface is entirely beyond geologic prediction. On the assumption that strong mineralization within the sedimentary rocks is possible, the lower part of the sedimentary section contains the most favorable beds for replacement, because of the predominance of easily replaceable limestones. Near the central part of the Kerber Creek syncline the most favorable beds would accordingly lie at very great depths beneath the surface, because all the overlying Permian red beds would occupy the central part of the trough. Therefore explorations to reach favorable beds within a minimum depth must necessarily be made near the eastern and western boundaries of the syncline. This limitation greatly narrows the areas where explorations beneath the lavas could be made, except at great expense.

Further evidence having a bearing on the possibility that the mineralizing solutions have attacked the underlying limestones is afforded by the E. D. vein, near Kerber Creek, which contains dolomite and other magnesium and iron-bearing carbonates associated with pyrite. (See p. 104.) As magnesium is a comparatively uncommon constituent of the vein carbonates of this district, it may be inferred that this magnesium was derived from silicification or other hydrothermal metamorphism of underlying dolomitic limestones. But this in itself does not indicate the deposition of ore, however great the importance given to this evidence. There must also have been other favorable structural conditions, and the solutions must have originally contained metals other than iron—features that can not be ascertained with the evidence at hand.

STRUCTURE OF THE TERTIARY VOLCANIC ROCKS

GENERAL RELATIONS

The structural history of the region in which the Bonanza district lies is closely tied up with the history of igneous intrusion and mineralization. The main elements that have produced the present structure of the district consist of the arching and tilting of the formations, the igneous intrusions, and the faulting. It appears reasonably clear that these elements are all closely interrelated and were part of a single cycle of deformation. The occurrence of areas of complex faulting and fissuring accompanied by mineralization has been commonly recognized in volcanic regions, and the causes of these processes have been variously correlated with the upthrusting force of bodies of molten rock beneath the surface, or gravitational adjustment attending the transfer of lava from one position to another within the crust, or the extrusion of lava to the surface. The lava flows of this region, which once lay essentially horizontal, are now tilted in various directions and intricately dissected by faults and fissures.

The cycle of deformation in the Bonanza district is believed to have been initiated by the intrusion of a large body of molten lava within the crust, probably at a depth of several thousand feet. The crust was consequently bulged upward, blocks of it were tilted in different directions, and these movements were accompanied by further injections and uprising of the lava. Eventually the rising lava broke through to the surface and may have in part escaped laterally from the underlying reservoir. The consequent loss of its pressure appears to have caused the bulged mantle of rocks to sink back, and because of their lack of solid support they were intensely broken and fissured. The lava beneath entered many of the openings thus formed, and these small intrusives are now exposed by erosion, but the main intrusive body is still concealed beneath the surface. It is presumed that during the solidification and cooling of this remaining lava water and other volatile constituents with dissolved material, including the heavy metals, were given off and forced outward through the fissures. Some faulting and readjustments of the rocks continued throughout and after the period of ore formation. As the essential features of such intense crustal disturbances are often concealed in a maze of minor or accessory details, the correct interpretation of the structure is commonly very difficult. This difficulty is further increased in the Bonanza district by the scarcity of good horizon markers in the volcanic series and by the comparative poorness of the exposures and the presence of rank vegetation over large parts of the district. Furthermore, the opportunities for solving structural problems by underground observation in the district are meager, because of the small amount of development, only a few of the larger mines being extensive enough or deep enough to assist in the solution of major fault problems. The developments of the Rawley and Cocomongo mines have, however, been of material aid in understanding certain essential features of the faulting. The purpose of this section is in the main to describe and interpret the essential features of the structure. Many secondary kinds of faulting and fracturing that have exerted perhaps equal influence on ore deposition will be discussed in connection with the occurrence of ore.

A visualization of the general nature and extent of the faulting and tilting of the rocks may be obtained from the geologic map and sections, but only by observations in the field or underground can the full complexity of the structure be realized. The data on which the structural and geologic mapping of the district are based were obtained to a great extent either at the surface or at very moderate depths. A great many faults in the district afford no data on their displacement, largely because of the absence of recognizable horizons in their walls. For this reason faults and fissures have been represented on the areal geologic map by the same symbol. A large proportion of the fissures so mapped are actually fault fissures, although the displacements of some of them may be small.

It is therefore emphasized that in many parts of the district the data are not sufficient to warrant the construction of very accurate cross sections representing the extension of structural features in depth. The sections given represent the best interpretation that could be made with the available data and should be used with this limitation in mind, especially in those areas where underground workings do not supplement the surface observations.

FAULTING

RECOGNITION OF FAULTING

The recognition of faulting as an influential element in the structure of the district has been very much hindered by the nature of the volcanic accumulations as well as by the comparatively poor exposures. The change in stratigraphy of the volcanic succession from place to place is roughly illustrated by the columnar section of Figure 3. It is certain, however, that many actual variations in the thickness of individual formations are not known. As the Rawley andesite covers much of the mineralized area where critical data on the faulting are desired, attempts were made to subdivide the formation into smaller stratigraphic units suitable for mapping, but the results were unsatisfactory. The Bonanza latite, the base of which lies 1,500 or 2,000 feet above the base of the volcanic section, consequently proved to be the lowest stratigraphic unit satisfactory for determining structural details; it therefore furnishes the key horizon for the structure over a large part of the district. In fact, one of the main features that first draws attention to the complexity of the faulting is the widespread repetition of the highly tilted basal part of the Bonanza latite. (See pl. 7.)

As the boundaries of formations are mapped in detail the rectilinear nature of the contacts becomes evident, and examination of mine workings further confirms the conclusion that the rocks are intensely fractured and broken by systems of closely spaced faults. Naturally a great many more fractures and faults may be recognized in the underground workings than at the surface, where only those faults that are conspicuous by reason of separating distinctive rocks or by some other feature can be traced with any degree of assurance. Criteria other than a distinctive change in the rocks for the recognition of fault or fracture planes at the surface are of three kinds—evidence of hydrothermal alteration with or without the formation of vein material, the presence of dikes intruded into the fault fissures, and the topographic expression of the faulted structure.

The value of evidence of hydrothermal alteration as a means of tracing fault outcrops is dependent upon the fact that the main parts of the systems of fault fractures were in existence when hydrothermal alteration and mineralization began. Alteration of walls of faults and fissures as seen at the surface produced results of two kinds—a softening and bleaching of the rocks, caused by the formation of sericite and carbonates, and a silicification of the walls, forming a zone of jasper. The first kind has a negative topographic expression, because the altered rock is softer than the surrounding unaltered rock; the second kind formed a hard, resistant rock that commonly crops out prominently if conditions are at all favorable. The intensity of either type of alteration and the amount of vein material change along the fault plane, so that prominent altered zones may be found only intermittently along the course of an outcrop. Prospect pits or more extensive explorations are in many places the only means by which fault zones may be located where they traverse heavily covered talus slopes.

Dikes intruded into fault fissures are probably much more common in the northern part of the district than is indicated on the areal geologic map. Small amounts of dike material are commonly found in the float on talus-covered slopes or in exposures too small to permit their being mapped in proper relation. Dikes that are exposed in mine workings either may not extend to the surface or are not recognizable in the altered and weathered outcrop. The porphyry dike of the Rawley vein, which is very prominent in the lower levels of the mine, has never been discovered at the surface. In the southern part of the district, in the area surrounding the volcanic neck of Greenback Gulch, the dikes intruded along fractures and faults are extremely abundant and constitute the main structural features. The mineralized fissures are of later age, though they partly follow preexisting fault lines or dike walls.

The topographic expression of the fault and fissure outcrops assumes a variety of forms. Where the rocks brought into contact have an unequal resistance to weathering and disintegration the outcrop of the fault line will be indicated by a more or less prominent scarp or by a line of intermittent outcrops of the more resistant rock. The basal flow of the Bonanza latite, unless much sheared and altered, is a particularly massive rock and where faulted into contact with the Rawley andesite usually forms the more prominent outcrops. The complicated structure of the outcropping bedrock has exerted consequently a very pronounced influence on the minor features of the topography. On many débris-covered slopes that otherwise lack any expression of the bedrock structure isolated knobs of some resistant rock may crop out and are usually found to be complexly jointed, so that their shape is controlled by intersecting fault systems or major joints. Where the faults cross spur ridges they are commonly well marked by depressions or saddles and less commonly by ridges of silicified rock, but on the lower slopes they are almost invariably concealed. Definite correlation of fissures over long distances is in consequence usually impossible. The determination of major faults that interrupt fissure zones is of great importance, for they have in many places exerted a marked influence on the localization of ore bodies. The commonest indication of major faults at the surface is the change in general structural relations at the faults. Changes of this nature are encountered along the course of many gulches and larger washes, indicating the tendency toward more rapid erosion of the weaker fractured zones. Rawley Gulch, for example, above the outcrop of the Rawley vein follows closely the course of the Paragon fault zone. The mapping of the extensions, intersections, and endings of many fissures that crop out on the surface has involved a considerable amount of personal interpretation, because the junction of fissures commonly forms a broken zone that is poorly exposed.

The criteria for the recognition of faulting reviewed in the foregoing paragraphs deal with those features that have a special bearing in this district. The common accompaniments of faulting, such as shearing and crushing of the rocks in the walls of the faults and the formation of gouge and fault striae, are also of aid in conjunction with other evidence.

GENERAL FEATURES

The faults recognized in the Bonanza district involve both normal and reverse displacement of the walls; but the normal faults, in which the hanging wall has moved down with respect to the footwall, appear to be the more common. For the most part the fault systems and accompanying fractures indicate that the stresses producing them were of shearing or tensional nature produced by gravitation, and that horizontally acting compressional stresses were of secondary importance. It is to be expected, however, that in a region that has undergone widespread gravitational adjustment of fault blocks great variations in the proportion of compressional and tensional stresses should have been developed. In order to obtain a clear analysis of the kinds of faults, a classification on the basis of these different stresses would be desirable, but as this can be accomplished only in part, the faults must first be considered largely according to their geometric features.

More than 200 faults and fissures recorded from about 14,000 feet of underground crosscut workings in the northern part of the district are plotted in Plate 8, *a*, which is so constructed as to show the relation between the strikes and the dips of fracture planes. The faults and fissures recorded are not entirely random observations but represent an essentially complete record from longer tunnels, such as the Rawley drainage tunnel, the Shawmut Tunnel, and the Antoro Tunnel. The distribution of the tunnels is, of course, erratic, but they are believed to give a fair sample of the fracture systems in the north-central part of the district. As the statistical value of such diagrams depends to a great extent upon the length and direction of the tunnels as compared to the fault pattern, the limitations of inferences based solely upon them must be fully realized. About 70 per cent of these fractures dip toward the eastern quadrants of the compass, a feature that may have some significance, because in the northern part of the district most of the larger faults are a series of step faults, the downthrown side of which is toward the east. (See cross sections, pl. 2.) In Plate 8, *b*, faults and fissures from more scattered underground explorations in the southern part of the district are plotted in the same manner. A large proportion of these strike northwest and dip northeast, but the number recorded is not sufficient to establish this relation as general.

A representation of the proportion of the faults and fissures of different dips in the entire district is shown in Figure 4, in which the number of observations is plotted against the corresponding group of dip readings, each group representing a range of 5°. From these records it has been determined that the average dip of all fault planes recorded underground is between 59° and 60°, and the figure shows further that the dips most commonly recorded are between 45° and 60°. One of the features of the faulting in the district obtained from general observation is the large proportion of fractures of comparatively low dip. Of the 270 faults represented by this figure, 24 per cent lie within a dip range between 15° and 45°, and nearly 40 per cent range between 15° and 50°. As shown by Plate 8, the average dip of the faults in the northeast and southeast quadrants is approximately 57°, and those in the northwest and southwest quadrants average about 64°—that is, the eastward dips are on the whole flatter than the westward dips.

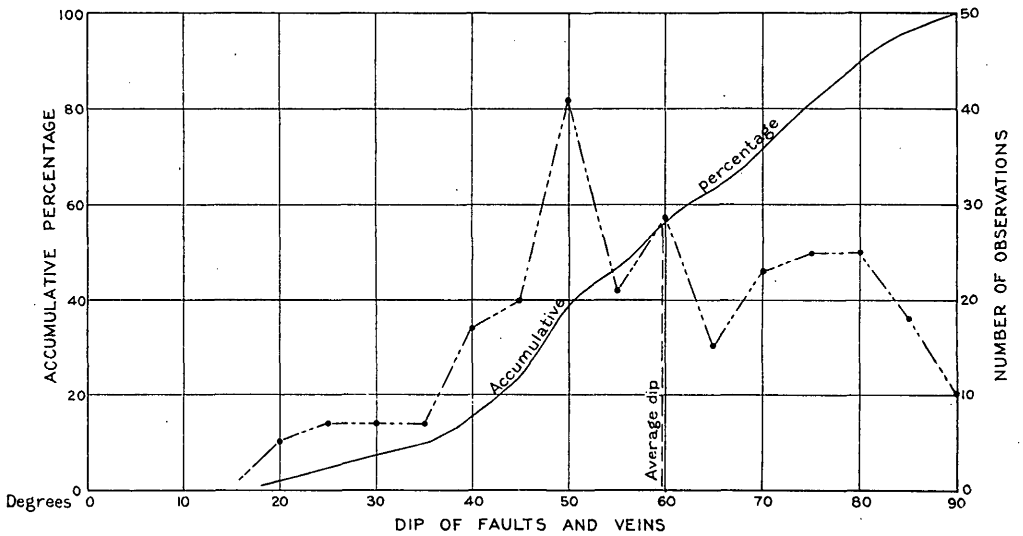


FIGURE 4.—Distribution of fault dips, from records taken in underground workings in the Bonanza district

There are two factors that may possibly have a bearing on the abundance of low-angle faults: One is the curvature of fault surfaces in a vertical plane, resulting in a flattening of dip with depth, and the other is the change in dips of faults caused by tilting of fault blocks. These two factors may also be in a way partly related, for it is obvious that displacements on curved fault surfaces may result in a tilting of fault blocks. Most of the fault blocks in the northern part of the district have been subjected to a westward tilting, which would tend to cause a flattening of eastward-dipping faults and possibly a reversal of steep westward dips.

Reliable information as to the main direction of movement can be obtained on very few fault planes. In some gouge zones striations in several directions can be seen. The pitch of striations observed ranges from 34° to directly down the dip. Evidently, therefore, there was some horizontal component of movement in the faulting, but it is believed to have been subordinate in general to the vertical movement. Changes in strike of formations occurring at cross faults may be due to rotation of blocks on axes essentially normal to the bounding fault plane, thus introducing a horizontal component of displacement on this plane. Such changes of strike, though commonly small, are very abundant in the district.

Although the surface of a fault is often referred to as a fault "plane," such a surface is rarely flat. The curvature and irregularities of fault surfaces are probably related both to the character of the rock traversed and to the nature of the stress that produced the rupture. Many irregularities are to be found in the fracture and fault surfaces in the district.

As for a large proportion of the faults the displacements of the walls are unknown or only approximately known, a comprehensive classification of them can be made only according to the shape of the fault surface and its relation to a horizontal datum plane. The field evidence indicates the presence of fault blocks bounded by both regularly and irregularly curved surfaces, but on the other hand some fractures have remarkably regular strike and dip. A fairly regular curvature in a horizontal plane, such as would be seen if the fault cropped out on a flat surface, is fairly well shown by some of the faults in the district, particularly those in the northwestern part. On the areal map the effect of curvature due to topography and that of actual curvature of the fault must be differentiated. Consequently the lack of underground exploration in much of this part of the district prevents a critical study of such curvature, but its existence can hardly be doubted. This is partly shown by the fact that the calculated dips of many faults determined by their intersection with the topographic surface fail to accord with other field evidence as to the actual dips of the fault surface. Regular curvature in a vertical plane or in the dip of faults is proved to exist in a few places by exploration of mineralized faults in depth, but as extensive workings are required to demonstrate such curvature unless it is very pronounced, the conditions in the district are generally unfavorable for such observations. Nevertheless, for convenience of discussion of these characteristics the faults will be separated into three classes—(1) high-angle faults (dips greater than 45°), (2) low-angle faults (dips less than 45°), and (3) faults of curved dip.[30]

HIGH-ANGLE FAULTS

GENERAL FEATURES

High-angle faults of both normal and reverse displacement represent the most common kinds in the district, but where the evidence is clear normal displacement of the walls is recognized most frequently. The main cause of the normal or tensional faulting was presumably the differential effect of the force of gravity, but the upward thrust of underlying bodies of lava was possibly a local factor.

Structure sections taken in an east-west direction through the northern part of the district as represented by sections A–A′, B–B′, C–C′, and E–E′, Plate 3, show that the rocks are broken by a north-south fault system that has thrown the fault blocks downward in steps toward the east. The relation, however, is not entirely as simple as this statement would indicate, owing to the fact that the beds in each block are steeply tilted, in parts at exceptionally high angles, toward the west, and the corresponding stratigraphic horizons assume a higher altitude in going from west to east. Thus the structure as it now stands suggests the progressive collapse of a tilted or domed section of the crust. The initial form of the crustal bulge prior to this normal faulting is a matter of speculation and will be considered in later paragraphs. Sections constructed in a north-south direction, such as section D–D′, Plate 3, show that the east-west fault system steps the fault blocks downward toward the southeast. South of the Eagle Gulch latite, however, there is a tendency for the northwestward-striking faults in the vicinity of Hayden Peak to throw blocks down toward the northeast. However, the displacements of faults in the region of Hayden Peak are difficult to determine, because of the slight knowledge of the variation in stratigraphy of the local volcanic accumulations; furthermore, irregular block faulting related to the intrusion of the Eagle Gulch latite and of the volcanic neck centering near Greenback Gulch considerably complicates the local structure.

The effect of the two main systems of faults in the north is to produce a fault pattern in which the downthrows of the two systems are combined. There are many complications in the local details, however, as all the faults can not be placed definitely in one system or the other, and there are also many exceptions to the general direction of downthrow. Probably during the collapse of the initial structure the rocks were broken into many small blocks, which during later gravitative adjustment moved to some extent singly or in independent groups so that the present features of the faulting have not entirely resulted from the intersection of distinct fault systems of definite age and trend. It is found that in one part of the district a north-south system of faults has been rather consistently displaced by northeasterly or northwesterly faults, whereas in another part of the district a different relation between the systems appears to exist. Many faults, particularly perhaps those of smaller displacement, terminate against transverse faults. The problem of the relation of different fault sets to one another is of great importance to mining development, and as the mineralization of the faults and fissures is so closely tied up with the history of the faulting, the discussion of different areas, in order to avoid needless repetition, will be presented in the section on the relation of mineralization and faulting. (See pp. 88–91.)

SUNKEN WEDGE FAULTING

One probably significant type of high-angle faulting is that illustrated near Alder Creek, in the northeastern part of the district, where fault blocks of one formation are inlaid into another formation by intersecting sets of steep faults. This same type of faulting is represented in certain areas throughout the north-central and southern parts of the district. An interpretation of the section across the Alder Creek

[30] See Willis, Bailey, Geologic structures, p. 68, New York, 1923. Willis introduces the terms "low angle" and "high angle" to designate faults of which the exact origin is in doubt or the nature of whose extension in depth is not known.

area is shown by section A–A′, Plate 3. The field conditions suggest that the faulting of this nature is in part of the sunken-wedge or keystone type. Several such dropped wedges lie within a border zone where the prevailing dips of crustal blocks are undergoing change. The dropped block of Bonanza latite shown near the middle of section A–A′ lies in a border zone between a region of nearly horizontal fault blocks on the east and a region of fault blocks tilted 30°–50° NW. on the northwest.

A similar change in dip of the fault blocks is shown between the western and eastern parts of sections B–B′ and C–C′. In the zone where the sharpest change in tilt occurs downthrown blocks of the wedge type are also in evidence. The zone of strongest mineralization in the northern part of the district is comparatively narrow and long, taking a curving path from the Joe Wheeler mine southwestward to Round Mountain and thence practically due south to Rawley Gulch near the Rawley and Whale veins. South of Rawley Gulch the zone is less well defined and wider and swings southwestward again toward Kerber Creek, where it appears to end. Whether this mineralized zone bears any relation to the structural zone within which the fault blocks have undergone their sharpest change in dip is worthy of consideration. From Alder Creek to Rawley Gulch the coincidence between the zones as to both position and width is very suggestive. Southwest of Rawley Gulch the change in structure is less sharply defined, and the mineralized zone is correspondingly wider. The sinking of wedge-shaped fault blocks that taper downward is generally explained on an assumption of tensional conditions in the crust, such as is commonly held to occur along the crest of an arch or bulge in rigid or competent rocks. (See fig. 5.) Zones of bending, if they involved sufficiently thick blocks, would contain open fractures in the upper parts of the blocks that would provide most favorable places for the deposition of ore bodies. The actual deposition of ore would depend also upon the existence of deeper channels permitting the access of mineralizing solutions and vapors of igneous origin. Strong alteration of the fissured rocks in this area is sufficient evidence of the access of mineralizing solutions, but the intense and closely spaced fracturing of the rocks appears to have caused the distribution of tensional openings throughout a wide zone and thus has in most places favored the formation of many small openings rather than a fewer number of larger ones. Therefore the most favorable conditions are not generally fulfilled.

HIGH-ANGLE SHEAR FAULTING

In contrast to this tensional type of faults are other kinds of high-angle faults, whose origin is of more speculative nature but is probably related to conditions of both tension and compression. Such faults are shown in a zone that lies west of the border zone described above and extends from the region of the pre-Cambrian outcrop near the head of Squirrel Gulch essentially due south to the junction of Kerber and Brewer Creeks. At the north the zone is probably about a mile in width, but it widens southward to a maximum of about 2 miles and then narrows abruptly to a strip along the west side of Brewer Creek. Throughout this area the rocks are not only intensely faulted but are tilted westward at angles of 40° to 75°. The most prominent faults have a direction north-south in general but vary considerably to each side of this trend. The interpretation of the structure in this area is shown in sections B–B′ and C–C′, although the representation of the extensions of the faults in depth lacks the support of underground observation. Exploratory work on veins in these areas is not as extensive as elsewhere, apparently because the character of the fissuring and of the rocks

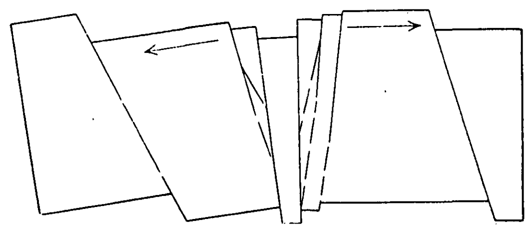


FIGURE 5.—Formation of a zone of maximum tensional conditions within a series of fault blocks tilted at different angles

is less favorable to the formation of gapping fractures. There are several features by which the faults in this zone differ from those in the border zone to the east. The fault pattern suggests the presence of fault blocks bounded by somewhat curved surfaces, and the highly tilted flows are sheared parallel to many of the north-south faults. Nearly all the surface flows involved in the faulting of this zone exhibit a prominent flow structure, and the direction of shearing of the rocks is noticeably influenced by their structure. Several of the sheared fault zones also dip westward, and where the flows are tilted to very high angles these shear faults essentially coincide in strike and dip with the tilted lavas. Structure of this type is best seen near the upper part of Squirrel Gulch and on the north side of Bear Gulch.

As the same general direction of downthrow toward the east is to be seen in the westward-dipping shear faults, it is evident that these are essentially reverse faults. Their displacement can only be inferred from the surface relations, nevertheless the overlapping or imbrication of long, narrow wedges of andesite, latite, and other rocks indicates displacements of many hundreds of feet. Further evidence that the displacements on these faults are very great is also given by the erratic displacement of a faulted dike that extends southwestward from a point near the junction of Squirrel Gulch and Sosthenes Gulch. (See pl. 1.) The several outcrops of pre-Cambrian gneiss within this zone near the head of Squirrel Gulch suggest two possible conditions—these outcrops mark the position of a hill or mountain of the underlying basement, or they imply displacements of the upfaulted blocks of several thousand feet. Regardless of either interpretation, the field evidence shows that the present contacts are faults of fairly large displacement, as otherwise exposures of the underlying basement would be more numerous or larger.

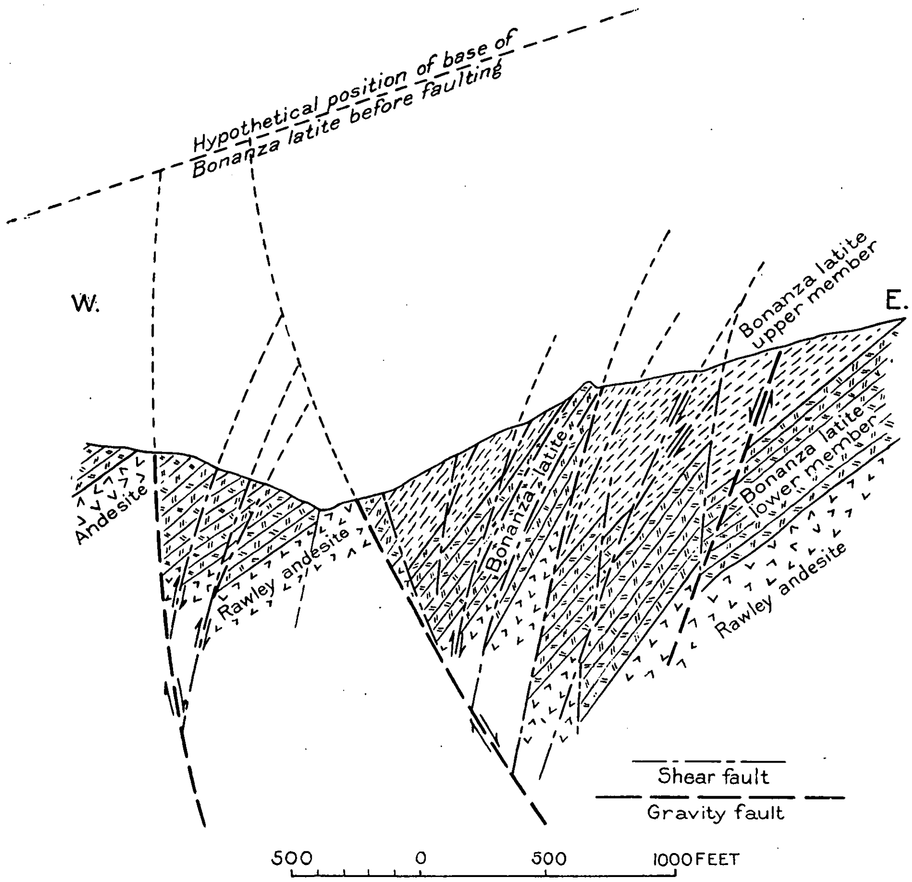


FIGURE 6.—Hypothetical conception of the structure of a major fault zone on Squirrel Gulch

The high-angle eastward-dipping faults of this zone are of normal displacement and indicate that at some stage in the deformation crustal extension took place. On the other hand, the high-angle westward-dipping faults, which show the same direction of downthrow, are reverse faults and suggest crustal shortening. The origin of these opposed types of faults and the relation between them have not been determined, as surface exposures are not adequate to solve the problem definitely. There appear to be several possible explanations of the origin of these faults, although they all lead to the consideration of hypothetical relations between the general structure of the region and the minor features of this zone.

Figure 6 presents a section of a complexly faulted zone across Squirrel Gulch about half a mile above the Rawley mill. The structural conditions at the surface shown by this section are known to be correct as to general features, and the dips of some of the faults where they crop out are approximately known, but the underground extension of the structure is by necessity hypothetical.

The large normal fault along the east side of Squirrel Gulch is exposed in places and is characterized by a strong silicified breccia zone. Its dip is eastward or nearly vertical, but an average eastward dip of 60° shown by the normal faults was assumed in the diagram. The footwall block is andesite, which is exposed in the valley floor, and the hanging-wall block is the Bonanza latite, which has a steep westerly tilt. Plate 7, *A* and *B*, shows the hanging-wall fault block as it appears looking up the valley and a close-up view showing the highly tilted and sheared condition of the Bonanza latite. The latite is much broken and faulted by shear fractures dipping 55°–70° W. The conditions show that the lavas have been sheared along surfaces that tend to follow the lines of greatest weakness in the rock—that is, the partings parallel to the flow structure. As there is no evidence that regional compression of the crust was the dominant cause of the major structure of the region, this shearing must be explained presumably by conditions existing during the settling and faulting of the crust under the force of gravity. The development of shearing stress in the walls of normal faults, under vertical pressure caused by gravitation, has been recognized by some geologists as a common condition. Willis [31] has analyzed the mechanics of this condition.

There is a further tendency for surfaces of shear where appreciable deformation occurs to be progressively deflected by the formation of secondary shears; therefore a curved surface of faulting would result from such shearing under favorable conditions. If we assume that in addition to the vertically acting gravitation, the rocks involved here also became subject at certain stages in the deformation to compressive forces acting tangentially, then conditions would be especially favorable to the development and extreme deflection of shearing faults until they dipped at

[31] Willis, Bailey, Geologic structures, p. 173, fig. 89, New York, 1923.

lower and lower angles. In this manner compressional stresses would be relieved along these shear faults by actual shortening of the section.

There are numerous features of the local and regional structure that accord with such an interpretation of the origin of these shears. The coincidence of the zones of highly tilted lavas with the observed shearing implies a fundamental relation between them. It is furthermore improbable that the present steep tilts of the lavas represent the original attitudes of these flows prior to faulting. This point will be further considered in connection with the relation of tilting and faulting. It is easily shown that movement on curved fault surfaces will result in the rotation of fault blocks about an axis paralleling the curved surface, as is illustrated in Figure 7, B. The tilting of the fault blocks in the Squirrel Gulch section is in the right direction to have been caused by such curved shear faults. The tangential compression could hardly find relief by reverse movements on steep eastward-dipping normal faults. The friction on these steep faults would be too great, and reverse movement would also be opposed by the general tendency shown by the fault blocks to fault progressively downward toward the east. On the other hand, westward-dipping shear faults would have afforded relief simultaneously both for the tangential compression and for the gravitational adjustment that continued to take place.

If the fault surfaces were curved and the blocks involved were tilted during displacement the crustal shortening might be accomplished in one or two ways—by the shortening that naturally accompanies certain kinds of reverse faulting, and by the rotation of narrow fault blocks so that the width and area of this section of the crust is reduced and its thickness correspondingly increased. The shearing of a fault block that results in a series of overlapping slabs tends to increase one of its dimensions and reduce the other, as is illustrated in Figure 8. Such structure, known as imbricate structure, has been commonly recognized in regions of intense horizontal compression, but it may readily develop under proper conditions of highly inclined stresses.

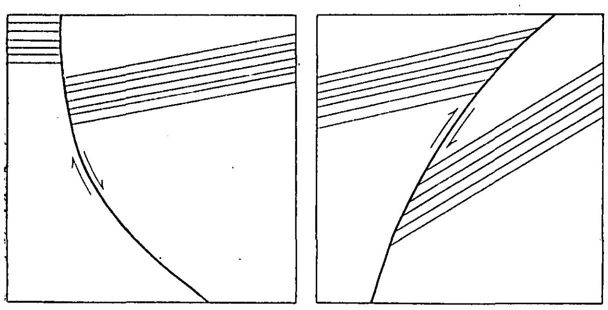


FIGURE 7.—Tilting of volcanic formations caused by curvature of the fault surface (A) in normal gravity faults and (B) in reverse shear faults

This hypothesis of origin of the structure is based in part on the supposition that tangential compression was developed as an accompaniment of gravity faulting. The first stage in the development of the present structure of the region appears to have been the intrusion of lava into the shallow part of the crust, causing it to tilt and bulge upward; the later settling of this bulge would possibly lead to the formation of compressional stress, on the principle of a subsiding arch. Such compressional stress would be caused by the accommodation of the rocks to the decreased length of the arch as it subsided, and the stress would consequently be relieved by failure and would only be of temporary existence. However, in order for the arch to be supported by the surrounding rocks and by the molten rock beneath, certain tangential compressive stresses must exist permanently on the flanks of the arched structure. The cause for the existence of this tangential compression may be deduced by a consideration of Figure 9. The pressure P represents the pressure of the intrusion, which would act essentially at right angles to the sides of the body because of the hydrostatic nature of this force. Because of the inherent weakness of rocks the arch could not remain if there were a large void in place of the intrusive body, and the weight (W) of the overlying rocks must therefore be supported by the outward pressure of the magma. The direction of the force P exerted by the magma would, of course, vary with the shape of the body, but would not generally be parallel with W, and a resultant tangential force, R, must then exist. This would tend to make the rocks slide down the flanks. If the rocks do not slide and equilibrium is attained tangential compression will then be developed equal to R. The exact direction of this resultant, R, will depend upon the magnitude of P and W and upon the direction of P, but in general the resultant force will have a large component tangentially to the arch. This compression will be cumulative on the flanks of the laccolith and will consequently be at a maximum near the edge. In some favorable position near the edge the compression might attain a magnitude that would have an appreciable influence on the fracturing and deformation of the rocks. Above the center of the laccolith

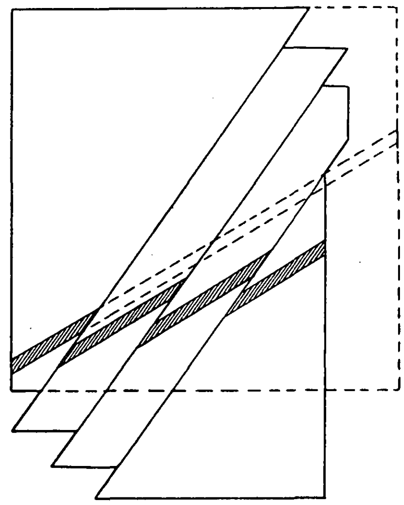


FIGURE 8.—Change in dimensions of blocks by displacements on a series of shear faults

this tangential force would be at a minimum, and more simple tensional forces would control the fracturing of the rocks. A very simple relation has been assumed in Figure 9—namely, that the forces P, W, and R all act through one point—but this would not in general be true, and as a consequence rotational force might be produced by the intrusion in addition to the simple tangential compression.

The field relations in the Bonanza district show the existence of a zone of tilted and sheared rocks along the edge of the west flank of the uplifted area (fig. 10), and it was also shown in the discussion of high-angle faults that evidence of greater tension is found to the east of this near the central part of the structure. Thus the general interpretation set forth above agrees with the relations found in the field so far as the positions of the zones of shearing and tension are concerned.

LOW-ANGLE FAULTS

Low-angle faults are of common occurrence in the district, but it is difficult to determine the relative direction of movement of the walls of many of them. Some of the best exposed, however, have proved to be normal faults in which the hanging wall has slid down over the footwall. A common characteristic of such faults is the thick gouge zones, which appear to have nearly filled large openings that may have temporarily existed, although these are also filled to some extent with ore. Plate 7, *D*, shows a photograph of the low-angle Exchequer fault, where the zone of altered gouge and crushed rock is 3 to 5 feet thick. Even thicker sheared zones, reaching 15 to 20 feet in width, are found along other mineralized faults, of which the Cocomongo fault of the Cocomongo mine and the Clark fault of the Rawley drainage tunnel are examples. These physical characteristics of the faults imply either that the fault surfaces were uneven and subject to great pressure during movement, that the displacements were large, or that all of these factors were effective. The low angle of dip of the faults is, of course, favorable to the development of great pressure between the surfaces in contact, as the force of gravitation is more nearly normal to them. If we assume that these low-angle faults had a constant dip throughout their extent, the occurrence of normal faulting along their surfaces is difficult to explain. If such faults were only minor fractures, they might be regarded as of little significance, but in many of them the displacement is known to be large. Near the Exchequer fault the Bonanza latite is much broken and blocks in the footwall are locally tilted, indicating that the fault is a zone of considerable dislocation. The Cocomongo fault is a low-angle fault of at least several hundred feet displacement; moreover, this fault flattens downward from a dip of 40°–48° near the surface to 20°–25° at a depth of 400 feet. Cross sections of this fault are shown in Plate 28, and the details of its structure are described on pages 95–96 and 117–118.

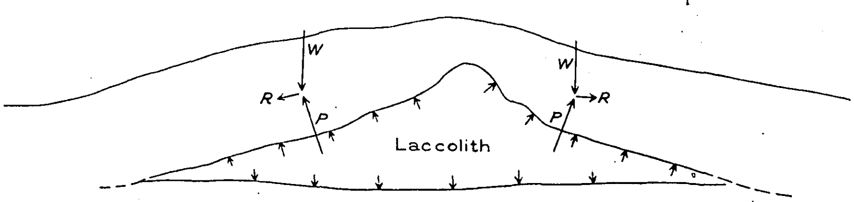


FIGURE 9.—An interpretation of certain stresses developed in the rocks above a laccolithic intrusion

Other typical examples of mineralized low-angle faults that have been explored are the Rico fault, dipping 25°–30° SE., the Hanover fault, dipping 28°–35° E., the Poverty fault of the Antoro tunnel, dipping about 35° N., and the Black Bess fault, dipping 40° E. Large numbers of unmineralized faults of this range are also exposed in crosscut tunnels. Of the 270 fissures and faults recorded in Figure 4, 24 per cent have dips of less than 45° and about 16 per cent have dips of less than 40°. The lowest dips recorded are near 20°. As the records shown in this figure give a systematic cross section of several long tunnels and smaller crosscuts representing about 14,000 feet, the proportion of low-angle fissures is probably fairly representative for the north-central part of the district. Faults having a dip between 45° and 50°, which come close to the arbitrary division set between high-angle and low-angle faults, are more numerous than those of any other equal dip range. An inspection of Figure 5 shows that most of these dip southeast or northeast.

The origin and present attitude of these faults may be explained as due either to flattening and fraying out of high-angle faults in depth or to tilting of fault planes that were initially steeper. If the upper parts of these fault surfaces had steeper dips the weight of the hanging-wall block would be transmitted more effectively to cause movement on the flatter portion of the fracture. The hanging-wall block under these conditions would naturally be tilted toward the fault surface. (See fig. 7, A.) Faulting of this type is similar to that recognized in the more superficial faults of landslide origin; whether or not it occurs in deeper-seated movements of the crust is a matter of speculation, but so far as known to the writer no examples have been described. It is obvious, however, that if the radius of curvature were great, so that the flattening occurred through a range of several thousand feet vertically, ordinary underground explorations would rarely detect such curvature. As 3,000 or 4,000 feet represents about the initial cover over the parts of the district in which faults are now exposed it is possible that most of the flat faults represent the roots or terminations of displacements starting at nearly vertical angles from the original surface. Most of the flat faults have a dip toward the eastern quadrants of the compass, which is the general direction in which the fault blocks may be presumed to have moved during the gravitational sinking. The tendency of the greater proportion of the fault blocks in the north-central part of the district to be displaced progressively downward toward the east and to be tilted westward indicates that some relatively uniform condition of stress existed throughout this part of the district. The evidence for the existence of vertically acting stress, probably to a large extent of gravitational origin, has already been given.

The formation of a comparatively large proportion of low-angle dislocations may be considered evidence that in addition some horizontal or nearly horizontal stresses of appreciable magnitude also existed. The deformation of the rocks may have been such that they tended to move horizontally eastward to equalize the loss of lava from the central part of the uplift. The fraying out of high-angle faults in depth to low-angle eastward-dipping breaks would afford relief for such stresses. A smaller number of low-angle faults dip west and under such conditions are possibly reverse faults, but in none of them has the exact direction of displacement been determined. As it appears fairly certain that the fault blocks were tilted westward to some degree during faulting, the tilting of fault planes must have taken place at the same time. Certainly the low angle of average easterly dip is due in part to this tilting, but it is not due entirely to this cause.

Several low-angle faults were seen where the stratigraphic relation between the hanging wall and footwall rocks appeared to indicate a reverse displacement, but nowhere could reverse displacement be definitely established. One example of such a relation was seen in the central part of sec. 5, T. 47 N., R. 8 E., northwest of the Joe Wheeler mine, in the northeastern part of the district, where the Rawley andesite appears to be thrust westward over the Bonanza latite. The fault plane coincides approximately with the northeast slope of the ridge and dips about 20° E. The fault is marked by strong silicification of the andesite and latite and is apparently broken by later high-angle faults. The full extent of the fault could not be determined.

TILTING OF THE VOLCANIC FORMATIONS

In some parts of the district the determination of the dip of the formations is a matter of some difficulty. The tracing of contacts between different lavas is the most satisfactory method, but these contacts are commonly faulted and partly concealed. Within the Rawley andesite the mapping of certain distinctive flows, such as the latites or of breccia beds that are interbedded in this formation serves to give the general tilt of the fault blocks. Although the flow planes are commonly not accurate guides to the attitude of beds of lava, the flow lines and accompanying sheeted structure in the Bonanza latite were found to be approximately parallel to its basal contact. Moreover, this latite is repeated a great many times in the district by faulting, and observations on many fault blocks in certain parts of the district covering several square miles are so consistent as to eliminate the possibility that the flow lines do not everywhere correspond with the attitude of the beds. The attitude of the Squirrel Gulch latite can be determined in some places by thin flows near the base or by the columnar jointing, which in general stands at right angles to the surfaces of the flows, although local variations are to be found. A general correspondence between the textural features of the flows and their attitude is also found in some lavas near the base of the Hayden Peak latite and the Brewer Creek latite. On the other hand, the rhyolite lavas of Porphyry Peak contain extremely distorted and curved flow lines, so that the attitude of the flows in this part of the district could be determined only from contacts between different lavas.

A key map of the main structural features of the district showing the general tilting of the fault blocks is given in Figure 10. The tilts represent those of individual fault blocks and not those of the larger crustal blocks as a whole. Within the area mapped there are evidently at least three distinctive major blocks in which the lavas show similar directions of tilting. In the central part of the district the lavas strike north and dip west, although the strike may locally diverge 10° to 20° from the general trend. Southeast of the Eagle Gulch latite the lavas strike parallel to the trend of this intrusion and dip southeastward, away from its flanks. The northernmost block lying north of Alder Creek contains steeply tilted fault blocks that dip toward the northwest. On Round and Manitou Mountains and near Alder Creek the formations show only moderate dips, but there is little consistency in them, and the general attitude of the rocks is nearly horizontal.

The distance to which these tilted fault blocks extend beyond the confines of the mapped area is only partly known. The Brewer Creek latite and the overlying andesite maintain a gentle westward dip as far as the base of the Antoro Range, a distance of 3 to 5 miles. There is evidence of less intense faulting throughout this area. Southwest and southeast of the district some tilting of the lava beds is evident, but its intensity seems to be much less than in the district. The structure east and north of the

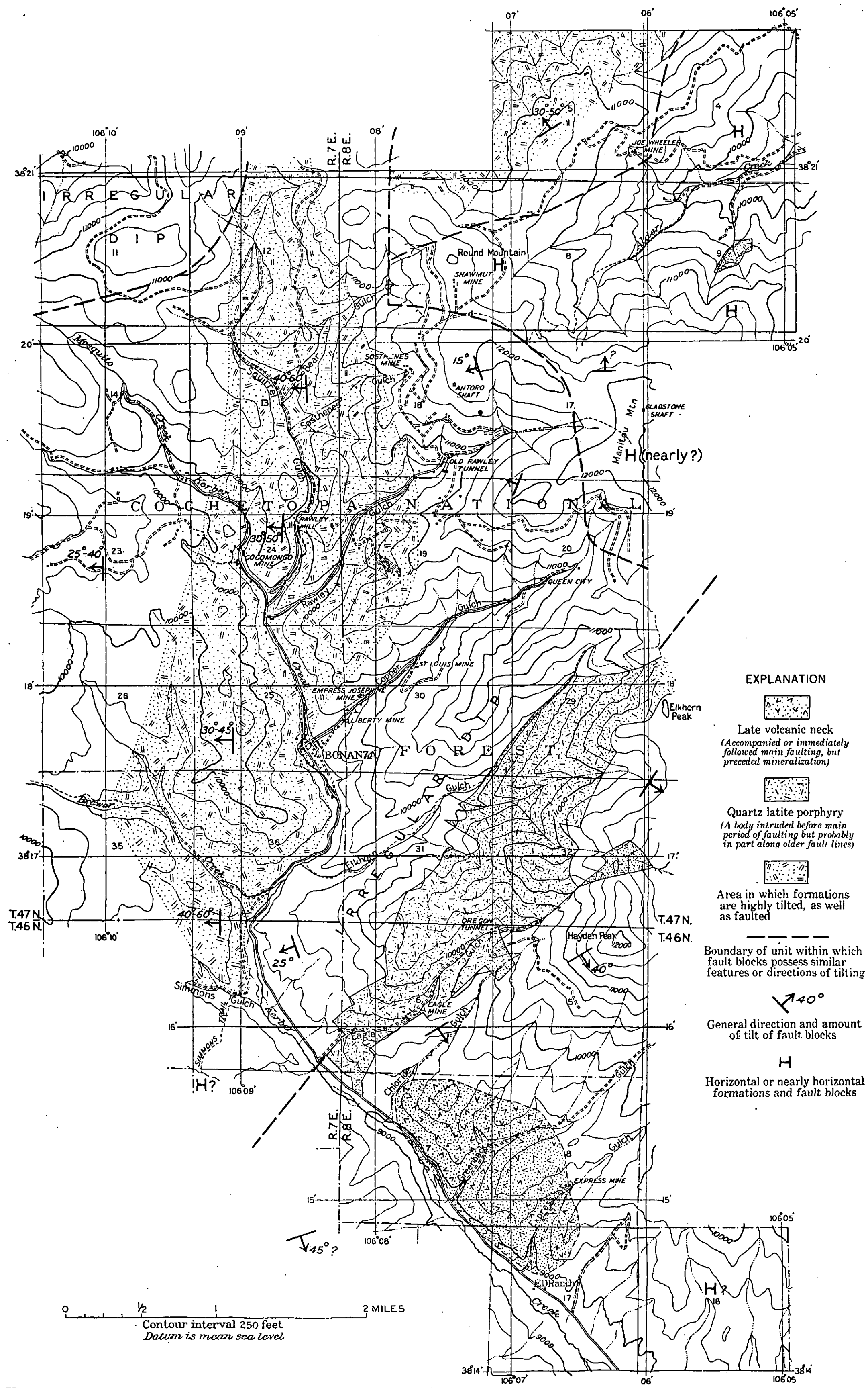


FIGURE 10.—Key map of the main structural features of the Bonanza district, showing the general tilting of fault blocks in different parts of the district

district is not known, but along the lower part of Alder Creek, several miles to the northeast, the lavas appear to be tilted gently westward away from the edge of San Luis Valley. The extent of the area of tilting is in consequence not completely defined, but the available evidence indicates that the tilting is a local feature covering possibly two or three times the area that has been mapped.

Part of the tilting, particularly within the narrow zone of steeply tilted formations, is believed to have been the direct result of the faulting of the rocks. A reconstruction of the arch produced by piecing together the tilts of small fault blocks in any of the cross sections results in an attitude of the larger crustal blocks that is inconsistent with what is known regarding the strength of rocks to depths of several miles. (See fig. 11.) Furthermore, if the crustal blocks were tilted by the upthrust of underlying lava in different directions and to a degree comparable with the attitude shown by the individual fault blocks, extremely large openings must have formed between

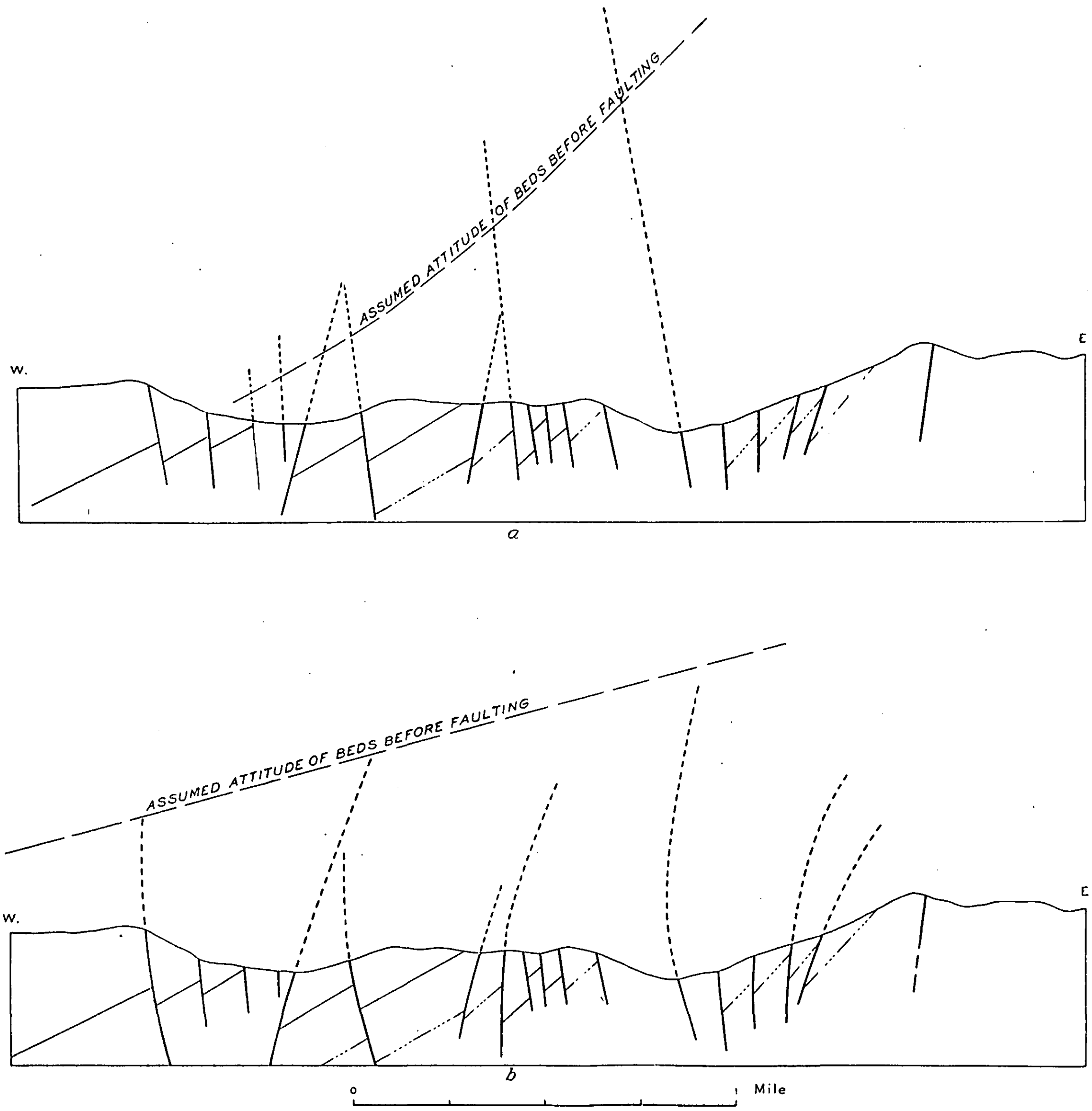


FIGURE 11.—Difference in interpretation of faulting of formations, based on assumptions that tilting occurred (*a*) entirely before faulting or (*b*) largely during faulting. In (*a*) it is assumed that the beds were first tilted to an angle shown by the line above the section and later faulted down to their present relative positions. In (*b*) it is assumed that the beds had a moderate initial tilt westward, which was afterward locally accentuated by rotation of fault blocks during faulting. The mechanism of the rotation is suggested by curved fault surfaces and by later shearing of fault blocks, but the actual mechanism is not definitely known

them. Unless the crustal blocks were very thick such openings would have penetrated to the underlying molten rock, and large intrusive bodies would occur along the boundaries between tilted blocks. One such intrusive body is perhaps represented by the Eagle

Gulch latite, but it is not wide enough to indicate more than a moderate tilting of the larger blocks. Moreover, the entire width of the Eagle Gulch latite outcrop can be accounted for by the southeastward tilting of the formations on its southern flanks, provided the tilted block is not thicker than the Hayden Peak formation. If this explanation is correct, the intrusive latite forms a laccolithic wedge-shaped intrusion, as shown by sections D–D′ and F–F′, Plate 2. It would appear that lava must have escaped through this opening to the surface.

As it is hardly conceivable that the present dips of the lavas in certain parts of the faulted sections could represent the initial tilting of large blocks of the crust, it appears that the present attitude of these smaller fault blocks resulted very largely from later tilting that accompanied the collapse and faulting of the up-bulged area. A hypothesis to account for the mechanics of such tilting as is presumed to have accompanied faulting is discussed on pages 49–50.

INTRUSIONS

The only large intrusive body exposed in the district is the Eagle Gulch latite, of which the general structural relations are described on pages 31–32 and indicated in sections D–D′ and F–F′, Plate 2. Some of its boundaries on the northern flank, along the upper part of Elkhorn Gulch, have a rectilinear outcrop, which suggests that it was intruded along old fault lines. Many of its southern boundaries also suggest intrusion between separated blocks of the faulted Hayden Peak latite. The much-faulted contact along the lower part of Eagle Gulch is difficult to explain, as some of the faults may be traced into the intrusive rock. Whether the main part of this faulting preceded or followed the intrusion has not been satisfactorily determined. It is possible that the fault lines were determined in part by fracturing accompanying the intrusion and the tilting of the latite on its flanks, but that later movement took place on these fault lines during the major deformation of the region or during the formation of the Greenback Gulch volcanic neck. The possible relation of the latite to the tilting of the Hayden Peak latite on its south flank is considered above in the discussion of tilting. Presumably the long, narrow shape of the latite body is due to intrusion along a major fracture between tilted crustal blocks. The latite is known to extend northeastward beyond the area shown on the geologic map, but the shape and size of this extension are unknown.

An intrusive mass of granite porphyry, the top of which is barely exposed, occurs south of Alder Creek. The intense alteration in the immediate vicinity of this intrusive and less intense effects of a similar nature extending about half a mile on all sides of the outcrop suggest the presence of a large unexposed body beneath this part of the district. It is possible that the exposure of pre-Cambrian rocks in the gulch of Alder Creek represents an upthrust mass of rock overlying such an intrusive body. The alternative explanation is that it represents a mountain or hill of the underlying basement.

The intrusion into fault fissures of many dikes of quartz latite and rhyolite and a few dikes of coarse-grained monzonite forms an important link in the evidence as to the relation between faulting and concealed deep-seated intrusions. This relation suggests that the mantle of faulted and fissured rocks now exposed rests upon an underlying intrusive mass of large dimensions. The fracturing of the tilted rocks afforded spaces into which the magma was intruded during deformation. The evidence of intense hydrothermal alteration and of mineralization along these same fractures constitutes a further indication that a large body of crystallizing magma remained beneath the region after faulting. The shape of this body can only be inferred from the surface structure; but as there has been some residual doming of the formations, as shown by the fact that the older rocks occupy the higher parts of the range, it is probable that the body was thickest near this central up-bulged area and thinned westward. Further mapping would be necessary to determine the extension of this intrusive mass beneath surrounding areas.

The most pronounced structural feature south of the Eagle Gulch latite is the intrusive complex near Greenback Gulch. The general outline of the central part of this complex is like that of a volcanic neck or pipe that extended through to the surface, but the rocks for a mile or so on all sides are greatly disturbed and intruded by rhyolite dikes of similar character to those in the central part. Within the central part of this area, between Greenback and Express Gulches, the rocks are much decomposed. (See pp. 35–36.) The general character of this structure suggests that the rocks were broken by some local force into an enormous breccia and then intruded by irregular bodies and dikes of rhyolitic and latitic lava. Local bodies of altered breccia occur within the central part of the neck, suggesting that the forces were, in part, of explosive character. The effect of this intrusive complex is largely local, but it gives evidence of the comparatively thin shell of solid formations that overlay the molten rock in this part of the district. The formation of this neck was later than the consolidation of the Eagle Gulch latite, as some dikes of similar nature to those of the complex intrude the Eagle Gulch latite near Kerber Creek. Here as elsewhere in the district further fissuring and mineralization have clearly followed the formation of this complex.

SUMMARY AND CONCLUSIONS

It has been shown that only a part of the Bonanza structure has been mapped in detail, but that deformation has produced a dome or a bulge probably of unsymmetrical shape. The oldest known group of volcanic rocks occupies a large area in the central part of this dome; the younger lavas dip away to the north, west, and southeast of the center. In the area east of the district the structure of the lavas is imperfectly known, but at a position somewhat remote from the intensely deformed rocks the lavas dip gently westward, toward the center of the district. Several miles west of the district, in the Antoro Range, the lavas dip gently westward toward the Saguache Creek Valley. Thus as the area of intensely deformed rocks is essentially surrounded by slightly deformed rocks, the conclusion is reached that the structure is caused by shallow deforming forces of local origin. Many of the faults and fissures are occupied by dikes of igneous rock, and there has been much fumarolic alteration and mineralization, which indicates that the deformed rocks are underlain by an intrusive body of large size. It is concluded that this intrusive body was the principal or only cause of the local doming and faulting.

Both normal and reverse faults are present in the district, and it is concluded from further field evidence that these faults were due partly to simple tension and partly to a combination of tensional and compressional forces. The simpler tensional faults are found to be largely in the central part of the domed area; shear faults are prevalent in zones bounding at least the north and west sides of the area. The close association between steeply tilted fault blocks and these zones of shearing of the lavas leads to the conclusion that the shear faulting and the extreme tilting of the lavas were related phenomena and probably of contemporaneous development. The explanation of this structure is based upon an assumption of local concentration of compressional forces which were developed on the flanks of the dome and which caused fault blocks to shear and rotate. On the west side of the dome the lavas dip consistently westward, and faulting has resulted in a series of step faults in which the downthrown side is toward the central part of the dome. It is suggested that this structural feature may have been caused by the rocks on the west flank of the dome sliding eastward during the final collapse to occupy a space vacated by the underlying intrusive magma. In view of the many low-angle faults dipping eastward toward the center of the deformed area it is suggested that the collapsing crust may have acted in a manner somewhat approaching the action of superficial landslides. If these low-angle faults are of curved dip, they may have caused part of the westward tilting of the formations.

The relative importance of either shear faulting, tension faulting, or intrusive action as the possible cause of tilting probably differs in different parts of the district, but the extreme tilting can probably be assigned largely to the shear faulting, as the other possible causes appear inadequate. The relative ages of the shear faulting and the low-angle normal faulting are not generally known, but the absence of shear faults that displace such low-angle mineralized faults as the Bonanza and Cocomongo suggests that the low-angle normal faults are of later age in this particular area.

One conclusion reached—namely, that a considerable part of the tilting and faulting were produced simultaneously—would seem to be an inherent part of any explanation of the structure. Simultaneous faulting and tilting have been previously suggested by Emmons and Garrey [32] for the structure in the Bullfrog district of Nevada, where the tilting of the lavas and certain features of the faulting appear similar to those at Bonanza.

Mineralization at Bonanza followed the main part of the deformation, but small gravitational adjustments of the rocks continued throughout and after the period of ore formation. The zones of most intense mineralization appear to coincide roughly with zones of simple tension, which existed along the border between areas of highly tilted and gently tilted fault blocks.

ORE DEPOSITS

PRODUCTION AND HISTORY

By Charles W. Henderson

Known records show that the Kerber Creek or Bonanza district produced over 99 per cent of the metal output of Saguache County in 1904 to 1929. From less reliable sources it is gathered that other districts in Saguache County yielded perhaps even a smaller percentage of the county output in 1880 to 1903 than in the later years. Therefore, the production of Saguache County from 1880 to 1929 very nearly represents the production of the Bonanza district.

[32] Ransome, F. L., Emmons, W. H., and Garrey, G. H., Geology and ore deposits of the Bullfrog district, Nevada: U. S. Geol. Survey Bull. 407, pp. 81–89, 1910.

Gold, silver, copper, lead, and zinc produced in Saguache County, Colo., 1905–1929, by districts

[In terms of recovered metal]

District	Ore sold or treated (short tons)	Gold		Silver		Copper		Lead		Zinc		Total value
		Fine ounces	Value	Fine ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
Baca Grant	1, 195	661. 28	$13, 670	850	$652	1, 422	$227	125	$5			$14, 554
Blake	145	41. 29	853	759	519	7, 848	1, 327	100, 916	5, 473			8, 172
Cochetopa	126	2. 23	46	106	77	2, 881	677	965	63	48, 791	$3, 050	3, 913
Crestone	12	19. 02	393	1	1	29	8					402
Crystal Hill	632	61. 89	1, 279	21, 916	19, 259	354	93	2, 042	155			20, 786
Embargo	64	22. 83	472	3, 815	2, 191	116	15	4, 324	214			2, 892
Iris	17			34	17			224	11	6, 560	813	841
Kerber Creek	503, 572	6, 512. 08	134, 617	3, 544, 749	2, 260, 093	12, 361, 638	1, 861, 745	27, 048, 753	1, 752, 362	2, 578, 610	191, 343	6, 200, 160
Unknown	87	34. 00	703	27	18					74, 302	4, 532	5, 253
	505, 850	7, 354. 62	152, 033	3, 572, 257	2, 282, 827	12, 374, 288	1, 864, 092	27, 157, 349	1, 758, 283	2, 708, 263	199, 738	6, 256, 973

Gold, silver, copper, lead, and zinc produced in Saguache County, Colo., 1880–1929 [1]

[In terms of recovered metal]

Year	Ore sold or treated (short tons)	Lode gold	Silver			Copper			Lead			Zinc			Total value
			Fine ounces	Average price per ounce	Value	Pounds	Average price per pound	Value	Pounds	Average price per pound	Value	Pounds	Average price per pound	Value	
1880			7, 734	$1. 15	$8, 894										$8, 894
1881			30, 938	1. 13	34, 960										34, 960
1882		$10, 000	77, 344	1. 14	88, 172										98, 172
1883		5, 000	77, 344	1. 11	85, 852										90, 852
1884		1, 000	77, 344	1. 11	85, 852										86, 852
1885		1, 000	55, 920	1. 07	59, 834										60, 834
1886		3, 936	55, 920	. 99	55, 361										59, 297
1887		756	7, 196	. 98	7, 052				12, 582	$0. 045	$566				8, 374
1888		4, 220	36, 101	. 94	33, 935				180, 272	. 044	7, 932				46, 087
1889									200, 000	. 039	7, 800				7, 800
1890		1, 745	11, 988	1. 05	12, 587	4, 290	$0. 156	$669	176, 193	. 045	7, 929				22, 930
1891		1, 422	21, 285	. 99	21, 072	68, 047	. 128	8, 710	260, 577	. 043	11, 205				42, 409
1892									250, 000	. 04	10, 000				10, 000
1893									250, 000	. 037	9, 250				9, 250
1894		17, 515	608, 224	. 63	383, 181				250, 000	. 033	8, 250				408, 946
1895		534	3, 939	. 65	2, 560				249, 166	. 032	7, 973				11, 067
1896		331	2, 447	. 68	1, 664	241	. 108	26	65, 465	. 03	1, 964				3, 985
1897		13, 746	2, 482	. 60	1, 489	2, 975	. 12	357	9, 266	. 036	334				15, 926
1898		19, 678	2, 618	. 59	1, 545	21, 711	. 124	2, 692	132, 462	. 038	5, 034				28, 949
1899		3, 886	14, 306	. 60	8, 584	35, 319	. 171	6, 040	441, 095	. 045	19, 849				38, 359
1900		7, 979	15, 793	. 62	9, 792	16, 129	. 166	2, 677	316, 061	. 044	13, 907				34, 355
1901		79, 972	20, 507	. 60	12, 304	15, 253	. 167	2, 547	235, 750	. 043	10, 137				104, 960
1902		5, 023	10, 486	. 53	5, 558	13, 669	. 122	1, 668	454, 995	. 041	18, 655	267, 100	$0. 048	$12, 821	43, 725
1903		2, 956	22, 424	. 54	12, 109	67, 410	. 137	9, 235	376, 711	. 042	15, 822	44, 600	. 054	2, 408	42, 530
1904	499	5, 519	60, 506	. 58	35, 093	48, 722	. 128	6, 236	699, 312	. 043	30, 070	15, 585	. 051	795	77, 713
1905	496	699	4, 401	. 61	2, 685	1, 135	. 156	177	203, 797	. 047	9, 578	2, 917	. 059	172	13, 311
1906	999	7, 628	737	. 68	501		. 193		49, 141	. 057	2, 801	74, 302	. 061	4, 532	15, 462

1907	170	649	6, 194	. 66	4, 088	1, 260	. 20	252	22, 528	. 053	1, 194				6, 183
1908	76	610	953	. 53	505	76	. 132	10	27, 715	. 042	1, 164				2, 289
1909	192	1, 196	2, 260	. 52	1, 175	3, 769	. 13	490	83, 463	. 043	3, 589				6, 450
1910	296	1, 025	4, 841	. 54	2, 614	5, 362	. 127	681	161, 068	. 044	7, 087				11, 407
1911	184	512	4, 664	. 53	2, 472	4, 984	. 125	623	74, 556	. 045	3, 355	46, 561	. 057	2, 654	9, 616
1912	9, 459	3, 805	19, 309	. 615	11, 875	29, 479	. 165	4, 864	504, 845	. 045	22, 718	534, 928	. 069	36, 910	80, 172
1913	980	4, 243	8, 694	. 604	5, 251	13, 277	. 155	2, 058	336, 886	. 044	14, 823	32, 964	. 056	1, 846	28, 221
1914	1, 488	16, 513	18, 293	. 553	10, 116	35, 783	. 133	4, 759	534, 872	. 039	20, 860	8, 941	. 051	456	52, 704
1915	692	5, 273	11, 266	. 507	5, 712	23, 360	. 175	4, 088	174, 447	.047	8, 199	44, 250	. 124	5, 487	28, 759
1916	3, 338	8, 024	48, 959	. 658	32, 215	92, 581	. 246	22, 775	255, 449	. 069	17, 626				80, 640
1917	4, 224	10, 350	76, 016	. 824	62, 637	144, 978	. 273	39, 579	310, 686	. 086	26, 719				139, 285
1918	1, 716	2, 553	89, 510	1. 00	89, 510	96, 866	. 247	23, 926	108, 253	. 071	7, 686				123, 675
1919	509	817	37, 767	1. 12	42, 299	36, 344	. 186	6, 760	52, 515	. 053	2, 783				52, 659
1920	9, 282	5, 031	94, 655	1. 09	103, 174	88, 386	. 184	16, 263	150, 063	. 08	12, 005				136, 473
1921	6, 412	1, 856	90, 871	1. 00	90, 871	49, 512	. 129	6, 387	198, 686	. 045	8, 941				108, 055
1922	9, 671	4, 849	63, 542	1. 00	63, 542	41, 622	. 135	5, 619	111, 782	. 055	6, 148				80, 158
1923	34, 456	4, 229	155, 723	. 82	127, 693	459, 477	. 147	67, 543	2, 919, 200	. 07	204, 344				403, 809
1924	1, 321	290	9, 939	. 67	6, 659	1, 748	. 131	229	86, 375	. 080	6, 910	115, 600	. 065	7, 514	21, 602
1925	27, 156	1, 986	63, 036	. 694	43, 747	1, 500	. 142	213	1, 269, 600	. 087	110, 455	1, 582, 000	. 076	120, 232	276, 633
1926	50, 926	5, 491	289, 505	. 624	180, 651	897, 285	. 140	125, 620	3, 085, 200	. 080	246, 816	265, 800	. 075	19, 935	578, 513
1927	112, 525	20, 012	845, 044	. 567	479, 140	3, 378, 504	. 131	442, 584	6, 030, 222	. 063	379, 904		. 064		1, 321, 640
1928	110, 598	23, 349	903, 759	. 585	528, 699	4, 300, 000	. 144	619, 200	4, 600, 000	. 058	266, 800		. 061		1, 438, 048
1929	118, 694	21, 043	722, 319	. 533	384, 996	2, 667, 000	. 176	469, 392	5, 806, 000	. 063	365, 778		. 066		1, 241, 209
		338, 251	4, 795, 103		3, 250, 277	12, 668, 054		1, 904, 949	31, 717, 256		1, 944, 960	3, 035, 548		215, 762	7, 654, 199

[1] Figures 1880–1923 from Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, p. 209, 1926. Figures 1924–1929 from Henderson, C. W., in Mineral Resources, U. S., 1924–1929.

Gold, silver, copper, lead, and zinc produced in Kerber Creek or Bonanza mining district, Saguache County, Colo., 1905–1929, and 1905–1930 [a]

[In terms of recovered metal]

Year	Ore sold or treated (short tons)	Gold		Silver		Copper		Lead		Zinc		Total value
		Fine ounces	Value	Fine ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1905	384			4,142	$2,527			177,200	$8,328	2,917	$172	$11,027
1906												
1907												
1908	33			330	175			27,715	1,164			1,339
1909	123	11.46	$237	1,558	810	3,769	$490	83,208	3,578			5,115
1910	284	49.58	1,025	3,887	2,099	5,362	681	159,587	7,022			10,827
1911	162	20.46	423	3,105	1,646	4,920	615	72,861	3,279	46,561	2,654	8,617
1912	9,394	158.31	3,273	19,171	11,790	28,913	4,771	504,281	22,693	510,528	35,226	77,753
1913	903	172.65	3,569	8,648	5,223	12,496	1,937	336,886	14,823	8,573	480	26,032
1914	1,469	793.34	16,400	18,244	10,089	35,001	4,655	534,375	20,841	8,941	456	52,441
1915	670	248.81	5,143	11,223	5,690	23,285	4,075	174,177	8,186	37,690	4,674	27,768
1916	3,260	380.23	7,860	47,012	30,934	92,581	22,775	255,262	17,613			79,182
1917	4,096	490.52	10,140	72,778	59,969	142,249	38,834	306,768	26,382			135,325
1918	1,657	122.39	2,530	88,018	88,018	96,866	23,926	108,253	7,686			122,160
1919	509	39.52	817	37,767	42,299	36,344	6,760	52,515	2,783			52,659
1920	8,974	199.06	4,115	85,444	93,134	85,957	15,816	148,600	11,888			124,953
1921	6,412	89.78	1,856	90,871	90,871	49,512	6,387	198,686	8,941			108,055
1922	9,627	70.58	1,459	63,248	63,248	41,622	5,619	111,782	6,148			76,474
1923	34,456	204.58	4,229	155,723	127,693	459,477	67,543	2,919,200	204,344			403,809
1924	1,303	7.64	158	9,930	6,653	695	91	86,375	6,910	115,600	7,514	21,326
1925	27,144	90.09	1,862	63,031	43,744	800	114	1,269,600	110,455	1,582,000	120,232	276,407
1926	50,916	265.53	5,489	289,497	180,646	896,285	125,480	3,085,200	246,816	265,800	19,935	578,366
1927	112,515	968.08	20,012	845,044	479,140	3,378,504	442,584	6,030,222	379,904			1,321,640
1928	110,595	1,123.46	23,224	903,759	528,699	4,300,000	619,200	4,600,000	266,800			1,437,923
1929	118,686	1,006.01	20,796	722,319	384,996	2,667,000	469,392	5,806,000	365,778			1,240,962
1905 to 1929	503,572	6,512.08	134,617	3,544,749	2,260,093	12,361,638	1,861,745	27,048,753	1,752,362	2,578,610	191,343	6,200,160
1930 [b]	56,300	504.99	10,439	328,040	126,295	1,200,000	148,800	2,238,000	116,376			401,910
1905 to 1930	559,872	7,017.07	145,056	3,872,789	2,386,388	13,561,638	2,010,545	29,286,753	1,868,738	2,578,610	191,343	6,602,070

[a] Compiled by Charles W. Henderson.
[b] From 11 months' actual production and estimate for December, by Charles W. Henderson.

An examination of the record shows that except for 1894 (figures for which are doubtful) production from the Bonanza district was relatively small until the reopening of the Rawley mine in 1923. The equipment of this property was torn down and sold after the closing in June, 1930.

The mining history of the district began in 1879–80, during the rush to the Gunnison River country (now Gunnison County). Miners were attracted by the manganese and silver-lead outcrops on Kerber Creek, and the town of Bonanza grew to a place of considerable importance before the fall of 1880. In 1882 the Director of the Mint [33] reported that the Rawley mine was one of the most productive mines in Saguache County, making regular shipments, although he believed the Empress Josephine was then the largest producer in the county. As early as 1884 there was record of the failure of a local smelter to treat the ores, but "some capitalists" proposed trying local smelting again by "remodeling the United States mill at Parkville." [34]

In 1900 two concentrators were erected in the district, and their influence is shown in the increased output in 1901 to 1904, but the output again fell in 1905, followed by nominal outputs until 1912, when Leadville operators, who had in 1911 remodeled one of the mills, for 10 months mined and milled about 30 tons a day of lead-zinc-silver-copper-gold sulphide ore from the Bonanza mine. This mill was again operated for about a month in 1913, but lead-silver-copper-gold ore from the Antoro, Bonanza, Elizabeth, and Empress Josephine was shipped in that year direct to smelters. In 1914 lead-silver-gold-copper smelting ore (much of it carrying some zinc) from the Antoro, Bonanza, Elizabeth, Memphis, and St. Louis amounted to 1,469 tons. Production in 1915 fell to 692 tons. In July, 1916, the Rawley again entered the producing list from operations above the 6,200-foot lower adit, which had been started May 7, 1911, and completed to the vein October 23, 1912. Other producers in 1916 (one to four cars each) were the Antoro, Bonanza, Cocomongo, Cornucopia, Empress Josephine, Jupiter, Michigan-Paragon, Minnie Lynch, Paddy Doyle, Rico, St. Louis, and Wheel of Fortune. In 1917 development and shipping of smelting ore continued from the Rawley, and there was increased output from other properties. The producers were the Antoro, Bonanza, Cocomongo, Cornucopia-Exchequer, Cuba, Eagle, Erie, Foster Group, Golden Wave, Jupiter, Legal Tender, Little Johnny, Memphis, Michigan-Paragon, Saguache, Shawmut, St. Louis, Vienna, and Wheel of Fortune.

[33] Burchard, H. C., Report of the Director of the Mint upon the production of the precious metals in the United States during the calendar year 1882, pp. 395, 539–545, 1883.

[34] Idem for 1884, pp. 238–239, 1885.

In 1918 no ore was shipped from the Rawley, but development was continued to July in blocking out ore in preparation for building a mill. The principal producer of the district was the Cocomongo, which yielded both dry silver ore and lead-copper-silver smelting ore. Other producers were the Antoro, Bloom, Brighton, Cuba, Erie, Memphis, and Michigan-Paragon. In 1919 the Cocomongo produced some silver ore. Other producers were the Joe Wheeler, Liberty, Now What, and Rico. In 1920 copper-silver ore was shipped to smelters from the Cocomongo-Bonanza group, but low-grade silver-copper ore from this group was milled by flotation in a remodeled mill in the district. The workings of the Eagle mine were cleared out, and the old dump plus some silver ore from the mine was milled in a new 40-ton flotation plant, yielding silver concentrates. Smelting ore was shipped from the Antoro and Liberty, and the Rawley adit was retimbered. In 1921 the Cocomongo and Eagle mills were both in operation. Smelting ore was shipped from the Baltimore, Hanover, Liberty, Mary McGinnis, and Paragon. The Rawley remained idle. In 1922 the Eagle mill was operated, but the Cocomongo mill was idle. Smelting ore was shipped from the Cocomongo, Essie, Liberty, Mary McGinnis, and Rico.

In July, 1923, monthly shipments of 2,000 tons of lead-copper-silver concentrate to the Leadville smelter were begun as a result of the reorganization of the Rawley Co., with help from the Metals Exploration Co. and the American Smelting & Refining Co., whereby a 300-ton mill was erected at the portal of the lower adit in Squirrel Gulch, 1½ miles from Bonanza. This mill was connected by a 7¼-mile aerial tram to loading bins at Shirley, on the Marshall Pass branch of the Denver & Rio Grande Western Railroad. The mine and mill were closed in December, 1923, because of financial and other difficulties. In that year the Eagle mill was idle, and the other producers, the Baltimore, Cocomongo, Essie, Rico, and St. Louis, shipped smelting ore. In 1924 a 75-ton gravity and flotation mill was completed in May and treated lead-zinc-silver ore from the Cocomongo-Bonanza. Other producers, the Erie, Essie, Royal, Coachman, and St. Louis, shipped direct to smelters. In 1925 the Cocomongo-Bonanza mill was run continuously, yielding lead-silver and zinc-lead-silver concentrates. The other producers, the Essie, Hortense, Rico, and St. Louis, shipped direct to smelters. In 1926 the Cocomongo-Bonanza mill was operated from January 1 to May 1, when the mine was put on a development basis for the remainder of the year. This mine has been idle from 1927 to the present time (February 7, 1931). The Rawley mill was completely remodeled early in 1926 and ran at an average of 320 to 330 tons a day throughout the rest of the year. Other producers, the Essie, Golden Wave, Rico, and St. Louis, shipped direct to smelters.

From 1926 to June, 1930, when the Rawley mill was closed and all its equipment sold for salvage value, the history of the district is expressed in the output of that mill plus small shipments of smelting ore from other mines.

CHARACTER AND DISTRIBUTION OF VEINS

The main deposits of the Bonanza district are veins containing lead, zinc, copper, and silver, in which up to the present time lead and silver have furnished the greater part of the productive value. The veins contain pyrite, sphalerite, galena, chalcopyrite, bornite, silver-bearing tennantite, and stromeyerite as the principal sulphide minerals in a gangue of quartz, manganiferous calcite, rhodochrosite, and barite. A number of other sulphides and gangue minerals are found in small amounts.

The veins occupy fault fissures or other openings produced in the rocks during their deformation, and the ore deposition has taken place largely by filling and to a minor extent by replacement within the fissure zones. Enrichment of the primary ores is of only local importance and is relatively shallow.

According to their mineral contents the principal veins of the district may be divided into two main classes—(1) quartz veins of relatively high sulphide content, carrying lead, zinc, copper, and silver, usually with negligible amounts of gold, and (2) quartz-rhodochrosite-fluorite veins of low sulphide content, only one of which enriched in silver has been productive. The veins of the first class include those from which the greater part of the production of the district has come and are represented by the Rawley, Bonanza, Cocomongo, Empress Josephine, Shawmut, and Whale veins. In the second class the Eagle vein is the only producer of consequence up to the present time. The oxidized portions of some of these rhodochrosite-bearing veins contain siliceous manganese ores, and a small production of manganese has recently been made from the Pershing vein, in Manganese Gulch.

Most of the productive veins lie in the Rawley andesite, although the veins are not confined to this formation but also occur in the other volcanic rocks and in the pre-Cambrian rocks of Alder Creek. The most strongly mineralized veins lie in the area adjacent to and east of Kerber Creek, extending north to the vicinity of Round Mountain. The eastern limit of the mineralized area is not known and apparently lies east of the boundary of the mapped area. Along the western edge of the district north of the junction of Kerber and Brewer Creeks, in a strip of country bounded roughly on the east by the westernmost outcrops of the Bonanza latite and extending northward to the vicinity of Porphyry Peak, a minor amount of prospecting along weakly mineralized faults has been essentially unproductive. The boundary of this strip appears to mark the western limit of fissures favorably mineralized at the surface. A highly mineralized area containing quartz veins of the mixed sulphide class lies in the northern part of the district and has a northeasterly trend, extending from the vicinity of the town of Bonanza to the head of Alder Creek with a width of 2 or 3 miles and a known length of 5 or 6 miles. It is not equally mineralized throughout. A few veins lying in the southern part of this area, confined entirely to the vicinity of Copper Gulch, contain some silver and gold tellurides and a somewhat higher gold content than the veins lying north of them.

In the southern part of the district, in the area drained by Eagle, Chloride, Greenback, Express, and Manganese Gulches, the veins are largely of the quartz-rhodochrosite-fluorite class of low sulphide content. Between these northern and southern areas essentially in the country drained by Elkhorn Gulch, there is a zone from which there has been little or no production, although there are a few small prospects in it.

East of the district there are some prospects on the east slope of the Hayden Peak and Manitou Mountain ridge, but they are not known to have been productive, and the area was not examined during the present investigation. In sec. 26, T. 47 N., R. 8 E., in the vicinity of Peterson Creek, there are a few claims said to have been developed for turquoise. The geologic occurrence of the turquoise is not known.

Northeast of the district, along the lower part of the valley of Alder Creek, there are a number of other prospects that have not been examined, but the production from them has been small. Part of these lie in pre-Cambrian rocks and part in volcanic flows. This area is generally referred to as the Alder Creek district.

In the southern part of the district a few veins and prospects that show some mineralization lie on the slopes west of Kerber Creek. At the surface the veins show quartz and iron, and manganese oxides. These veins have not been developed sufficiently to show their character.

Quartz veins containing native gold are not represented within the main area of mineralization, but a single example of the occurrence of native gold is found in Columbia Gulch, several miles south of the mapped area.

CONTENT OF ORE

Both concentrates and crude ore have been shipped from the district, although at present crude ore of shipping grade is not as readily obtained as it was during the earliest productive period, when the moderately enriched outcrops of ore shoots were being mined. The value of the crude ore has been mainly in lead and silver. Shipments of lead and silver ores showed a wide range in metal content, running from 10 to 40 per cent of lead and 5 to 50 ounces to the ton in silver. In the ore from many of the veins partial elimination of the high zinc content was necessary before shipment. The gold content was generally negligible, although some ore shipped from the St. Louis vein, in Copper Gulch, contained from 1 to 7 ounces of gold to the ton. Some sorted crude ore produced from the Eagle vein between 1902 and 1904 contained from 91 to 200 ounces of silver and about 0.25 ounce of gold to the ton.

From the examination of the few available smelter records and from statements[35] regarding the value of ores from different veins in the district it appears that the shipping ores ranged in value from $10 or less to more than $200 to the ton, but on account of the incompleteness of the records it is not possible to give an accurate average. They probably have not averaged more than $35 to $40 a ton over the whole period of production, although the value may have been much higher in the early days. That profitable crude ores were soon exhausted is shown by the decline in activity of the district after the early period of this type of production and by the early construction of mills in an attempt to treat the ores. The inaccessibility of the district and the low grade of the unenriched ore are unfavorable to the shipment of crude ores.

Small bodies of relatively high-grade crude ores contain 10 to 15 per cent of combined lead and zinc and 2 to 8 ounces to the ton in silver. From milling ore containing around 6 to 8 per cent of combined lead and zinc, in which the ratio of zinc to lead was about 1½ to 1, the Cocomongo mill in a short run during 1926 produced lead concentrates containing about 42 to 45 per cent of lead, 7 to 9 per cent of zinc, and about 20 ounces to the ton in silver and zinc concentrates containing 30 to 38 per cent of zinc, 12 to 15 per cent of lead, and about 20 ounces to the ton in silver.

During 1926 and 1927 crude milling ore from the Rawley mine contained about 3.4 per cent of lead, 2 to 3 per cent of zinc, 2.3 per cent of copper, and 8.3 ounces of silver, and 0.01 ounce of gold to the ton. The concentrates produced yielded 14 to 15 per cent of lead, 10 to 11 per cent of copper, and about 37 ounces of silver, and 0.043 ounce of gold to the ton. The zinc in the concentrates amounted to about 5.5 per cent and was lost during smelting.

Some ore from the lower levels of the Eagle vein treated in the Eagle mill between 1920 and 1922 averaged about 4 to 5 ounces of silver to the ton, with 1 per cent or less of lead and a negligible amount of gold, and the concentrates produced from it averaged about 185 ounces of silver and 0.21 ounce of gold to the ton.

The crude shipping ores of the district are mainly siliceous, ranging from 15 to more than 70 per cent of insoluble material, but they probably average between 40 and 60 per cent of silica. The lime content is ordinarily very low. In the concentrating ores the silica probably averages higher. The iron content generally runs from 5 to 35 per cent, but most of the mine-run ore does not contain more than 10 to 15 per cent, although some of the copper-lead-silver ores may average higher. In some of the veins of the southern part of the district the manganese content may be around 8 to 10 per cent or even as much as 30 per cent in ore in which rhodochrosite is predominant as a gangue mineral. The sulphur content varies inversely with that of the silica, ranging from 10 per cent or a little below to over 30 per cent, and possibly averages around 15 to 20 per cent in the moderately siliceous ores.

STRUCTURAL AND TEXTURAL FEATURES OF VEINS

Very few ore shoots in the district have been sufficiently developed to permit complete determination of their full extent and shape, and these few differ so much that generalizations as to prevailing directions of pitch or as to shape or size are not possible. The greatest explored length of a shoot is that of the Rawley vein, about 950 feet, and in its productive parts this shoot ranges in width from 2½ to 5 feet, although parts 12 to 15 feet wide are encountered locally. This shoot narrows downward and up to the time of writing (July, 1928) had been productive to a depth of about 800 feet below the outcrop of the vein. The explored lengths and depths of most of the veins and ore shoots are much less than that of the Rawley vein.

Partly mineralized fault zones of great length and width are found in the district, such as the Paragon fault, which can probably be traced for 2 miles or more. This fault zone is in places at least 50 feet wide, and the fractured rock accompanying it covers a considerably greater width. Fissures within this zone contain small shoots of ore from a few feet to 30 or 40 feet in length. Considerable ore may be scattered throughout fault zones of this character, but

[35] Patton, H. B., op. cit.; reports of the Director of the Mint, 1880–1891; personal communications.

the shoots are characteristically small and are likely to be separated by unprofitable stretches that are of greater extent than the shoots themselves.

It is characteristic of most of the veins of the district that even within a major ore shoot the ore pinches and swells abruptly within short distances, a feature which is naturally unfavorable to small operators who depend upon a constant supply of ore. This feature has probably been the cause of the abandonment of many a prospect, even though the vein may have contained in the aggregate a large amount of ore. It is probably due to the fact that most of the veins lie in fault fissures that are locally choked by gouge, and irregularities in the walls of the faults cause an alternation of open and tight places. Horses of wall rock, splits, and other irregularities are encountered within ore bodies—for example, there is a large split in a vein on the 400-foot south level of the Rawley mine. Parallel or branching mineralized fractures in either wall of a vein are of common occurrence. Vertical breaks in the hanging walls of some of the flatter veins are also found, and some have proved productive in at least one mine, the Cocomongo.

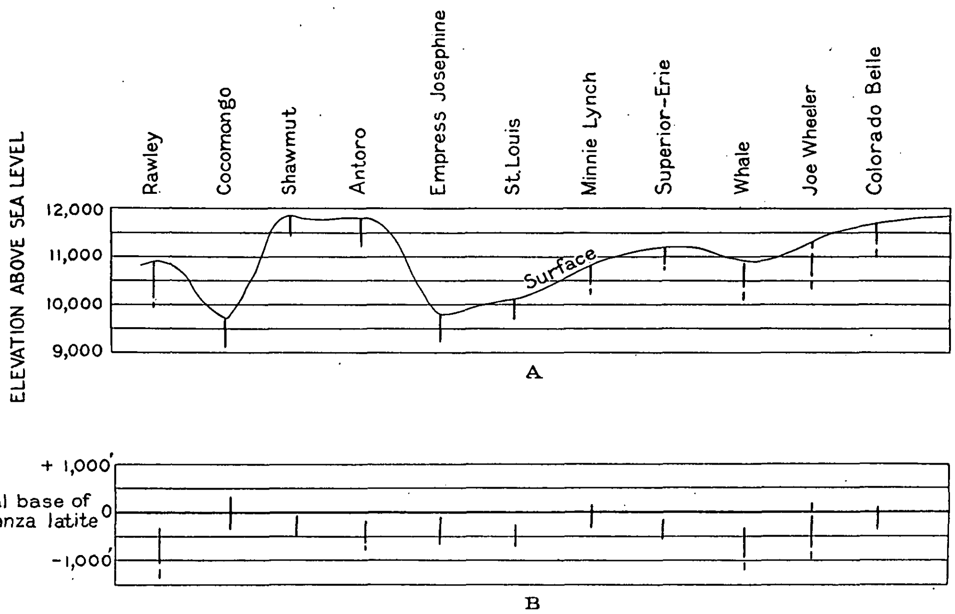


FIGURE 12.—Relations of ore bodies in the Bonanza district to the present topography and to the horizon of the Bonanza latite. A, Known vertical range of ore bodies with relation to sea level; B, known vertical range of ore bodies with relation to base of Bonanza latite. The horizontal relations are not shown to scale. See Plate 1 for relative positions of mines

Many veins terminate abruptly against other mineralized faults, and their extension and direction can not be predicted much beyond what is disclosed by actual development. The connecting of distant vein outcrops that have the same trend is not warranted anywhere unless actual trenching or other development supports their identity. Where a vein becomes narrow and unproductive at its horizontal termination the fissure may split into a zone of small breaks that spread outward and usually display lower angle dips than the main fissure.

The greatest depth from the outcrop to which any vein has been explored is 1,200 feet, reached on the Rawley vein. The shoot has been productive so far, however, only to a depth of 800 feet. Many of the ore shoots in the district have been bottomed at much shallower depths, ranging from 200 to 500 feet below the outcrop. As many of the developments were abandoned at the bottom of the outcropping shoots it is not known whether these veins may contain deeper shoots that are not exposed. The bottoms of productive ore shoots in the northern part of the district range in altitude from 11,500 feet in the Shawmut mine down to about 9,200 feet in the Empress Josephine and Cocomongo mines, near the town of Bonanza, a difference of 2,300 feet. This appears to show that the shoots bear some relation to topography, but this relation is undoubtedly only incidental and not genetic. The difference in altitude of the base of the Bonanza latite between Round Mountain and the vicinity of Bonanza is roughly 2,500 feet, so that it might equally well be argued that the shoots bear a definite relation to structure, and this argument could be much better supported because of the undoubted primary nature of the ores within the shoots. (See fig. 12.) From the available evidence it can also be contended that during mineralization there was a vertical range of at least 3,000 feet throughout which conditions were favorable for the precipitation of ores.

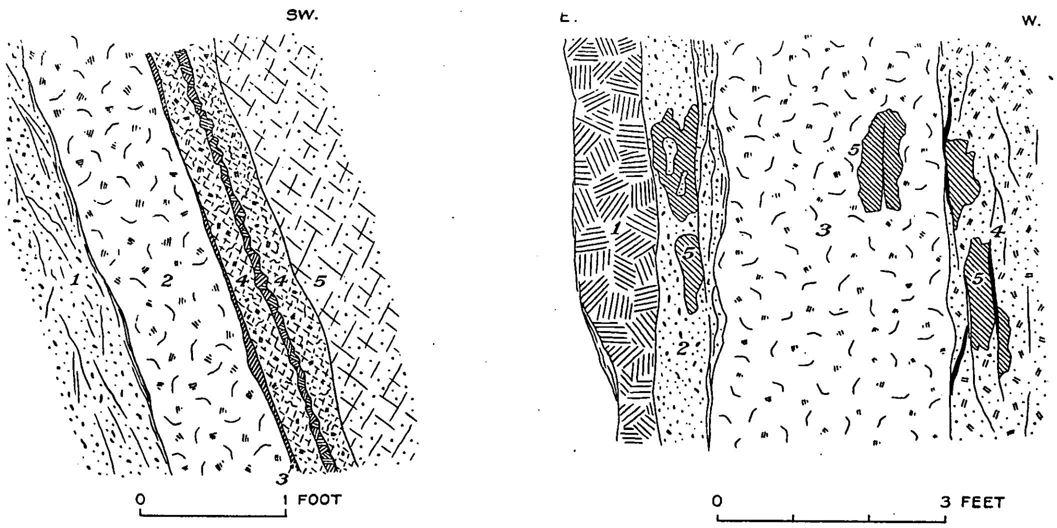
Finely banded structure of the veins is not typical of the district, the vein filling usually being of a rather massive type, with irregularity in the size of crystals and their boundaries. Vugs are not uncommon in the veins, but they are irregularly distributed and usually bear no definite relation to the vein walls. Comb structure is seen rarely in very thin, small veins, but it has never been seen on a large scale in the larger veins of the northern part of the district. In some places the vein matter is a massive intergrowth of quartz and sulphides of relatively fine texture; in others the sulphides, particularly galena and sphalerite, may be coarsely crystalline and free of quartz. These massive sulphide bodies are commonly of a vein-like character and cut across the earlier mixed quartz-sulphide vein matter irregularly or lie between the quartz and the vein walls. (See fig. 13.) This mode of occurrence of the galena supports the evidence obtained by a study of polished sections that the main period of deposition of quartz preceded that of the galena.

Breccia structure in the vein material is also not uncommon and is caused by fragments of the country rock having formed a rubble between which the sulphides were later deposited.

MINERALS OF THE ORE DEPOSITS

The following brief descriptions, which are arranged in mineral groups according to Dana's system, are confined to those minerals that are closely associated with the ore deposits or that occur in altered rocks. In the subjoined alphabetic list a question mark indicates that the mineral is probably present in the district but that its identity has not been definitely established.

Adularia.
Altaite.
Alunite.
Anatase.
Anglesite.
Apatite.
Argentite.
Azurite.
Barite.
Bornite.
Bromyrite (?).
Calcite.
Cerargyrite.
Cerusite.
Chalcedony.
Chalcocite.
Chalcopyrite.
Chlorite.
Chrysocolla.
Clay.
Copper (native).
Covellite.
Diaspore.
Dolomite.
Embolite (?).
Empressite.
Enargite.
Epidote.
Fluorite.
Galena.
Gold (native).
"Gray copper."
Gypsum.
Hematite.
Hessite.
Jarosite.
Kaolin.
Limonite.
Malachite.
Manganite.
Manganosiderite.
Muscovite.
Orthoclase.
Pearceite(?).
Petzite.
Proustite(?).
Psilomelane.
Pyrargyrite.
Pyrite.
Pyrolusite.
Quartz.
Rhodochrosite.
Rhodonite.
Rickardite.
Rutile.
Sericite.
Siderite.
Silver (native).
Sphalerite.
Stromeyerite.
Sylvanite.
Tellurium (native).
Tennantite.
Tetrahedrite.
Wad.
Zunyite.



A B

FIGURE 13.—Arrangement of ore in the Express and Tip Top veins. A, Express vein: 1, Altered sericitized country rock, broken and gougy; 2, quartz with chalcopyrite, enargite, and pyrite; 3, calcite seam; 4, mostly fluorite, with quartz carbonate and species of galena, sphalerite, and other sulphides, seam of rhodochrosite in center; 5, silicified wall rock. B, Tip Top vein: 1, Massive galena with minor amounts of other sulphides; 2, sericitized gouge with fragments of jasper (red silicified country rock); 3, quartz vein with pyrite, chalcopyrite, enargite, etc., showing small ragged cavities in quartz partly filled with quartz, pyrite, chalcopyrite, and latest minerals, rhodochrosite and galena; 4, amygdaloidal andesite, partly silicified (early) and sericitized and chloritized, with stringers of pyrite and disseminated pyrite; 5, remnants of silicified country rock

NATIVE ELEMENTS

Copper.—Native copper is probably widely distributed in small amounts adjacent to copper ore and within a short distance of the surface. It is found in small masses and in the form of thin sheets along joint cracks in the upper levels of the Rawley vein but is probably mostly within 50 feet of the outcrop of the vein.

Gold.—Native gold was mined from a small vein on Little Kerber Creek, several miles southeast of the district. It is said to occur there in visible amount in vein quartz. (See p. 60 and pl. 3.) Native gold is not visible in any of the ores of the district high in gold, such as some mined from the St. Louis vein, on Copper Gulch. It may, however, be present in these ores or may occur as "mustard gold" from the oxidation of gold-bearing tellurides.

Silver.—Native silver has been found in the upper levels of the Eagle mine (p. 151), where it is unquestionably of secondary origin (supergene). It occurs in the form of wire silver. Native silver is said to have been found within 20 to 40 feet of the surface impregnating parts of the walls of the Antoro vein, and it probably occurs under conditions favorable to enrichment in the uppermost parts of many veins. Except in the Eagle vein, it is not known to have been found in quantities sufficient to be of economic importance.

Tellurium.—Native tellurium occurs in the Empress Josephine vein in small masses of tin-white color, but its relation to the other tellurides is not known. A small amount of rickardite was associated with it in one specimen examined.

SULPHIDES

Galena (PbS).—Galena (sulphur, 13.4 per cent; lead, 86.6 per cent) is the only valuable ore of lead in the district, as the oxidized lead minerals are negligible. The most common crystal form of the galena seen is the simple cube, or cleavable masses in which the cubic cleavage is very prominent. Where the galena has crystallized in vugs or open spaces it commonly has the form of cubo-octahedrons, and rarely the cubical faces may be entirely lost or very subordinate to the octahedral faces. Very beautiful crystals of this character are found in parts of the Joe Wheeler vein, on Alder Creek. Galena in large quantity was deposited in the open spaces of the fissures. Locally it may have replaced gouge and the fine matrix of breccia material to some extent, and polished sections show that it has replaced other sulphides, notably sphalerite and pyrite.

Peculiar intergrowths of galena and quartz found at the Queen City prospect, in Copper Gulch, seem to indicate a contemporaneous intergrowth of galena and the gangue. This gives the specimens an appearance like that of steel galena, although a study of the polished ore shows that many of the small irregular galena areas are continuous in crystallographic orientation with neighboring ones. This is the only locality where this peculiar type of intergrowth was seen. The silver in the ores of the district is probably only to a very slight extent associated with the lead. The richest silver-bearing ores of the Rawley vein are those in which copper minerals are predominant. An assay of galena published by Patton[36] shows only 5.18 ounces of silver and 0.02 ounce of gold to the ton.

Argentite (Ag_2S).—A mineral appearing pale brownish gray in reflected light under the microscope occurs in minute amounts in some of the ores richer in silver. It is not common but where seen was associated with covellite and stromeyerite, apparently as an alteration product of stromeyerite. Argentite of supergene origin is reported by Wuensch[37] as occurring in the Eagle vein. (See pp. 153–154.)

Chalcocite (Cu_2S).—Chalcocite is found in small amounts both as a primary and a secondary (supergene) mineral in the veins. It occurs in graphic intergrowths with bornite on several levels of the Rawley vein. In ore from the 900-foot level it forms irregular areas in bornite, which suggest a primary origin. It is also found in minute cracks in practically all the sulphides, where it is associated with late chalcopyrite or is partly altered to covellite. These cracks possibly represent small capillary openings in the ore, and their sulphide filling may have been deposited by surface waters percolating downward along the vein. They are of negligible importance, however, with regard to the total volume of the sulphide ores. Sphalerite contains coatings of bluish-black sooty chalcocite and covellite in partly oxidized ore near the surface. This occurrence is undoubtedly the result of interaction with surface waters containing copper in solution.

Stromeyerite ($(Ag.Cu)_2S$).—Stromeyerite was first identified as a constituent of the Rawley ore by M. N. Short, who reported as follows concerning one of a suite of specimens examined by him:

"Bornite contains rounded blebs of a soft gray mineral which has the appearance and gives the etching tests of argentite according to the tables of Davy and Farnham. It is slightly brittle, however; argentite is sectile. It gives strong anisotropism, which is characteristic of stromeyerite rather than argentite, which is isotropic or shows feeble anomalous anisotropism. It gives a good microchemical test for silver, but it could not be tested for copper, as some bornite was mixed in the sample. * * * However, its universal association with bornite suggests that the mineral also contains copper and is stromeyerite rather than argentite."

[36] Patton, H. B., op. cit., p. 83.

[37] Wuensch, C. E., Secondary enrichment at Eagle mine, Bonanza, Colo.: Am. Inst. Min. and Met. Eng. Trans., vol. 69, p. 99, 1923.

A large number of polished sections from different parts of the district, including many from the Rawley vein, have since been examined by the writer, and strömeyerite was recognized in ore from the Cocomongo and Joe Wheeler veins and less definitely in ore from the Rico, Liberty, and Express veins. In ore from the 400 north level of the Rawley mine it was possible to find small areas of stromeyerite relatively free of impurities, and tests for both copper and silver were obtained. Etching tests of the mineral gave somewhat variable results but agree essentially with the tests given by Davy and Farnham[38] for either stromeyerite or argentite. The reaction with ferric chloride was rather quickly brown to iridescent, rubbing to a bluish iridescent surface in most specimens. The mineral was found to be associated with bornite, tennantite, galena, and chalcopyrite in all the occurrences and is a primary mineral of the veins. It occurs in the 400 north level of the Rawley vein intergrown with tennantite in such a manner as to indicate contemporaneous deposition, and both of these minerals are replacing bornite. Stromeyerite also appears to be the result of a late stage of primary (hypogene) silver enrichment, and as yet no evidence has been found to prove that it was deposited by descending surface waters. Photomicrographs showing the relation of this mineral are given in Plate 18.

Stromeyerite is probably an important source of silver in many of the veins of the district, and its universal association with primary copper minerals shows it to be related to the deposition of copper in the veins or to have been derived from the breaking down of silver-bearing copper minerals.

Sphalerite (*zinc blende*) (ZnS).—Sphalerite (sulphur, 33 per cent; zinc, 67 per cent) commonly exceeds galena in quantity as a constituent of the veins in the district, the ratio being somewhat less than 2 to 1. The quantity of sphalerite does not appear to decrease so markedly with increasing depth as that of galena in the higher-grade lead ores in the district. In the Rawley vein the quantity of zinc is fairly constant, near 2 or 3 per cent, throughout the explored part of the vein, although it may be somewhat less abundant in the higher-grade lead ores of the southern part. During the operation of the Cocomongo mill in 1926 (p. 116) the mill heads showed that zinc exceeded lead in the ratio of 1½ to 1. This is also about the ratio of zinc to lead in the ore blocked out in the Cocomongo mine as shown by mine samples.

Sphalerite occurs both in the veins and to a very minor degree in replaced wall rock. Skeletal crystals of sphalerite are seen in some of the siliceous replacement deposits associated with pyrite, but the amount is so small as to indicate that the solutions depositing zinc did not have nearly the penetrating power of those that formed pyrite in the wall rock. Large bodies of sphalerite occupy positions in veins which indicate that like galena it was deposited mainly in relatively open spaces in the veins or in breccias. It is not unusual, however, for small breccia fragments within the vein walls to show considerable replacement by the common sulphides, particularly by pyrite and sphalerite.

The sphalerite found in the district ranges from yellowish resinous varieties to nearly black varieties containing iron.

Polished sections of ore containing sphalerite show that some of it contains blebs of chalcopyrite where it is associated with copper minerals. Although its crystallization is in places contemporaneous with the other original (hypogene) sulphide minerals, much of the sphalerite has been subjected to replacement by chalcopyrite, bornite, galena, and to a lesser extent by silver minerals. Sphalerite rarely replaces pyrite.

[38] Davy, W. M., and Farnham, C. M., Microscopic examination of the ore minerals, p. 67, New York, 1920.

In ore that has been subjected to the action of surface waters containing copper sulphates the sphalerite is coated with a bluish-black film composed largely of covellite; such sphalerite resembles blackjack unless the surface is broken to show the nature of the black coating.

Covellite (CuS).—Covellite, like chalcocite, is probably of both primary and secondary (supergene) origin in this district, but is also present only in very small amount. It occurs in graphic intergrowth with galena in primary ore. Covellite also occurs in small capillary cracks and replaces late chalcopyrite and chalcocite. Associated with anglesite and cerusite, it replaces massive galena peripherally, an occurrence that is undoubtedly of supergene origin. Covellite forms a thin coating on sphalerite that has been subjected to the action of waters containing copper sulphate in the lower part of the zone of oxidation or just below.

Bornite (Cu_5FeS_4).—The only ores in which bornite (sulphur, 28.1 per cent; copper, 55.5 per cent; iron, 16.4 per cent) has been recognized, so far as is known to the writer, are those of the Rawley, Joe Wheeler, and St. Louis veins, although it is very probably present in many other veins in small amounts. It commonly occurs in massive form associated with chalcopyrite and pyrite. In the Rawley vein it is found in noticeable quantities only on and below the 300-foot level and was especially abundant on the 700-foot level. Where it has crystallized in openings the crystals are commonly rounded with imperfect curved faces and occur together with crystals of chalcopyrite and tennantite. It is not as abundant as chalcopyrite as a constituent of the veins in which it is found but is much more common than enargite in the Rawley vein. It always appears as a primary mineral of comparatively early formation.

Chalcopyrite (*copper pyrites*) ($CuFeS_2$).—Chalcopyrite (sulphur, 35 per cent; copper, 34.5 per cent; iron, 30.5 per cent) is one of the abundant copper minerals of the district and is present in small amounts at least in practically every vein containing sulphides. It occurs in massive form intimately intergrown with granular pyrite and other sulphides and as small crystals in open cavities in the ores. In the Rawley vein the massive copper ore which is found on the lower levels consists mainly of intimate mixtures of pyrite, chalcopyrite, and bornite, probably in order of abundance as named. The abundance of chalcopyrite would not be suspected in some of the massive pyritic ores, as the intergrowths are on a microscopic scale. (See pl. 15.)

Chalcopyrite is found less commonly as small crystals in cavities of some of the ores. Good examples of this are seen in the Joe Wheeler vein, in the Alder Creek region. The form of the chalcopyrite is tetrahedral. Patton[39] reports plus and minus tetrahedrons.

Chalcopyrite replaces pyrite, sphalerite, and bornite extensively and evidently has a wide range of deposition compared to some of the other sulphides. It both preceded and followed galena and also was formed at a very late stage in small cracks in other sulphides where it may be wholly of supergene nature.

Patton[40] reports chalcopyrite to contain 0.05 ounce of gold and 35.35 ounces of silver to the ton, but the silver content may be due largely or at least partly to an intergrowth with silver-bearing tennantite, as this mineral is in many places intimately associated with chalcopyrite. (See pl. 16, *B*.)

Pyrite (FeS_2).—Pyrite (sulphur, 53.4 per cent; iron, 46.6 per cent) is in many of the veins the most abundant sulphide mineral. The iron content of many of the heavier sulphide ores ranges from about 5 to 35 per cent, and in many veins the iron is contained mostly in pyrite and to a minor extent in chalcopyrite or bornite.

Pyrite has several modes of occurrence in association with ore deposits, as it is found both in the silicified wall rocks and in the massive sulphide ores. As a general thing it is much better crystallized where it occurs in jaspers than in the veins themselves, although pyrite is occasionally found in well-formed crystals as much as a quarter of an inch in diameter embedded in rhodochrosite or other gangue minerals of an early stage of crystallization. In Plate 11, *A*, is shown a typical occurrence of pyrite in hematite-bearing jasper from the Rawley tunnel. The most usual habit is that of the 12-sided pyritohedron or pentagonal dodecahedron. Cubical crystals are found in the jaspers but are less common. The crystals are very evenly distributed through the silicified wall rocks. The latter mode of occurrence is presumably of different origin from that of pyrite found in and near pyritic veins and represents the later stages of fumarolic or solfataric activity.

In the veins pyrite occurs either as a rather massive form associated with quartz, or intergrown irregularly with other gangue minerals, and as small crystals in vugs of the veins. The pyrite when examined microscopically proves to be an aggregate of small irregular microscopic grains, 0.0025 to 0.50 millimeter in diameter, as seen in a number of polished sections from the Rawley and Cocomongo veins. (See pls. 15 and 17, *A*.) Very commonly the coarser-grained pyrite of typical crystal outline was the earlier form to crystallize and was embedded in the vein quartz, whereas the granular pyrite occupies spaces interstitial to quartz prisms. Both of these modes of occurrence are likely to be represented in the same specimen. The differences in crystal form and in time of formation are probably to be explained by changes in the chemical nature or concentration of the solutions. The change from one mode of occurrence to the other is in places gradual and exhibits intermediate textural relations. The later granular pyrite may be intimately intergrown and probably in part contemporaneous in formation with sphalerite, chalcopyrite, and bornite. Granular pyrite may also be extensively replaced, especially by chalcopyrite and bornite and rarely by sphalerite. (See pl. 15.)

Pyrite exhibiting a colloform concentric structure is seen rarely. It was probably formed in connection with the colloidal deposition of silica, with which it is associated. It appears to be an early form of this mineral.

An assay of the gold and silver content of pyrite was made under the direction of Patton[41] during his study of the Bonanza district. This was made by Messrs. Ho and Wang and showed 0.04 ounce of gold and 7.16 ounces of silver to the ton. No statement was given regarding the purity of the sample, and as no microscopic examination of polished surfaces is mentioned the possibility of the intergrowth of pyrite with silver-bearing minerals is not eliminated. Growths of tennantite and other silver-bearing minerals interstitially to pyrite occur in places on a minute scale, visible only on polished surfaces under the microscope.

TELLURIDES

Sylvanite or krennerite ((Au, Ag) Te_2).—A telluride containing both gold and silver, with gold predominating, is found associated with other tellurium minerals in ore from the Empress Josephine vein. Under the microscope on polished surfaces this mineral has a pinkish or creamy-white color and gives the following etching reactions: HNO_3, effervesces after some time and turns brown; HCl, negative or turns faintly

[39] Patton, H. B., op. cit., p. 79.
[40] Idem, p. 83.
[41] Patton, H. B., op. cit., p. 83.

brown; KCN, negative; $FeCl_3$, negative; $HgCl_2$, stains brown. These reactions do not check exactly with those given by Davy and Farnham for sylvanite or krennerite but are closer to these than to the reactions given for other gold-bearing tellurides. Microchemical tests indicate that gold is greatly in excess of silver, but the proportion of tellurium could not be judged. It was not found in sufficient quantity to reach definite conclusions, but the various tests indicate that the mineral is probably sylvanite.

Sylvanite is listed by Patton[42] as one of the minerals having been found in the Empress Josephine vein, but no details are given as to its identification.

Empressite (AgTe).—Empressite was first recognized as a new mineral species by Dr. R. D. George, in telluride ore from the Empress Josephine mine. It was not analyzed except qualitatively at the time of its discovery but has since been quantitatively analyzed by Bradley[43] and Dittus,[44] and its identity as a mineral species has been established. As the mineral does not appear in current editions of American mineralogies, these analyses are repeated for reference in the table below. It is, however, listed by Doelter[45] as a mineral species and its properties and constitution discussed. Doelter[46] calls attention to the fact that the pure silver monotelluride, empressite, in contrast to the silver gold telluride, muthmannite, (Ag, Au) Te, possesses no cleavage. He also records that the only natural occurrence of the mineral yet known is that in the Empress Josephine mine. Bradley discusses the chemical and blowpipe reactions of the mineral and gives its hardness as 3 to 3.5 and its specific gravity as 7.510.

In polished sections under the microscope the mineral appears pale bluish gray beside altaite or hessite but is more brownish than galena. Etching tests based on an examination by M. N. Short and repeated on tests of additional specimens by the writer are given below. The paragenetic relations of the mineral are discussed in the description of the Empress Josephine mine on page 142.

Empressite was found only in small pockets in the Empress Josephine vein, and very few specimens are now preserved. The writer is indebted to Dr. R. D. George, of the University of Colorado, and to Mr. Frank Leavitt, of Bonanza, Colo., for the loan of specimens for study.

Analyses of empressite from the Empress Josephine mine

	1	2	3	4
Specific gravity	7.510			
Ag	45. 16	45. 17	43. 71	43. 68
Fe	. 30	. 15	2. 17	2. 16
Te	54. 62	54. 89	53. 86	53. 81
Insoluble matter	. 38	. 39	. 32	. 34
	100. 46	100. 60	100. 06	99. 99

1, 2. Bradley, W. M., analyst. Am. Jour. Sci., 4th ser., vol. 38, pp. 163–165, 1914.
3, 4. Dittus, E. J., analyst, in Patton, H. B., op. cit., p. 110.

Microscopic tests on polished surfaces gave the following results: Bluish gray, soft, anisotropic; HNO_3 forms iridescent stains, or its fumes produce a slight tarnish; HCl quickly stains differentially iridescent or some specimens almost negative; KCN, negative; $FeCl_3$ instantly stains differentially iridescent and brings out structure; KOH, negative; $HgCl_2$ instantly stains iridescent.

Hessite (Ag_2Te).—Hessite has been recognized only in ore from the Empress Josephine mine, although it may also occur in other veins in this vicinity in which unidentified tellurides are known to be present. In the specimens examined it was associated with empressite and altaite, together with the more common sulphides sphalerite, galena, and chalcopyrite. A mineral that is probably hessite was identified by M. N. Short in two specimens, lent by Dr. R. D. George, and the same mineral was identified by the writer in one specimen supplied by Mr. Frank Leavitt, of Bonanza.

The appearance of the mineral in polished sections is described by Short as follows: "It has a brownish tinge in places and varies in color in different grains, probably owing to different orientations. It is strongly anisotropic and gives the following etch tests: HNO_3 stains brown, developing scratches; HCl, negative; KCN, negative; $FeCl_3$ slowly stains brown to iridescent, action slower than with empressite; KOH, negative; $HgCl_2$ slowly stains brown, action slower than with empressite."

Petzite ($(Ag.Au)_2Te$).—Petzite is listed by Patton[47] as one of the minerals found in the Empress Josephine vein, but it was not identified in any of the specimens of telluride ore examined during the present investigation.

Rickardite (Cu_4Te_3).—Rickardite in very small amounts associated with native tellurium was identified by M. N. Short in one specimen from the Empress Josephine vein. It is also listed by Patton as having been found in this vein. No other occurrence is known in the district.

Altaite (PbTe).—The lead telluride, altaite, is found in ore from the Empress Josephine and usually is closely associated with galena, about which it forms a shell in contact with other tellurides. (See pl. 19, *C*, *D*.) No other occurrence of the mineral is known in the district.

SULPHOSALTS

Tennantite ($Cu_8As_2S_7$).—Tennantite is very widely distributed in the district and appears to be an important source of the silver in all the veins. It is commonly referred to as "gray copper," but it is not the more common antimonial variety, tetrahedrite, as shown by the chemical analysis (p. 67). This analysis is in agreement with much "gray copper" found in Colorado.

Tennantite usually occurs in solid masses or in intimate mixtures with the other sulphides but is also found in crystal form in vugs associated with chalcopyrite and galena. Patton[48] reports having observed crystals in cavities of the ore, where it occurs either in simple tetrahedrons or in tetrahedrons slightly modified by other forms. The crystal form is usually imperfect, however, and not easily determinable.

As seen in polished sections of the ores tennantite has a distinct greenish-gray color, in contrast with the usual brownish gray of tetrahedrite. Although it does not give a microchemical test for silver by the ammonium chromate method, which yields results with freibergite, a pure sample of tennantite carefully separated by M. N. Short, and assayed by E. T. Erickson, of the United States Geological Survey, ran 385.4 ounces of silver to the ton. The gold was visible but not weighable, and Erickson estimates it at less than 0.1 ounce to the ton. This sample came from the Rico prospect, on the north side of Round Mountain. Patton[49] cites an assay of a sample of tennantite from the Rawley vein, which ran 0.08 ounce of gold

[42] Patton, H. B., op. cit., p. 108.
[43] Bradley, W. M., Empressite, a new silver-tellurium mineral from Colorado: Am. Jour. Sci., 4th ser., vol. 38, pp. 163–165, 1914.
[44] Dittus, E. J., in Patton, H. B., op. cit., p. 110.
[45] Doelter, C., and Leitmeier, H., Handbuch der Mineralchemie, Band 4, erste Hälfte, pp. 873, 874, Dresden and Leipzig, 1926.
[46] Idem, p. 875.
[47] Patton, H. B., op. cit., p. 108.
[48] Idem, p. 80.
[49] Idem, p. 83.

and 105.52 ounces of silver to the ton. A commercial assay of picked tennantite-bearing ore from the Cocomongo vein showed copper, 16.1 per cent; lead, trace; zinc, 5.9 per cent; iron, 3.7 per cent; silver, 374 ounces to the ton. The percentages of copper, zinc, and iron show that this sample was not pure tennantite, although the silver assay is unusually high. Stromeyerite is associated with some of the tennantite in this vein, and very likely this high silver value is due partly to its presence. (See pl. 18, *A*.)

All the tennantite is probably of primary (hypogene) origin and not in any way connected with deposition by surface waters, as it is intimately associated with chalcopyrite, bornite, and enargite in the Rawley ore and with chalcopyrite and galena in the Cocomongo ore. In some places tennantite appears to have been deposited almost contemporaneously with chalcopyrite and galena, but it also replaces pyrite, sphalerite, chalcopyrite, and galena.

The following analysis was made by the Fahlerz method:

Analysis of tennantite from the Cocomongo mine, Bonanza, Colo.

[E. P. Henderson, analyst]

Antimony (Sb)	12.85	Zinc (Zn)	5.29
Arsenic (As)	18.62	Lead (Pb)	Trace.
Copper (Cu)	35.49	Silver (Ag)	Present.
Iron (Fe)	5.93		

Pyrargyrite ($3Ag_2S.Sb_2S_3$).—Pyrargyrite is found in the silver-bearing shoots of the manganese veins of the southern part of the district. It appears to be the main source of the silver in some of these veins. It forms delicate deep-red crystals in cavities in the ore, where the bases of the crystals are intergrown with rhodochrosite and galena. Small specks also occur entirely within galena, and the mode of occurrence of the mineral is such as to suggest that it is of primary (hypogene) origin. Its common occurrence within small, comparatively isolated shoots of sulphides in large bodies of barren gangue, as in the Eagle vein, also suggests that it is not the result of supergene enrichment. It is found in the Eagle vein to a depth of about 640 feet. It is a late mineral of the sequence and commonly has replaced galena. (See pl. 22.)

Proustite ($3Ag_2S.As_2S_3$).—Although proustite has been reported as occurring in the Eagle vein, all the specimens of ruby silver obtained by the writer, on being tested microchemically by M. N. Short, proved to be pyrargyrite.

Pearceite (Ag_9AsS_6).—A microscopic greenish-gray mineral having chemical and physical properties that appear like those of pearceite was found intergrown with galena in the ore from the 600-foot level of the Eagle mine, and also with galena from the 400-foot level of the Rawley mine. The amount of the mineral was too small to be isolated and clearly identified. Both occurrences seen appear to be clearly primary. If the mineral of the Eagle vein is pearceite, then pearceite is of earlier formation in this vein than pyrargyrite, but it is not nearly as common.

Enargite (Cu_3AsS_4).—Enargite (sulphur, 32.6 per cent; arsenic, 19.1 per cent; copper, 48.3 per cent) was recognized only in the ore from the Rawley and Express veins and usually can be identified only by examination of polished sections under the microscope. It is a very minor constituent of the sulphides, and during the present study of the Rawley ores was found only in ore from the 700 and 800 north levels, but it is undoubtedly present at higher levels, because Patton,[50] at a time before the 700 level was driven, reported its occurrence in the vein. The enargite in the Rawley vein occurs in intricate intergrowth with bornite and tennantite and associated with pyritic ore. It possesses a decided pink color as seen under the microscope in polished sections and gives a microchemical test for antimony as well as arsenic, although the arsenic appears to be in excess, so that it is doubtless "rose enargite" rather than famatinite. It usually appears to be a somewhat later mineral than bornite and to have been replaced by tennantite. Together with bornite it is undoubtedly primary.

[50] Patton, H. B., op. cit., p. 81.

Enargite is commonly seen by microscopic examination to have partly broken down and altered to tennantite. (See pl. 16, *C*.) As most of the enargite seen was largely altered to tennantite, it appears that enargite was very unstable during the later stages of vein formation.

HALOIDS

Chlorides and bromides of silver.—The term "chlorides and bromides" used by many prospectors and miners throughout the West is commonly applied to vein material stained green or blue by carbonates of copper in or near the outcrop. Some of this stained material contains little or no silver, but some is rich in silver, and although the mineral containing the silver has not been determined it is probably cerargyrite (AgCl) or embolite (Ag(BrCl)), both of which may have a light-green color. Highly oxidized ores of this character are not of great economic importance in the Bonanza district, although they may have yielded returns to individual prospectors in the early days. A body of horn silver (cerargyrite) is said to have occurred at the outcrop of the Eagle vein in Eagle Gulch. (See p. 151.)

Fluorite (CaF_2).—Fluorite (fluorine, 48.9 per cent; calcium, 51.1 per cent) is a fairly common gangue mineral in the veins of the southern part of the district, including some of the veins of the Express mine, the Eagle vein, and the Oregon vein, and is seen on dumps from several other inaccessible veins. In these veins most of the fluorite is green, though both green and purple varieties are associated in vein material from the dump of the Eagle mine. Some fluorite is reported to have been found in the Bonanza vein of the northern part of the district, but it is a very rare mineral north of the vicinity of Eagle Gulch. A small fissure containing fluorite was seen in the Rawley drainage tunnel.

OXIDES

Quartz and chalcedony (SiO_2).—Quartz is a conspicuous constituent of the gangue in most of the veins in the district and is the most abundant gangue mineral in the ordinary lead-zinc-copper-silver veins, where it exhibits several modes of occurrence.

An abundant form of the earliest quartz is that commonly called "jasper," which has replaced the wall rock of the veins. Siliceous replacement of this kind was very widespread in the district but did not occur everywhere and was confined largely to the country rock adjacent to fissures (pp. 71–75). In places, however, sulphide ore is intimately associated with broken or brecciated jaspers. The siliceous material of this origin that contains no ferric oxide or hematite is white, gray, or greenish gray of different shades, but where hematite or some other form of disseminated iron oxide is present the color is brown, reddish brown, or brick-red, as in true jaspers. Microscopic examination shows that the silica is present largely as cryptocrystalline quartz and partly as chalcedony. The quartz is apparently in part metacolloidal, however, as it shows smoothly curved or banded structures due to various proportions of impurities or differences in crystallization, and in many places the structure of the replaced rock is perfectly preserved. (See pl. 12, *A*.) Where recrystallization has been more complete the quartz may be more granular, and the original texture of the rock may be completely destroyed. The accessory minerals commonly present in small amounts in siliceous replacement deposits of this kind are pyrite, hematite, and rutile; less common are barite, sphalerite, sericite, and minerals allied to kaolinite. In many of the reddish jaspers disseminated pyrite crystals are present, forming a rock of striking appearance. (See pl. 9, *B*.) Red jasper containing pyrite is common in parts of the Rawley drainage tunnel and adjacent to the veins along Copper Gulch but is also found at many other places. Strongly silicified wall rock occurs on some of the lower levels of the Cocomongo mine, where the slightly reddish stained jaspers appear to have replaced andesitic wall rock, and the gray or white quartz has commonly replaced the Bonanza latite. Although the texture of the rocks is in some places partly preserved, the recrystallization has been so complete in other places adjacent to the Bonanza vein that it is exceedingly difficult or impossible to determine what the original wall rock was. Some photomicrographs of thin sections of typical siliceous replacement deposits are shown in Plates 9–12.

Within the ore bodies the quartz occurs as a fine-grained mineral replacing rock that has undergone brecciation, as relatively fine to irregularly grained aggregates which probably represent replacement and crystallization in soft breccia or gouge material, and as typical drusy quartz and small, clear terminated quartz crystals formed largely by crystallization in open spaces. Isolated and doubly terminated quartz crystals as much as half an inch long are found in heavy gouges. Very coarse drusy quartz is uncommon, as the larger crystals are in general not more than half an inch to an inch in length and a quarter of an inch in diameter. White milky quartz and chalcedonic quartz are rare in association with sulphide ores in the district but are found in places, mostly outside of the intensely mineralized areas. Chalcedony banded and mottled in red, white, or gray is found along some fault planes in association with coarser crystalline quartz, but such occurrences are usually barren of sulphides.

Some kinds of veins contain comparatively little quartz, particularly certain gouge-filled fissures containing tennantite or gray copper as the principal ore mineral. As the silver-bearing tennantite represents a rather late stage of the sulphide mineralization it may be taken as an indication that the greater part of the quartz in the Bonanza ores was deposited in the earlier stages. Tennantite is found commonly in association with quartz, but it usually appears to be a later mineral that has filled cavities within the quartz mass.

Quartz occurs in some veins as platy pseudomorphic growths that may in part be determined as having replaced barite and as intergrowths with barite from which the barite has later been removed by some process not understood. Negative pseudomorphs of quartz after carbonates are also found. They are present in the ore of the Eagle mine and in many prospects in other parts of the district.

Specularite (hematite) and other forms of ferric oxide.—Specular hematite (Fe_2O_3) and less definitely crystallized aggregates of ferric oxide are commonly present in the siliceous deposits that have replaced the wall rock and give the jaspers a reddish or brownish color. Small veins consisting mostly of dark specular hematite occur in some of the jaspers and in places are sufficiently abundant to give the jaspers a nearly black color. The occurrences of ferric oxide may be associated with ore in some veins, because of the fact that the products of the earliest stages of alteration with which the ferric oxide is associated may be preserved in some of the fault breccias in which the sulphide ore was deposited. Intense pyritization and recrystallization of red jaspers may have resulted in the destruction of some of the earlier hematite, and rarely during this process it was replaced by pyrite pseudomorphically.

Some of the red coloring matter in the jaspers may consist of hydrated forms of ferric oxide, such as turgite ($2Fe_2O_3.H_2O$) or göthite ($Fe_2O_3.H_2O$).

Rutile (TiO_2).—Rutile is present in many of the sericitic gouges of the veins and also usually in small amounts in some of the vein quartz and siliceous replacement deposits. It occurs as small yellowish or yellowish-brown crystals of the usual prismatic habit, which are visible only under the microscope. In the jasperoids or siliceous deposits replacing the wall rock rutile is almost invariably present and occurs in two forms—ordinary prismatic crystals, which are very clear and of pale color, and irregular grains or fine aggregates, which are nearly opaque and dark yellowish brown or yellow. The larger irregular grains are generally crackled.

Anatase (octahedrite) (TiO_2).—Anatase is recognized very rarely in the gouge clays in the district. Microscopic flattened octahedral and tabular crystals of a light to deep bluish color were seen in gouge clays from the Cocomongo and Rawley veins. Their association was similar to that of rutile, but they are distinguished from rutile by their optically negative character and tabular mode of crystallization. This mineral was suspected of being present in other gouge clays, but its identity could not be definitely established, because of the small size of the grains.

Diaspore ($Al_2O_3.H_2O$).—So far as is known diaspore (alumina, 85 per cent; water, 15 per cent) is not found as a vein mineral in the district, but it occurs in some intensely silicified rocks. It is associated with kaolinite, sericite, and zunyite.

Pyrolusite (MnO_2).—Pyrolusite is found in quantities of economic importance only in the oxidized zone of manganese carbonate and silicate veins in the southern part of the district. The Headlight or Pershing vein (pp. 158–159), in the upper part of Manganese Gulch, contains pyrolusite associated with psilomelane, siliceous material, and minor amounts of iron oxides. It occurs in radial prismatic aggregates, in granular crusts, and in distinct prismatic striated crystals which are probably pseudomorphic after manganite.

Manganite ($Mn_2O_3.H_2O$).—The hydrated manganese oxide, manganite, had not been definitely identified in the ore of the Pershing vein at the time of investigation, but in all probability was originally present in the vein. The prismatic striated crystals of pyrolusite which line drusy cavities in the ore are probably pseudomorphic replacement deposits due to dehydration of manganite. Manganite is probably present in the veins in small amounts but has been so largely dehydrated to pyrolusite that it is difficult to recognize in the mixtures. Several polished surfaces of the mixed manganese oxides fail to disclose its presence.

Psilomelane (H_4MnO_5?)—Psilomelane is present in the mixed oxides in hard, compact masses which are generally intergrown with limonite. It is distinguished from pyrolusite by its hardness, lack of crystal form, and on polished surfaces by these properties and its reaction with hydrogen peroxide. It appears to be very subordinate to pyrolusite in the Pershing vein.

The paragenetic relations of the different manganese minerals are very complex, but their original source is undoubtedly in large part rhodochrosite and to a lesser extent rhodonite of the primary veins. (See pp. 88 and 159.)

Wad.—Some indistinct mixtures of oxides of manganese and iron associated with the manganese ores form what is commonly called wad.

Limonite ($2Fe_2O_3.3H_2O$).—Mixtures of hydrated iron oxides generally referred to as limonite occur in the oxidized zones of all the veins. Most of the iron has resulted from the oxidation of pyrite but part of it from other iron-bearing minerals. Limonite occurs mixed in different proportions with the manganese oxides and is a minor constituent of the oxidized manganese veins, such as the Pershing vein (p. 159). Complete oxidation to mixtures of limonite, pyrolusite, psilomelane, and wad may extend to depths of several hundred feet in veins of the southern part of the district, as in the Eagle and Oregon veins. In the northern part of the district limonite is not usually found in appreciable amounts at such depths except along local watercourses.

PHOSPHATES

Apatite (or dahllite) ($(CaF)\ Ca_4(PO_4)_3$).—Some mineral probably of the apatite group occurs in a few places so intimately associated with quartz, carbonates, and sulphides as to make it definitely a gangue mineral; it was seen only in a few sections, but these came from widely separated veins. The mineral occurs as colorless hexagonal or rectangular grains, 0.5 millimeter or less in diameter, of very sharp crystal outline, characterized in some of the larger grains by anomalies of birefringence and of optical orientation. The index of refraction varies in different occurrences, but its range and the birefringence and optical character of the mineral correspond to those of the apatite group. The mineral is possibly dahllite or podolite, carbonated apatites in which the calcium fluoride is replaced by calcium carbonate, as it is everywhere associated with carbonates, and its optical properties are too variable to correspond with ordinary apatite. This mineral was identified in gangue from the Cocomongo and Little Jennie veins.

Ordinary apatite occurs sparingly in some of the altered and silicified wall rocks, where it has evidently been recrystallized and locally concentrated during the vein-forming processes.

SILICATES

Adularia ($KAlSi_3O_8$).—Adularia (vein orthoclase) is found in some of the low-temperature quartz rhodochrosite-fluorite veins of the southern part of the district. It is particularly common associated with quartz in vein material from the Chloride mine, in Chloride Gulch. It also occurs in small veinlets cutting altered country rock close to the veins in other parts of the district. It was noted especially in altered latite wall rock from the Cocomongo mine, where the relatively high potash content of the latite may have assisted in its precipitation.

Epidote ($HCa_2(Al, Fe)_3Si_3O_{13}$).—Ordinary epidote is fairly common as an alteration product of the country rock. It occurs in altered Eagle Gulch latite and was found in the hanging-wall latite of the Cocomongo vein associated with sericite, quartz, and carbonate (pp. 32 and 79).

Small veinlets in altered andesite on Alder Creek (Manitou-Sunlight, pl. 1) contain radial growths of an acicular prismatic epidote which has the following optical properties: Optically +; $2V=70°\pm$; dispersion strong, $\rho>v$, birefringence moderate, 0.025 to 0.30; refractive index, β is about 1.75; pleochroism, Y dark smoky brown, X and Z are pale pinkish brown or yellowish; axial plane perpendicular to elongation of fibers. This mineral was identified by W. T. Schaller, of the United States Geological Survey, as ordinary epidote, although its color and optical properties are somewhat unusual. It is associated with chlorite, calcite, pyrite, and chalcopyrite. This mineral is quantitatively insignificant, but its occurrence and associations indicate a comparatively high temperature of formation for these small veins.

Sericite ($H_2KAl_3(SiO_4)_3$).—Sericite, a finely divided form of muscovite, is a common alteration product of the country rock adjoining veins, and some of the vein gouges may be largely sericite, though including possibly some of the minerals of the clay group. Sericite and kaolin are associated in some of the altered rocks of the southern part of the district. In places sericite is intergrown in small amounts with vein quartz and is a constituent of some silicified wall rocks.

Chlorite.—Chlorite, a hydrated silicate of aluminum, iron, and magnesium of variable composition, is a very common constituent in the country rock adjoining mineralized fissures but is rare as a vein mineral. Small amounts of it are associated with quartz and jaspers. Some chlorite was seen as a constituent of small veins in altered andesite on Alder Creek. It is associated with quartz, pyrite, calcite, chalcopyrite and epidote.

Kaolin minerals.—A mineral corresponding in optical and crystallographic properties to one of the kaolin minerals that occur in the Red Mountain region of Silverton, Colo., is found as an alteration product associated with the silicified rocks in the Bonanza district. This mineral occurs in microscopic platy crystals that occasionally show pseudohexagonal outlines but more commonly are intergrown and of irregular shape, having a size near 0.01 millimeter. Extinction angles of 15° or more were obtained on the small plates in some individuals that were large enough to permit study of the optical properties. The birefringence is low, and the indices of refraction all lie between 1.56 and 1.57. By comparison with some of the kaolin minerals from the Red Mountain region [51] to which the writer had access it is clear that the kaolin of the two areas is identical. The kaolin of the Bonanza district occurs as a by-product of the silicification of the volcanic rocks and so is of hydrothermal origin. It is commonly associated with quartz, barite, sericite, and other fine-grained fibrous clay minerals of doubtful identity. In the southern part of the Bonanza district it commonly fills small pockets in the silicified rocks or has replaced the feldspar phenocrysts. It appears in some occurrences to have either replaced quartz or filled small cavities that have been formed by solution of the quartz. Its association with the silicified rock is similar to that of alunite, diaspore, and zunyite (see pp. 73, 74), but as compared to these minerals, it is probably a product of either lower temperature or of solutions of lower acidity.

Other claylike minerals of doubtful identity are commonly associated with sericite and quartz. One of these minerals occurs with sericite in the silicified rock from the altered area between Chloride and Greenback Gulches. (See analysis 8, p. 78.) The mineral is in small fibrous or scaly aggregates with a somewhat lower index of refraction and lower birefringence than sericite, but it has a higher birefringence than typical kaolinite. It may be a potash-bearing clay. Its relation to sericite is obscure because of intimate intergrowth, but both it and the sericite are later than the quartz.

[51] Silver Belle and National Belle mines; collected by F. L. Ransome in 1899. See U. S. Geol. Survey Bull. 182, pp. 73–74, 124–131, 234, 1901.

Some minerals of the clay group are present in and near the veins. Wuensch[52] describes a claylike alteration product in the Eagle vein (now inaccessible) associated with rhodochrosite in which the mineral is yellowish white and tends to form claylike earthy masses. From a commercial analysis made of this mineral Wuensch determined it to be nontronite, but as the analysis was made on an impure mixture containing an excess of carbonates of manganese and calcium containing iron, and as no optical data were given, the identification is open to doubt. Microscopic examination of a nearly white clay mineral collected by the writer from the Eagle dump shows its indices of refraction and optical properties to correspond to kaolinite[53] or some closely allied mineral, and it does not possess the properties of the minerals that have been listed as nontronite by Larsen.[53]

The gouge "clays" of at least the northern part of the district consist mainly of sericite, but it is likely that a more comprehensive study of gouge clays, particularly of unmineralized fissures, would reveal the presence of other minerals of the clay group. In ore containing supergene covellite from the Paragon mine a yellowish claylike mineral filling cavities was found to have moderate birefringence and the higher indices of refraction near 1.57. As it gave a negative test for sulphate, it is probably one of the clay minerals such as beidellite.

Rhodonite ($MnSiO_3$).—The silicate of manganese, rhodonite, occurs in very intimate intergrowth with rhodochrosite and quartz in veins of practically all parts of the district but is an uncommon gangue mineral. It is usually found in very hard fine-grained pink or rose-red material from the vein containing small amounts of sulphide. It can not usually be recognized in the hand specimen but is easily recognized in thin sections under the microscope. In most of the sections examined both rhodonite and quartz have been partly replaced by the later rhodochrosite, the rhodonite showing greater susceptibility to replacement. Rhodonite is also probably present in the Eagle vein. Where its relations can be seen clearly rhodonite is an early mineral in the vein paragenesis, crystallizing before any sulphides except possibly the two earliest, pyrite and sphalerite.

Zunyite ($8Al_2O_3.6SiO_2.9H_2O(O,F_2,Cl_2)$).—Zunyite, a basic orthosilicate of aluminum, is an isotropic colorless mineral (index 1.59) with prominent octahedral cleavage and was found in microscopic grains in a silicified dike rock from the southern part of the district, associated with diaspore and later sericite as an alteration product of the feldspars of the rock. (See pl. 10.) It was not present in sufficient quantity to permit chemical tests, but its distinctive optical properties and cleavage are identical with those of the mineral found at the Zuñi mine, in the San Juan region, which is also associated with diaspore, and its identity as zunyite is therefore beyond reasonable doubt.

CARBONATES

Calcite and "manganocalcite."—Calcite ($CaCO_3$) occurs sporadically as a gangue mineral, generally as a filling in more open parts of the vein, and in many places contains small amounts of manganese and iron and traces of magnesium. Some of it contains sufficient manganese to give it a pale pink color and to warrant its classification as a manganocalcite. The chemical properties of even the pink varieties, however, indicate a content of only a small percentage of the manganese carbonate molecule. Although pure calcite is not an abundant constituent of the ore deposits, it is found in many places as an alteration product in the lavas at some distance from the fissures. (See pp. 79–80.)

Dolomite ($(Ca,Mg)CO_3$).—Dolomite was identified as a vein mineral in the E. D. vein, in the extreme southern part of the district, near the Villa Grove road, opposite the E. D. ranch. It is associated with calcite and siderite. As this part of the district is very probably underlain by the Paleozoic limestones, the magnesium may have been derived largely from these beds at depths of 500 to 1,000 feet below the outcrop of the vein. Magnesium does not appear to have been commonly precipitated from the vein solutions of the district, as chemical tests by the writer show only traces of magnesium in the common carbonates as manganocalcite, manganosiderite, and rhodochrosite.

Siderite ($FeCO_3$).—Siderite was identified in the Rawley and Clark veins and in some pyritic veins in the southern part of the district. It occurs as small brown rhombohedral crystals of the usual habit, which were found as drusy coatings in small cavities and were deposited upon calcite or manganocalcite. The siderite in the Clark vein contains some manganese and probably is allied to manganosiderite. In the southern part of the district in a small vein near the Villa Grove road, opposite the E. D. ranch, siderite occurs as a late carbonate on calcite and dolomite crystals. The iron carbonate was followed here by a still later pyrite.

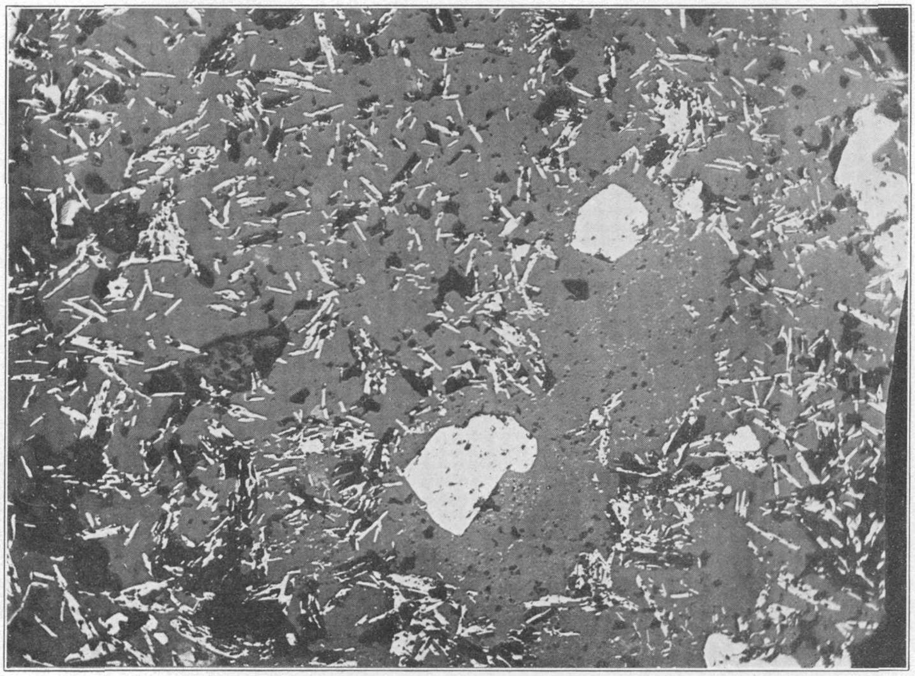
Rhodochrosite ($MnCO_3$).—Rhodochrosite is distributed throughout the district as a subordinate gangue mineral, and is found in abundance only in some of the veins in the southern part of the district. In both the Eagle vein and the "rhodochrosite vein" of the Express mine rhodochrosite in association with fluorite is an abundant constituent of the gangue. It is nearly pure manganese carbonate, though rough checks on the chemical composition show small amounts of iron and calcium but only traces of magnesium. The index of refraction (ω) is somewhat greater than 1.80. Where the mineral is abundant it occurs in slightly warped rhombohedrons of deep-pink or rose-red color. The veins in the northern part of the district contain in places some pale pinkish carbonate in which manganese is present, but this rarely proves to be pure rhodochrosite. Its optical and chemical properties indicate that it is mainly a manganiferous calcite containing 10 per cent or less of $MnCO_3$, small amounts of iron, and traces of magnesium. Pinkish carbonate of this nature is found in both the Cocomongo and Rawley veins. In the Clark vein of the Rawley tunnel nearly pure rhodochrosite occurs associated with manganocalcite and manganosiderite. A pink carbonate high in manganese ($\omega = 1.78\pm$) and associated with rhodonite occurs in the Little Jennie vein.

Thus while carbonates high in manganese are found in nearly all parts of the district, veins with a large percentage of true rhodochrosite are limited to the southern part of the district, in the so-called "manganese belt."

Cerusite ($PbCO_3$).—Cerusite occurs in small amounts throughout the district and is in places found practically at the outcrops of lead ores, indicating the weakness of oxidation in the district. In partly oxidized ore from some position in the two upper levels of the Bonanza vein cerusite and anglesite are associated with covellite, forming a shell on massive galena. Their relations clearly show that the covellite and anglesite were formed first and were followed by the cerusite.

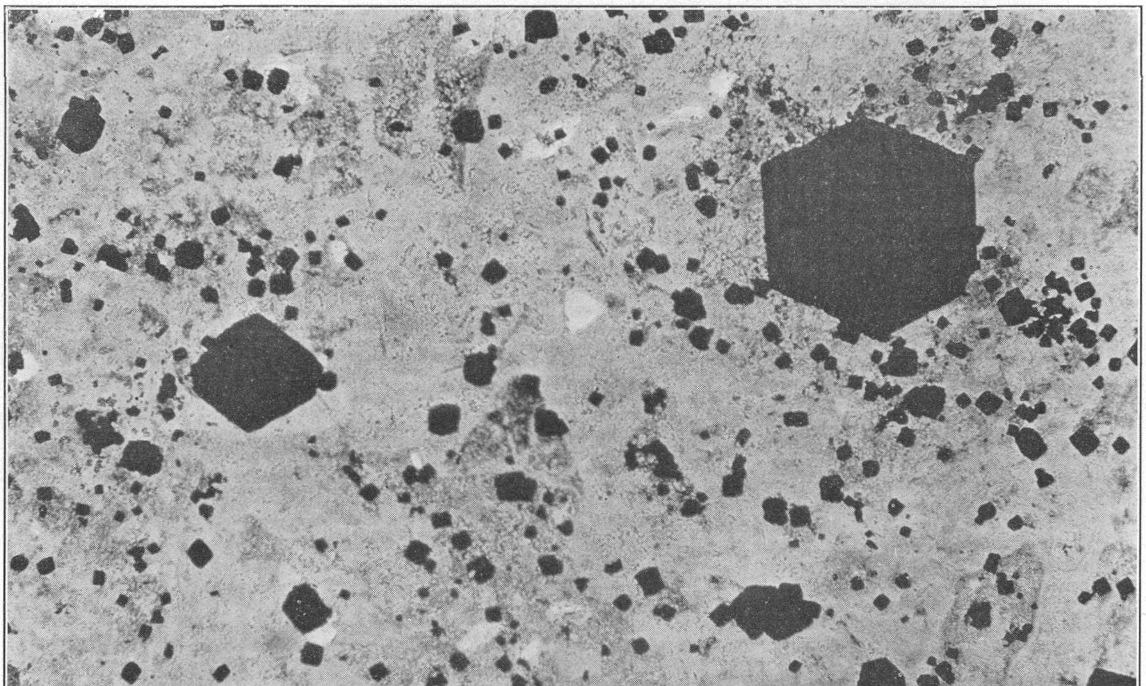
[52] Wuensch, C. E., Secondary enrichment at the Eagle mine, Bonanza, Colo.: Am. Inst. Min. and Met. Eng. Trans., vol. 69, pp. 104–108, 1923.

[53] Larsen, E. S., Microscopic determination of the nonopaque minerals: U. S. Geol. Survey Bull. 679, pp. 217, 249, 251, 252, 259, 1921.



A. PHOTOMICROGRAPH OF SILICIFIED ANDESITE SHOWING PYRITE AND HEMATITE

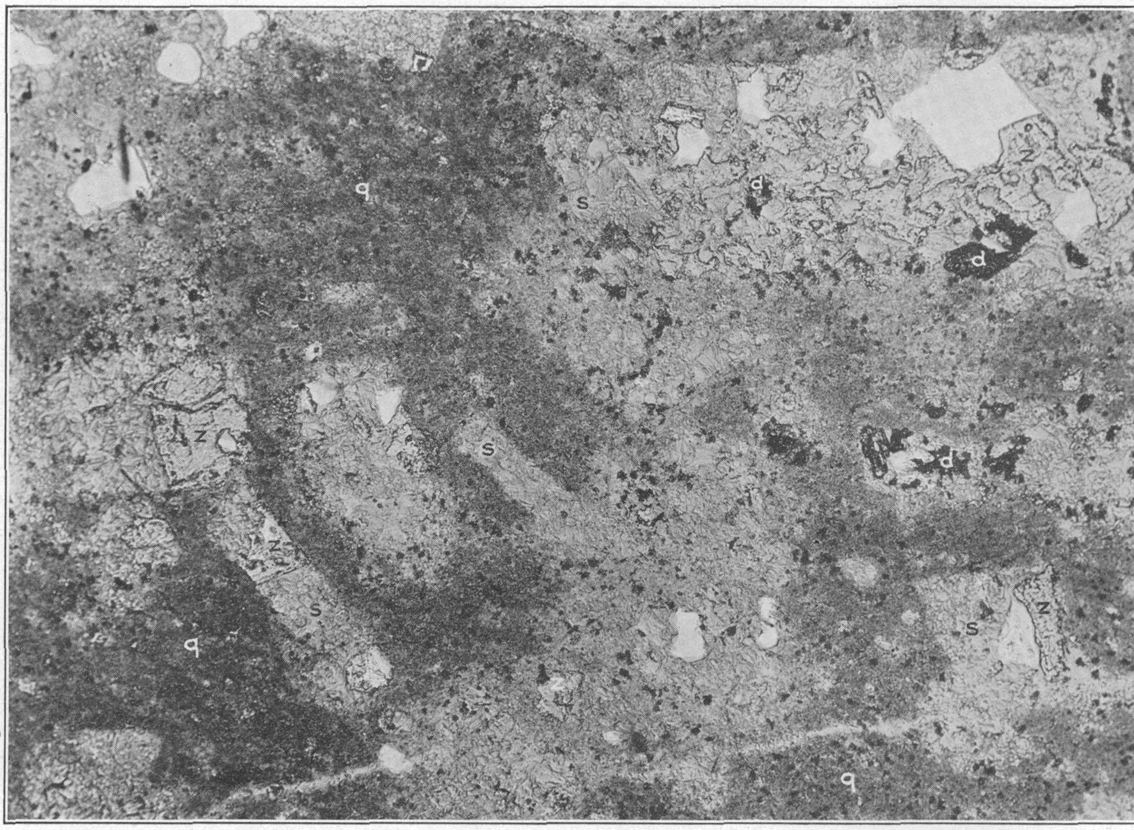
From the Manitou-Sunlight vein, Alder Creek. Reflected light. × 100.



B. PHOTOMICROGRAPH OF DISSEMINATED PYRITE (BLACK) IN RED SILICIFIED ANDESITE FROM THE RAWLEY DRAINAGE TUNNEL

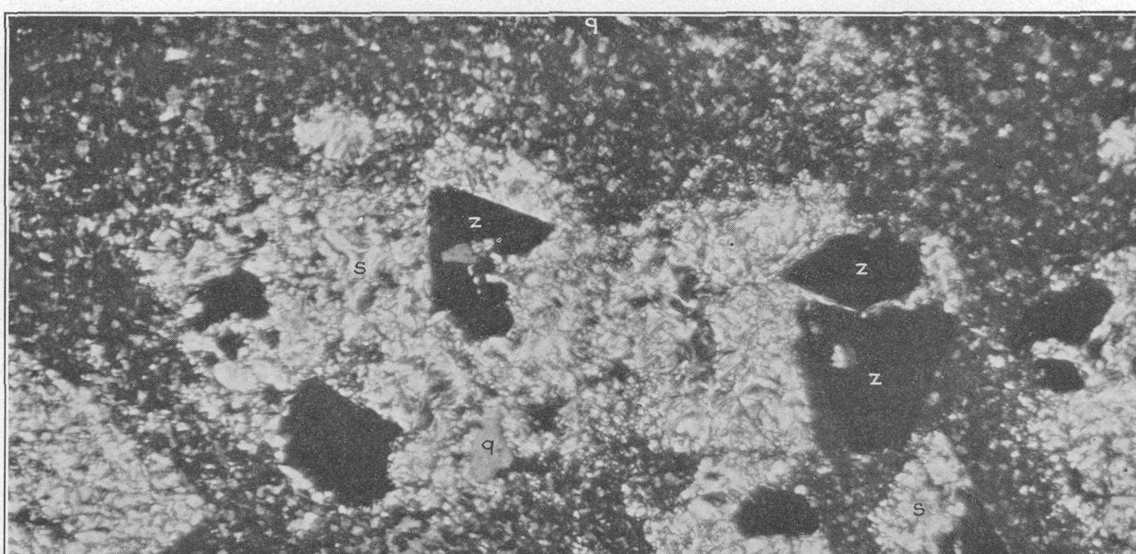
Illustrates even distribution of pyrite crystals in massive jasper. Plain transmitted light. × 40.

PHOTOMICROGRAPHS OF ALTERED ROCKS



A. PHOTOMICROGRAPH OF SILICIFIED PORPHYRITIC ROCK IN WHICH THE FELDSPAR CRYSTALS ARE REPLACED BY DIASPORE, ZUNYITE, AND SERICITE

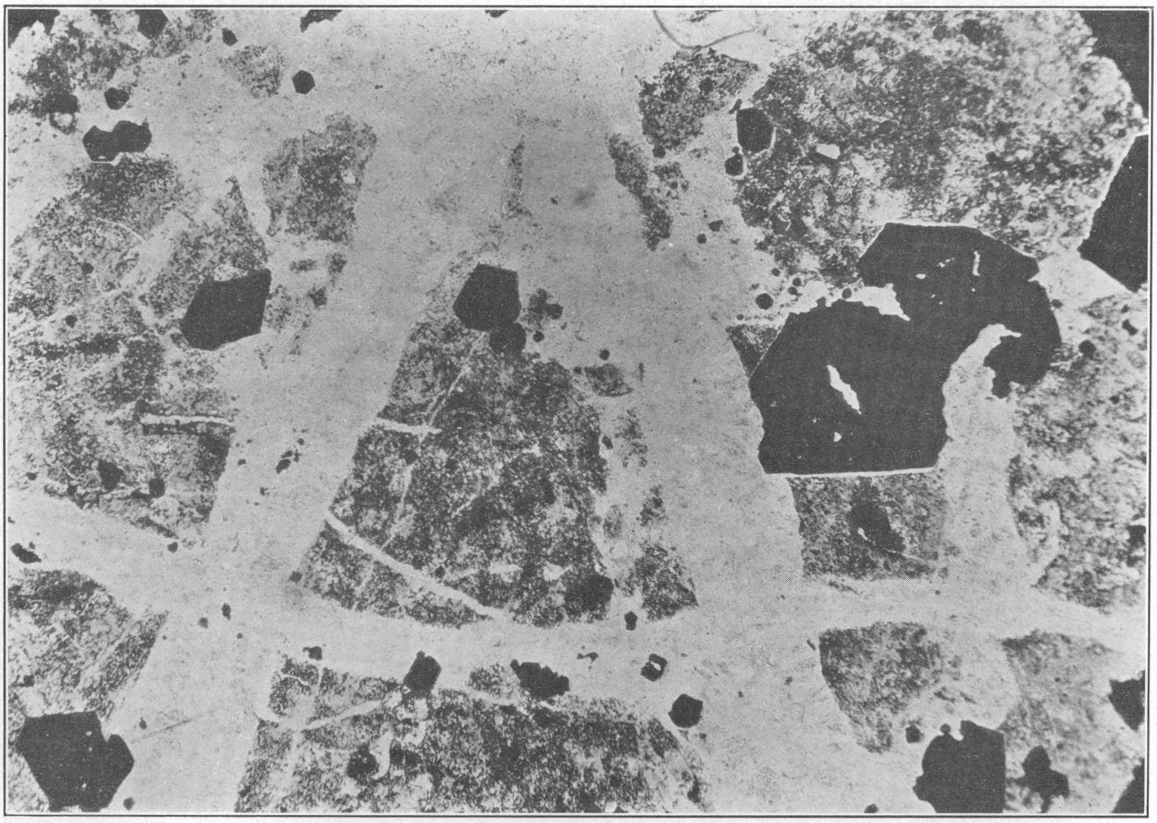
The sericite (s) has partly replaced the earlier formed diaspore (d) and zunyite (z). q, Quartz. The dark specks scattered through the silicified groundmass are in part diaspore and rutile. From the north side of Greenback Gulch, same locality as that shown in Plate 6, *B*. Plain transmitted light. × 45.



B. DETAIL AT HIGHER MAGNIFICATION FROM THE LEFT SIDE OF *A*

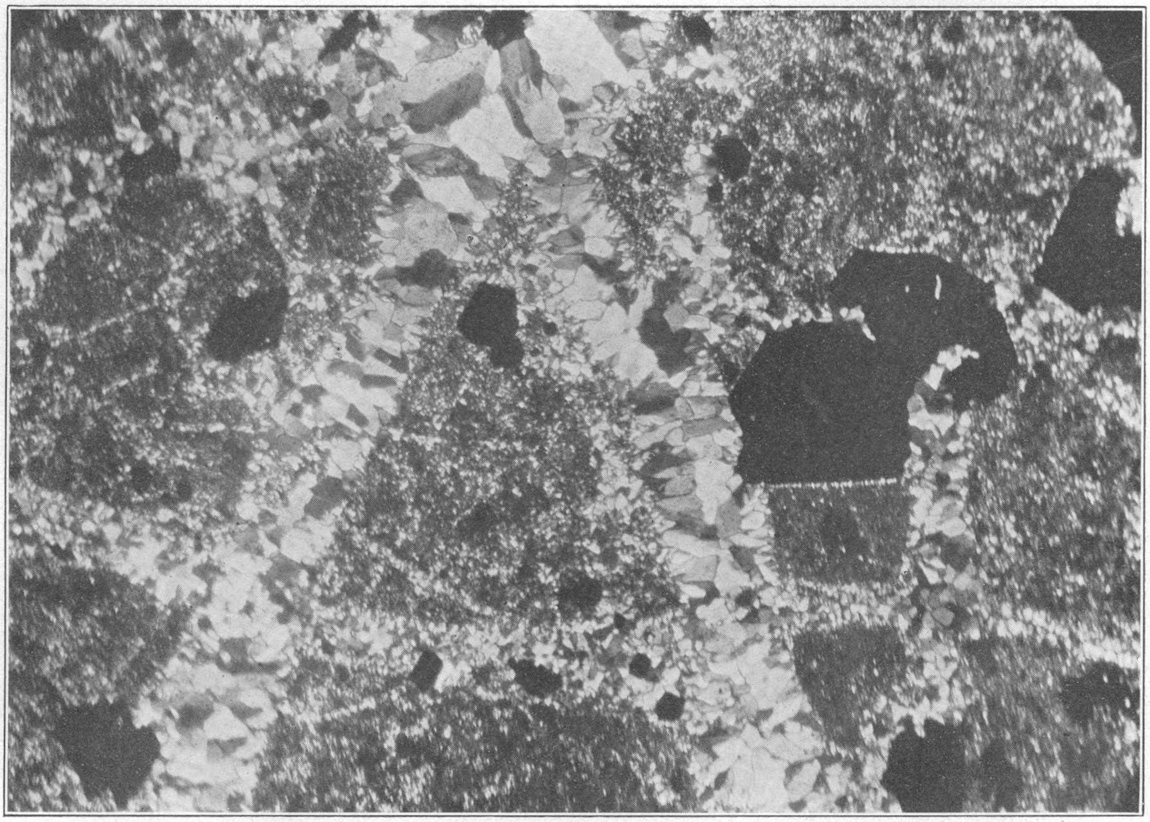
Shows the fine granular character of the quartz replacement and also the zunyite, veined and partly replaced by sericite. q, Quartz; s, sericite; z, zunyite. Transmitted light, crossed nicols. × 74.

PHOTOMICROGRAPHS OF ALTERED ROCKS



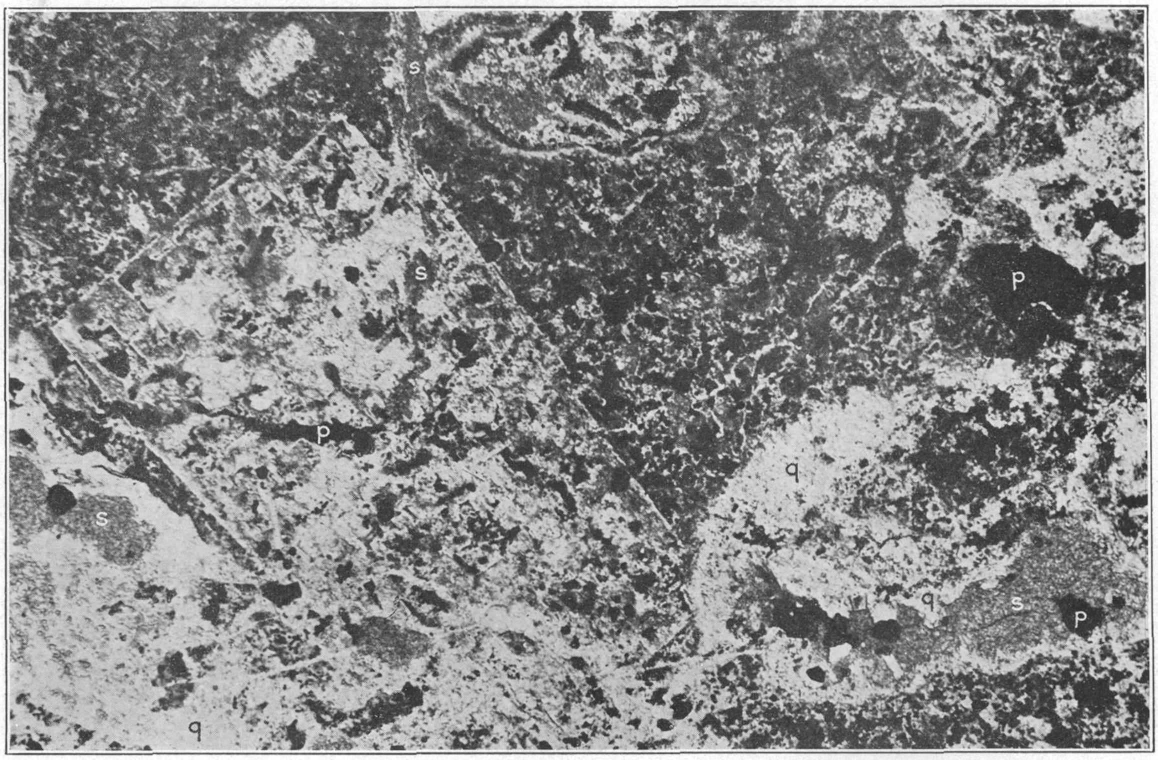
A. PHOTOMICROGRAPH OF RED JASPER FORMED BY SILICIFICATION OF ANDESITE, BRECCIATED AND VEINED BY QUARTZ OF A LATER STAGE

The large opaque crystals are pyrite, and the fine dark material in the jasper is ferric oxide, which gives the jasper its red color. Plain transmitted light. × 40.



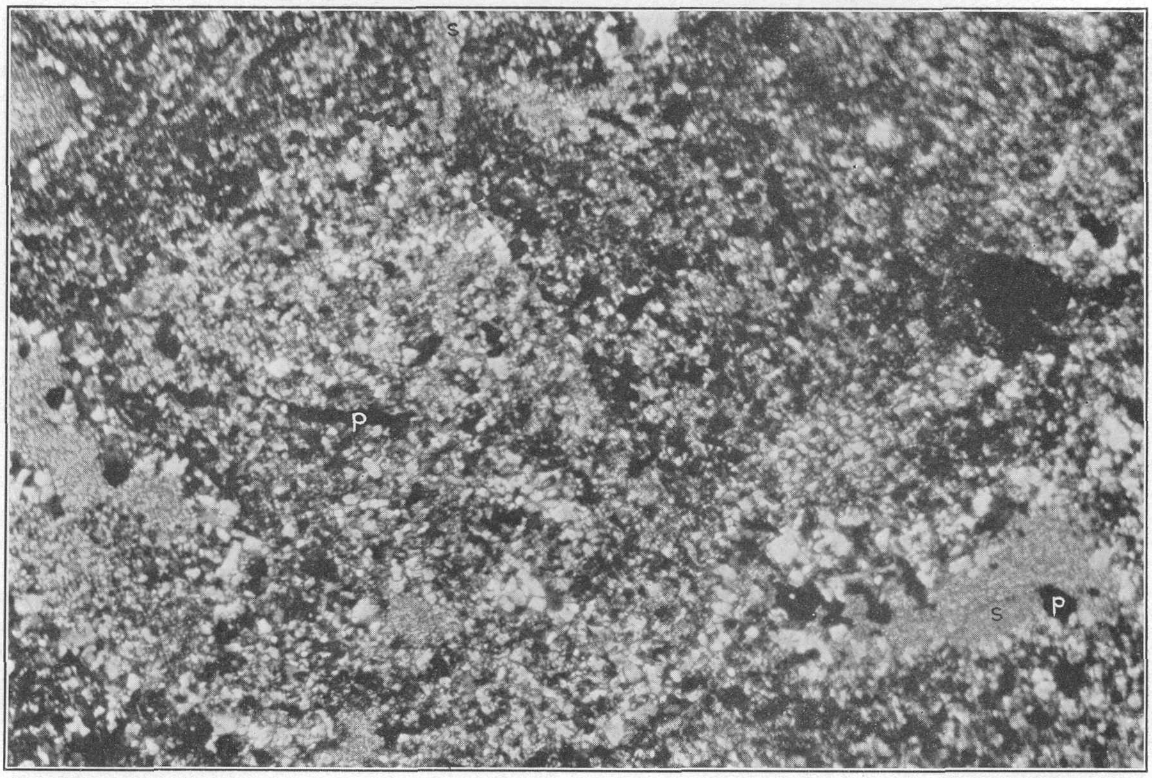
B. SAME AS *A* BUT WITH CROSSED NICOLS, SHOWING DIFFERENCE IN SIZE OF THE EARLIER AND LATER QUARTZ GRAINS

PHOTOMICROGRAPHS OF ALTERED ROCKS



A. PHOTOMICROGRAPH OF SILICIFIED ANDESITE

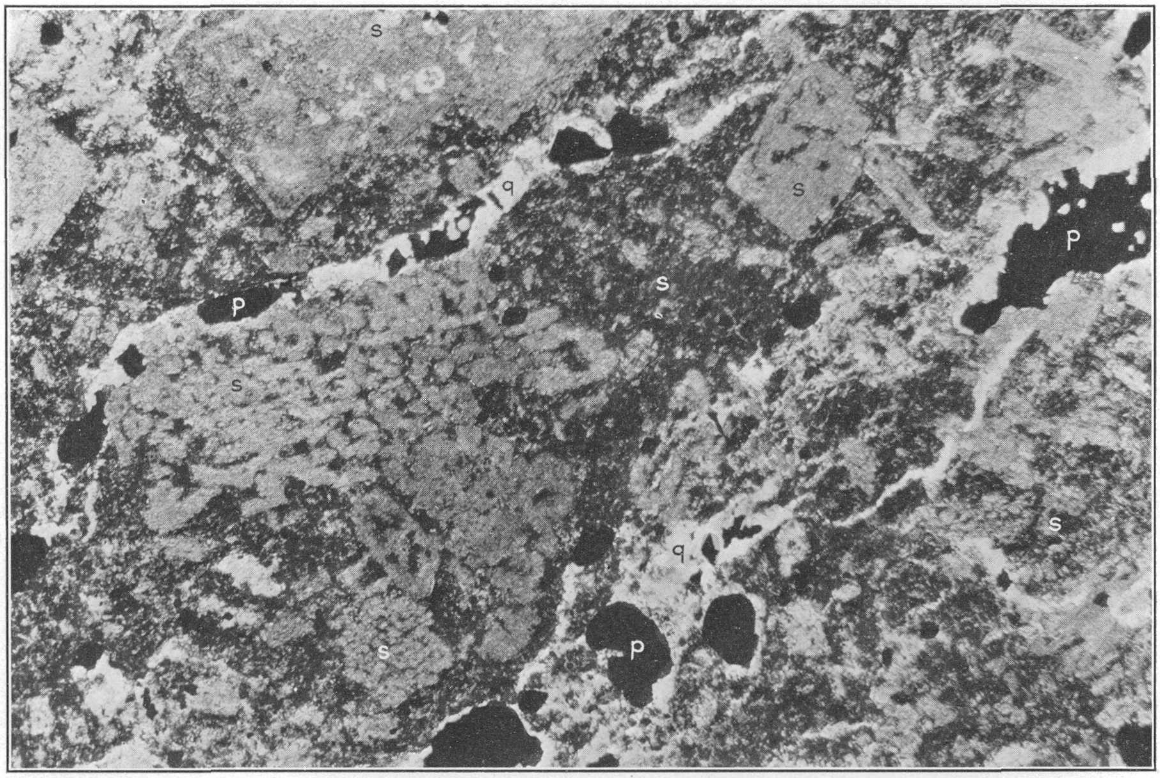
Shows remarkable preservation of certain details of the original texture, particularly the large feldspar phenocryst. The early siliceous material is veined and partly replaced by later quartz (q), pyrite (p), and sericite (s), that were introduced during sulphide mineralization in neighboring fissures. From the Rawley drainage tunnel. Plain transmitted light. × 34.



B. SAME AS *A* BUT WITH CROSSED NICOLS, SHOWING TEXTURE OF THE SILICEOUS REPLACEMENT

p, Pyrite; s, sericite.

PHOTOMICROGRAPHS OF ALTERED ROCKS



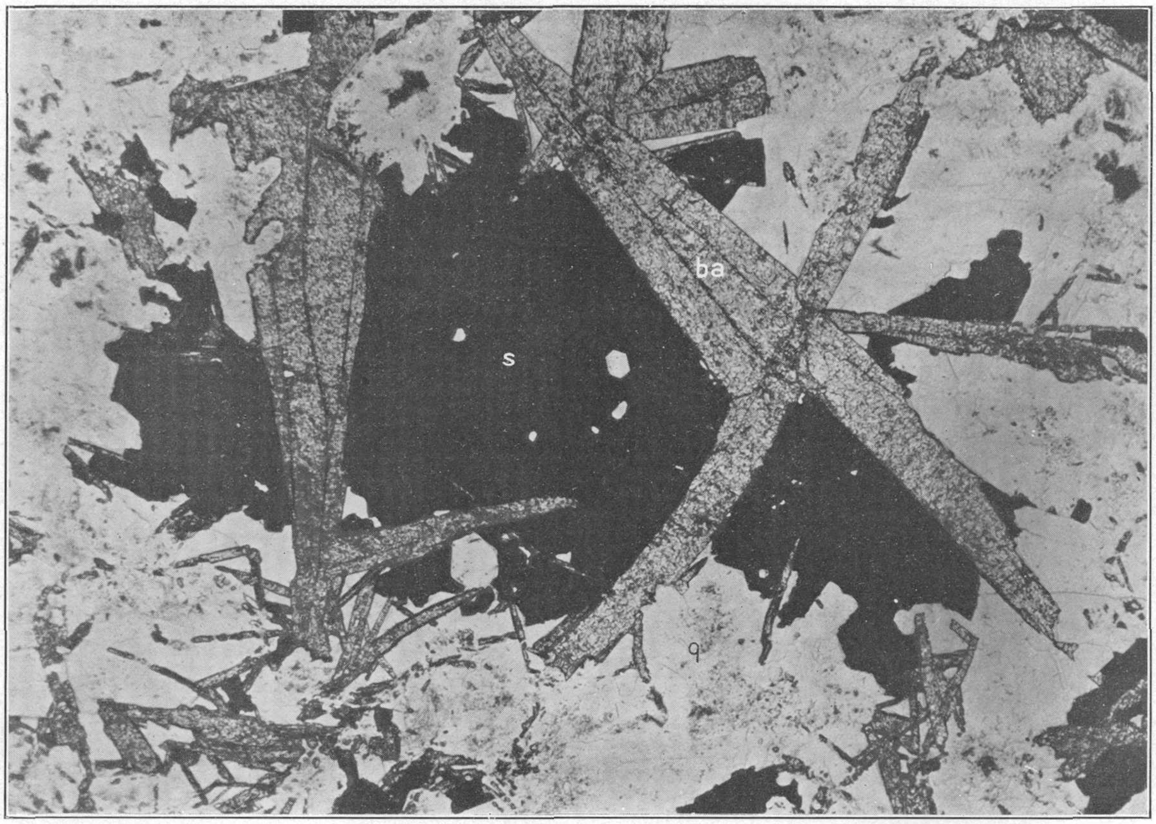
A. PHOTOMICROGRAPH OF ANDESITE ALMOST COMPLETELY REPLACED BY SERICITE AND VEINED BY QUARTZ AND SULPHIDES

Specimen taken near the wall of a mineralized fissure in the Rawley drainage tunnel. Cloudy particles in the sericitized groundmass with some quartz and iron oxide suggest that the formation of sericite has followed early silicification. Compare Plate 12, *A*. p, Pyrite and other sulphides; s, sericite; q, quartz. Plain transmitted light. × 37.

B. PHOTOMICROGRAPH SHOWING GHOSTY OUTLINES OF NEARLY COMPLETELY REPLACED RHODONITE CRYSTALS IN RHODOCHROSITE

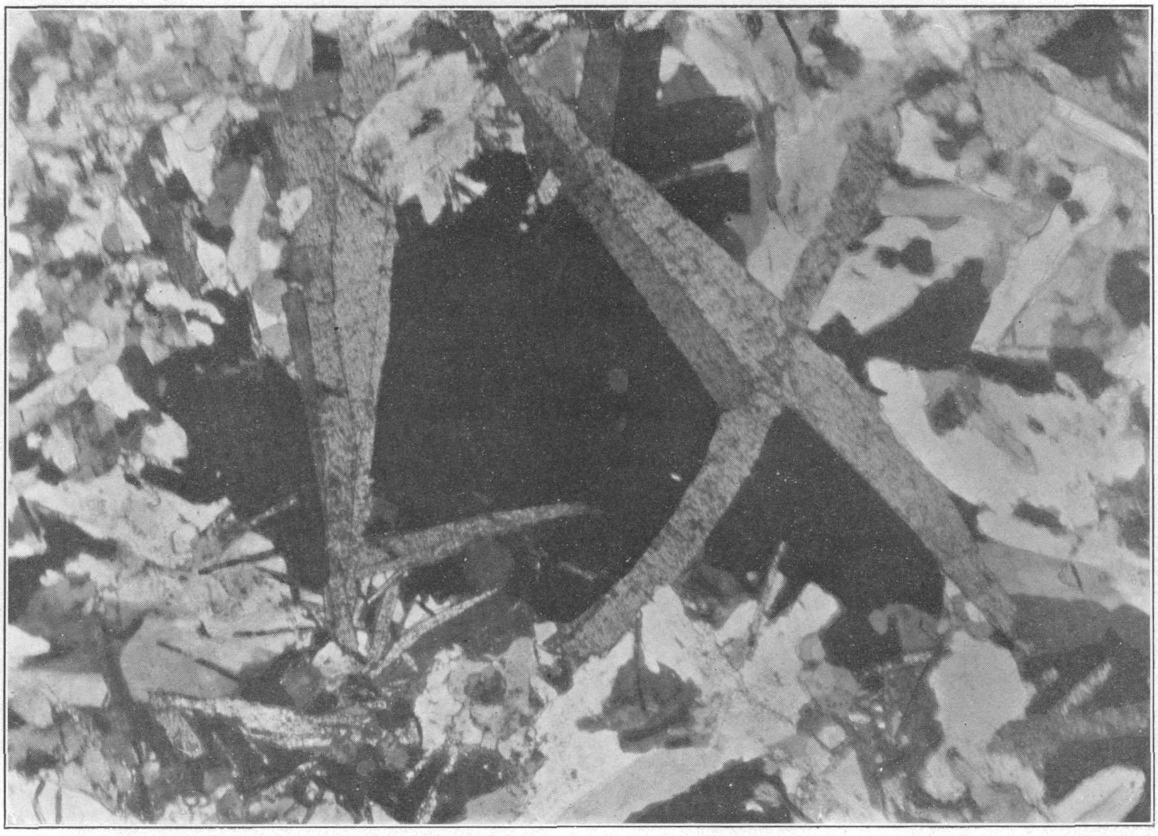
Sphalerite (s) partly incloses some of the rhodonite, which was the earliest mineral to form. Gn, Galena. From the Little Jennie vein. Plain transmitted light. × 100.

PHOTOMICROGRAPHS OF ALTERED ROCK AND VEIN MATTER



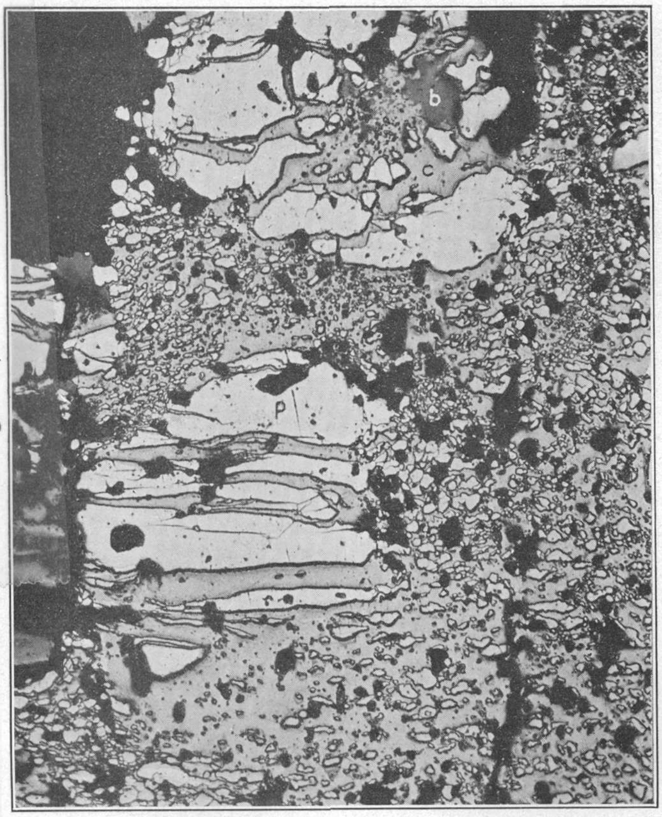
A. PHOTOMICROGRAPH OF EARLY BARITE (ba) SURROUNDED AND SLIGHTLY REPLACED BY QUARTZ (q) AND SULPHIDES (s), LARGELY PYRITE AND CHALCOPYRITE

From the Joe Wheeler vein, Alder Gulch. Plain light. × 28.



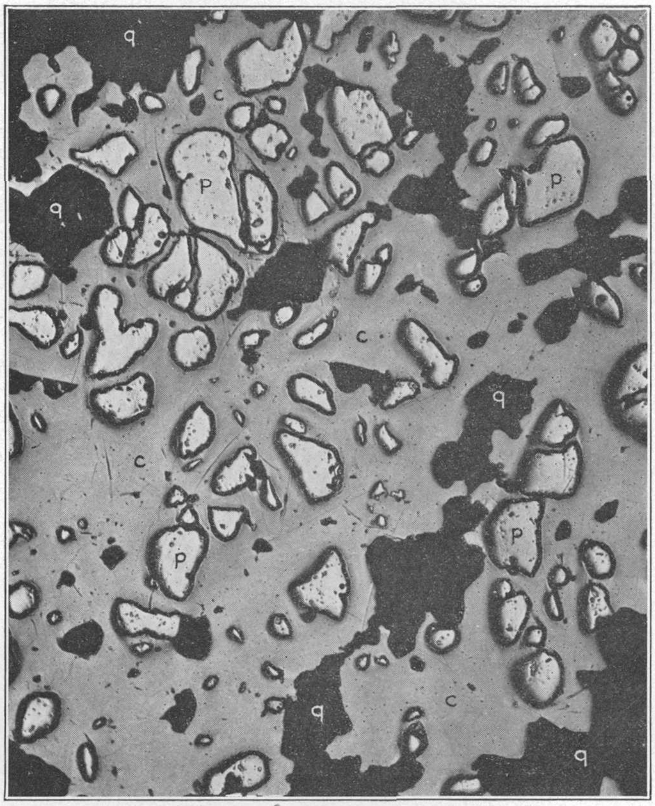
B. SAME AS *A* BUT WITH CROSSED NICOLS. × 28

PHOTOMICROGRAPHS OF VEIN MATERIAL



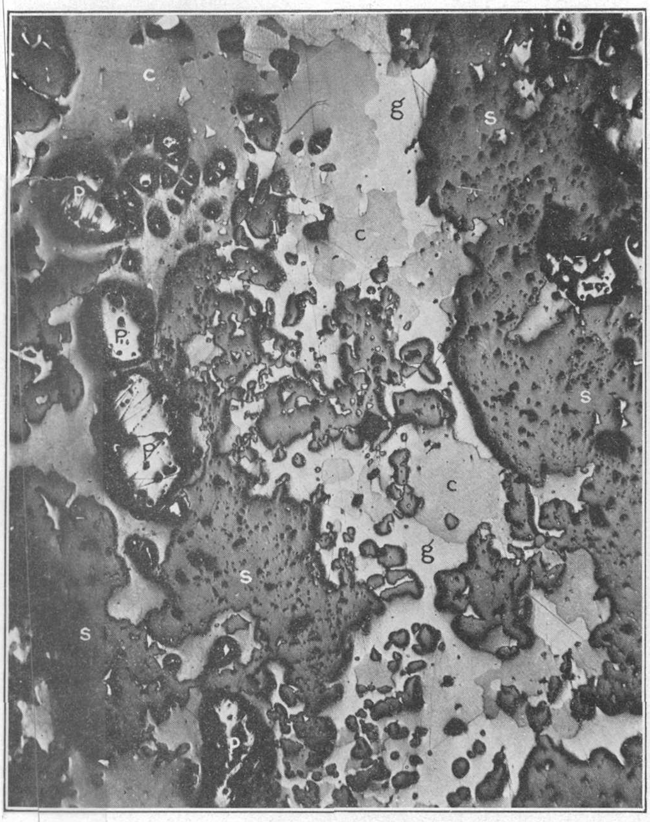
A. BRECCIATED PYRITE (p) PARTLY REPLACED BY CHALCOPYRITE (c) AND BORNITE (b)

Rawley mine, 400 level. Reflected light. × 100.



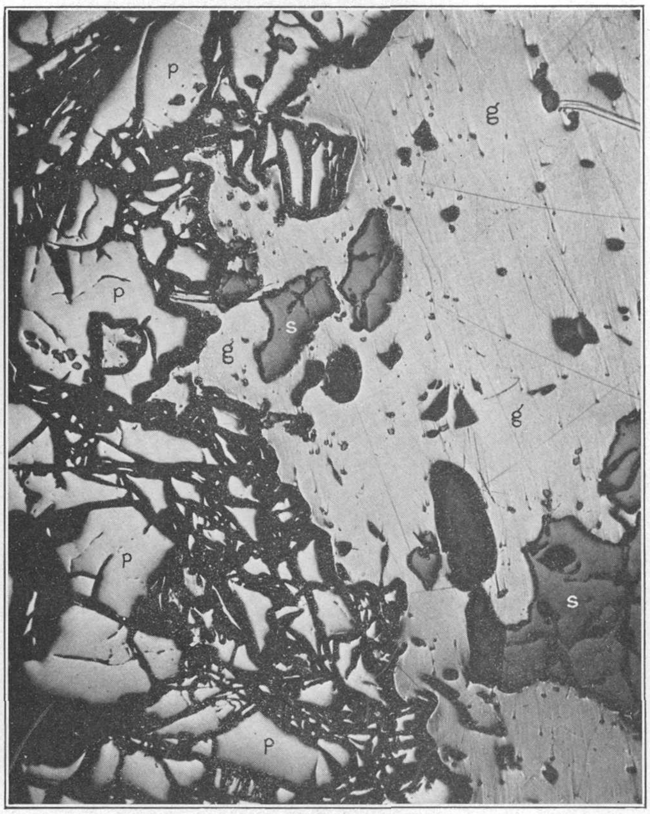
B. PYRITE PARTLY REPLACED BY CHALCOPYRITE

Chalcopyrite (c) and quartz (q) were also probably deposited in part interstitially to pyrite grains (p). Rawley mine, 200 level. Reflected light. × 100.



C. INTERGROWTH OF GALENA (g) AND CHALCOPYRITE (c) WHICH HAS PARTLY REPLACED PYRITE (p) AND SPHALERITE (s)

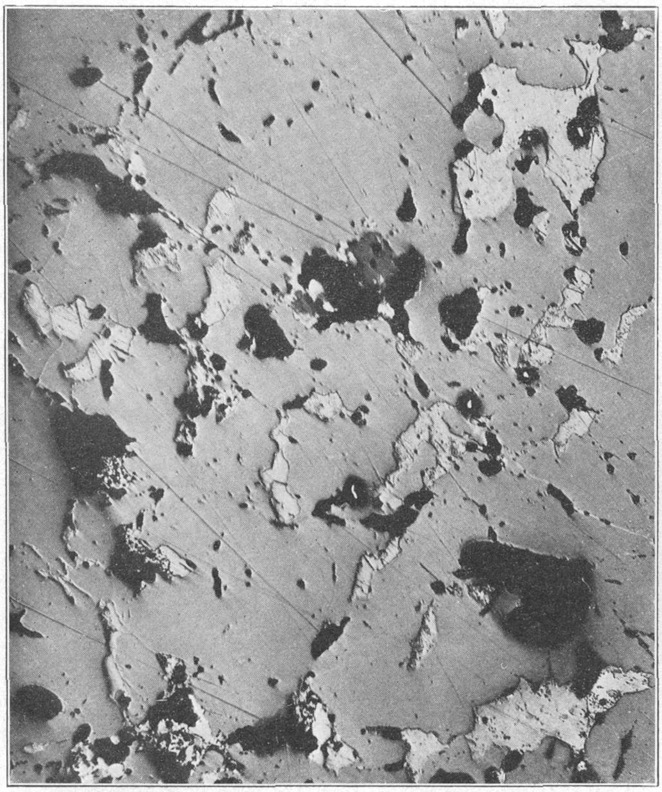
Rawley mine, 600 level. Reflected light. × 45.



D. INTENSE BRECCIATION OF PYRITE (p), FOLLOWED BY DEPOSITION OF SPHALERITE (s) AND GALENA (g)

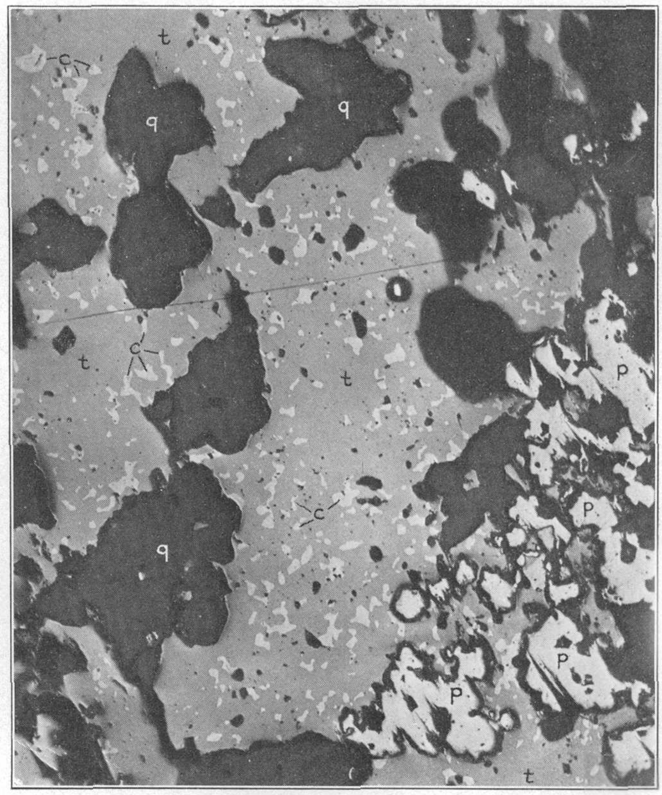
The sphalerite is slightly broken, but the galena is entirely free from brecciation. An example of movement of walls of fissure during period of ore formation. Rawley mine, 1,200 level. Reflected light. × 45.

PHOTOMICROGRAPHS OF ORES



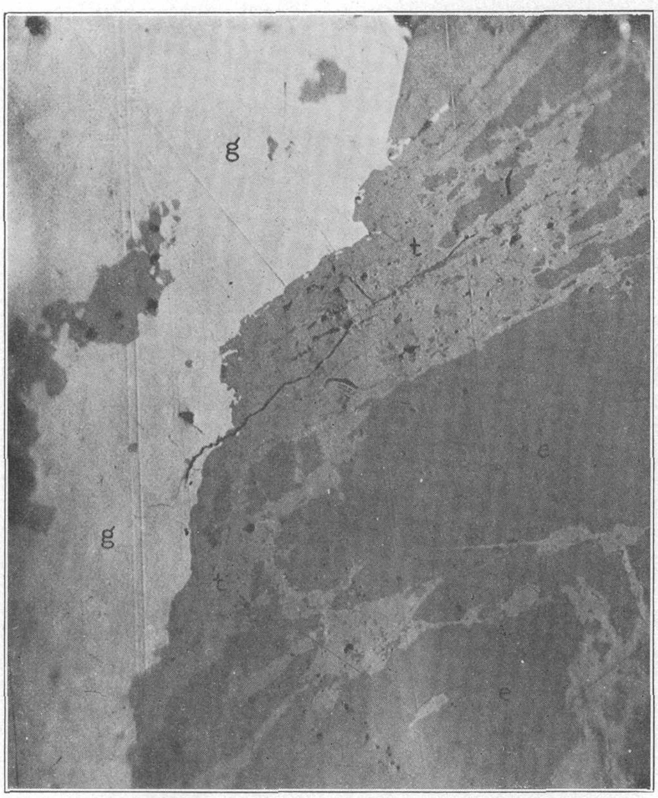
A. TENNANTITE (DARK GRAY) OF HIGH SILVER CONTENT SHOWING INTERGROWTH WITH AN UNKNOWN SILVER-BEARING MINERAL, PROBABLY AN ARGENTIFEROUS LEAD-BISMUTH MINERAL

Cocomongo mine, 300 level. Reflected light. × 100.



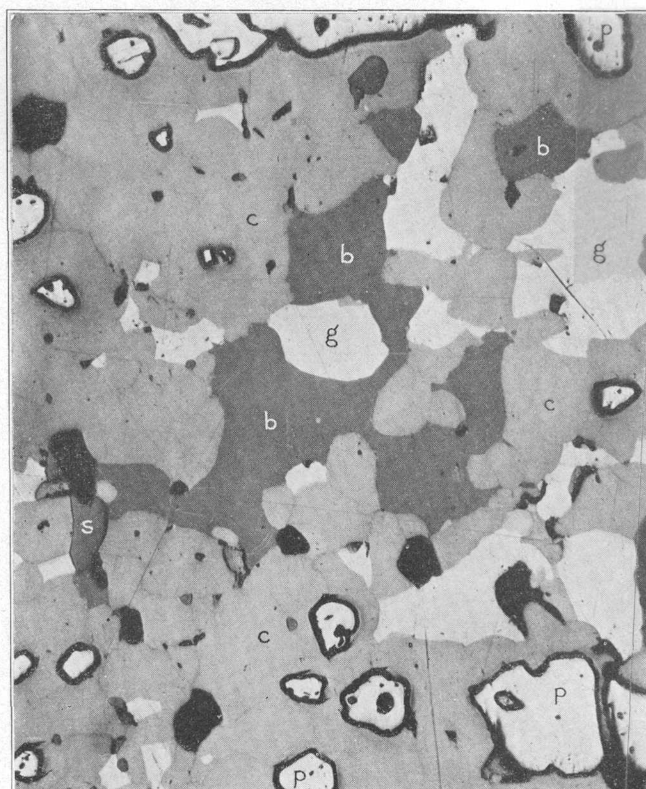
B. SILICEOUS COPPER ORE SHOWING INTERGROWTH OF TENNANTITE (t) AND CHALCOPYRITE (c)

q, Quartz; p, pyrite. Tennantite has partly replaced chalcopyrite. Rawley mine, 600 level. Reflected light. × 100.



C. VERY CHARACTERISTIC ALTERATION OF ENARGITE (e) TO TENNANTITE (t)

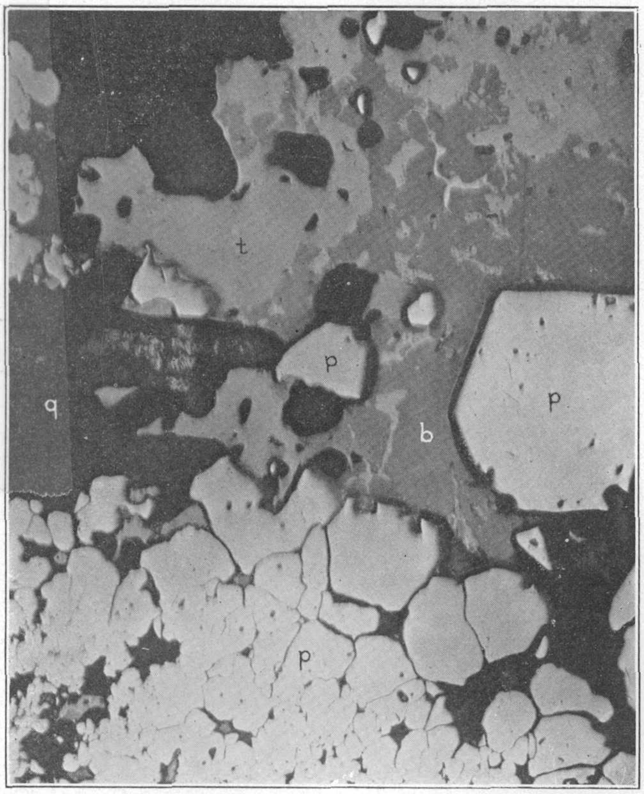
In the deeper level copper ores of the Rawley mine (from 1,200 level). g, Galena. Reflected light. × 450.



D. A TYPE OF MUTUAL INTERGROWTH OF BORNITE (b), CHALCOPYRITE (c), AND GALENA (g)

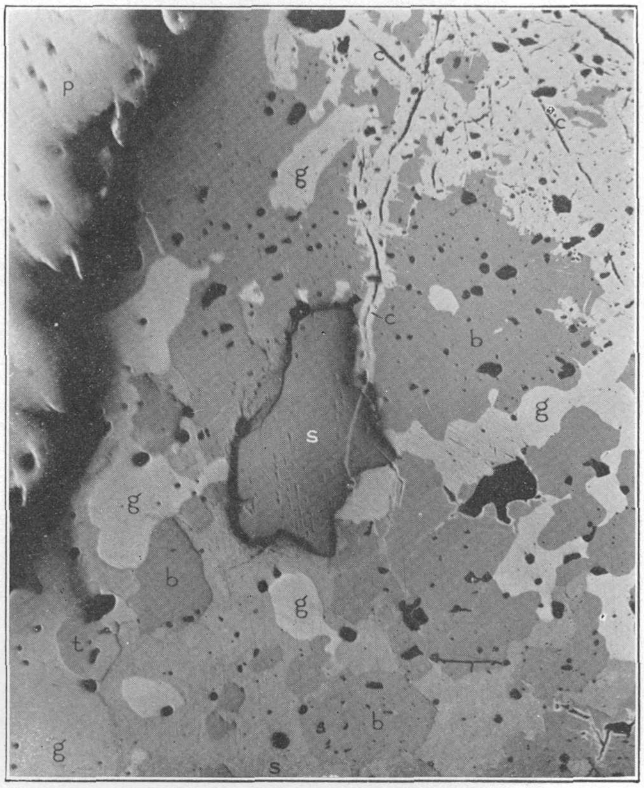
Galena is interpreted to have partly replaced the other minerals along grain boundaries, but the relations are debatable. Boundaries of chalcopyrite grains may be faintly seen. p, Pyrite; s, sphalerite. Joe Wheeler vein, Alder Creek.

PHOTOMICROGRAPHS OF ORES



A. TYPICAL SILICEOUS AND PYRITIC COPPER ORE FROM THE 700 LEVEL OF THE RAWLEY MINE

Consists of granular pyrite (p), bornite (b), and tennantite (t). The tennantite is to a large extent a replacement of enargite as shown in Plate 16, *C*, but the intergrowth can not be seen at this magnification. q, Quartz. Reflected light. × 63.

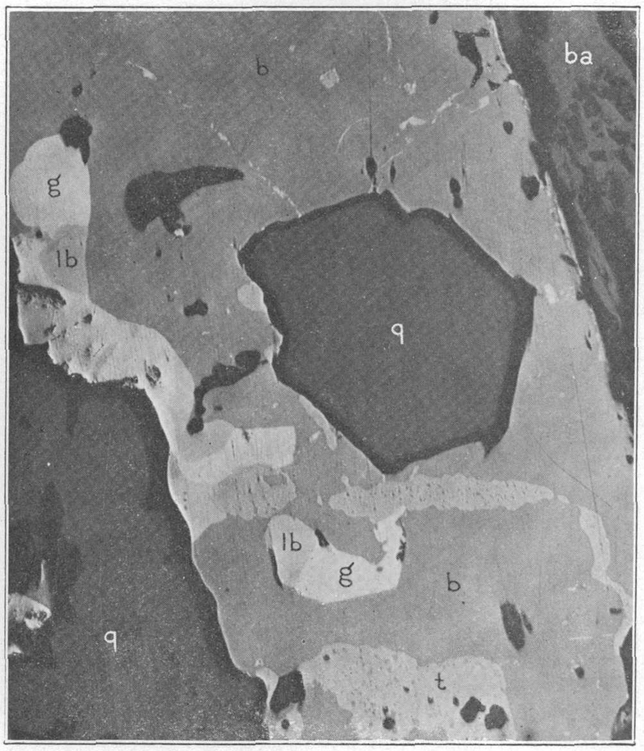


B. MIXED SULPHIDE ORE FROM 400 LEVEL, RAWLEY MINE

Shows supergene chalcopyrite (c) forming along open cracks. p, Pyrite; s, sphalerite (dark gray in center); b, bornite; g, galena; t, tennantite; and s, stromeyerite (light gray). Reflected light. × 100.

C. SMALL ROUNDED MASSES OF STROMEYERITE (s) ASSOCIATED WITH AN UNKNOWN LEAD-BISMUTH MINERAL (lb) IN BORNITE (b)

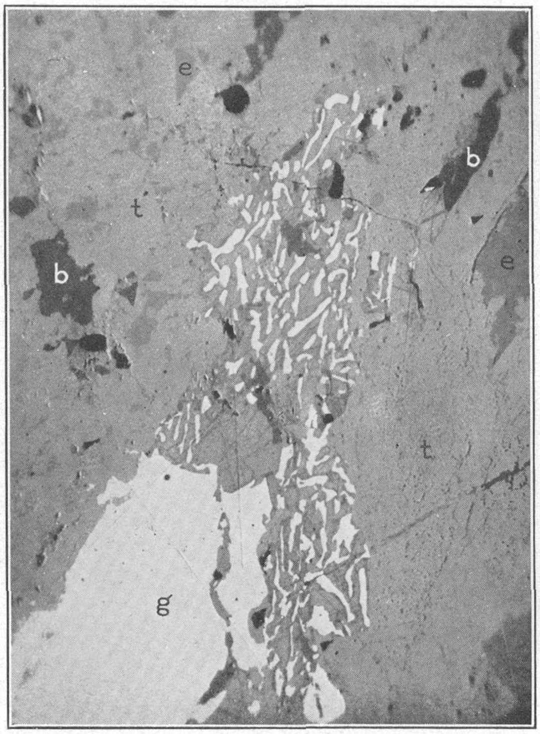
Chalcopyrite (c) occurs along small cracks. From the Joe Wheeler vein, Alder Creek. Reflected light. × 220.



D. ASSOCIATION OF UNKNOWN LEAD-BISMUTH MINERAL (lb) WITH GALENA IN ORE FROM JOE WHEELER MINE, ALDER CREEK

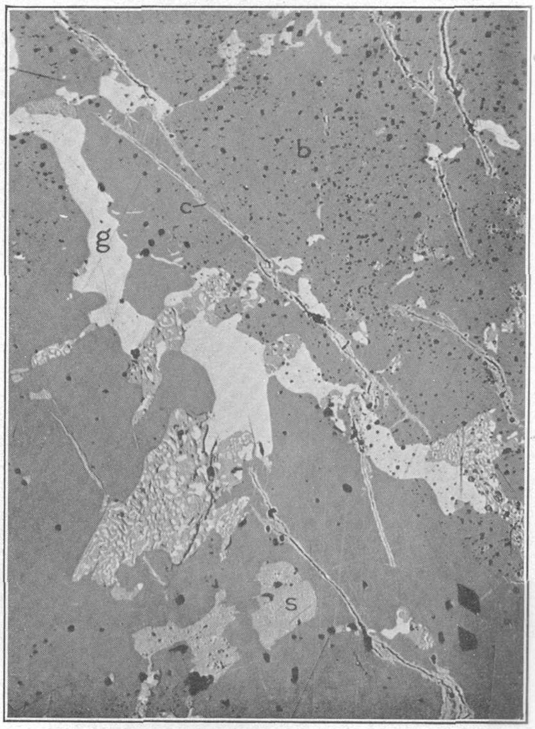
Consists of quartz (q), barite (ba), bornite (b), and tennantite (t). Reflected light. × 100.

PHOTOMICROGRAPHS OF ORES



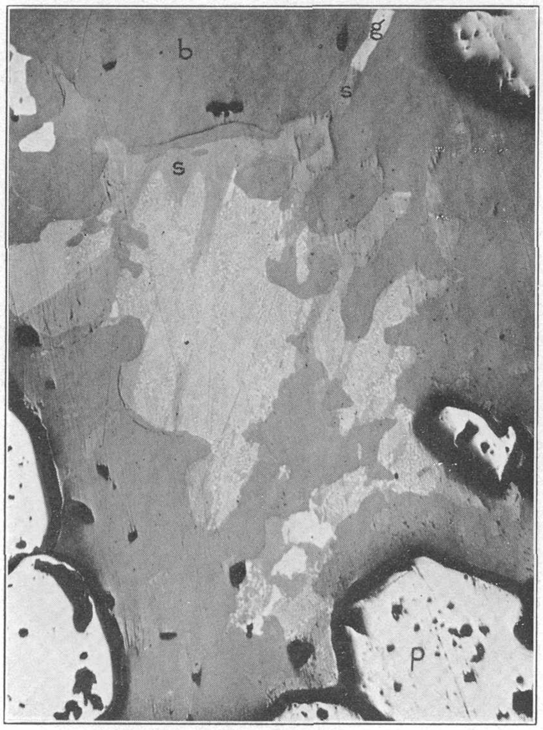
A. ORE OF HIGH SILVER CONTENT PROBABLY ENTIRELY OF HYPOGENE ORIGIN

Interpreted as resulting from successive breaking down of earlier formed minerals and their replacement by later ones. The order of formation is difficult to determine. Consists of bornite (b), enargite (e), galena (g), and tennantite (t), which consists of a fine intergrowth of tennantite and stromeyerite. Rawley mine, 1,200 level. Reflected light. × 450.



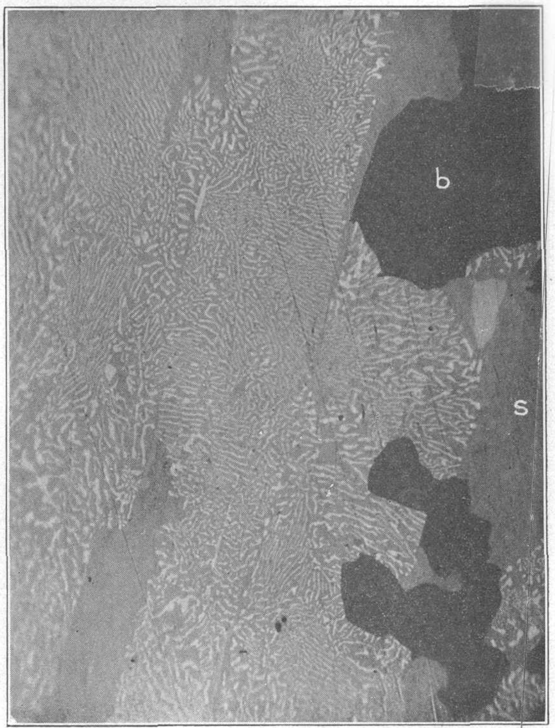
B. GALENA (g) AND STROMEYERITE (s) IN GRAPHIC INTERGROWTH IN BORNITE (b)

Supergene chalcopyrite along open cracks (c). Rawley mine, 900 level. Reflected light. × 100.



C. EXTREMELY FINE GRAPHIC INTERGROWTHS OF GALENA (g) AND STROMEYERITE (s) IN BORNITE (b)

p, Pyrite. Rawley mine, 900 level. Reflected light. × 100.



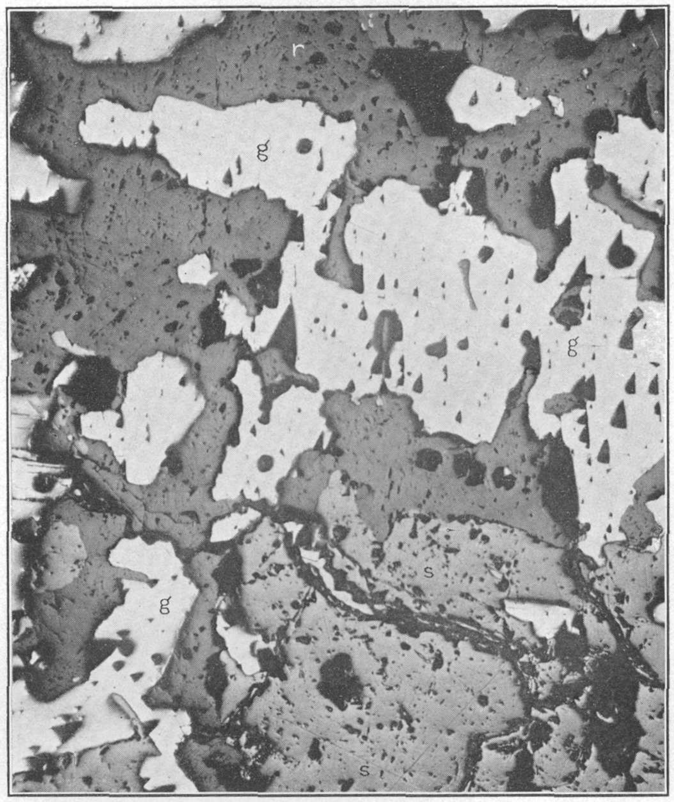
D. SAME AS *C*, ENLARGED TO SHOW TEXTURE OF INTERGROWTH

Bornite (b), stromeyerite (s), and galena (white). Reflected light. × 450.

PHOTOMICROGRAPHS OF ORES

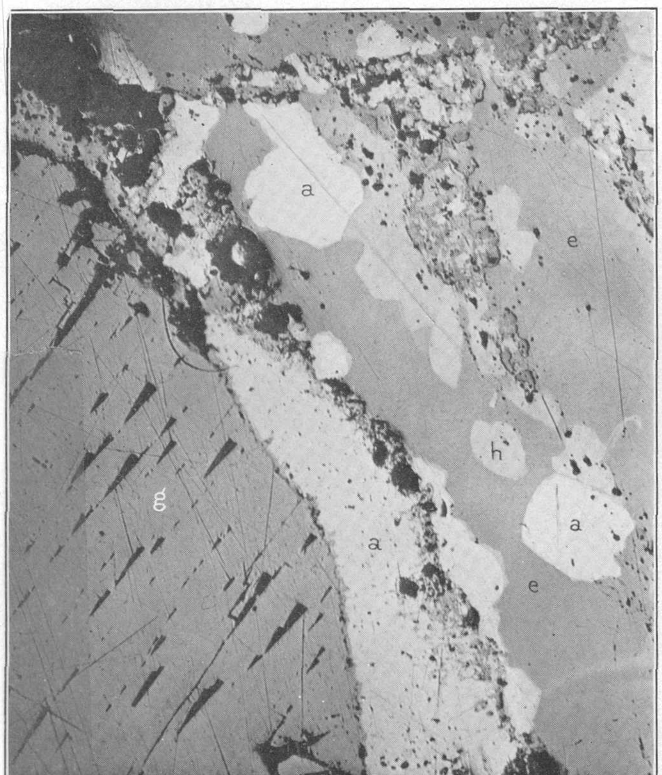
A. COMMON ASSOCIATION OF SPHALERITE (s), GALENA (g), AND QUARTZ (q) *IN THE VEINS OF THE NORTHERN PART OF THE* DISTRICT

Galena appears to have replaced sphalerite to some extent. Rawley mine, Parallel vein, 300 level. Reflected light. × 65.



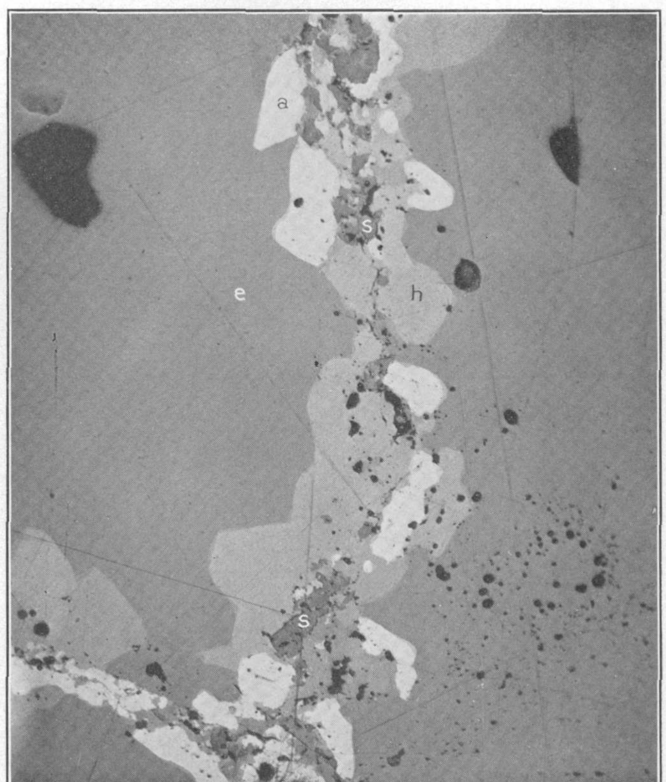
B. TYPICAL ASSOCIATION OF SPHALERITE (s), GALENA (g), AND *RHODOCHROSITE* (r) *IN THE MANGANESE-BEARING VEINS OF* THE SOUTHERN PART OF THE BONANZA DISTRICT

Eagle mine, 500 or 600 level. Reflected light. × 45.



C. RIM OF ALTAITE (a) FORMED BETWEEN GALENA (g) AND THE LATER TELLURIDES, EMPRESSITE (e), AND HESSITE (?) (h)

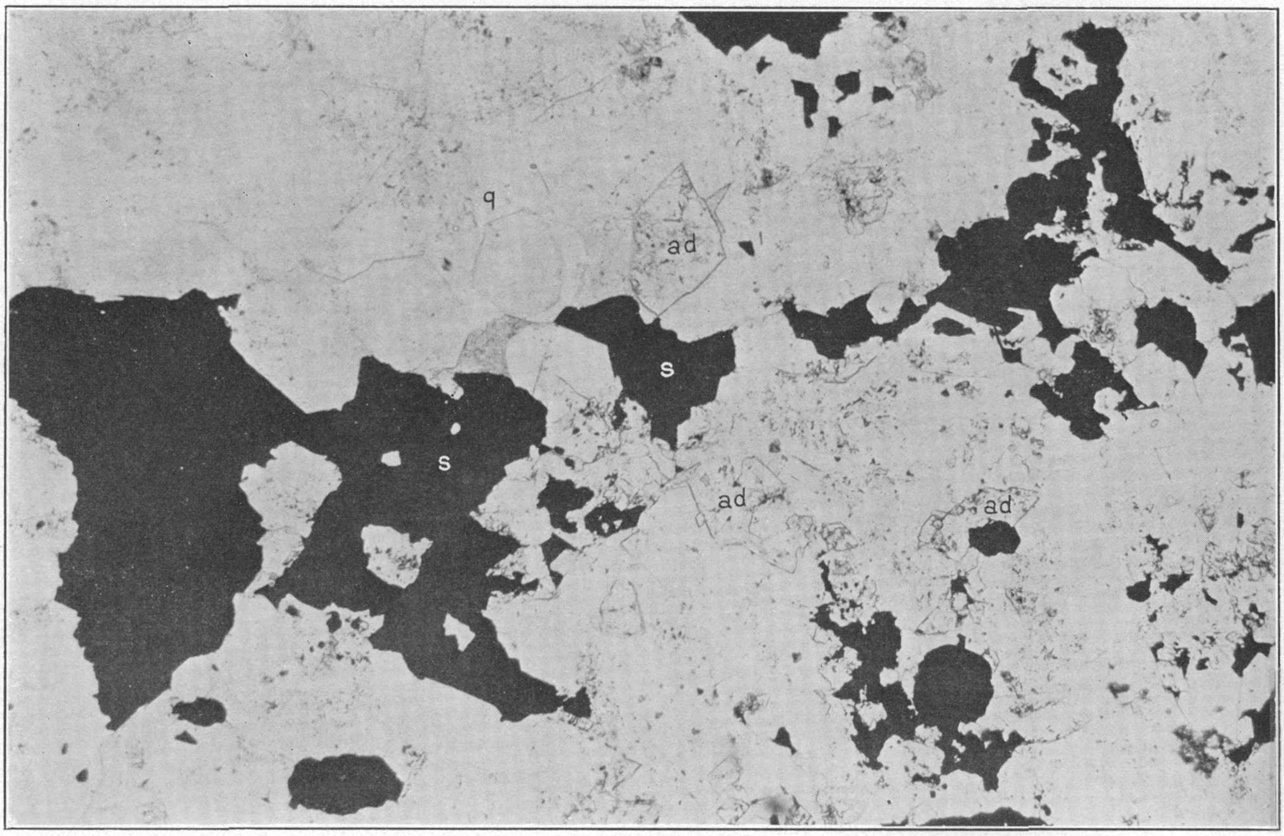
Empress Josephine mine, Copper Gulch. Reflected light. × 63.



D. MODE OF ASSOCIATION OF ALTAITE (a), HESSITE (?) (h), AND SPHALERITE (s), PROBABLY ALONG HEALED CRACKS IN EMPRESSITE (e)

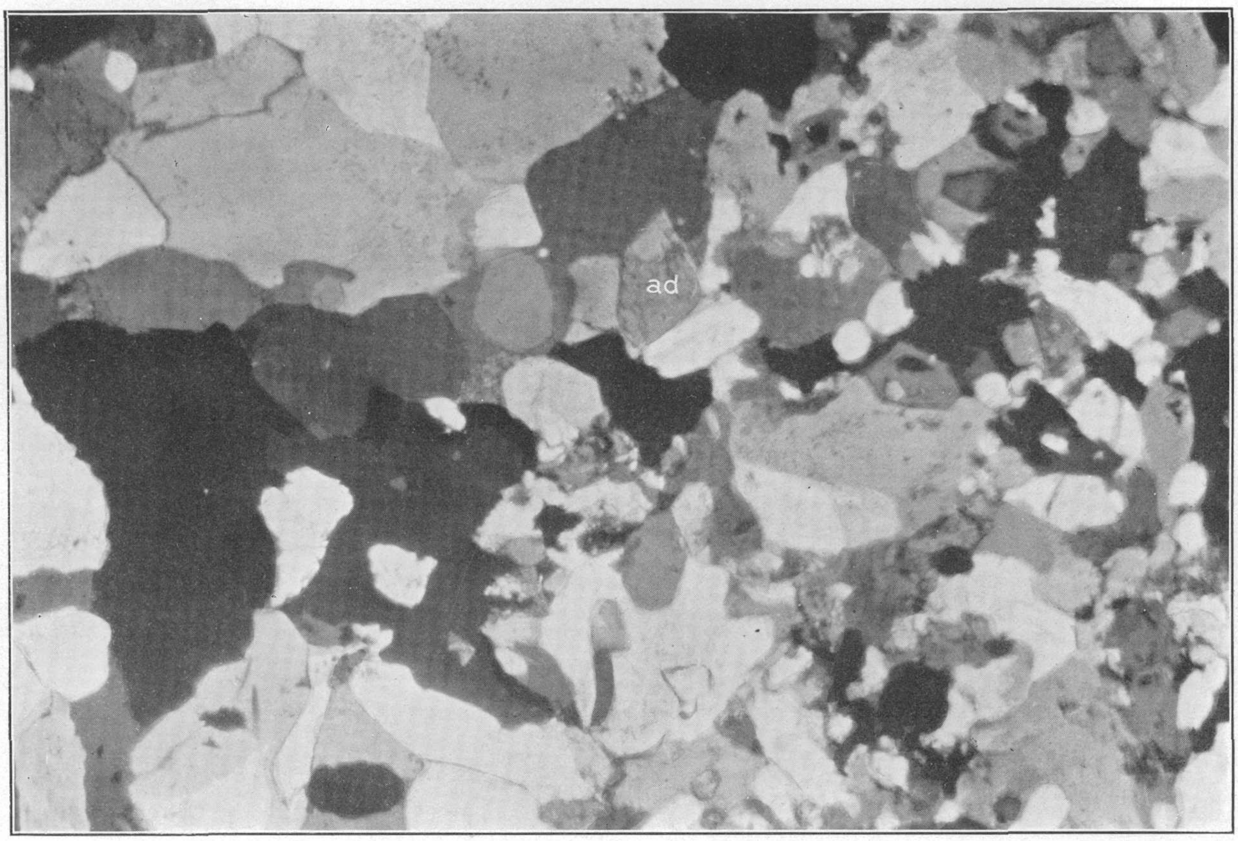
There is commonly a little chalcopyrite in these zones. Reflected light. × 100.

PHOTOMICROGRAPHS OF ORES



A. ASSOCIATION OF MINOR AMOUNTS OF SULPHIDES (s) WITH QUARTZ (q) AND ADULARIA (ad)

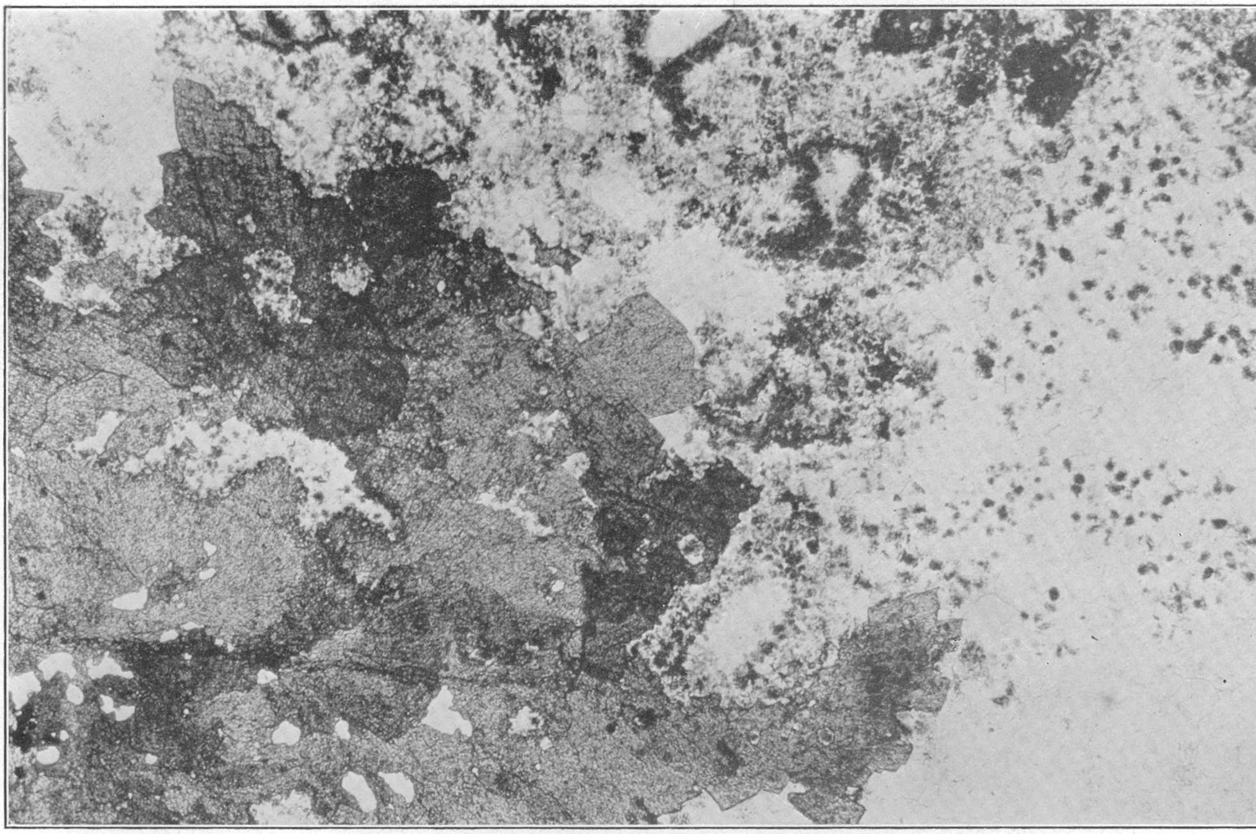
From the Chloride mine, Chloride Gulch. The opaque sulphides consist of pyrite, sphalerite, and galena. Plain transmitted light. × 34.



B. SAME AS *A*, BUT WITH CROSSED NICOLS

Shows character of vein quartz. ad, Adularia. × 34.

PHOTOMICROGRAPHS OF VEIN MATERIAL



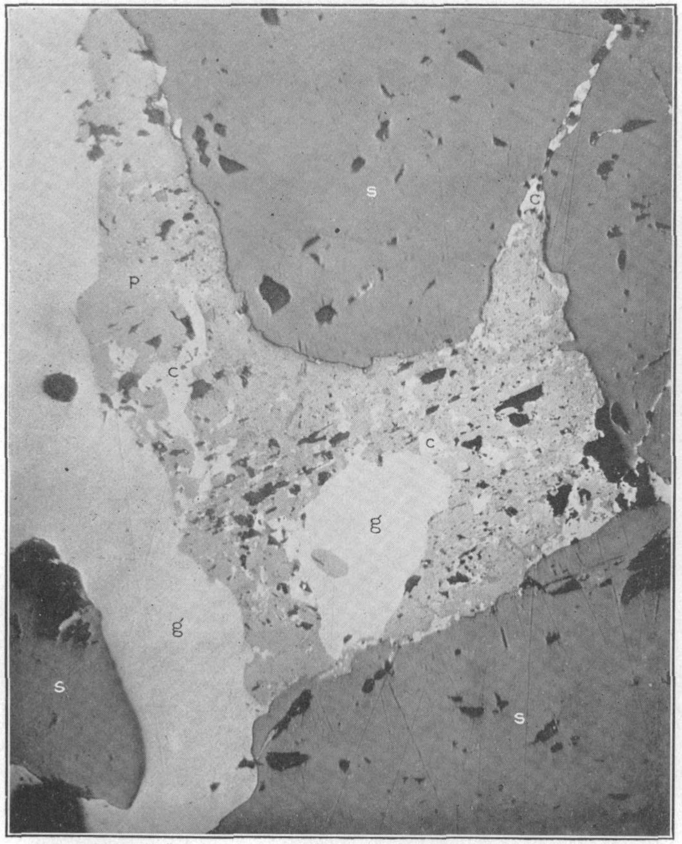
A. EARLY VEIN QUARTZ, PARTLY REPLACED BY RHODOCHROSITE (GRAY) OF A LATER STAGE

Eagle mine. Plain transmitted light. × 38.

B. EARLY VEIN QUARTZ (q), AND FLUORITE (f), BRECCIATED AND REPLACED BY RHODOCHROSITE (r) OF LATER STAGE OF VEIN FORMATION

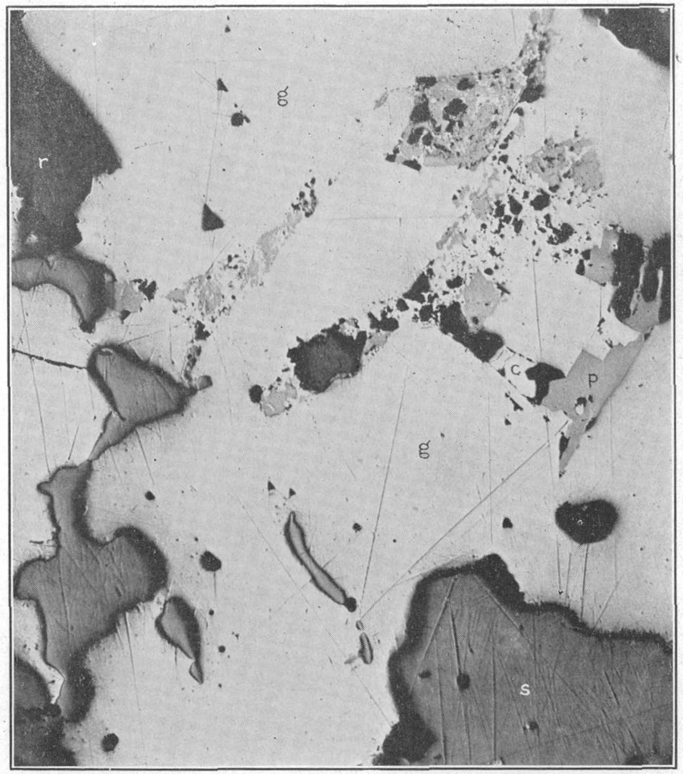
The same succession as shown in *A*, but in this vein brecciation of part of the early filling took place during formation of the vein. Plain transmitted light. × 34.

PHOTOMICROGRAPHS OF VEIN MATERIAL



A. PYRARGYRITE (p) AND CHALCOPYRITE (c) WHICH HAVE PARTLY REPLACED GALENA (g) ALONG BOUNDARY BETWEEN IT AND SPHALERITE (s)

Eagle mine, 500 or 600 level. Eagle Gulch. Reflected light. × 220.



B. PYRARGYRITE (p) AND CHALCOPYRITE (c) WHICH HAVE REPLACED GALENA (g) ALONG CLEAVAGE DIRECTIONS

s, Sphalerite; r, rhodochrosite. Eagle mine. Eagle Gulch. Reflected light. × 100.

PHOTOMICROGRAPHS OF ORES

Malachite and other copper minerals.—Malachite ($CuCO_3.Cu(OH)_2$) occurs as a superficial coating and in tufts near the outcrops of copper-bearing veins. Other oxidized minerals of copper such as azurite ($2CuCO_3.Cu(OH)_2$) and chrysocolla ($CuSiO_3.2H_2O$) probably occur under similar conditions but are of no importance other than as indications of the presence of copper.

Smithsonite ($ZnCO_3$).—The zinc carbonate, smithsonite, is reported to have been found in very small amounts associated with cerusite in oxidized zones in the Bonanza vein. It is only of mineralogic interest as an indication of the extent of local oxidation.

BASIC HYDROUS PHOSPHATES

In ore from the Liberty and Empress Josephine mines of Copper Gulch some small vugs are partly or completely filled with soft white minerals resembling kaolin. Chemical and optical tests show, however, that the white mineral is a hydrous aluminum phosphate. Its exact identity could not be determined without chemical analysis, for which there was insufficient material. Under the microscope it is seen to be composed of rounded particles of radial or concentric growth, possessing very low birefringence, and an index of refraction of about 1.58.

In this same ore in partly oxidized state there also occurred some orange-yellow crusts of a resinous mineral having an index of refraction of about 1.62 (isotropic). Chemical tests showed the presence of ferric iron, phosphate, and sulphate.

There may be many other minerals of this kind, but they are of little importance. They are compounds of the group of which hinsdalite ($2PbO.3Al_2O_3.P_2O_5.2SO_3\,6H_2O$) is an example.

SULPHATES

Barite ($BaSO_4$).—The distribution of barite in the veins is very irregular, and it is entirely subordinate to quartz as a gangue mineral. However, in some parts of the Joe Wheeler vein, in the Alder Creek region, barite is the principal gangue mineral in association with ore rich in chalcopyrite and bornite, but this is the only occurrence of this kind seen, and even there the presence of barite to the exclusion of quartz is not typical of the greater part of the vein. Some veins apparently do not contain barite, but in many of the veins it is present at least in small amounts. It was not seen, however, in the ore of a number of the larger veins, including the Eagle, Express, and Oregon veins, in the southern part of the district. Quartz-barite veins were seen in the country adjacent to Greenback Gulch, although they contained only small amounts of sulphides.

The barite occurs in its characteristic white or less commonly gray platy crystals and is usually one of the earliest minerals to have crystallized. It is found in small amounts in some of the jaspers or siliceous replacement deposits in minute irregular crystals, visible only under the microscope. Microscopic examination of some quartz gangue material shows barite in different stages of replacement by quartz or in bladed crystals between which the other minerals have crystallized. (See pl. 14.) It is rarely found associated with manganiferous calcite of a late postsulphide stage.

Gypsum ($CaSO_4.2H_2O$).—Gypsum was not recognized as a gangue mineral in the ordinary sulphide veins but occurs in altered andesite as veinlets filling joint cracks. Its relation to the ordinary mineralization was not determined, and it may have been deposited by sulphate-bearing ground waters.

Alunite ($K_2O.3Al_2O_3.4SO_3.6H_2O$).—Alunite is found associated with silicified rocks. Its most abundant occurrence is on the top of the broad flat-topped mountain south of Porphyry Peak, where the rhyolites are completely altered into tough jaspery masses of light color composed of quartz, alunite, and minor amounts of other minerals such as rutile. Alunite was not found in any of the silicified wall rocks of the veins, but a small amount of it is present in the area of solfataric alteration near Greenback Gulch.

Jarosite ($K_2O.3Fe_2O_3.4SO_3.6H_2O$).—Jarosite forms microscopic veinlets in a silicified rock near the Chloride mine in the southern part of the district. It apparently is not a common mineral in the district but may be widespread in very small amounts. Most of the yellowish-brown coatings on oxidized ores that were chemically tested proved to be basic phosphates and sulphates of iron and aluminum.

HYDROTHERMAL METAMORPHISM OF THE WALL ROCKS

During the period of mineralization certain constituents of the mineralizing solutions penetrated the country rocks adjoining fissures and altered them to different degrees. Some kinds of alteration appear closely related to ore deposition; others, so far as the available evidence shows, are much less definitely related. Three principal kinds may be distinguished, based upon the intensity of the alteration and upon the principal residual products of rock decomposition—silicification, sericitization, and propylitization. The characteristic results of these kinds are described below, and an attempt is made to show the probable character of the solutions causing them and to coordinate their periods with that of ore deposition.

SILICIFICATION

Silicification is one of the most prominent and characteristic effects of hydrothermal alteration in the district. Although found in the walls of many veins in the district, it is by no means confined to rocks near ore bodies but is of very widespread distribution. It is, however, clearly related to fault fissures or other fractures in the volcanic rocks and belongs to an earlier part of the same volcanic period of hydrothermal activity as that which produced the ores.

In its simplest and most intense form this type of alteration is characterized by the substitution of silica for the greater part of the original mineral constituents of the volcanic rocks. Silicification of limestone is a common process in many mining districts, as illustrated at Leadville.[54] This, however, is a comparatively simple process compared to the silicification of the difficultly soluble aluminous rocks that are found in the Bonanza district. In silicate rocks silicification may consist of two separate actions—(1) an increase in the free silica content of the rock by the breaking down of primary silicates and (2) a direct addition of free silica from the solutions causing the decomposi-

[54] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U. S. Geol. Survey Prof. Paper 148, pp. 217, 218, 1927.

tion. As will be seen from the analyses of the altered rocks (p. 78), direct addition of free silica has taken place in many of the silicified rocks of the Bonanza district. The breaking down of silicates with the formation of free quartz is a common result of other types of hydrothermal alteration, but the process of silicification described here consists mainly of a direct addition of silica above that set free from the silicates.

The replacement appears to have been at least in part of a colloidal nature, and the present texture of the rocks is a result of later gradual or perhaps nearly immediate crystallization. Plate 12 shows a photomicrograph of a typical example of silicified volcanic rock. In most of the sections examined quartz is the more common form of silica or is present to the exclusion of chalcedony. The hydrothermal solutions that accomplished the silicification were sufficiently corrosive to dissolve and carry away many of the constituents of the silicate rocks. They were, however, saturated with silica, either derived from the solution of other rocks at depth or occurring as a primary constituent of the solutions themselves. Certain less soluble constituents of the rocks, such as the alumina and ferric iron, were taken into solution but apparently were not carried great distances. There are consequently associated with the silicified rocks certain products of decomposition of the original rock which have been deposited in cavities in the rocks or in cracks and larger fissures. The mineral form assumed by these decomposition products depended apparently on the local chemical and physical conditions under which the alteration took place. The depth from the surface and the influence of changing composition of the solutions in the fissures are possible factors that have not been entirely evaluated. For example, it is not understood why the alumina precipitated in the cavities of silicified rocks at one time combined only with water to form diaspore, at another time combined with silica and water to form kaolin, and at still other times combined into more complex molecules of alunite, zunyite, or sericite. As the chemistry of such hydrothermal processes is not yet sufficiently understood, the silicified rocks are differentiated and described here according to their appearance and to the nature of the by-products contained in them, and the discussion of theoretical matters relating to their genesis will be left to following pages.

KINDS OF SILICIFIED ROCKS

The amount and nature of the other insoluble products of decomposition found in the silicified rocks permit the distinction of five more or less gradational kinds—(1) white or grayish silicified rocks in which quartz or chalcedony or both are the major constituents; (2) reddish, brownish, or less commonly black silicified rocks or "jaspers," in which quartz and chalcedony are the major constituents with some ferric and ferrous oxides, the ferric oxide either in some hydrous form, as finely divided hematite, or in the form of crystallized hematite (specularite); (3) white or gray rocks that consist largely of quartz and alunite; (4) white, grayish-white, or slightly iron-stained rocks in which quartz is the principal constituent with some kaolin [55]; and (5) white or grayish-white rocks that consist of a mixture in various proportions of quartz, kaolin minerals,[55] and sericite. An accessory mineral common to nearly all these rocks is rutile, and barite is fairly common in very small amounts, but zircon is apparently rare. Diaspore and zunyite are constituents of some of the silicified rocks. The number of specimens studied from some parts of the district was insufficient to determine the extent of the distribution of such minerals as alunite and diaspore. But all these minerals are considered to be common by-products of the process of silicification. Some of these products may be deposited locally in small aggregates or bodies in which free silica is subordinate, but they have evidently been transported and deposited from solutions that have previously effected the decomposition of some more or less distant body of rock. Where silicification has occurred in rocks adjacent to ore bodies or in some areas where silicification is particularly strong the rocks are likely to contain pyrite.

PETROGRAPHIC FEATURES AND DISTRIBUTION

In the north-central and northeastern parts of the district the first two of the five kinds of silicification enumerated above are those which have been most commonly recognized. These are represented by analyses 4, 5, and 7 on page 78. The white or gray silicified rocks consist almost entirely of quartz or chalcedony or mixtures of these, with minor amounts of rutile or other accessory minerals. They are very hard and flinty and break with a conchoidal or splintery fracture. Microscopic examination shows them to consist of cryptocrystalline quartz or less commonly of chalcedony. The quartz occurs in extremely small interlocking grains, which in one specimen studied ranged from 0.005 to 0.025 millimeter in diameter, but the grain size may differ greatly in different specimens or even in the same one. The chalcedony forms fibrous aggregates characteristic of this mineral. In some silicified rocks both quartz and chalcedony are present. The texture of the original rock may be partly preserved, but where recrystallization is of a

[55] The term "kaolin" is used here in a general sense to include several of the minerals of hydrothermal origin related to kaolinite, some of which may contain potash. (See p. 69.)

coarser nature it may be more or less obliterated. Barite where present occurs in very small scattered grains. (See pl. 12.)

Red or brown "jaspers" are very common in the northern part of the district and are usually the product of replacement of andesitic rocks. (See analysis 4.) The color of these rocks is caused by the presence of ferric iron, which occurs either as metacolloidal and possibly hydrous oxides or as very finely divided crystals of hematite. Hematite crystals large enough to be recognized can usually be seen only on a polished surface that is examined with the higher powers of the reflecting microscope. (See pl. 9.) Both quartz and chalcedony are usually present. In none of the rocks was any opal or other amorphous form of silica recognized.

In the northern part of the district the rocks of these two kinds are found either in the walls adjoining veins or at considerable distances from any known ore bodies. It is clear that they are not directly related to the deposition of ore. Those found adjacent to ore bodies represent a mode of alteration which preceded the sulphide mineralization. The red jaspers are at some places brecciated and veined or cemented with later quartz, sulphides, and sericite, or they may form one or both of the walls of a vein. (See pls. 11 and 12 and fig. 14.) The white or gray silicified wall rock may grade imperceptibly into the later quartz that forms the vein material, and because of lack of contrast in color their age relations are not everywhere evident in the field. Microscopic examination shows, however, that silicification of wall rock almost invariably preceded the formation of sericite, which took place mostly during the earliest stage of vein filling. Veinlets of sericite cutting a silicified andesite are shown in Plate 12.

The red or brown "jaspers" that contain disseminated crystals of pyrite are illustrated by Plate 9, *B*, and their composition is shown by analysis 6. They are most abundant at the surface in and adjoining the Copper Gulch region, but are also found at other places. The Rawley drainage tunnel penetrated large bodies of pyritized jasper. Intense alteration next to veins may have been accompanied by the introduction of other sulphides, as sphalerite, and by the formation of sericite. Such rocks are partly bleached and may have lost most of their original red or brown color.

Silicified rocks of the third kind, containing alunite, have been found only on the large flat-topped mountain south of Porphyry Peak, in the extreme northwestern part of the district. Part of this area of silicification is indicated on the geologic map. No chemical analysis of rock of this type has been made. Large bodies of rhyolitic rock have been affected by this alteration, particularly on the west slope of the mountain along the Silver Creek and Mears road. (See pl. 1.) The alteration products are quartz and alunite, with minor amounts of titanium minerals, of which the species could not be determined. The alunite is subordinate to the quartz in two specimens that were studied microscopically. The textures of the original rhyolitic rocks are partly preserved. Pyrite is found in them only along some of the sericitized fault zones.

In the southern part of the district both reddish and grayish-white siliceous rocks of the first two kinds are found. These rocks are free from sericite, kaolin, and alunite or at least contain these minerals only in very small amounts. There occur in addition, however, siliceous rocks containing a notable proportion of either kaolin or sericite (see analysis 9), or both, and rarely small amounts of diaspore and zunyite. The largest area of such rocks is the volcanic complex near Greenback Gulch, east of Kerber Creek between Manganese and Chloride Gulches. Within this area the original character of the volcanic rocks has been so largely destroyed that geologic mapping is seriously hindered. Here and there small bodies or inclusions of the outlying andesitic country rock can be identified in the central part of the altered area. The altered zone embraces a small volcanic vent, through which molten rock, gases, and solutions escaped during and subsequent to the main period of faulting. A number of prospected veins lie in and near this zone, including the Express, Chloride, Whitney group, Crown Point, Hayden Mountain, and Schoville claims, but as yet there has been little production from them. Consequently, the claims are developed only to a small extent, and the more extensive workings are inaccessible. Therefore it is not known to what depth this alteration extended. It is apparent, however, from such examination as could be made near the surface and from shallow mine workings, that silicification and kaolinization were the earlier stages of alteration, a condition partly parallel to that in the northern part of the district, just described. The kaolinite has either replaced feldspars in partly silicified rocks in association with potash-bearing clays and sericite or occurs as irregular veinlets or nests in the silicified groundmass. Microscopic sections examined have not revealed any clearly decipherable age relation between the kaolin minerals and associated sericite. Field evidence indicates that intense sericitization is characteristic of altered rocks in the vicinity of the fault fissures and ore-bearing veins in all parts of the area and is clearly later in age than general silicification. As the formation of kaolin was a more widely distributed process and closely associated and contemporaneous with silicification, the deduction would be that the development of that sericite found in the walls of veins followed the formation of hydrothermal kaolin.

The typical mode of alteration of the rocks in the Greenback Gulch area consisted of a complete replacement of the groundmass of porphyritic rocks by fine granular quartz or chalcedony, while the feldspar phenocrysts were replaced by kaolin and quartz, in some places together with barite, or by a mixture of kaolin and sericite. In one example, illustrated in Plate 10, the feldspars were first replaced by an intergrowth of quartz, diaspore, and zunyite. These minerals, including part of the silicified groundmass, were all partly replaced by later sericite. In volcanic breccias the textural relations are much more complex. Close to the surface the softer products of alteration, consisting of kaolin and sericite, have been more or less completely removed from the silicified rocks, leaving cavities in place of the original feldspar crystals or in place of the fragments in breccias. The result is a very porous rock having in extreme examples somewhat the character of a clinker. These alteration products usually remain in place in bedrock immediately below the surface.

The outcrops of certain fissures in the area affected by this alteration are characterized by dikelike masses and knobs of the silicified rocks, consisting largely of quartz. At intersections of fissures large irregular bodies of the rocks are so altered. Outcrops known locally as quartzite dikes adjoin Chloride and Greenback Gulches, and a heavy siliceous outcrop crowns the hill known as Little Platoro, between these gulches. (See pl. 6, *A*, *B*.) Rocks in which abundant kaolin and sericite are associated with the quartz are much less resistant to disintegration and crop out less prominently.

Some of the siliceous rocks are said to contain gold but not in economically valuable quantities. They are generally free from sulphides, except locally where they are impregnated with minute pyrite crystals.

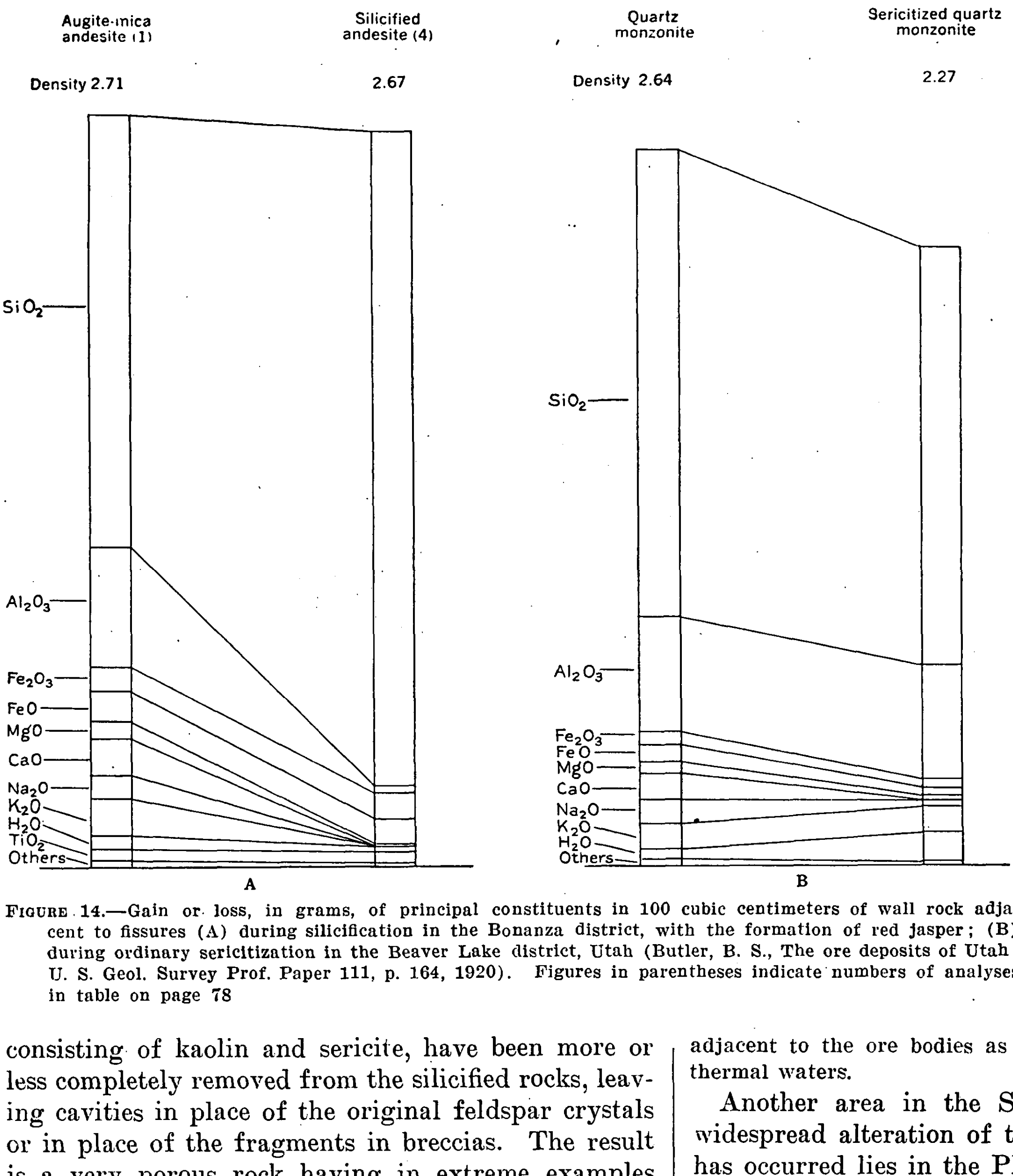


FIGURE 14.—Gain or loss, in grams, of principal constituents in 100 cubic centimeters of wall rock adjacent to fissures (A) during silicification in the Bonanza district, with the formation of red jasper; (B) during ordinary sericitization in the Beaver Lake district, Utah (Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 164, 1920). Figures in parentheses indicate numbers of analyses in table on page 78

Silicification of the general character above described is not uncommon in mineralized volcanic areas and is found in other parts of the San Juan region. Very similar alteration in the Red Mountain district of the Silverton quadrangle has been described by Ransome.[56] Here it likewise occurred close to bodies of intrusive porphyry, and the andesite breccia, porphyries, and rhyolite have all been affected by it. It is known to extend to a depth of at least 500 feet. Ransome[57] says regarding the occurrence of kaolinite, one of the abundant products of the decomposition of the lavas:

> It was not possible to investigate the occurrence of kaolinite in any of the deeper workings of the Red Mountain mines, but from what could be seen it appears to have accompanied the ores to the greatest depths there attained—about 1,300 feet. It was evidently derived from the country rock adjacent to the ore bodies as a product of its alteration by thermal waters.

Another area in the San Juan region in which widespread alteration of this same general character has occurred lies in the Platoro-Summitville district. The alteration has been described by Patton,[58] who states that the most intensely altered rocks lie in a

[56] Ransome, F. L., Economic geology of the Silverton quadrangle: U. S. Geol. Survey Bull. 182, pp. 114–131, 1901. See also Cross, Whitman, Howe, Ernest, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), p. 33, 1905.

[57] Op. cit. (Bull. 182), p. 73.

[58] Patton, H. B., Geology and ore deposits of the Platoro-Summitville mining district, Colo.: Colorado Geol. Survey Bull. 13, pp. 46–53, 1917.

large triangular area between Elephant Mountain, Sheep's Head Mountain, and Gilmore, in which the sides of the triangle measure about 12,000, 14,000, and 18,000 feet. To judge from Patton's description the modes of alteration are very similar, except that alunite is probably more abundant in the altered rocks in the Platoro-Summitville area. In that area the products of rock decomposition are quartz, kaolin, sericite, and alunite. With regard to the relation between sericite and kaolinite Patton [59] says:

> So far as one may be justified in drawing conclusions from these few cases, the proximity of ore veins has been favorable to the development of sericite rather than kaolinite. On the other hand, all the altered rocks in which kaolinite has been developed are remote from ore veins. We are not, however, to infer that sericite is confined to rocks in proximity to ore veins, as it occurs in two other cases associated with kaolinite, and as it is a very common secondary mineral in all the rocks of the district outside of this area of intense decomposition.

CHEMICAL FEATURES OF SILICIFICATION

The details of the chemical changes involved in the silicification of the lavas of the Bonanza district are illustrated in the accompanying tables (p. 78) and in Figures 14–16. Three analyses of fresh or slightly altered andesites and six analyses of the different kinds of silicified rocks are given. The first three analyses, one of which was taken from the report of the State geological survey, may be considered representative of the extreme variation in the composition of the andesites of the Rawley formation. The two new analyses (Nos. 1 and 2) show a relatively high potassium and sodium content as compared with calcium. The lava of No. 2 approaches a quartz latite in composition, although it possesses an andesitic habit and is closely associated with the andesite flows of the Rawley formation. Because of the widespread alteration in the district fresh lava corresponding to each type of altered rock could not be found. The chemical changes that took place during silicification were so pronounced, however, that it matters little which of analyses 1 to 3 is used in comparing the altered and unaltered lavas. In the table showing gain and loss of constituents in 100 cubic centimeters of fresh and altered lava, analysis 1 has been used as probably typical of the fresh andesites, though it records a small amount of calcite. In computing the gains and losses it was assumed that essentially no change in volume occurred during silicification. This assumption is very probably true for the greater part of the silicified rocks, as in many examples the original texture of the rock is perfectly preserved. As the fresh and altered rocks were not collected from adjoining positions a calculation of the change in porosity during silicification can not be used to verify this assumption.

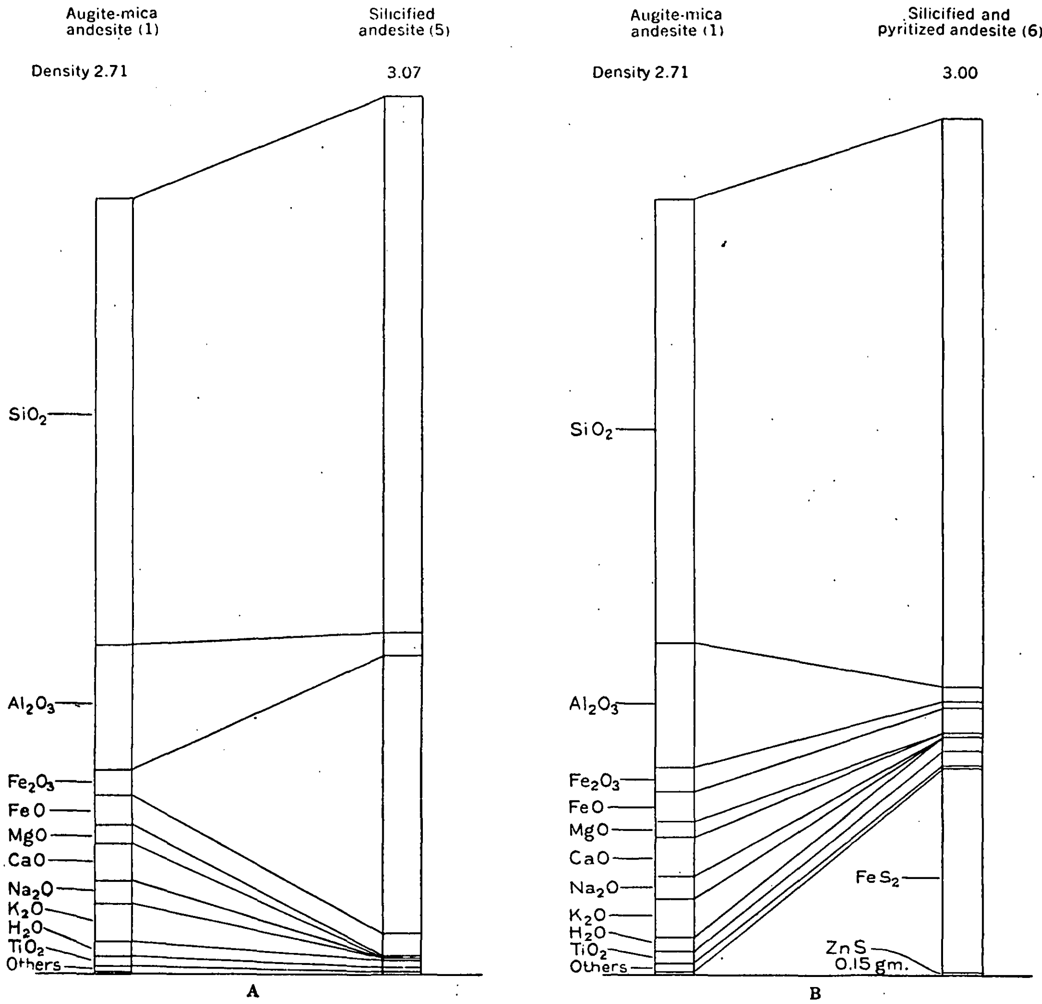


FIGURE 15.—Gain or loss, in grams, of principal constituents in 100 cubic centimeters of wall rock adjacent to fissures during silicification in the Bonanza district, (A) with the formation of black jasper containing hematite; (B) with the formation of red jasper containing pyrite crystals and a small amount of sphalerite. Figures in parentheses indicate numbers of analyses in table on page 78

In samples 8 and 9 the increase in porosity is appreciable, suggesting that the interchange was not molec-

[59] Patton, H. B., op. cit., p. 48.

ular but that some material has been carried away in solution without a corresponding deposition of quartz or other material to take its place. That small cavities were actually formed in some of the lavas during silicification is also indicated by the structure of alteration products representing original feldspar crystals. The crystals appear to have been attacked vigorously and their constituents carried away, leaving empty cavities. Some of these cavities were later filled with quartz and kaolinite, as shown by the fact that the quartz within and bordering the cavities shows minute prismatic terminations similar to those of vein quartz that has crystallized in an open space. The groundmass in the same rock, however, contains no terminated quartz, but is composed of closely packed and irregular quartz grains, formed evidently by a simultaneous exchange of constituents between the solution and the rock. In other examples angular inclusions within a breccia subjected to silicification show similar differential solution probably with the formation of cavities. Where such rocks have been subjected to weathering close to the surface the softer minerals such as kaolin and sericite have been dissolved or washed out, the result being a very porous rock composed mostly of silica.

In the altered jaspery rocks represented by analyses 4, 5, 6, 7, and 8 the potassium, sodium, calcium, and magnesium have been so completely leached that no significant difference is shown by the several analyses. Calcium is fixed in the altered rocks to a very slight extent, presumably as apatite. The 0.27 per cent of potassium in sample 6 occurs probably as sericite, traces of which were recognized microscopically in the rock.

In the very siliceous rocks from which sericite and kaolin minerals are absent there has been a marked dehydration of the lavas (Nos. 4, 5, and 7).

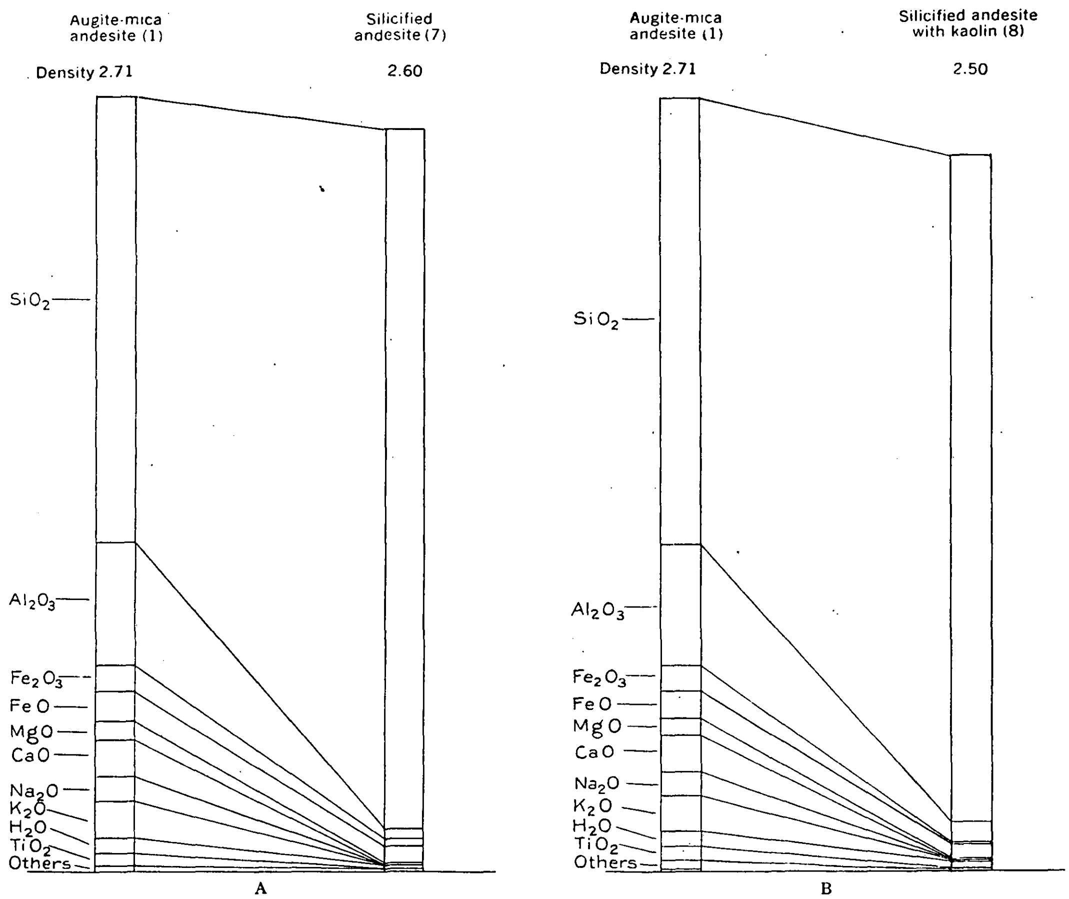


FIGURE 16.—Gain or loss, in grams, of principal constituents in 100 cubic centimeters of wall rock adjacent to fissures during silicification in the Bonanza district, caused by simple solfataric action, (A) with the formation of an extremely siliceous type of altered rock, common in all parts of the district; (B) with the formation of siliceous rock containing a small amount of kaolinite. Figures in parentheses indicate numbers of analyses in table on page 78

The six analyses of altered rocks represent somewhat different kinds of silicified rocks found in the district. Analyses 4 and 7 represent extremely siliceous types containing, so far as can be detected microscopically, quartz with some iron and titanium oxides and traces of pyrite and some other indeterminable minerals: No. 4 is a red jasper colored by ferric oxide; No. 7 is a nearly white siliceous rock with only traces of recognizable ferric oxide. Ferric iron is comparatively high in No. 4 compared to No. 7, and to it may be ascribed the dark-red color. The form in which most of the ferrous iron occurs in these rocks is not known, though a little pyrite is present in No. 4 and possibly a little magnetite and siderite in No. 7. The quartz usually contains many minute specks of indeterminable minerals, and some iron-rich chlorite may be present. The iron oxides have remained essentially constant in No. 4 compared to the unaltered lavas, but both have been appreciably leached in No. 7. Only small amounts of alumina remain fixed in these altered rocks, possibly as kaolin, diaspore, or more complex aluminum-bearing silicates. No aluminum minerals were detected microscopically in the two samples. Titanium has remained essentially constant, but phosphorus appears to have been partly leached.

Analysis 6 represents a dark-red jasper similar to No. 4 except that it contains many scattered crystals of pyrite. (See pl. 9, *B*.) The bulk of the rock is granular or microcrystalline quartz, with hematite, amorphous ferric oxide, rutile, and traces of barite, sericite, sphalerite, and apatite or possibly other phosphates. Pyrite as shown by the analysis makes up about 25 per cent of the rock. The formation of the pyrite was not accompanied by any appreciable development of sericite, nor was the ferric oxide noticeably reduced. The relatively large percentage of ferrous oxide is unaccounted for in the mineral analysis unless it is present in combination with alumina and silica, as in chlorite. Chlorite was not definitely identified by microscopic examination, although there are some minute almost submicroscopic mineral grains present in the quartz. Films of siderite were identified in some rocks along joint cracks.

Analysis 5 represents an unusual type of nearly black siliceous rock collected from a zone of strong silicification in the Rawley drainage tunnel. It contains abundant hematite and probably represents a zone in which ferric iron has been precipitated from solutions that have effected the silicification and leaching of adjacent or perhaps more or less distant bodies of rock. Besides silica and ferric iron small amounts of barite have apparently been added from the solutions.

Analysis 8 represents a silicified andesitic or latitic rock in which the feldspar phenocrysts are mostly represented by aggregates of kaolin containing a few grains of barite and quartz crystals. The groundmass of the original porphyritic rock is composed of microcrystalline quartz, with a little rutile, chlorite, and ferric oxide. The ferrous iron may be largely in iron-rich chlorite or siderite, though microscopic evidence hardly indicates sufficient of these minerals to account for nearly 2 per cent of ferrous iron. Some magnetite may be present.

An altered siliceous rock from the southern part of the Bonanza district containing an abundance of kaolin and sericite is represented by analysis 9. This rock was collected comparatively near the surface, because of the inaccessibility and lack of deeper explorations in this part of the region. The rock is very porous and soft, so that satisfactory determinations of specific gravity could not be obtained. The most abundant additions during the alteration appear to be silica, water, and traces of the sulphate radicle. All the other constituents have been appreciably leached, although alumina to a very much less extent than in the more siliceous types of alteration. The alumina in the altered rock is probably in large part combined in kaolin minerals and sericite, although there may be small amounts of alunite. The presence of sericite and the fixation of both potash and alumina indicate that the alteration occurred in part under conditions different from those which existed during the formation of the more highly silicified rocks. In contrast to the other siliceous types of alteration a distinct hydration is noticeable.

Analyses showing siliceous alteration of lavas adjacent to fissures, Bonanza district

	1	2	3	4	5	6	7	8	9
SiO_2	57. 62	59. 66	54. 23	88. 73	61. 28	66. 48	95. 18	93. 17	82. 57
Al_2O_3	15. 84	16. 09	18. 82	. 97	2. 42	1. 64	1. 20	2. 52	11. 44
Fe_2O_3	3. 05	2. 57	1. 69	3. 50	31. 49	. 64	. 77	. 19	. 16
FeO	3. 90	3. 53	4. 06	3. 56	2. 49	2. 74	2. 27	1. 92	. 65
MgO	2. 14	2. 29	2. 25	. 05	. 05	Tr.	Not det.	. 03	Tr.?
CaO	4. 81	4. 48	6. 62	. 24	. 28	. 20	Not det.	. 05	. 00
Na_2O	3. 07	3. 08	3. 91	Not det.	Tr.	Tr.	Tr.	Tr.?	Tr.?
K_2O	4. 95	4. 92	3. 08	Not det.	. 19	. 27	Tr.	. 15	1. 89
H_2O-	. 24	. 25	. 08	. 02	. 05	Tr.	. 00	. 09	. 43
H_2O+	1. 39	1. 84	1. 51	. 69	. 58	1. 64	. 40	1. 03	2. 98
TiO_2	1. 30	1. 00	1. 43	1. 50	. 50	1. 45	. 25	. 63	. 35
CO_2	1. 06	. 10	2. 13	Not det.	. 00	Not det.	Not det.		
P_2O_5	. 44	. 35	. 16	. 20	. 20	. 43	. 06	. 10	. 09
SO_3	. 05		Tr.	Not det.	. 28	. 00	Tr.	. 20	. 12
Cl	Not det.		Tr.	Not det.	Tr.	. 09	Not det.		
F	Not det.			Not det.	. 00	. 00	Not det.	. 00	. 00
S	Not det.		Tr.	Not det.	. 06	Present.	Not det.		
MnO	. 15		. 17	Not det.	Not det.	Not det.	Not det.		
BaO	. 04			. 00	. 30	Tr.?	. 00	. 07	. 06
ZrO_2	Not det.		Tr.						
FeS_2	Not det.				Tr.	24. 96			
ZnS	Not det.				. 00	. 05			
	100. 05	100. 16	100. 14	99. 46	100. 17	100. 59	100. 13	100. 15	100. 74
Specific gravity:									
Particles	2. 732	2. 723		2. 786	3. 227	3. 106	2. 688	2. 704	
Lump	2. 713	2. 686		2. 667	3. 072	2. 998	2. 598	2. 497	
Weight of sample ... grams	75	60	200	96	30	90			

1. Fresh black augite-mica andesite, with a little secondary calcite and chlorite. From Rawley andesite. Rawley Gulch above Superior mine. J. G. Fairchild, analyst.
2. Fresh gray quartz latite of andesite habit. Superior member of Rawley andesite, Rawley Gulch near Superior mine. J. G. Fairchild, analyst.
3. Augite andesite, with secondary calcite, chlorite, and sericite. From Rawley andesite. Patton, H. B., Geology and ore deposits of the Bonanza district, Saguache County, Colo.: Colorado Geol. Survey Bull. 9, p. 54, 1916. George Rohwer and E. Y. Titus, analysts.
4. Altered andesite, red jasper type of alteration. Rawley drainage tunnel, about 4,070 feet from portal. J. G. Fairchild, analyst.
5. Altered andesite, black jasper containing hematite. Rawley drainage tunnel about 4,450 feet from portal. J. G. Fairchild, analyst.
6. Altered andesite, red jasper containing pyrite crystals. Rawley drainage tunnel, about 2,600 feet from portal. J. G. Fairchild, analyst.
7. Silicified andesite, ridge north of Express Gulch. J. G. Fairchild, analyst.
8. Silicified volcanic rock with sericite and kaolin minerals, from hillslope between Chloride and Greenback Gulches about 1,500 feet northeast of Kerber Creek.
9. Silicified volcanic rock with kaolin minerals, from Greenback Gulch about 3,000 feet northeast of Kerber Creek.

Weight, in grams, of constituents in 100 cubic centimeters of fresh and altered lavas adjacent to fissures, Bonanza district, showing gain or loss during alteration, as based on an assumption of no change in volume

	1	2	3 [a]	4	5	6	7	8	Increase (+) or decrease (−) from No. 1				
									4	5	6	7	8
SiO_2	156. 3	160. 3	148. 1	236. 6	188. 3	199. 3	247. 3	232. 6	+80. 3	+32. 0	+43. 0	+91. 0	+76. 3
Al_2O_3	43. 0	43. 2	51. 4	2. 6	7. 4	4. 9	3. 1	6. 3	−40. 4	−35. 6	−38. 1	−39. 9	−36. 7
Fe_2O_3	8. 3	6. 9	4. 6	9. 3	96. 7	1. 9	2. 0	. 48	+1. 0	+88. 4	−6. 4	−6. 3	−7. 8
FeO	10. 6	9. 5	11. 1	9. 5	7. 7	8. 2	5. 8	4. 8	−1. 1	−2. 9	−2. 4	−4. 8	−5. 8
MgO	5. 8	6. 2	6. 2	. 1	. 15	Tr.		. 08	−5. 7	−5. 6	−5. 8	−5. 8	−5. 7
CaO	13. 1	12. 0	18. 1	. 6	. 9	. 6		. 12	−12. 5	−12. 2	−12. 5	−13	−13. 0
Na_2O	8. 3	8. 3	10. 7		Tr.	Tr.	Tr.	Tr.	−8	−8. 3	−8. 3	−8. 3	−8. 3
K_2O	13. 4	13. 2	8. 4		. 6	. 81	Tr.	. 37	−13	−12. 8	−12. 6	−13. 4	−13. 0
H_2O-	. 7	. 7	. 2	. 05	. 15	Tr.	. 0	. 23	−. 65	−. 55	−. 7	−. 7	−. 5
H_2O+	3. 8	4. 9	4. 1	1. 8	1. 8	4. 9	1. 04	2. 58	−2. 0	−2. 0	+. 1	−2. 8	−1. 2
TiO_2	3. 5	2. 7	3. 9	4	1. 5	4. 3	. 65	1. 57	+. 5	−2. 0	+. 8	−2. 8	−1. 9
CO_2	2. 9	. 3	5. 8		. 0				−2. 9	−2. 9	−2. 9	−2. 9	−2. 9
P_2O_5	1. 2	. 9	. 4	. 5	. 6	1. 3	. 16	. 25	−. 7	−. 6	+. 1	−1. 0	−. 7
SO_3	. 1				. 86	. 0	Tr.	. 50		+. 76	−. 1	−. 1	+. 4
Cl						. 27					+. 27		
S					. 18					+. 2			
BaO	. 1				. 92		. 0	. 17		+. 8		−. 1	−. 07
FeS_2	None.					74. 8					+74. 8		
ZnS	None.					. 15					+. 15		
									−5. 2	+36. 7	+29. 3		

[a] Based upon an assumed specific gravity of 2.73.

SERICITIZATION

Alteration in which fine-grained white mica, or sericite, was formed has affected all the different kinds of volcanic rocks in the district, and its products are invariably found in the wall rocks or the gouges of mineralized veins.

All the vein gouges that were examined microscopically proved to be made up largely of sericite, with which were mixed some pyrite, quartz, carbonate, and titanium oxide, either rutile or anatase. The pyrite in several specimens occurred as small cubes. Apatite also appears to be present in many of them. None of the kaolin minerals were identified in any of the vein gouges, and the common presence of sericite in gouges is therefore considered to be evidence of the premineral age of the faulting. Sericitization was not as pronounced where the wall rocks of veins had been previously replaced by silica. Microscopic examination of silicified wall rock adjacent to ore bodies, however, shows that the quartz has been partly replaced or veined by sericite. (See pl. 12.)

Near veins sericite in the altered wall rock is accompanied by pyrite and carbonates, but in some places these minerals may be present only in minor amounts. In a few places, as in some small veins containing calcite and chlorite along the upper part of Alder Creek, sulphides such as pyrite and chalcopyrite occur in fractures in chloritized rocks, where sericite is absent. The alteration that produced this result was apparently characterized by the introduction of magnesium or by the breaking down of minerals containing magnesium, but it was uncommon or at least of minor importance.

Sericitization may be considered indicative of conditions favorable to the formation of sulphides, which it almost always accompanies, but on the other hand most of the sericitized fissure zones are not known to contain a commercial concentration of metals. It is fairly certain that sericite was introduced into the altered rocks during the early part of the period of vein formation. This is indicated by the fact that it accompanies pyrite and other sulphides that were introduced along fractures in silicified rocks. It appears to be later than the pyrite crystals formed in the jaspers described on page 73.

Sericitization and the formation of secondary carbonates has resulted in a pronounced bleaching of the dark-colored volcanic rocks along fissures and faults in all parts of the district. The width of the bleached zones ranges from a foot or less to several hundred feet. Very wide zones or areas in which the formations have been bleached are probably the result of circulation of the altering solutions through zones of complex fracturing in the faulted rocks. Scarcely a fault of any size is free from such alteration, so that sericitization as a process of rock alteration was widely distributed but has not affected so large a volume of rock as silicification.

Alteration along fault zones has not only caused a bleaching of the formations but has softened them and reduced their resistance to weathering. The softening effect produced by the formation of sericite and carbonate in the lavas is in contrast to the results of silicification previously described. The outcrop of a fissure may thus be marked either by a depression or by a ridge, depending upon which of the two processes of alteration has locally predominated.

PROPYLITIZATION

Alteration of a propylitic type has very commonly attacked the volcanic rocks in the district. Its results are particularly noticeable in the andesitic lavas, scarcely any piece of which is entirely unaffected by it, although the rock may appear perfectly fresh to the unaided eye. The mineralogic changes are usually recognizable only by comparison of fresh and altered rocks under the microscope and consisted in the formation of secondary chlorite, calcite, quartz, epidote, sericite, and rutile. Sulphides and sericite are commonly absent except close to mineralized fissures. The degree of alteration varied, and certain phases of it appear to have graded into more intense sericitic alteration adjacent to fissures. On the other hand, alteration of a weak propylitic character is exhibited especially by certain kinds of rocks. For example, sericite and epidote are widely distributed as alteration products in the Eagle Gulch latite but do not appear as commonly in some of the other volcanic rocks.

The origin of propylitic alteration is a question over which there has been difference of opinion.[60] Some ascribe it entirely to solutions charged with carbon dioxide that invaded the rocks during the period of ore deposition. Others have considered that it occurred when the lavas were erupted, as a result of the escape of steam and carbon dioxide from the cooling lava flow. Ransome,[61] on the other hand, believes that at Breckenridge, Colo., the relation of the propylitically altered rock to the surface indicates the action of meteoric solutions working downward, although he recognizes the probability that other agencies were effective in different districts.

In the Bonanza district there is no apparent evidence of any relation between this type of alteration and the surface, as rocks at depths of 1,000 feet or more in the Rawley drainage tunnel are altered similarly to those broken from outcrops. There is evi-

[60] Lindgren, Waldemar, Mineral deposits, 3d ed., pp. 530–535, New York, 1928.

[61] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U. S. Geol. Survey Prof. Paper 75, pp. 101–102, 1911.

dence, however, which at different places may support either an origin related to mineralizing solutions or an origin related to the consolidation of the molten rock. Some of the andesitic lavas of the district are characterized by a constant association of certain secondary minerals, such as chlorite, calcite, quartz, and hematite. The original biotite or augite is nearly everywhere altered to chlorite, quartz, calcite, and titanium minerals such as rutile. In certain flows these alteration products have the same characteristic mode of occurrence, even though the outcrops examined may be separated a mile or more. It is very likely that this weak alteration is in part related to the consolidation of the lava. The formation of epidote and sericite in the Eagle Gulch latite, which is probably an intrusive porphyry, also appears to be a phenomenon related to its consolidation.

Near some veins the formation of chlorite and calcite, usually with sericite, was definitely related to the mineralization. This alteration is well illustrated in the hanging wall of the Cocomongo fault in the Cocomongo mine, beyond the northern edge of the main ore shoot. The Bonanza latite, which forms the wall rock, even within a few feet of the unproductive part of the fissure, is of a greenish color and very soft. The feldspars are altered to masses of sericite, and the groundmass contains scattered chlorite and calcite with only a very little pyrite. The original biotite is altered to white mica and rutile. Closer to the ore shoot the latite is more bleached and the altered groundmass contains more abundant calcite and pyrite with irregular areas of secondary quartz, calcite, and apatite. The biotite and feldspars are sericitized. Immediately adjacent to the ore shoot the latite wall consists of a mass of quartz and sericite in which sphalerite and small amounts of other sulphides may be present in addition to pyrite. The texture of the rock may still be partly preserved. There appears to be a gradation outward from the veins into altered rock in which quartz and sericite predominate, and then into rock in which secondary carbonates and chlorite are abundant with smaller amounts of sericite and quartz. It is not apparent, however, whether this alteration graded outward into the still weaker propylitic type in which sericite and pyrite were generally not formed.

NATURE OF THE MINERALIZING SOLUTIONS

SOLUTIONS PRODUCING SILICIFICATION

The earliest stage of hydrothermal alteration was characterized by the formation of silica, with minor amounts of ferric oxide, titanium oxide, and compounds of alumina as the final products of rock alteration. The amount and kind of matter carried away in solution varied from place to place, but large amounts of alumina, alkalies, and alkaline earths have been removed from the original rocks; the principal additions were silica and minor amounts of sulphur. For the purpose of considering the nature of the solutions that caused the early silicification of the rocks the products of this process may be divided into four major types—(1) those consisting of nearly pure quartz with minor amounts of iron and titanium oxides, represented by analysis 7 (p. 78); (2) those of red color consisting of quartz or chalcedony with ferric and ferrous oxides and other minor constituents, represented by analysis 4; (3) those containing in addition to the silica some minerals in which alumina with or without potash is present—kaolinite or sericite, or both (see analysis 9), and less commonly diaspore and alunite; and (4) those containing disseminated pyrite in appreciable quantity.

Rock alteration in which the principal products were silica and kaolinite, with or without the formation of diaspore, has been generally attributed to the solfataric action of acid waters. Examples of altered rock of this type are found at Rosita Hills and Red Mountain, Colo.; Goldfield, Nev.; De Lamar, Idaho, and other places. Where alunite has been an abundant product of the decomposition it has led to the conclusion that the acidity of the waters was due to the presence of free sulphuric acid. At Goldfield [62] there are silicified masses of dacite known as "ledges," which appear to be similar to those found in parts of the Bonanza district. The characteristic alteration products at Goldfield are silica, kaolinite, alunite, and pyrite. The ores are of somewhat later origin, occurring in shattered parts of the silicified rocks. Ransome considered that sulphuric acid was generated near the surface by the oxidation of hydrogen sulphide and that the oxidized solutions carried the sulphuric acid downward, where it intermingled with the rising alkaline solutions. In the Engineer Mountain and Red Mountain districts of Colorado, described by Ransome,[63] the products of alteration of the volcanic rocks consist, at the Polar Star lode, of quartz, kaolinite, pyrite, diaspore, and sericite. At Red Mountain the addition of silica and the formation of kaolinite, usually without sericite, constituted the characteristic alteration. The alteration was not limited to the vicinity of ore bodies, although many of the ore bodies crop out in siliceous knobs.

Recent work by Day and Allen [64] on the hot springs at Lassen Peak and The Geysers, Calif., throws con-

[62] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 150–157, 1909.

[63] Cross, Whitman, Howe, Ernest, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), p. 33, 1905.

[64] Day, A. L., and Allen, E. T., The volcanic activity and hot springs of Lassen Peak: Carnegie Inst. Washington Pub. 360, pp. 113, 140–145, 1925. Allen, E. T., and Day, A. L., Steam wells and other thermal activity at "The Geysers," California: Carnegie Inst. Washington Pub. 378, pp. 45–50, 1927.

siderable light on the different conditions under which alunite and kaolinite may form as products of rock decomposition by waters containing sulphuric acid. It is shown by them that at both these localities, the final residue of rock decomposition was silica in the form of opal, accompanied by minor amounts of other oxides. They state in referring to the chemical decomposition of the lavas at Lassen Peak:

The active agents are hydrogen sulphide and especially sulphuric acid. When sulphuric acid decomposes a silicate the final products are free silica and sulphates of the metals contained in the silicate, and these products are found in all of the springs.

They state that the sediments in the springs constitute the products of decomposition that have been precipitated from the waters and consist in this region of two types—(1) silica and kaolin, and (2) silica and alunite. Whether the product shall be kaolin or alunite in conjunction with silica in any given spring they considered to be dependent upon the relative concentration of sulphuric acid in the waters, as kaolinite is decomposed by strong sulphuric acid into silica and aluminum sulphate. This assumption is supported by the conditions of acidity at the different springs.

In contrast, however, to the conditions at Lassen Peak the sediments in the springs at The Geysers contained no product which could be identified with kaolinite or other clay minerals, and the major constituent of the sediments was opal. In consideration of the cause of this difference they say:

A more plausible hypothesis in explanation of the absence of kaolin from the springs at The Geysers—at least from the acid springs—is that its formation is prevented by the relatively high acid concentration which is found here.

Both at Lassen Peak and at The Geysers the sole cause of the acidity of the springs is sulphuric acid, as only traces of the halogen acids are present. At Lassen Peak the acid waters contained from 19 to 436 milligrams of H_2SO_4 per liter, at The Geysers the concentration was much greater. The temperature of the hotter springs at these localities ranged from 80° to nearly 100° C. It would appear, then, that the action of hot solutions containing different concentrations of free sulphuric acid could account for the range in the character of the silicification at different places in the Bonanza district. The siliceous rocks that are free from kaolinite and contain only minor amounts of other oxides such as iron and titanium presumably indicate the action of waters of relatively high acidity or were produced by the long-continued action of solutions saturated with silica. The presence of ferric oxide and hematite in many of the silicified rocks is compatible with their formation by acid waters. The fixation of ferric iron could reasonably be accounted for by conditions favoring the hydrolysis of ferric sulphate. In addition such solutions containing free sulphuric acid would be capable of transporting alumina. As kaolinite and other aluminum minerals are usually absent from the red or brown jaspers, either the acidity or the temperature of the waters that deposited them was presumably fairly high. Silicified rocks containing associated kaolin and sericite probably indicate a lowering acidity during the formation of kaolin, for sericite is considered to form only from alkaline solutions. The presence of both minerals indicates a fluctuating or changing condition. As having a possible bearing on the relation between the periods of acidic and alkaline alteration, the replacement of diaspore, zunyite, and quartz by sericite, as shown by the specimen illustrated in Plate 10, is of particular interest. This specimen, coming from Greenback Gulch, near the center of the area of strongest solfataric alteration, indicates at this position a change from acid to alkaline solutions during the period of rock alteration. This same sequence is also invariably shown in the northern part of the district, where the silicified wall rock of veins or the red jaspers have been replaced by pyrite and sericite or brecciated and cemented by sulphides. (See pl. 13, *A*.)

During periods of active oxidation some secondary deposition of kaolin may have taken place adjacent to oxidizing sulphide bodies (p. 154). This process represents the commonly described kaolinization produced by meteoric waters near ore bodies and is here definitely differentiated from the hydrothermal kaolinization described above.

SOLUTIONS CAUSING PYRITIZATION OF THE SILICIFIED ROCKS

Pyrite is commonly disseminated through the silicified rocks, usually in positions adjacent to mineralized fissures or ore bodies, though in places pyrite is found in jaspers hundreds of feet from any known ore bodies. The characteristic feature of the pyrite in such occurrences is its well-developed crystal form, usually the pyritohedron, but the sizes of the crystals differ. (See pls. 9 and 11.) In the red iron-bearing jaspers of the northern part of the district much of the pyrite is strikingly well crystallized, some of the larger crystals ranging from 3 to 5 millimeters in diameter. An analysis of such a rock is given as No. 6 on page 78. In the southern part of the district in the silicified area adjoining Greenback Gulch pyrite is present in parts of the quartz-kaolin-sericite rock, but much of it is in crystals so minute that it is easily overlooked unless the rock is examined with a hand lens.

Pyrite occurs in the spring deposits at Lassen Peak, Calif., associated with opal and kaolin under conditions of rock alteration similar to those at Bonanza. Day and Allen [65] attribute its formation to the coexistence of ferrous salt, hydrogen sulphide, and sulphur in the spring waters. The significant feature of its occurrence at Lassen Peak and at The Geysers is that distinctly crystallized pyrite was confined to the acid springs, while all the minerals referred to pyrite found in the alkaline waters were of a cryptocrystalline or amorphous nature.[66] Marcasite did not occur in the acid springs associated with the crystalline pyrite. By analogy, then, some of the pyrite in the silicified rocks at Bonanza may have formed from acid waters containing hydrogen sulphide.

Pyritization particularly near ore bodies, where the rocks have been brecciated and veined with pyrite and other sulphides, was usually accompanied by sericitization and was probably a later process than that described above. A partial or nearly complete loss of the red color of silicified rocks has resulted. The bleaching of red rocks and the replacement of hematite by pyrite may have marked the transition between early acid and later alkaline conditions that continued naturally through the later period of normal vein formation.

The transition stage may be explained by an increase in the concentration of hydrogen sulphide, which would cause the precipitation of pyrite, even in solutions of slight acidity. The bleaching of some of the red rocks near veins agrees with the natural antipathy between ferric oxide and sulphide compounds that has often been recognized. This was first emphasized by Butler [67] and has been discussed in more recent papers.[68] Hematite usually appears only in deposits relatively low in sulphur, and where associated with later sulphides it is as a rule partly destroyed or exhibits evidence of instability. However, at variance with this normal relation some of the red jaspers of the Bonanza district contain pyrite crystals thickly embedded in them and yet show little evidence of the destruction or instability of the ferric oxide. This suggests that ferric oxide may be stable under certain conditions when pyrite is being formed. In this example the condition may have been one of acidity caused by the presence of free sulphuric acid or other acid in the altering solutions.

[65] Day, A. L., and Allen, E. T., op. cit. (Lassen Peak), pp. 137–138.

[66] Idem, pp. 121–122; Allen, E. T., and Day, A. L., op. cit. (The Geysers), p. 48.

[67] Butler, B. S., Suggested explanation of the high ferric oxide content of limestone contact zones: Econ. Geology, vol. 18, pp. 398–404, 1923.

[68] Gilbert, Geoffrey, The significance of hematite in certain ore deposits: Econ. Geology, vol. 21, pp. 560–577, 1926. Butler, B. S., and Burbank, W. S., Relation of the electrode potentials of some elements to the formation of hypogene mineral deposits: Am. Inst. Min. and Met. Eng. Yearbook, 1929, pp. 341–353.

SOLUTIONS FORMING THE VEINS

The sulphide ores of the veins are similar to those of many other vein deposits of the low or intermediate temperature zone and were deposited presumably from alkaline solutions. In addition to the valuable metals that were deposited in the veins these solutions must have carried silica, iron, manganese, calcium, barium, potassium, probably sodium, sulphur, phosphorus, fluorine, and carbon dioxide. In the higher-temperature veins of the northern part of the district the solutions were apparently relatively high in potassium and silica, as shown by the intense sericitization and the high silica content of the ores. Magnesium was apparently present only in relatively small quantities, as the vein carbonates rarely contain but little of this element. In the southern part of the district dolomite was deposited together with pyrite and other carbonates, notably in the E. D. vein, near the Kerber Creek road. The presence of dolomite is rather unusual, and its magnesium may have been derived from the dolomitic Paleozoic limestones which presumably underlie the volcanic rocks in this area, probably at a depth of at least 800 feet.

Some alumina must have been carried in the vein solutions of the southern part of the district, as adularia is associated in some places with the vein quartz, though only in small amounts.

ORIGIN OF THE MINERALIZING SOLUTIONS

There are no outcrops of large intrusive masses in the district that could have been the source of the ore-depositing solutions. However, the occurrence of small bodies of intrusive granite porphyry in the vicinity of Alder Creek and of latite, rhyolite, or monzonite dikes in considerable abundance in all parts of the region point to the existence of some molten body of rock beneath the surface immediately before the faulting and mineralization. The depth of this body can not be estimated, but it probably lay at a not very great depth below the present surface, as in some parts of the district scarcely a fault is free from some intrusive material. The solutions that deposited the ores were probably not derived from the same parts of the intrusive body as the small dikes, as all the dikes except those of monzonite were greatly altered by the mineralizing solutions. As no dikes are known to cut ore bodies, it is likely that the upper parts of the intrusive body had become solidified before ore deposition began. The acid solutions which appear to have caused the earliest period of alteration may have come entirely from the underlying intrusive mass during an early stage of its crystallization, or they may have had some other source, as will be considered farther on.

In regions of recent volcanic activity some of the constituents of hot springs are believed to represent primary emanations from crystallizing and cooling bodies of lava below the surface. Both acid and alkaline springs are found, but as to the cause of the acidity or alkalinity and the relations between them opinions in the literature differ and some of the evidence on record is conflicting. Day and Allen [69] in summarizing their own views on this problem, say:

> The problem is one that calls for detailed observation in many localities, but at present the weight of the evidence clearly inclines the student of the subject to the conclusion that the acid hot springs constitute a stage of volcanism, logically following the acid fumaroles, and that the alkaline springs develop subsequently as a necessary result of the processes of rock decomposition.
>
> Speaking generally, all volcanic hot springs in the lapse of time should become alkaline as a result of the gradual decline in the amount of sulphur gases and halogen acids in the volcanic emanations as the temperature of the batholith falls. (This statement supposes that the chemically active gases disappear before the steam. It is supported by a considerable body of evidence.) A uniform decline would not, however, explain the coexistence of acid and alkaline springs in the same area.

The evidence offered by wall-rock alteration and ore deposition at Bonanza appears to accord with a gradual decline in acidity of the active solutions and may be considered as supporting the contention of Day and Allen regarding the decrease in acidity of batholithic emanations during the period of solidification and cooling.

As against this theory it might be contended that the acid solutions which resulted in the early silicification and kaolinization were derived, as was postulated by Ransome [70] for the conditions at Goldfield, by the oxidation of alkaline hydrogen sulphide solutions as these reached the surface of the ground. After the hydrogen sulphide became oxidized by the atmosphere to sulphuric acid, the solutions would carry the sulphuric acid downward to intermingle with the rising alkaline solutions. It is known that hydrogen sulphide gas may react with air, forming as a direct product sulphuric acid, and small amounts of acid might thus be produced in porous ground adjacent to fumaroles or springs. Sulphuric acid can also be formed by interaction of hydrogen sulphide with solutions of ferric salts. These were the reactions to which Day and Allen attributed the formation of sulphuric acid at Lassen Peak [71] and at The Geysers. However, the small amounts of sulphuric acid which are known to result from such processes hardly seem sufficient to account for extensive alteration to depths of several thousand feet below the surface. The acidity of such solutions would be lost rapidly as they descended by interaction with the rocks, in addition to their neutralization by the rising alkaline solutions.

Alteration characteristic of low acidity would be expected at depth, yet in the Bonanza district red jaspers and silicified rocks free from kaolin are found in the deepest mine workings associated with deposits of intermediate temperature. The rocks showing alteration of low acidity type found in the southern part of the district are associated with deposits probably formed nearer the surface. It is also difficult to conceive under these conditions why such oxidizing processes suddenly ceased and failed to recur after the beginning of sulphide deposition, inasmuch as the sulphides were surely deposited from solutions containing hydrogen sulphide. The sulphides in the veins show no effect of interaction with later acid solutions except within a very shallow oxidized zone that is clearly related to the present topography and hence caused by meteoric waters. It might conceivably happen that in a few springs oxidation for some fortuitous reason suddenly stopped and thereafter only alkaline solutions circulated in the feeding fissures underground. The fact that this appears to have happened in nearly every fissure in the district, however, necessitates some other explanation than mere chance. It is evidently necessary to postulate either some significant change in the character or amount of solutions coming from the magmatic source or a change in conditions at the surface whereby further oxidation of the rising solutions was prevented. The second alternative can be dismissed as improbable, because conditions like those at Bonanza are commonly found in other mineralized districts in volcanic regions. It is also unlikely that a sudden increase in volume of the magmatic emanations took place, because most regions of fumarolic or hot-spring activity are characterized by a gradual decrease in activity. Furthermore, in the Bonanza district the wider distribution and greater volume of rock affected by silicification as compared with alteration attributable to ore-forming solutions indicate a greater volume of the earlier emanations. The only plausible explanation, therefore, appears to be some change in composition of the primary or hypogene solutions, and the simplest interpretation is that the solutions became more alkaline. This conclusion is in accordance with the hypothesis of Allen and Day with regard to the gradual decrease in primary acid constituents. It remains to be considered, however,

[69] Day, A. L., and Allen, E. T., op. cit. (Lassen Peak), p. 169.

[70] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 193–195, 1909.

[71] Day, A. L., and Allen, E. T., op. cit. (Lassen Peak), pp. 138–140.

whether the decrease in acidity occurring at the surface was entirely the result of some primary change at the source of the solutions or whether this primary change was only a directing influence.

According to Day and Allen, both at Lassen Peak and at The Geysers the alkaline waters have resulted from chemical change of waters that are acid nearer their source. They further state: [72]

Thus we find logical grounds for the conception that volcanic hot springs may be originally alkaline, or originally acid changing later to alkaline, but no basis for the conclusions that volcanic springs originally alkaline may become acid by later development.

Although they admit that sulphates may conceivably arise from the oxidation of sulphide or thiosulphate they say, "There appears to be no convincing evidence that either of these reactions has ever been observed in alkaline solutions through the agency of air alone." [73] Their conclusions, therefore, seem opposed to the hypothesis that sulphuric acid may have been generated by original alkaline springs.

Even if it is assumed that the primary "solutions" or "emanations" at Bonanza were acid in the early stages, this does not exclude the possibility that at least some or all of the sulphuric acid may have been generated at or close to the surface by oxidation of hydrogen sulphide in acid solutions. Under these conditions the primary acidity would necessarily have been largely due to halogen acids. Chlorine has been found in the zunyite molecule, but this is the only mineral associated with silicification in which chlorine might have become fixed. Primary sulphates, however, are known to occur in some hypogene deposits under conditions where the assumption of surface oxidation seems hardly justified.[74]

The effects of the early emanations on the rocks and analogy with the recent hot springs and fumaroles

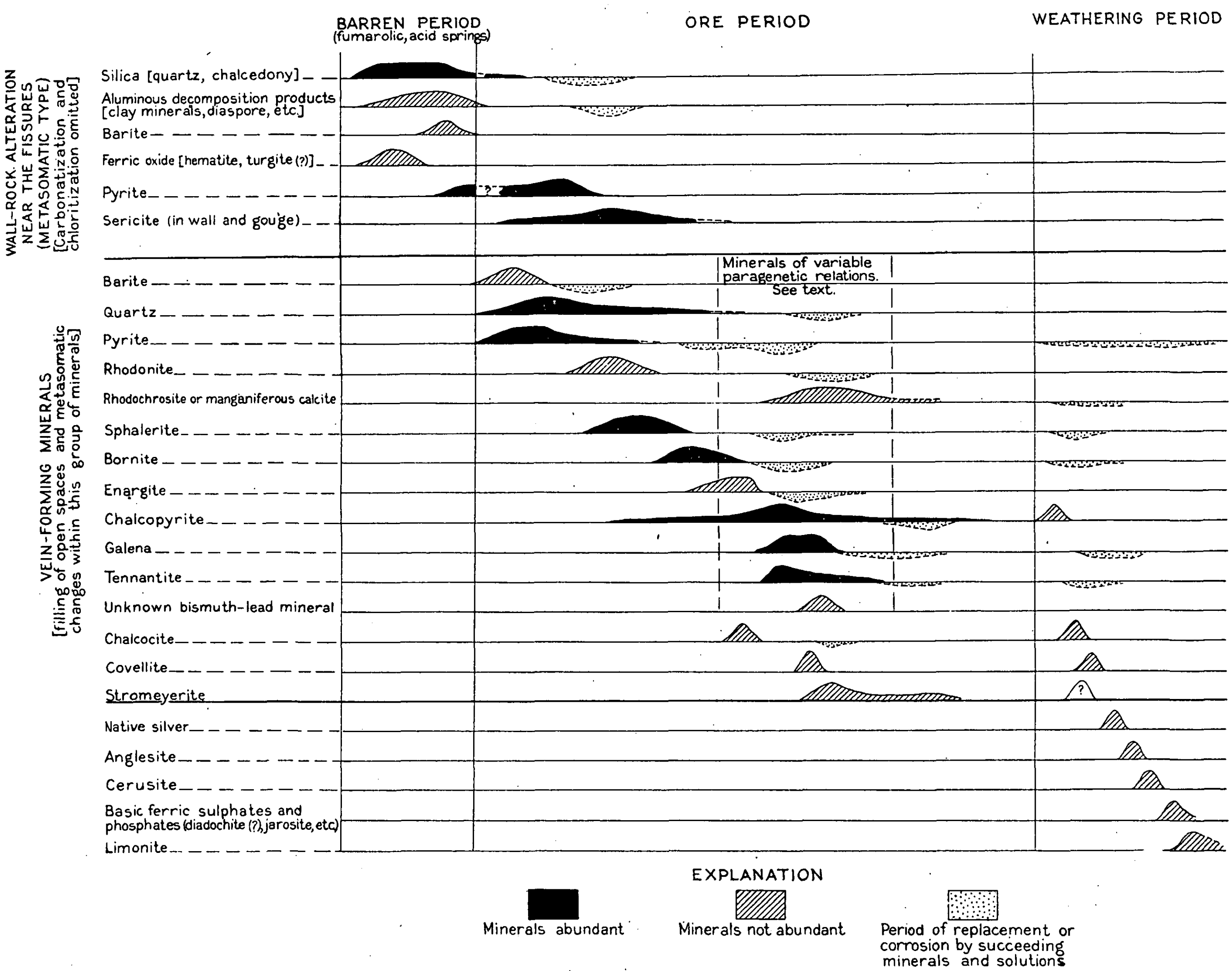


FIGURE 17.—General paragenetic relations of silicification and of the vein minerals of the base-metal quartz-sulphide veins of the northern part of the Bonanza district

[72] Day, A. L., and Allen, E. T., op. cit. (Lassen Peak), p. 170.
[73] Allen, E. T., and Day, A. L., op. cit. (The Geysers), p. 81.
[74] Butler, B. S., Primary (hypogene) sulphate minerals in ore deposits: Econ. Geology, vol. 14, pp. 581–609, 1919.

would suggest the general conclusions that these emanations were acid originally and undersaturated with many of the common rock constituents. Whether this primary acidity was produced mainly by halogen acids or by sulphuric acid is not apparent, but presumably the oxidation of sulphur would be favored by the presence of other acids, whether or not this action occurred at the surface or at great depths. The emanations vigorously attacked the rocks and must either have originally carried silica or soon became saturated with it, for the earliest effect observed is silicification. Locally or at later stages the solutions were also saturated with alumina.

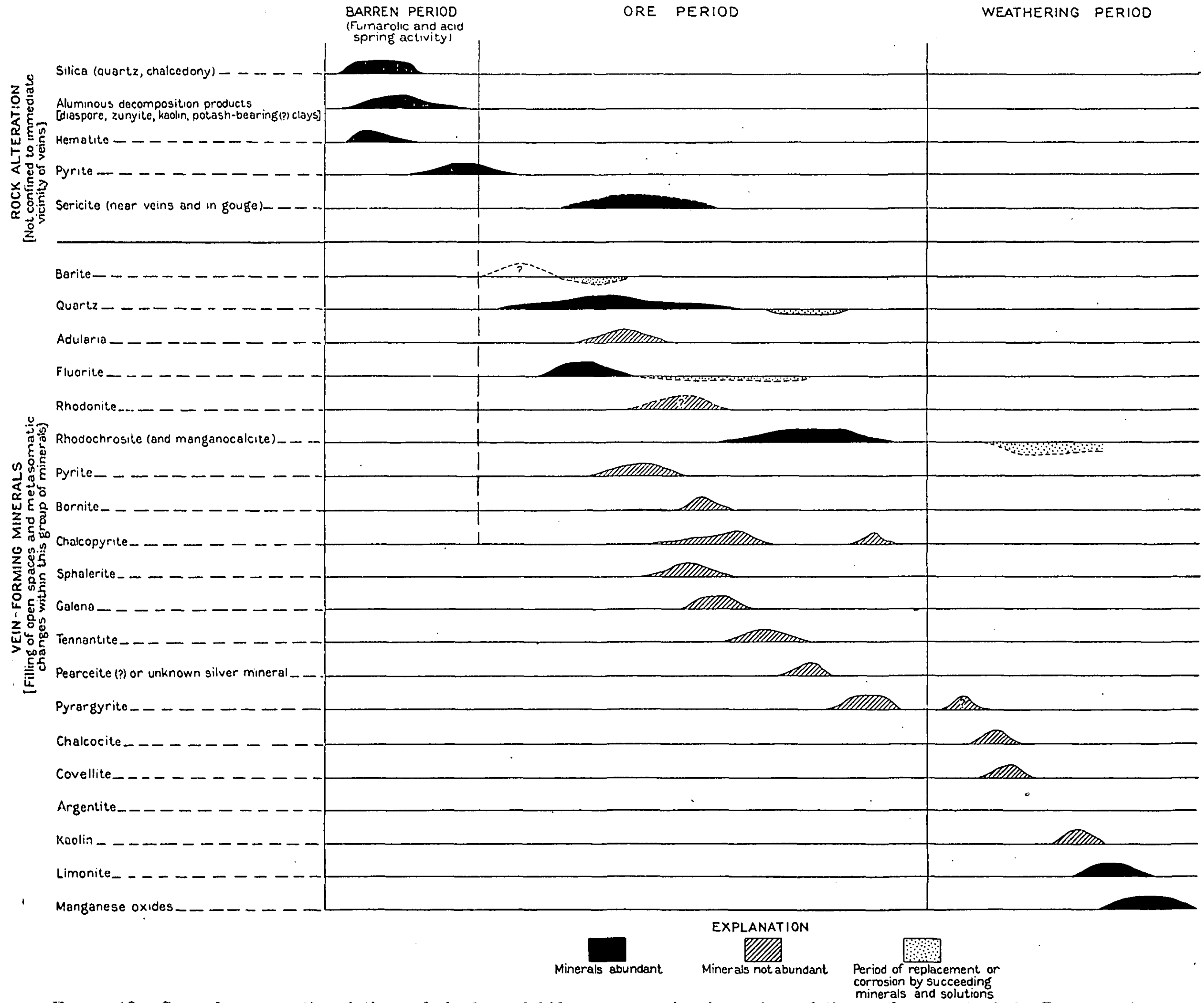


FIGURE 18.—General paragenetic relations of the low-sulphide manganese-bearing veins of the southern part of the Bonanza district

PARAGENESIS OF THE PRIMARY ORES

The sequence and character of the mineralization vary in detail from place to place within the district, but the general sequence of mineral formation shown in Figure 17 holds for the greater number of veins in the northern part of the district. The order of formation of minerals in the veins of the southern part of the district, such as the Eagle vein, is shown in Figure 18.

The main stages in the history of ore formation are (1) silicification of the wall rock, in some places with the formation of ferric oxide; (2) deposition of the vein minerals, barite, early quartz, pyrite, and sphalerite, with sericitization and pyritization of the walls probably beginning during the early part of this period; (3) deposition of the later vein sulphides (overlapping the preceding stage more or less in places) in the order (*a*) bornite and enargite, (*b*) galena and chalcopyrite, (*c*) tennantite, chalcocite, and stromeyerite. Photomicrographs illustrating many of the relations of the different ore minerals are given in Plates 13–22.

The greater part of the vein quartz is of early formation, perhaps in many places overlapping the pyrite and sphalerite, but its deposition commonly extended into later stages, and in one specimen from the Cocomongo vein it cements brecciated galena and chalcopyrite. Barite has commonly preceded quartz and is partly replaced by it (pl. 14); in only one specimen, in small amounts, was it seen associated with manganocalcite of a late postsulphide stage. Rhodonite where present in the gangue appears as an early mineral closely following pyrite and intergrown with quartz; it preceded sphalerite. Rhodochrosite invariably followed rhodonite and quartz, both of which it has replaced, although preferentially it replaced rhodonite. (See pl. 13, *B*.) Rhodochrosite and galena are in places intergrown in such a manner as to indicate essentially contemporaneous formation, but the deposition of the carbonate continued after that of galena. Manganocalcite or calcite and siderite (in places manganosiderite) appear to be late minerals and usually fill cavities or occur in vugs between the sulphides. They are not abundant vein minerals. All the carbonates have replaced the vein quartz to some extent.

A difference in the mutual relations of the sulphide minerals may appear even in the same vein, the deposition of galena relative to that of the copper minerals being the most variable. Galena both followed and preceded chalcopyrite, and in general it may be said that the chalcopyrite, galena, and tennantite greatly overlap. In the upper levels of the Rawley vein, where galena is the most abundant, it appears to be a very late mineral and followed chalcopyrite, but in some of the lower levels where copper minerals are common the paragenesis is more variable and complex. The relations suggest an overlapping history in which the earlier minerals after ceasing to be deposited became unstable in the presence of the solutions depositing the later ones and hence were slightly corroded and partly replaced. Less commonly sphalerite, chalcopyrite, and galena may all have been deposited in overlapping sequence, the grains interlocking in an irregular manner. (See pl. 15, *C*.)

The minerals most subject to advanced replacement by later ones are pyrite and sphalerite. Bornite and chalcopyrite in particular have both replaced pyrite extensively. (See pl. 15, *A*, *B*.) Galena has replaced sphalerite and pyrite. Rarely sphalerite has replaced pyrite.

Relations more nearly universal than any others are the deposition of sphalerite interstitially to pyrite grains and of the later sulphides interstitially to sphalerite. Replacements other than those mentioned above were common but do not appear to have involved any extensive change of material; they consisted rather in a moderate or slight corrosion of the different grains. Both chalcopyrite and galena have replaced bornite locally. Chalcopyrite and chalcocite occur in two stages, of which the later is represented by small veinlets of one or both minerals in most of the earlier sulphides. (See pl. 18, *B*.) These occurrences are probably of supergene origin, as they follow either capillary cracks or even cleavage lines of galena. Covellite is observed in similar relations, having replaced galena, bornite, or chalcocite. Where covellite and chalcocite occur as primary minerals they are later than bornite and galena and form eutectoid intergrowths with them that probably are in the nature of replacements.

Stromeyerite is undoubtedly in large part a primary mineral, occurring in irregular blebs in bornite or intimately intergrown with galena, tennantite, and primary chalcocite. (See pls. 17, *C*, *D*, and 18.) Its relation to tennantite in some places suggests that the components of these two minerals were deposited in a solid solution which at later vein stages separated into an extremely fine intergrowth containing many ramifying veinlets of stromeyerite. These intergrowths may be so fine as to be hardly resolvable without oil-immersion objectives and appear as one mineral until differentially etched with some reagent. (See pl. 18, *A*.)

CHANGE OF ORE IN DEPTH

One of the main geologic features to be considered from the point of view of the miner is the changes that may be expected in the character of the mineralization below depths of the present explorations. The only criterion which the geologist has at present for such predictions is an empirical comparison, based upon mineral composition and types of rock alteration, between regions of similar igneous activity and mineralization. Two main classes of ore deposits are found in the district. One of these classes includes quartz veins of moderate sulphide content, containing lead, zinc, copper, and silver. The minerals of these veins are quartz, barite, pyrite, sphalerite, galena, chalcopyrite, bornite, tennantite, and stromeyerite, with small amounts of enargite, covellite, chalcocite, rhodonite, rhodochrosite, and calcite. These veins are considered to be of the shallow intermediate-temperature type.

The veins of this class have been developed through the greatest vertical range, amounting to about 1,200 feet at the Rawley mine and to much shallower depths in other veins. The Rawley and Whale veins show an increase in copper content on their lower levels, with a corresponding decrease in lead. As the Whale vein is not accessible, conclusions regarding the significance of this change must be based solely on the Rawley vein. During the development and mining of the Rawley vein in 1926, 1927, and 1928 the ore obtained below the 600-foot level and that obtained from and above the 500-foot level were mixed before treatment in the Rawley mill. The mill heads therefore fail to reflect the full difference in character of the ores of the upper and lower levels, although they show a gradual falling off in the ratio of lead to copper. The table on page 111 shows from what data are available the change in the ratio of lead to copper from the upper to the lower levels.

The change from a lead ore in the upper levels to copper-silver ore in the lower ones is not as abrupt mineralogically as the change of the metal content shown by the analyses would indicate, as small bodies of massive galena ore are encountered at several places below the 600-foot level. These small sporadic bodies are merely indicative, however, of the irregular nature of the bottom of the main body of lead ore as it fingers out in depth. The mixed character of the ore on the 500-foot level, which lies about at the horizon of the change from predominating lead to predominating copper, indicates that the change is a gradual one rather than caused by two widely separated periods of copper and lead mineralization. Microscopic examination of the relations of the lead and copper minerals also fails to support two periods of mineralization, as the galena, bornite, and chalcopyrite are in some ores nearly contemporaneous, particularly in ore from the lower levels. Such ore perhaps represents the early stages of the formation of galena. The segregation of massive galena ore from the other sulphides which is noticeable in parts of the Rawley vein appears to be due to the greater tendency of galena to be precipitated in the more open parts of the fissures and to local reopening of the fissures during the later stages of formation of galena.

It is probably then, justifiable to conclude that the change in character of the ore in depth is a primary downward change. The physicochemical causes of such primary changes are not understood, but studies of ore deposits throughout the world have shown that a certain succession of metals usually holds, and that many lead and zinc veins pass downward into veins of predominating copper and iron.[75]

Similar changes are common in other parts of the San Juan region. Regarding this feature in the mines of the Silverton quadrangle, Ransome [76] says in part:

> In spite of the diversity shown by the different ore bodies, there is, after all, remarkable uniformity to be found in the change at very moderate depths—usually less than 300 feet—from ore consisting chiefly of argentiferous galena to highly argentiferous silver-copper ores, and then a gradual diminution of value downward through the increasing proportion of low-grade pyrite in the ore bodies. These changes are best recorded in the Yankee Girl, Guston, and Silver Bell mines. * * * Although there was on the whole a general change from argentiferous lead ores to argentiferous and auriferous copper ores and finally to slightly argentiferous and auriferous iron sulphide (pyrite), yet the progression was an overlapping and irregular one in detail. Iron pyrite and chalcopyrite occurred at practically all depths, while galena in small bunches was sometimes found far below the point at which it had ceased to be the principal ore.

Although both silver and gold are more abundant in many of the Silverton ores than at Bonanza the changes in base metals shown in these veins are sufficiently like those at Bonanza to justify the drawing of some parallel as to what may be expected at still greater depths. Copper ore in general probably has a much more extensive vertical range than high-grade lead ores. The vertical range in the lead ore of the Rawley vein is about 400 to 450 feet, and there is no reason to think that the copper-silver ores will not continue downward through at least as great a range. Up to the present time productive copper-silver ores have not been found below the 800-foot level, although the reasons for this possibly lie in structural conditions or in insufficient development.

The galena of the ores of the Bonanza district is not notably argentiferous (p. 64), and the range of silver content corresponds very closely to that of the copper content. The silver of many of the veins in the district is partly present as stromeyerite. To judge from the microscopic study of the ores, this mineral has a strong tendency to be associated with tennantite and bornite, although small amounts of it are later than all the other copper minerals. In general more silver is to be expected in the copper ores than in the lead ores, and this has proved to be almost invariably the rule in the veins of the northern part of the district. The silver of the Rawley vein increases very perceptibly down to at least the 800-foot level. It is probably to be expected, however, that at greater depths chalcopyrite and pyrite will increase in amount and that the silver content will gradually decrease. In the Guston mine of the Silverton district stromeyerite, according to Ransome,[77] had a definite lower limit, being present in greatest abundance between the predominating galena ore of the upper levels and the bornite and chalcopyrite ores of the lower levels.

Probably the vertical range of 900 to 1,000 feet represented by the Rawley shoots is as great as may be expected in any of the veins in the district—in fact, most of those developed have a much smaller vertical range than this. Very few ore shoots in the district have been productive below 300 to 500 feet.

The veins of the second kind are quartz-rhodochrosite-fluorite veins of relatively low sulphide content,

[75] Emmons, W. H., Primary downward changes in ore deposits: Am. Inst. Min. and Met. Eng. Trans., vol. 70, pp. 964–997, 1924.

[76] Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colorado: U. S. Geol. Survey Bull. 182, pp. 111–112, 1901.

[77] Idem, p. 226.

the economically valuable metal being mainly silver. Besides the gangue minerals mentioned they contain pyrite, sphalerite, galena, chalcopyrite, pearceite (?), and pyrargyrite. Small amounts of adularia and barite occur in the gangue, and small amounts of tennantite, enargite, stromeyerite, and covellite occur with the sulphides. The veins are clearly of the shallow, low-temperature or epithermal class.

These veins are confined mainly to the southern part of the district and appear to present an entirely different problem as to the nature of their extensions in depth. The presence of adularia, fluorite, and abundant manganese carbonates in the gangue are indicative of low temperature during their deposition. The large area of altered rock between Chloride and Greenback Gulches, which contains quartz, kaolin, diaspore, and perhaps other minerals characteristic of solfataric alteration, is also typical of shallow zones of alteration in volcanic regions. Around some very similar zones rich ores of the "bonanza" type have been found. Few veins have been developed in the southern part of the district, and as none of those most developed are accessible, conclusions based upon sound premises can not be drawn as to changes of mineralization in depth. The Eagle vein has been opened to a depth of 600 feet. The ore of the lowest levels, according to available information (p. 152), though of high grade occurred only in small discontinuous pipes or lenses lying between relatively long stretches of barren quartz and rhodochrosite. The pyrargyrite found on the 600-foot level appears from microscopic examination to be a primary silver mineral. Chalcopyrite is a common mineral in small amounts in all the veins of the southern area. It may be expected to increase slightly in depth.

Small amounts of enargite, tennantite, and stromeyerite are found with the other sulphides, as in the "rhodochrosite vein" of the Express property. This particular association of minerals suggests that some of these veins may change downward into sulphide veins of the type common in the northern part of the district. Experience in the development of veins of this type in other regions does not, however, support this suggestion, as many such deposits have passed into barren gangue in depth. Whether the copper, lead, and zinc ores would reappear at still greater depths can not be definitely stated. Such barren zones, which are commonly found at the base of silver deposits in volcanic regions, have never been explored far below the base of the productive shoots. The outcrop of the Eagle vein lies about 2,500 feet below the summit of Hayden Peak. The Hayden Peak formation appears to thin somewhat rapidly westward, so that the amount of cover removed by erosion from above the present outcrop of this vein can not be easily estimated. It may, however, have been as much as 2,000 feet. If this is true the Eagle ore shoot probably represents only the roots of the original mineralized portion of the vein. Many of the other veins may bear similar relations to their eroded portions, as they have characteristically a low sulphide content.

Many veins in this part of the district show conspicuous outcrops of manganese oxides, some of which may furnish manganese ores but of a siliceous grade. Well-oxidized manganese ores probably can be expected to extend only a few hundred feet downward, although where they cross high ridges the veins may be partly oxidized to much greater depths. The oxidation in the Eagle vein was not strong below 100 feet. Just below such oxidized zones in veins of moderate sulphide content some silver enrichment may have occurred, as in the Eagle. On the other hand, rhodochrosite veins originally nearly barren of sulphides may show only negligible enrichment. A careful study of the oxidized ore would be the only means of determining if sulphides were originally present in abundance. Here and there some masses of partly oxidized sulphides should be preserved.

The only encouragement for extending developments below the bottom of the zone of silver ores in this part of the district would appear to be the possibility of finding metal deposits of a higher-temperature origin in the Paleozoic sediments, which presumably underlie certain parts of the southern area of volcanic rocks. Such a possibility is of a very speculative nature and is discussed in more detail in the section on future exploration in the district (p. 103).

GEOLOGIC RELATIONS OF THE ORE DEPOSITS

RELATION BETWEEN MINERALIZATION AND FAULTING

A large proportion of the veins of the district occupy fault fissures or fissures closely associated in origin with the faulting of the volcanic rocks. As many of these fault fissures do not separate recognizable stratigraphic units that would permit displacements to be measured, the relative favorableness of faults of different magnitude as sites of ore deposition is a matter that can not be determined by accurate statistical study. Some ore bodies of the district occupy openings along fractures, where there has been little or no relative movement of the walls; others occupy faults that are known to have displacements of several hundred feet. It would be desirable if possible to classify the vein fissures according to their origin in relation to faulting, but only a small proportion can be rigidly classified in this manner. Among the several kinds are the following: (1) Fissures or openings that have been formed along fault planes or within fault zones, which are usually known as fault fissures. Many of the fault fissures of this district were produced by rupture of the volcanic rocks under gravitational stress, as described in the section on geologic structure (pp. 46–50). The Cocomongo and Paragon faults are examples. (2) Fissures which are formed in the walls of gravitational faults by the opening of tension or compression fractures but along which there is comparatively little or no faulting. The vertical fissure veins of the Cocomongo mine represent this type. (3) Fissures of uncertain origin that are less directly related to large faults. These may be tensional or torsional fractures that were formed by stresses developed in bodies of rock during the period of faulting. Their relation to any individual fault is perhaps remote. Some faulting may have subsequently taken place even along fissures of this type. Certain features of the different types of faults are considered in the section on structure.

In the Bonanza district not only the fissures but even some of the larger fault zones seem to have served as channels of circulation for ore-bearing solutions. Large openings in those major fault zones that have been mineralized were rather irregularly distributed and comprised only a small proportion of the total volume of the fault zones. Movements that continued during the period of ore deposition were apparently of vital importance in the mineralization of these large faults and in aiding the movement of the solutions and their access to neighboring fissures that perhaps did not have direct connection with the deep-seated sources of the metals. It will therefore be well to consider in detail the relations between the period of faulting and the period of ore formation. Practically all the faults that separate dissimilar rocks and are known to have appreciably large displacement exhibit some degree of mineralization, such as the deposition of quartz and sulphides along them or alteration of their wall rocks by silicification, sericitization, or pyritization. In some large faults the only noticeable alteration at the outcrop was silicification. Alteration of this type has occurred in the walls of many faults along which the displacement is probably measured in hundreds of feet, such as the fault contacts between pre-Cambrian rocks and andesite near the head of Squirrel Gulch. Many fault contacts between the Rawley andesite and Bonanza latite, where the displacement is 400 or 500 feet or more, show both silicification and bleaching of the wall rock. (See pl. 1.) Vein minerals such as quartz, barite, and minor amounts of sulphides commonly occur in small amounts and have encouraged the prospecting of many such fault zones, although a large proportion of them were either too tight or too gougy for ore formation or perhaps did not have direct enough access to the source of the ore-bearing solutions of high metal content. This latter possibility is also suggested by the fact that at some distance from the centers of stronger sulphide mineralization the only vein matter present is barren quartz or chalcedony.

Silicified zones in the walls of faults are of much more common occurrence than the mineralized zones of commercial importance, in which, superimposed upon the early silicification, occurred other types of wall-rock alteration specifically related to sulphide deposition. There can hardly be any doubt that the phenomenon of silicification, evidence of which is so common throughout the district, represented the earliest stage of hydrothermal activity. (See pp. 71–75.) It may therefore be assumed that faults which show only this stage of alteration are older than the ore deposits, even though they are comparatively barren of sulphides or vein matter. Many faults whose walls were silicified have subsequently been relatively inactive, so that, although they were, when formed, comparatively permeable channelways, they have been effectively sealed against later mineralization. This seems to be true of many faults of large displacement. The evidence so far as it relates to premineral faulting therefore favors the view that this faulting was very intense and that most of the major faults of the district were in existence before the period of ore formation.

Few examples of an ore body displaced by faults that are entirely of postmineral age have been recognized. Postmineral fault displacements of a few feet, where the fault zone is essentially open and unaltered, have been recognized in the Cocomongo mine. Such small faults seem to be of little significance, because minor adjustments of the rocks commonly continue in regions of intense deformation for long periods of time. Minor faulting continued even into Pleistocene time in the Leadville district.[78] In other places, however, ore ends abruptly against faults that give evidence of having been in existence before ore formation, yet the ore may be crushed and apparently faulted off where it abuts against the fault. Where the cross fault is clearly premineral it is apparent that movements along this fault have continued even after the formation of the abutting vein. It is well recognized not only from geologic evidence but from seismologic studies of modern faults that fault movements are commonly of an intermittent nature and have extended over long periods of time. That many of the faults of the Bonanza district were not only active before and during the period of mineralization but continued so for some indefinite time afterward is well demonstrated by the nature of the vein filling and by the crushing of vein matter. In the Rawley vein, along which there has been comparatively little fault-

[78] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, pp. 85–86, 1927.

ing, at least several major periods of movement may be easily recognized. (See fig. 13.) Along faults of large displacement, such as the Paragon fault, there were probably many successive major movements. As each movement may be in a somewhat different or even an opposite direction from the others, it is easy to see that the early history of a fault may be largely obscured by the effects of its latest movements. Thus it may not be possible to determine whether the greater part of the fault movement occurred before, during, or after the period of ore formation. The relations already deduced, however, that the major displacements of many large faults were premineral and that postmineral dislocations were of minor amount indicate that the main adjustments along old fault lines had established approximate equilibrium either before the period of mineralization or early in that period.

Evidence of postmineral movement along intersecting veins or fissures, if sufficiently pronounced, may be easily misinterpreted as showing that the brecciated ore found in one fissure is drag ore that has been derived entirely from the other one. Even ore that has been dragged many feet by movement on an intersecting fault does not in itself prove that this fault zone is of postmineral age. It has been said that ore from the Rawley vein was dragged 10 or 15 feet into the Paragon fault, yet it can also be shown that the Paragon fault zone, because of its content of vein matter, must have been in existence before the main period of ore formation. (See pp. 108–109.) Other criteria than faulting of ore must be applied to determine the age of formation of a fault zone. It is probably rarely possible, however, on faults of this kind to determine the relative amounts of the movements that preceded and followed ore formation. The distribution of ore in a vein with relation to a cross fault may give some evidence on this problem. If the ore in a displaced vein on both sides of a fault is much the same and continues uniformly to the fault on each side it is probably reasonable to assume that the faulting was mostly of postmineral age. If, on the other hand, the vein noticeably widens or becomes choked near the fault, if the ore shoots bear some relation to the fault, or if the mineralization and banding of the vein on the two sides are greatly different, it is clear that the cross fault has influenced the width of the fissures and the distribution of the mineralization in them. Under such conditions the fault movements are more likely to be partly premineral and partly of the same age as the mineralization. Minor changes in the structure of the vein across a fault fissure can not be considered very conclusive evidence, because different parts of a once continuous vein might be faulted into juxtaposition and so give the appearance of a change in character of the vein.

The parallelism of an ore shoot to a cross fault or change in metal content near the fault is excellent evidence that the fault has influenced ore deposition. Where a vein has been formed by repeated openings of the fissure, so that the vein structure is more complex in one or the other wall of the cross fault, the possible influence of the fault on ore deposition should be suspected. For example, if a vein were reopened along a cross fault at such a time during the period of mineralization that the fissure filling of this stage consisted largely of galena, then the occurrence of galena shoots paralleling the sides of the fault would constitute evidence of its influence. Minor galena shoots that are probably of this origin are noticeable in the Rawley vein under the footwall of the Paragon fault. The Empress Josephine and Now What veins also exhibit ore shoots that follow the walls of cross faults. In the Empress Josephine these shoots consisted of telluride ore high in silver and gold, so that the influence of cross faulting was of considerable economic importance. If the mineralization is only of the base-metal type these shoots may enrich or widen the vein sufficiently to "sweeten" the ore near the faults, but small base-metal shoots of this character occurring in small veins would rarely be of economic importance in themselves.

If the vein ends against a cross fault and nothing is known regarding the distribution of ore shoots relative to this fault other than is exposed in a single drift, the determination of the age of the fault must depend upon the presence or absence of drag ore, or of mineralization within the fault itself. Mineralogic criteria can generally be applied to determine if any given fault or fissure is of premineral origin. The presence of silicified rock or jasper in the wall or of altered rock of the other types previously mentioned constitutes an indication that the fracture existed before the ore period. The jasper may have been brecciated and subject to later alteration, such as sericitization or pyritization, which would show that it continued to be active during the period of ore formation. If this later faulting movement was sufficient to form open cracks in which sulphides and quartz were deposited the evidence is of course conclusive. Too great formation of gouge may, however, have effectively sealed the fissures from later veins and sulphides, with the possible exception of pyrite. Even though the gouge may have choked the fissures so that veins were not formed, most of them were sufficiently permeable to be subject to some degree of hydrothermal alteration. The kind of alteration associated with the ore period resulted in the formation of sericite, quartz, carbonates, and pyrite within the gouge. Some gouges in fissures that contain no visible vein material may by examination with a hand lens show the presence of small crystals or cubes of pyrite or of terminated crystals of quartz.

Microscopic and chemical examination will enable the easy recognition of carbonates and sericite. In highly altered fault gouges the titanium that was contained in the rock silicates has commonly been set free in the form of rutile or anatase. (See pp. 68, 120.) The presence of these minerals can be recognized only under the high power of the microscope. Their association with sericite may be considered conclusive evidence that the altering solutions were of comparatively high temperature and belonged to the ore-forming period.

Although in different parts of the district the fault systems differ in their directions and relations to one another, the same general time relations between ore deposition and faulting holds true throughout the district.

INFLUENCE OF COUNTRY ROCK ON ORE DEPOSITION

The influence of country rock on ore deposition in the Bonanza district is difficult to evaluate, but all the evidence accords with the conception that the basis of this influence lies in the physical rather than the chemical properties of the rocks. Most of the developed deposits lie between walls that are either entirely andesite, or andesite and latite in fault contact, or entirely latite, but no constant differences in the character of the gangue or ore minerals are apparent under these different conditions, although the greater number of ore bodies occur in mines in andesitic lavas, which have yielded the greater part of the production.

The formation of premineral gouge, which probably had an important influence on the migration of ore-bearing solutions and the deposition of ore, seems to have been dependent on several factors—the reaction of the rocks to fissuring, the amount of softening caused by wall-rock alteration, and the displacement and attitude of the faults. Faults of comparatively gentle dip, such as the Cocomongo, Clark, Rico, Hanover, and Exchequer, and those of great displacement, such as the Paragon, contain large amounts of sericitized gouge filling. However, many fissures and faults in the younger latitic and rhyolitic lavas, including the upper rhyolitic member of the Bonanza latite, seem on the whole to be more choked with altered gouge and rock fragments than those in the underlying, more massive flows. It must be admitted that such a comparison is based on rather unsatisfactory statistical evidence, as the amount of development in the different formations is not comparable. Even casual observation of fissures exposed in small prospect pits and tunnels, however, suggests the conclusion that the lavas in which platy partings are well developed parallel to the flow banding tend to form shatter zones and small stringers and to break into fragments that are smaller and more platy than those formed in massive structureless rocks such as andesite.

The distribution of sericitized and carbonatized rocks with reference to fissured zones and the conditions revealed by microscopic examination of such rocks suggest the importance of surface attack of the solutions outward from the larger fissures along small fractures, grain boundaries, or permanent cleavage lines. Thus as the amount of chemical reaction of the wall rocks with the ore-bearing solutions appears to be dependent primarily on the surface exposed to attack, rocks that shattered more completely would expose greater surface to this attack and would become softened near the fissures. Recurrent fault movements during the period of alteration would thus more readily reduce the partly altered rock to gouge. The amount of chemical attack involved in sericitization and carbonatization may in this manner have played a part by hindering the formation of openings favorable to ore deposition in certain of the lavas.

The field relations of the silicified rocks, on the other hand, indicate that the silicifying solutions gained access to the rocks by diffusion through the pores of the rocks from near-by open trunk channels. The boundaries of the silicified zones end sharply, without any very definite relation to major or minor textural features of the rock, although here and there the silicification of latites and rhyolites is seen to have proceeded along prominent parting planes.

Although the diffusion of alkaline solutions into the pores of rocks was a factor in the process of sericitization, there is ample evidence that the diffusion of acid solutions, which promoted silicification, was of a vastly greater order of magnitude. Perhaps for this reason silicification seems to have affected all types of volcanic rocks about equally. So far as can be observed it had no unfavorable effect on later mineralization; on the contrary, there is good reason to believe that silicification of the walls favored later fissuring. Moreover, as it tended to strengthen the wall rock and rendered it more resistant to the formation of the relatively soft carbonates and of the much softer micaceous minerals, such as sericite and chlorite, silicification reduced the later formation of gouge. The walls of practically all the larger veins in the district were silicified to different degrees. Many good ore shoots have walls of brecciated jasper, indicating that movement occurred along the fissure after the silicification of the walls but before the ore was deposited. It is generally noticeable that under such conditions minimum amounts of premineral gouge were formed.

Besides the chemical and mechanical effects of wall-rock alteration on ore precipitation, there is the effect of the reaction of different formations to deformation during the period of faulting. Lavas that are characterized by pronounced platy partings or flow structure undoubtedly reacted to stresses producing deformation somewhat differently from the more massive lavas. This difference is particularly noticeable in the western or northwestern part of the district, where the Bonanza latite and overlying flows are the predominant surface rocks. Throughout this area these flows are tilted to moderately high angles, so that where they were faulted there has been a strong tendency for shearing to occur approximately parallel to the parting planes. The result has been the formation of parallel branching fissures which constitute a shear zone rather than a simple break. (See pl. 2 and fig. 6.) The effects of this change in formation may be seen by comparing the structural pattern of the faulting in the areas mentioned with the more blocky pattern occurring in the massive andesitic lavas to the east. (See pl. 1.)

Effects produced by change in country rocks on fissure systems have been noted in other districts in the San Juan Mountains. Purington[79] refers to this subject in describing the fissure veins of the Telluride quadrangle, saying:

> The fissure systems enumerated, and consequently the veins, penetrate all the rocks occurring within the area. There seems to be little doubt, however, that a mechanical influence on both the nature and degree of development of the fissured zones has been exercised by the rocks of the various horizons which they traverse. Thus in the case of the Smuggler and Tomboy veins it is evident from observation that the lodes[80] are continuous from the breccias of the San Juan formation through the andesite and rhyolite flows above. In the upper workings on the Smuggler vein, however, where excellent exposures on the vein may be seen in both the rhyolite and underlying rocks, considerable differences are apparent. No change was observed in the amount of fissuring between the breccias and the overlying andesite, but in the upper rhyolite, although the fissures are constant in direction and although the zone is equally wide, the amount of space now filled with ore is much less, and the fissures themselves did not apparently afford as much open space as did those below. It seems probable that the upper rock offered a greater amount of resistance to the rupturing force than those below.

A similar constriction of the Camp Bird vein,[81] in the same region, has been noted, where it passes from the andesite breccias and flows into the overlying Potosi volcanic series.

It is clear from the conditions observed at Bonanza, as well as from the similar examples cited above from other areas in the San Juan Mountains, that the mode of deformation of volcanic rocks differs appreciably from one formation to another. In deposits of certain types of high-grade ores the existence of irregularly fissured ground, comprising many small fractures or fissures that form a zone of the lode type, is especially favorable; on the other hand, for base-metal deposits of the kind found in the Bonanza district, the existence of a few openings of large size is distinctly more favorable than these more complex types of fissuring. But whether the mechanical effects of such differences can account for the distribution of ore between the different formations in the Bonanza district or whether other factors have been equally or more important is difficult to judge. The principal reason for this difficulty is that the upper rhyolite member of the Bonanza latite and the overlying rhyolites and latites have been eroded from the parts of the range where the mineralized fissures have received the bulk of the mining development.

In Figure 12 some of the larger veins of the northern part of the district are plotted, showing their vertical range relative to the surface of erosion and to the base of the Bonanza latite. Nearly all the veins occur within a vertical range that extends 500 to 1,000 feet below the base of the Bonanza latite and several hundred feet above it. The Rawley, Whale, and Joe Wheeler veins, in the andesite, probably reach the greatest depth below the base of the latite, and the Cocomongo and Bonanza veins are the highest productive veins above its base. In many of the developed veins the better bodies of lead ore ceased to be profitable several hundred feet below the outcrops. In relatively few of the mines mentioned above were deeper explorations attempted, and these gave different degrees of success, but all of them indicated that the lead decreases markedly in depth. Little or no evidence is available to show how much of the upper parts of the ore bodies has been eroded from veins that cropped out, but the lead and zinc ores could not have extended upward above their present outcrops indefinitely, as the nature of some of their minerals is such that they would hardly have formed under conditions existing close to the surface. The overlying cover of lavas, now eroded, probably was within a range in thickness of not less than 1,500 to 3,000 feet, judged only by what is known of the lava sequence. As none of the lavas above the lower member of the Bonanza latite have been found to contain lead-zinc ores or other vein deposits of favorable nature, it becomes necessary to consider the possibility of a definite upper limit as well as a lower limit to the valuable base-metal mineralization.

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79 Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 16, 1899.

80 Purington defines lodes as "narrow zones of closely spaced fissures, which have been filled with ore."

81 Spurr, J. E., The Camp Bird compound vein dike: Econ. Geology, vol. 20, p. 129, 1925.

One of the outstanding features of the distribution of ore in the northern part of the district is that the zone of productive veins bordering Rawley and Copper Gulches stops relatively abruptly toward the west or southwest beyond Kerber Creek. West of a line along or near Kerber Creek extending from the town of Bonanza northward to a point above the Cocomongo and Bonanza veins there are no veins that have yielded production of any importance. There appear to be at least two possible explanations of this—(1) that the zone of mineralization, which may be assumed to be related to some favorable structural feature, such as a zone of particularly strong tensional conditions, or to an underlying intrusive body, is limited to the belt within which productive veins crop out; or (2) that the exposures of the zone of mineralization are limited by reason of unfavorably fissured surface rocks, and that part of the zone lies concealed beneath the lavas. If the upper limit of deposition of high-grade galena ores had occurred roughly at the horizon of lavas overlying the massive lower member of the Bonanza latite, some ore bodies are perhaps concealed beneath unfavorably fissured ground in the region just west of the northern area of mineralization. The only means of definitely deciding this question will be exploration to greater depths in this part of the district. At present the deepest known exploration along Kerber Creek is at the Cocomongo mine, which extends only to a vertical depth of a little more than 400 feet below the outcrop of the Bonanza vein. That the character of the fissuring might become more favorable in depth in these parts of the district is suggested by reasoning that the underlying andesite would have promoted the formation of more open fractures and that the increased pressure at greater depth would have favored less complicated fissure systems. On the other hand, there are certain unfavorable features to discourage deeper explorations, such as the possible existence of temperatures that were too high for the formation of lead ores. Moreover, the evidence on the whole favors some major structural feature of the district, rather than change in character of country rock, as a primary cause of the limits of the strongly mineralized zones.

In the southern part of the district any relation of deposits to country rock does not seem to be well defined. So few veins have been developed that generalizations can not be made. Veins are found in many of the different kinds of rocks. Practically all production of the southern part of the district has come from one mine, the Eagle mine, in Eagle Gulch (No. 21, pl. 1). The Eagle vein lies in the Eagle Gulch latite. The Oregon vein also lies along the border of this intrusive porphyry, and numerous smaller viens have been prospected within its boundaries.

On the north flank of this porphyry mineralization seems to have been comparatively feeble, at least at the horizons exposed by the present erosion surface. The zone of mineralization extends south of Eagle Gulch practically to the southern limit of the area mapped, but in the extreme southern part of the district the fissure filling is largely quartz with manganese and iron oxides and relatively small quantities of sulphides. The veins occur in the Rawley andesite, in some of the Hayden Peak latite flows, or associated with intrusive bodies of quartz latite and rhyolite in fault fissures. So far as can be told from the few developed veins the effect of the country rock on the nature of the fissures and vein filling was not marked. The present development of this part of the district seems to furnish little reason for considering any of the formations particularly unfavorable for exploratory work with the possible exception of the rhyolite intrusions. Exploration in the Express mine is not yet of sufficient extent to indicate the influence of the country rock on the vein system. The rocks at present encountered in the workings are of two types—intrusive porphyries associated with the center of intrusive activity north of the mine and andesitic lavas representing the older country rock, which lies mainly to the south. So far as known little mineralization of economic value has occurred in the neck of intensely altered rhyolitic intrusive rocks and breccias which lies between Express and Chloride Gulches. The general impression obtained from studying the small veins and meager explorations in this part of the district is that veins in the andesitic lavas or in the Eagle Gulch latite are more favorably mineralized than those close within the area of the rhyolitic intrusives.

The Hayden Peak latite is also devoid of productive ore bodies, but here again the reasons are possibly structural rather than related to some chemical or textural effects of the vein walls. Alteration in the main part of the Hayden Peak latite has been relatively weak compared to that in the areas to the west, and it would appear that for some reason the faults in this part of the district were less favorably situated for the ore-depositing solutions to gain access to them. This statement is not intended to imply, however, that the area occupied by this formation is entirely unfavorable for prospecting but merely that the possibilities appear less promising than in certain other parts of the district.

RELATION OF ORE SHOOTS TO STRUCTURE

INFLUENCE OF MINOR STRUCTURAL FEATURES

The problem of the formation of ore shoots largely resolves itself into an investigation of the causes of openings in rocks, as the veins are due much less to the replacement of wall rock than to the filling of fissures. As there are many structural conditions which may produce favorably fissured ground but many of which are not understood, even as to structural mechanics, it is apparent that there are many difficulties in predicting the position of an ore shoot much in advance of actual development. However, it seems possible that ground toward which exploration should be directed may be recognized by the application of structural studies.

Many of the causes of the formation of ore shoots have been discussed at length in mining and geologic literature, and some of the favorable conditions are mentioned incidentally in this report in the sections on mineralization and faulting. It will be well, however, to review and discuss briefly certain of the causes of ore shoots that appear to have been effective or that may have application in this district. These causes may be enumerated as follows: (1) Changes in either strike or dip of fault fissures, or in both, aided by the relative faulting motion of the walls; (2) intersections of fissures and the presence of cross faults; (3) simple opening of fissures, by tensional or torsional stresses developed by movements on nearly transverse major faults, or by stresses developed by gravitational adjustments of large fault blocks in which the fissures lie; (4) intrusion of dikes between fissure walls; (5) production of breccia or gouge during faulting and mineralization.

1. The greater part of the production of the district has come from a comparatively few veins of steep dip. The Cocomongo and Bonanza veins are partial exceptions, although the production from these came largely from stopes in which the dips ranged from 40° to 60°, the flatter portions of the veins having so far yielded little ore. Some of the veins and faults in the district have a tendency to flatten in depth, those in the northwestern part of the district flattening toward the east. This phenomenon is believed to have been produced by normal faulting of the gravity or landslide type. In the western part of the district some of the faults may be expected to flatten in depth, and this is probably a condition unfavorable to the existence of large or continuous shoots of high-grade lead or zinc ores at still greater depths. It is obvious that flat faults can not remain open under great pressures except over short stretches, as the hanging wall will be deformed under its own weight and tend to close any opening produced during fault movements. The intense fracturing and jointing of all the formations within the area of greatest faulting is very likely the result of small adjustments of this nature. Many flat faults are mineralized, however, although they are characterized by small lenticular ore shoots separated by barren gougy stretches. Unless such ore shoots are of high enough grade to pay for finding and developing them, which is rarely the case in base-metal veins, the gently dipping fault fissures are commonly unfavorable as major sources of ore. They are likely, however, to have had favorable effects on the mineralization of neighboring steeper fissures in the hanging wall or footwall. None of the very low angle faults of the district have ever been profitable, except in a small way, and the total amount of production from them has been small.

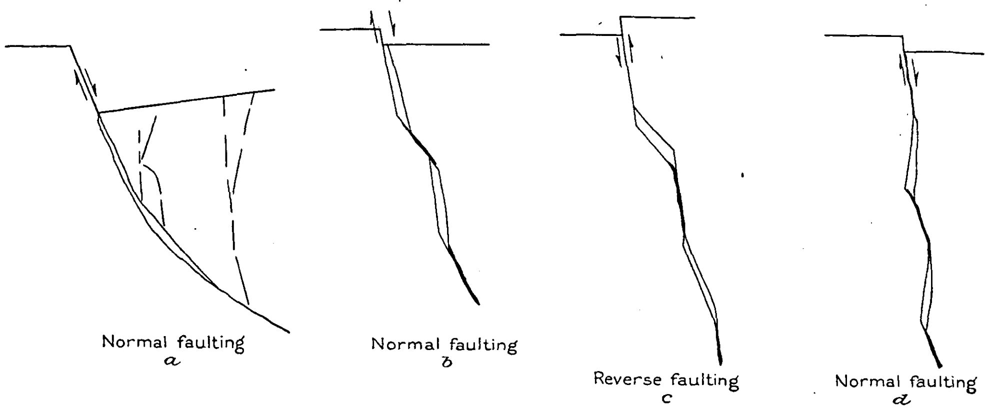


FIGURE 19.—Formation of open spaces in fault fissures such as are encountered or likely to be encountered in the veins of the Bonanza district. *a*, Conditions encountered in a large normal fault of the Cocomongo-Bonanza type; *b*, *c*, *d*, ideal formation of openings caused by normal and reverse faulting where the fissure undergoes irregular changes in dip; *d* is a special case of *b* showing reversal of dip where opening is formed

As most of the fissures show fault movement, changes in dip or strike, which are caused by curved or abrupt angular irregularities of the fault planes, are probably among the common causes of openings in which ore shoots lie. In practice these irregularities can be detected and to some extent predicted by continuous recording of the strike and dip of both walls and plotting of such records on mine plans and sections. The effect of irregularities of the walls depends on the character and direction of fault movement. If the movement is predominantly down the dip, as in normal faulting, an abrupt flattening of the dip may cause an opening above the flatter portion of the vein, owing to the unconformity of the adjoining walls. (See fig. 19, *a*.) An abrupt steepening or reversal of the dip in a normal fault may cause an opening below the flatter portion of the fissure. (See fig.

19, *b*, *c*, *d*.) Changes in strike may cause similar openings along the vein by reason of a horizontal component of movement along the fault plane.

An opening that appears to be due to a local steepening or reversal of dip is shown in the Joe Wheeler vein, but this was not sufficiently developed to disclose the normal dip of the fissure. An ore shoot possibly due to flattening and reversal of dip is also shown by the section between the 600 and 700 foot north levels of the Rawley vein. (See pl. 26.) The 680-foot level showed the richest ore body, which as seen from the sections lies in a very favorable position below a slight reversal of the dip (the normal dip of the Rawley vein is 85° E.) and above a flattening portion of the vein. The exact amount of the movement on the Rawley fissure could not be determined, but there was probably a small displacement of the normal type—that is, downthrow of the hanging wall of the fissure (p. 108).

2. Cross faults intersecting a mineralized fissure appear to have favored the formation of small ore shoots at the intersection. The ore shoots in the Empress Josephine vein have a pitch to the east in conformity with a series of small faults of the same pitch. Many of the shoots are said to be bounded on one or both sides by these faults. (See pl. 33.) The Empress Josephine vein was not accessible during the present investigation, but what is apparently a relation very similar to that above mentioned was seen in the Now What vein, on the opposite side of Copper Gulch. This is an east-west vein that is faulted by a series of small north-south faults, most of which dip eastward. (See fig. 40.) The main vein is noticeably wider and more strongly mineralized immediately in the footwall of several of the eastward and westward dipping cross breaks. The cross breaks, though showing some alteration, are tight and gougy and not strongly mineralized themselves. It is probable that the cross faulting occurred in part during the period of mineralization and therefore controlled the movement of solutions in the segments of the slightly faulted vein. Some of the cross faults show slight postmineral movement.

Probably, however, ore shoots closely related to cross faults are not as a rule large enough to be of economic importance unless the mineralization has produced high-grade ore, such as was found in the Empress Josephine. Shoots that probably had this origin have been found in the Rawley vein close under the footwall of the Paragon fault. The openings containing these shoots were formed at such a time during the period of mineralization as to become filled largely with galena and to enrich the ore near the fault.

3. The formation and opening of transverse fractures in the walls of major faults is clearly one of the causes, but possibly a minor one, by which ore shoots are formed. On a small scale the hanging-wall or so-called "vertical" veins of the Cocomongo well illustrate this in principle. The exact cause of the formation of these fractures is obscure, but they are restricted to the hanging-wall block and are steeper than the main fault. Their strike is transverse to that of the main fissure, and their intersection consequently rakes down the dip. The position of some of these vertical faults appears to be related to variations and "rolls" in the strike or dip of the main Cocomongo fault, and so they were presumably caused by tensional stresses produced in the hanging-wall block where it bore against the ridges in the footwall (see pl. 29), or by shearing induced where the support of the hanging wall was in some manner unequally distributed. The gaping of these fractures also appears to be related to tensional stresses developed by movements on the major fault, as the fissure or fissured zone becomes narrower outward and upward from the main fault. (See pl. 28.)

Fissured zones of this type are probably more likely to be found in the hanging-wall blocks of normal faults that are of fairly large displacement and not very steep. One of the favorable features of this type of fissuring is that some of the fissures show but little faulting movement and are in consequence relatively free of gouge, but the veins may be more or less "frozen" to the altered wall rock. In regions of high-grade ore or replaceable wall rock small fractures of this type in the walls of mineralized faults assume considerable importance. Fractures in the Creede district that are probably like these have been figured and described by Larsen.[82] In base-metal deposits the only parts of these transverse fractures likely to be of economic interest lie near the intersections of the fractures with the main fault. (See fig. 20.) In the Cocomongo mine, where the development of one hanging-wall vein was carried to a distance of about 300 feet from the main fault, the fissure became reduced to only a foot or so in width. It is conceivable that in a region so intensely faulted as the Bonanza district fractures of this origin, especially if developed early in the period of deformation, may have later become fracture zones along which faulting took place. (See fig. 21.) The structure of the Bonanza vein of the Cocomongo mine, which is considered in more detail in the description of this mine, is believed to have resulted from a hanging-wall fracture of the Cocomongo fault that later developed into a fault fissure.

[82] Larsen, E. S., Geology and ore deposits of the Creede district, Colorado: U. S. Geol. Survey Bull. 718, pp. 150–151, 1923.

It appears likely that where the main fault undergoes a change in dip transverse hanging-wall fractures may swing appreciably in their course, tending to parallel the main fault, and consequently may develop into gravity faults by reason of stresses that exist in the active hanging-wall block. That the Bonanza fault

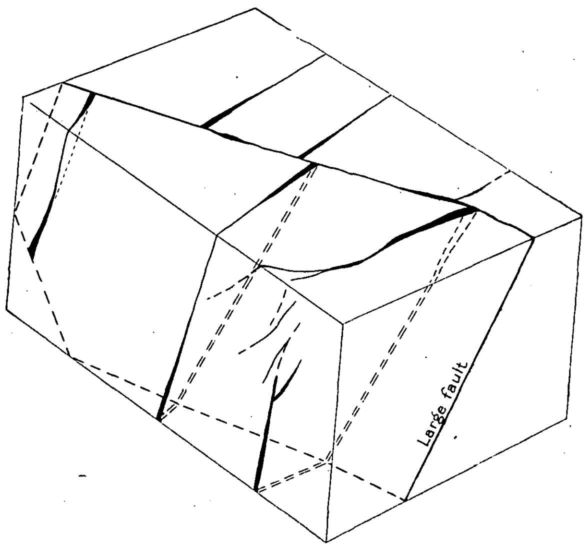


FIGURE 20.—A series of fissures transverse to a main fault, in which the more strongly mineralized parts of the fissures lie near the main fault. Movements on the large fault during ore deposition tended to keep the fissures open. The main fault may perhaps be too choked with gouge to contain large ore bodies

fissure may have had this origin is suggested by the fact that in the broken zone near the intersection of the Bonanza and Cocomongo fissures the fractures have the direction and characteristics of steep transverse fractures developed by torsional or tensional stresses in the wall (pl. 28), but the Bonanza vein veers southeastward away from the Cocomongo fault and assumes the characteristics of a gravity fault more nearly paralleling the strike of the Cocomongo fault. This is illustrated diagrammatically in Figure 22.

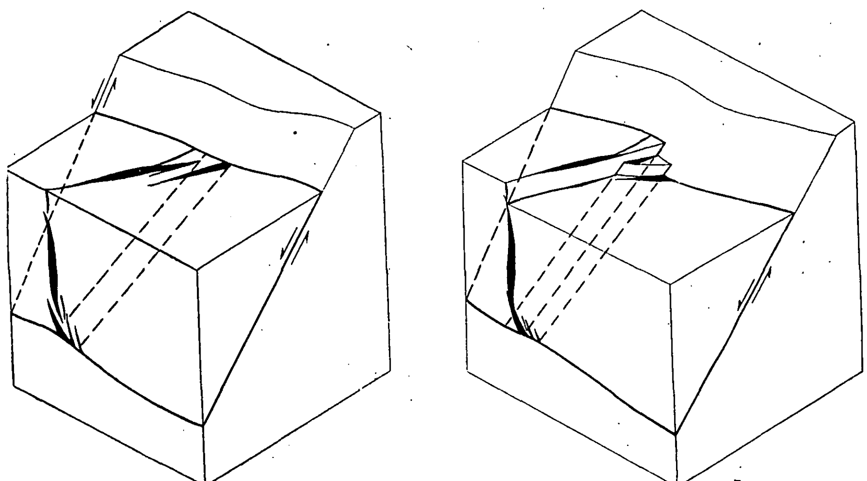


FIGURE 21.—Development of transverse fractures in the walls of large faults. *a*, Simple hanging-wall fracture; *b*, hanging-wall fracture later developed into a fault

The development of complex systems of tensional stresses in fault blocks induced by gravitational adjustments may very likely have been more influential in producing ore shoots than the formation of the

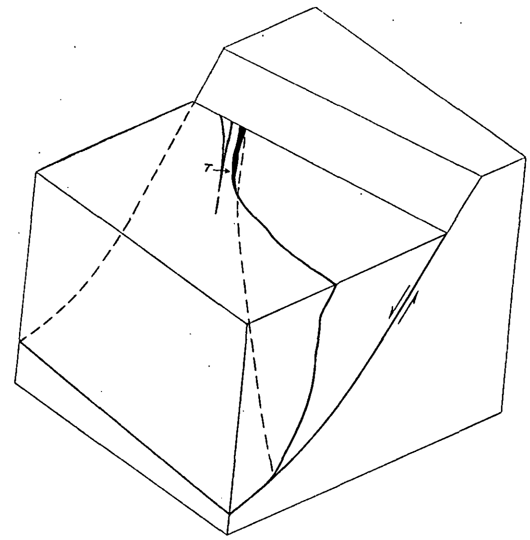


FIGURE 22.—A transverse fracture swinging from its transverse strike to one nearly parallel to the main fault, forming a gravity fault supplementary to the main fault

minor transverse fractures just described. In the examples cited the stresses had their maximum development fairly close to the fault plane, and their influence became weak at distances of several hundred feet from the fault. Near major faults of large displacement, such as the Paragon fault, the influence of secondary stresses developed during the subsidence of fault blocks may extend much farther from the place of its origin. Large fault blocks that are bounded by major faults may become subjected to combinations of such systems of stress, which are called torsional stress. If preexisting fractures are present in the fault block these stresses may be partly relieved by movements of the walls of such fractures; if there are no preexisting fractures and the stresses are great enough, new fractures may be developed transverse to the bounding faults. The possibility that stress of this nature may have had an influence on the opening of fissures and the consequent formation of ore shoots may be illustrated by the major fault and fissure systems near Rawley and Sosthenes Gulches. In this vicinity the north-south fissures are generally disrupted by a series of east-west faults, the largest of which is the Paragon fault. Running east and west roughly along the line of Sosthenes Gulch is another zone of faults, of less magnitude than the Paragon.

South of Rawley Gulch there is a third series of parallel east-west fault fissures. Practically all the economically important ore bodies of this area that have been discovered up to the present time lie in the north-south fissures but near the strongest zones of east-west faulting. The east-west faults are nearly all mineralized, but most of them have been too choked with gouge to be themselves especially favorable to the formation of ore shoots. The character of the mineralization in them shows that the latest faulting movements were of greatest strength along these faults. The north-south fissures, though having in general less fault displacement, are so mineralized as to indicate successive reopenings during the period in which the east-west faults were active. (See fig. 16.) Therefore as the forces that caused the gaping of the north-south fissures probably had their origin near the major faults, their influence would have become less effective away from these faults, because of the dispersion of the relief along minor branching fractures. This condition is possibly illustrated by the Rawley fissure, which splits and becomes less productive northward from the Paragon fault. The productive part of the Michigan fissure also lay well within 1,000 feet north of the Paragon fault. On the south side of the Paragon fault is the Rawley-Tip Top vein, which to the time of writing had been developed only a few hundred feet into the hanging wall of the Paragon and had encountered other east-west breaks. The Whale vein is inaccessible, but it is likely that the vein lies between east-west faults paralleling the Paragon and other east-west fissures to the south, such as the Superior and others beyond. The Merrimac and Vallejo fault of Sosthenes Gulch dips southward like the Paragon. North-south ore shoots that have been developed near it are the Sosthenis on the north and the Little Jennie on the south, which splits southward from the gulch. At the north end of the Antoro vein there are cross faults, and the south end of the ore shoot is limited by the east-west mineralized Poverty fault. The Payson ore shoot, which may lie in the northward continuation of the Antoro fissure zone, also lies between zones of cross fissuring.

4. The intrusion of dikes between fissure walls may assist to some extent in holding apart the walls subsequent to the solidification of the dikes, and as some of the dikes apparently terminate upward without having reached the surface these bodies may play an important part in controlling the movements of mineralizing solutions. The dikes themselves, other than as an indication of the depth to which the fractures extend, probably bear no direct relation to mineralization. They are certainly not the source of the mineralizing solutions. The porphyry dike of the Rawley vein lies in lean parts of the fissure, but it may have exerted some control on the structure of the fissure immediately adjacent to it, or it may have acted as a barrier to free circulation of the solutions and in that way indirectly influenced the position of ore shoots. So far as is known the dikes in the district are of premineral age, as they are nearly all altered in a manner similar to the wall rocks and are not seen to intrude ore bodies. Some of the coarse-grained monzonitic dikes may be of very late age, as they are but slightly altered, but their time relation to ore deposition has not been determined.

5. In some of the ore shoots in the district the ore shows clear evidence of being due to filling and replacement of breccia material. The breccia fragments are generally siliceous, the original minerals having been replaced by quartz, with some pyrite and zinc, and between the fragments heavier sulphide ore has been deposited. The relations indicate that the space between vein walls was more or less filled with rubble sufficiently coarse to be easily permeable to migrating solutions. Coarse brecciated material of this character would appear in general to be very favorable ground for deposition. If, however, the size of the material is too greatly reduced by attrition, as would result between fault surfaces of great displacement and low dip, the clayey gouge thus produced would act as a barrier to circulation and free deposition. Clayey or gougy breaks are present in many veins on one or less commonly both walls of an ore body, but the heavy gouges that are characteristic of flat faults in the district are generally found to be unfavorable. Gougy breaks in the walls of even the steeper veins have, however, caused some difficulty in the district in several places where shrinkage-stope methods have been used, as the barren wall has partly fallen in and diluted the ore. Exceptions to the nonoccurrence of ore shoots adjoining heavy gouges are found in parts of the Cocomongo vein and in the Clark vein of the Rawley drainage tunnel, but the shoots are apparently lenticular and liable to be cut off abruptly either horizontally or vertically. A few of the small lenses of silver-bearing ore that occur in such gouge material, as mentioned above, may be mined.

RELATION TO MAJOR STRUCTURAL FEATURES

Within the area north of Elkhorn Gulch (see pl. 1) about one-half of the rock exposed at the surface is andesite. Exclusive of the production of the Rawley mine since 1926, about 65 per cent of the total production from this area since 1880 has come from veins in andesite; the remainder came from veins in the lower part of the Bonanza latite. There has been no production of any consequence from overlying lavas which flank this area on the west, yet these lavas are equally faulted, and the effects of the hydrothermal activity that accompanied mineralization extended for a mile or two west of the zone of producing veins. It is of importance with a view to guiding future exploration to examine the geologic setting of the mineralized fissures and to consider possible causes of this restriction of the productive veins. It seems probable that the influence of structural features has been much greater than that of the chemical properties of the rock. Two main kinds of faulting have occurred in the district—tensional faulting due to the vertical force of gravity and compressional or shear faulting caused by the bulged area of the crust. During the deformation of the rocks large blocks of the crust were tilted in various directions, as shown in Figure 10. The productivity of the fissures is much less in zones of steeply tilted rocks than in the zones of flatter-lying formations. The strongly mineralized areas in the north seem to coincide with the zones within which fault blocks were undergoing rapid change in tilt. (See fig. 5.) Within such areas in the vicinity of Alder Creek dropped wedges of Bonanza latite are inlaid into the Rawley andesite. (See pl. 2, section A–A′ and A_1–A_1'.) Whether or not the prevalence of tensional faulting in certain areas has localized the zones of favorable mineralization can not be definitely answered, but it appears to be the most plausible explanation of the conditions found.

In the southern part of the district the difference in structure between different areas is less pronounced than in the north. The most steeply tilted fault blocks, however, lie in the vicinity of Hayden Peak, and most of the mineralized veins lie farther southwest or west.

TYPICAL FISSURE AND VEIN SYSTEMS

RAWLEY GULCH

Extending north from the vicinity of the Rawley and Whale mines in Rawley Gulch is a strong zone of mineralized fissures which has an average width of several thousand feet and is traceable northward at least as far as the vicinity of Round Mountain. The north-south direction of fissuring in this zone is very strongly developed and is indicated at the surface by roughly parallel fissure and joint systems of this trend. The continuity of the north-south fissures is broken, however, by a smaller number of more or less prominent easterly faults, the best known of which is the Paragon fault. None of the north-south fissures are traceable for great distances, apparently in part because they are interrupted by the easterly cross faults and in part because the individual fissures tend to branch and fray out in one direction or the other. The Rawley fissure has been explored north of the east-west Paragon fault for about 1,000 feet to a point where the vein splits into diverging fissures. The east split of the upper levels may possibly be traceable into Antoro property nearly 800 feet farther northeast, but this extension has not yet been proved by developments. It can not be accurately traced on the surface. The 1,000 feet of development on the Rawley fissure north of the Paragon fault constitutes the greatest length to which a fissure has proved profitable in this entire north-south zone. Although it is possible that some fissures of this zone may extend essentially uninterrupted for even greater distances, little confidence can be placed in the continuity of commercial mineralization over such extensions.

Many of the larger fault fissures form barriers of comparatively low permeability between different fault blocks and have exerted a noticeable influence on the mineralization of abutting veins. In the vicinity of Rawley Gulch the most prominent east-west cross fault is the Paragon fault; east of the Rawley vein this strikes N. 70°–80° E. and dips about 50°–55° S., but west of the Rawley vein the strike seems to swing somewhat north of west. This fault may be traced for a distance of about 8,000 feet with certainty and perhaps for several thousand feet more, as the zone appears to extend from Squirrel Gulch at the west eastward nearly to the head of Rawley Gulch. The displacement on this fault 2,000 feet west of the Rawley vein where it faults latite into contact with andesite is perhaps roughly 1,000 feet. It is pretty certain, however, that the displacement becomes smaller in either direction from this position. As the rock, particularly in the hanging wall of the fault, is broken into minor fault blocks by abutting faults, it is probable that the displacement may change abruptly at some places by being partly taken up on certain of these transverse faults.

On the north side of the Paragon fault in the Rawley Gulch area there are two main abutting north-south veins—the nearly vertical Rawley vein just mentioned, the average strike of which for 1,000 feet is a little west of north, and the Michigan vein, which strikes N. 15°–20° E. and dips about 50° or 55° E. Between these two developed veins there are a number of parallel north-south fissures exposed at the surface, but none of these, so far as known, are well mineralized. On the south side of the Paragon fault is a north-south fissure which lies about 50 feet east of the strike line of the Rawley vein. Although this fissure may be the faulted continuation of the main Rawley fissure it lies in a different fault block, which is rather effectively sealed from the north side of the Paragon by the wide zone of crushed and gougy material of the fault. Other north-south fissures on the south side of the Paragon are the Hanover, the Whale, and several other small fissures encountered in the 400-foot adit-level crosscut of the Rawley mine. Farther east, on the south side of Rawley Gulch, is the Essie-Little Jeff vein, a north-south fissure dipping east which has been explored to some extent.

The relations between these several north-south fissures on the Paragon fault have been exposed in the workings of the Rawley and Paragon mines. The relation of the Paragon fault zone and the Rawley vein at the end of the 500-foot south level of the Rawley mine is shown in Figure 23. The Rawley vein narrows as it nears the Paragon fault and is displaced a foot or so at a time in small step faults that parallel the Paragon. Some of these small faults are at least partly postmineral. At its end the drift penetrates one of the main fault fissures of the Paragon fault zone, which strikes east and dips 58° S. This fault contains sericitized gouge and vein material composed of quartz, pyrite, galena, and sphalerite. Although this ore is partly crushed by postmineral movement, the mineralization was caused by the circulation of ore-bearing solutions within fissures of the fault zone. In the Paragon No. 2 adit (fig. 33), 1,000 feet east of the Rawley vein, the continuation of the Paragon fault is more strongly mineralized, but here also the ore is partly crushed, indicating similar postmineral movement on the fault. Still farther east in the same tunnel the intersection of the northeasterly Michigan vein and the fault is exposed. The ore in the Michigan vein gradually pinches close to the Paragon fault and spreads laterally to some extent into the Paragon at the intersection. There is little evidence of dragging of the Michigan ore at this tunnel level, and the mineralization of the two fissures could have been contemporaneous.

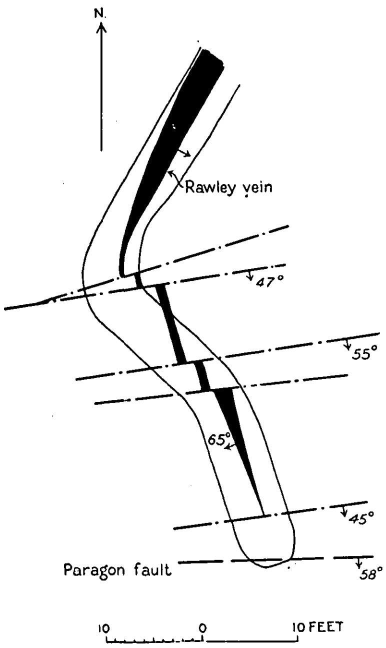


FIGURE 23.—Relations of the Rawley vein and the Paragon fault on the 500-foot level of the Rawley mine

Now, if it is assumed that the Paragon fault movement was for the most part later than the formation of the Rawley and Michigan veins it becomes necessary to assume two periods of similar mineralization to account for the ore found in the Rawley and Paragon mines. The relations shown, however, can be somewhat more simply explained by assuming that there was only one period of mineralization, which followed the formation of a large part of these intersecting fissure sets, and that minor faulting movements continued on the Paragon fault after ore formation.

Probably in part the north-south fissures are older than the Paragon fault and have been displaced by it, but other transverse fissures very likely owe their origin to stresses developed by movements on this large fault. Faulted continuations of fissures of this origin will of course not be found in the other wall of the fault.

It has been shown in the experimental production of intersecting fracture sets by torsional stress that apparent displacements of fracture may result, even though the intersecting sets are of the same age. The two sets of fractures in Rawley Gulch resemble very much those produced by torsional stress in brittle materials, so that their initial development may represent the result not of two separate and different stresses developed in the crust at different times but of stresses that were essentially contemporaneous. Steplike displacements of the Rawley fissure by the Paragon fault show, however, that movements continued longer on the east-west fault. To accept as the most common relation between the two sets that the north-south faults are interrupted or slightly displaced by the east-west faults does not imply that the east-west faults are all of postmineral age and have faulted off the veins, as many fissures of both sets are found to be mineralized. The sequence of the fissure and vein formation may be summarized for this region somewhat as follows, although the actual conditions are probably much more complicated and exceptions are to be expected.

1. Formation of north-south fissures and faults, closely followed or in many places essentially contemporaneous with No. 2.
2. Formation of east-west or northeast faults and associated transverse fractures.
3. Intrusion of dikes into fissures.
4. Early stage of barren wall-rock alteration (jaspers).
5. Continued movement on fault fissures and brecciation of jaspers, probably with the formation of new breaks and production of gouge.
6. Formation of ores in fissures and in brecciated jasper zones, accompanied by bleaching and micaceous alteration of wall rocks. Small adjustments continued on fault fissures during ore deposition, brecciating ore, forming new openings, and producing gouge streaks.
7. Minor postmineral faulting and movement on mineralized fissures. Probably the strongest on the large faults, such as the Paragon and its parallel breaks. Further production of gouge and minor brecciation of ore.

The postmineral brecciation of ore in the larger fault fissures at some places in this part of the district has been incorrectly interpreted as a result of the dragging of ore from intersecting veins.

SOSTHENES GULCH AND ANTORO MINE

The gulch lying north of the Rawley Gulch is unnamed on most maps of the district but may conveniently be referred to as Sosthenes Gulch, from the Sosthenis mine, which is near the head of the gulch. Across the head of this gulch, extending 2,000 to 3,000 feet west from the Antoro shaft, there is a zone of closely spaced north-south fissures within which is the somewhat narrowed northward continuation of the mineralized zone of Rawley Gulch. Partly because of the configuration of the topography the north-south fissures are the more prominently indicated at the surface. Among those which are mineralized are the Antoro, Payson-Radcliff, Wisconsin, Sosthenis, Little Jennie, and Gypsy Queen. Among the known east-west fissures which are mineralized and developed are the May Queen (Merrimac) and Vallejo and the Poverty vein of the Antoro tunnel. Tunnels near Sosthenes Gulch, however, intersect many other east-west faults and fissures, and although many of them are of premineral age few are strongly mineralized. The general relations between the two sets are similar in most respects to those of Rawley Gulch. Several of the mineralized north-south fissures in Sosthenes Gulch are displaced by the intersecting east-west faults, but these are mostly of premineral age, and there is also some indication on the north side of the gulch of a late system of fissures striking about N. 30°–40° E.

The Antoro vein (pl. 31) is cut off at the north end of the Antoro mine by a nearly vertical northwesterly fault. About 350 feet south of this position the northwesterly Poverty fault forms a second cross fault of the east-west series. All the developments on the Antoro vein proper lie between these two cross faults. As the relation between the Antoro fissure and the Poverty fault is not well exposed in the mine workings it is not known whether this fault displaces the Antoro vein, but it presumably interrupts it. About 200 feet south of the Poverty fault is exposed a north-south vein, known as the Zinc vein, that lies about in line with the Antoro fissure but has not been connected with it by workings. At its south end the Zinc vein ends abruptly, however, against an east-west fault. Of the east-west fissures in these workings the Poverty fault is the only one well mineralized, and a small amount of stoping has been done on this fault west of the tunnel level. A few other east-west fissures contain some vein material. The conditions suggest that the Antoro fissure was broken into several short segments by the east-west faults and that later both sets were partly mineralized.

VICINITY OF ROUND MOUNTAIN

In the vicinity of Round Mountain the Maybelle, Shawmut, Vienna, and Rico explorations are practically the only accessible workings that show the character of the fissuring and mineralization. The Yellow Type vein was inaccessible. Nearly all the veins of these groups strike northeast and dip southeast. The fissures in this area show a greater tendency to strike northeast than the fissures of the zone between the Antoro and Sosthenis mines, 3,000 to 4,000 feet to the south. The north-northeasterly set of fissures represented by the Shawmut (N. 30° E.), the Maybelle (N. 45° E.), and the Yellow Type or Vienna (north-south?) possibly represent the north end of the wide mineralized fissure zone that extends from the vicinity of the Rawley mine, in Rawley Gulch, north across the head of Sosthenes Gulch. No east-west cross faults were seen in any of the underground workings examined, although the geologic structure at the surface indicates the presence of several cross faults.

COPPER GULCH

To the south of Rawley Gulch, in the vicinity of Copper Gulch, a somewhat different and possibly more complex relation is exhibited between the fissure and vein systems. At least two main systems and perhaps several minor systems of fault fissures can be recognized. The Rawley andesite and the Bonanza latite, the two formations exposed at the surface, are broken into sets of complex fault blocks bounded by fault planes striking northeast and northwest, so that the Bonanza latite is inlaid into the Rawley andesite in an irregular pattern. The relation between the two sets does not appear to be consistent and is difficult to establish by observations at the surface alone. A few short accessible tunnels which are driven on nearly east-west mineralized fissures show that these are rather consistently faulted by a northerly set and a northwesterly set of fissures. This condition is encountered in the Empress Josephine, Hortense, and Now What veins. The northerly fissures at their intersections with the mineralized east-west fissures have exerted a noticeable influence on the width and grade of the ore. According to those familiar with the Empress Josephine mine the richer ore shoots of the mine are said to lie against and to pitch parallel with the dip of northerly or northwesterly faults that have displaced the Empress Josephine fissure at several places. The fact that the northerly faults are themselves in part mineralized and the influence which they had on the ore deposition in the faulted fissures show that both sets are of premineral age. This influence on the ore is to be ascribed to renewed movements on the cross faults during ore formation.

The results of the early stage of barren siliceous replacement of the andesite and latite in the walls of the fissures are especially conspicuous in this area. There are many ledges of jasper which have apparently sealed many of the early fissures so completely that they were not reopened and mineralized by the later stage. In the Empress Josephine fissure both stages of mineralization are represented, the later stage apparently occurring alongside the jasper or in brecciated parts of it.

Some of the north-south cross faults in the Hortense and Now What tunnels were affected by only the later stage of mineralization and hence may have formed by fracturing of the major fault blocks after the earliest period of faulting and silicification.

At the risk of being considerably in error because of the meager opportunity for underground observations in this area, a tabulation of the geologic events is offered below—mainly, however, as a basis for further investigation.

1. Formation of the northeast, northwest, and other sets of faults during the subsidence of the region, producing the complex block-fault pattern of the andesite and latite shown on the map.

2. Early stage of barren silicification in both sets of fissures.

3. Continued movements on the early faults and some fracturing of the major fault blocks by later fissure sets, possibly represented by some of the minor north-south and east-west fissures. Some of the silicified fault zones were reopened; others were not.

4. Second stage of the mineralization, represented by quartz, barite, and base-metal sulphides with some silver.

5. Minor reopening of some fissures, especially near cross faults, and third stage of mineralization, represented by gold and silver tellurides and native tellurium. Minor amounts of base metals accompanied the tellurides, perhaps representing largely a solution and redeposition of early sulphides. In many fissures this stage is wanting or very weak.

6. Minor postmineral movements along the veins and elsewhere.

It should be realized that the stages enumerated above are more or less arbitrary divisions, as the events overlapped, and only those that appear to be of significance are included.

KERBER CREEK

The fissure and vein systems along Kerber Creek near the town of Bonanza are similar to those of the lower part of Copper Gulch. North of the junction of Squirrel Gulch there is a mineralized zone within which lies a series of fault fissures that strike north or northwest and dip at comparatively low angles to the east or northeast. The individual faults can not be traced for great distances along their strike. The mineralized Cocomongo fault, which strikes N. 30° W. and dips 35°–45° E., has been explored for about 500 feet along its strike and for about an equal distance for the dip. At the north end of the mine it is displaced by a series of cross faults, which seem to form a local limit to the ore body.

Minor mineralized fissures that are found in the walls of the Cocomongo fault are described on pages 118–120. A few barren and open postmineral faults of north-south trend are also found in the Cocomongo mine, but the displacements seen are not more than a few feet.

The Bonanza vein, which strikes N. 50° W. and dips northeast, occupies a fault fissure in the hanging wall of the Cocomongo fault and terminates against it. The Bonanza fissure has been explored for 400 or 500 feet southeast from its intersection with the Cocomongo fault. The Exchequer fault, which lies south of the Cocomongo mine, strikes about north and dips 30° E. and has been explored for several hundred feet. The Cornucopia fissure is another fault dipping eastward at a relatively low angle and lies east of the Cocomongo mine.

These faults together form part of a complex fault zone of a general north-northwesterly trend, which can be traced for about 3,000 feet north from the junction of Kerber Creek and Squirrel Gulch. The total displacement of this fault zone is large and has resulted in faulting down the Bonanza latite toward the east, so that its outcrop is repeated many times on the slopes adjoining Kerber Creek. (See sections D–D′) and F–F′, pl. 2.) Many of the ore bodies in these larger faults seem to have become narrow and unprofitable in depth, largely, perhaps, because of the low angle of dip of the fissures.

In addition to these large fault fissures there are many steeply dipping fissures which have an easterly strike and some of which are mineralized, such as the Baltimore and Memphis. The most common relation between the systems as shown by surface exposures would indicate that most of the east-west fissures belong to a younger set and displace or interrupt the larger mineralized faults of northerly or northwesterly trend. The possibilities at depth of these east-west mineralized fissures where they enter the Rawley andesite beneath the Bonanza latite still remain untested.

ALDER CREEK

The only underground workings in the Alder Creek region that afford any data on the relation of faulting and mineralization are a few tunnels on the Joe Wheeler fissure zone and some belonging to the Manitou-Sunlight group of claims. On none of these workings are the developments extensive enough to disclose the general relations between different fault or fissure systems. In the Joe Wheeler tunnel, on the slope north of Alder Creek (pl. 1, No. 38), the Joe Wheeler vein is encountered only in the last 100 feet or so of the adit. (See fig. 47.) The fissure in which the vein occurs strikes about N. 10° W., with an irregular but nearly vertical dip, and is probably a fault fissure. At the north this fissure ends abruptly against a gougy mineralized fault striking about N. 10°–20° E. and dipping west. Although both of these fissures probably belong to north-south fault zones, the mineralization in the two was somewhat different, the northeasterly fault containing a heavier gouge and more sphalerite. The N. 10° W. fissure contains a compound vein filling of barite, quartz, and copper minerals on one wall and mainly sphalerite and galena with a little chalcopyrite on the other wall, the two parts of the vein being separated by altered wall rock and gougy matter.

The mineralogic differences in the ore of the two parts appear to be the result of recurrent movements on the fault during vein formation, so that first one and then the other wall of the fault became the channel of the ore-forming solutions. As the walls of both of these fault fissures consist of considerably altered andesite it is not possible to determine their displacements. The geologic relations at the surface in this vicinity show that the rocks are broken mainly by two sets of faults, which may be very roughly classified as north-south and east-west systems, and that the Bonanza latite is inlaid into the Rawley andesite by faults of normal displacement belonging to these two systems. Fissures of both systems seem to have been equally subject to mineralization, to judge from the intensity of wall-rock alteration and the vein material seen in outcrops and prospect pits. The Joe Wheeler vein appears to lie within the fault zone which bounds the west side of the latite body that caps the ridge to the north. The dip of this latite body is not known accurately but appears to be gentle toward the northwest. Regardless of this dip, the displacement of the bounding faults can not be less than several hundred feet. (See section A–A′, pl. 2.) The intersecting fissures of northerly trend in the tunnel below the latite suggest that the fault is composed of a number of fissures rather than a single one. The fissures and altered zone in the saddle at the west end of the latite is 100 to 200 feet in width. An altered and fissured zone of about equal width is found at the east side of the latite block, and the northeasterly fissure encountered in the Joe Wheeler tunnel may possibly belong to this group.

In parts of the Alder Creek region where east-west and north-south fissure systems intersect there is some suggestion in the shapes of the fault blocks that the east-west system more commonly interrupts the north-south fissures, but there are evident exceptions. The Colorado Belle vein, which belongs to the east-west system, shows all the stages of mineralization beginning with the earliest period of silicification. However, some small easterly cross fissures in the Joe Wheeler tunnel show only very weak alteration but sufficient to indicate that they are of premineral age. Their relation to the Joe Wheeler fissure is not exposed, but they appear to fault a small northwesterly fissure containing some zincy ore.

In the western part of sec. 5, T. 47 N., R. 8 E., the fault systems swing into northwesterly and northeasterly trends. The northwest faults are the more persistent, though both sets are weakly mineralized. Several small tunnels and shafts in the bottom of Alder Gulch and in the tributary gulches at its head expose both north-south and east-west fissure systems, and both systems are mineralized, although the veins matter is narrow and of low grade.

Evidently the major part of all the faulting in the Alder Creek region is of premineral age. There is evidence that faulting or small adjustments of the fault blocks continued through the period of ore formation and perhaps even later and so influenced the distribution of ore within individual faults and near fissure intersections. The meager developments seen failed to disclose any postmineral faults of importance.

The most strongly mineralized areas of the Alder Creek region lie on the slopes of the high ridge that extends from the vicinity of the Joe Wheeler mine westward to the Colorado Belle mine and on the northeast slope of Round Mountain. The faulting throughout this area produced many dropped wedges of Bonanza latite, a type of faulting believed to be suggestive of conditions of maximum tension, favorable to the existence of open fractures. (See pp. 46, 47.) Whether similar faulting extended southward across Alder Creek can not be easily determined, because of the difficulty of recognizing the displacements of faults that lie entirely within the Rawley andesite, but to judge by surface indications only the mineralization on the south side of the creek was noticeably weaker. The fault blocks of Bonanza latite on the northwest slope of the Alder Creek ridge are steeply tilted toward the northwest, essentially forming a dip slope to the ridge. The beds are broken by many minor faults which steepen the local angle of tilt, but the faulting was too complex to decipher on the heavily timbered slopes. However, the general character of the structure of the Alder Creek region is believed to be correctly shown in sections A–A′, and A_1–A_1′, Plate 2.

SOUTHERN PART OF DISTRICT

Most of the mineralized fissures of the southern part of the district have a northerly or northwesterly strike and dip east or northeast. There are many northeasterly faults which displace the northwest system and against which some of the fissures and their ore shoots end. Both systems are commonly of premineral age, however, although possibly the postmineral movement was more pronounced on the northeasterly fault fissures.

Underground explorations in the southern part of the district are not extensive enough to form a basis on which to generalize regarding the fault systems. Hence it is not known whether there are many local variations from the relations mentioned above.

The fault and vein systems of the Eagle mine have been described by Wuensch[83] in some detail, and the conditions in this mine are probably typical of the southern part of the district. The conditions in the Hawk tunnel are described by Wuensch as exhibiting an "unusual example of simultaneous faulting and mineralization."

FUTURE EXPLORATION IN THE DISTRICT

In considering the future of the district it is desirable first to review what has been done in the past. Many of the smaller operations have doubtless been profitable to individual lessees and operators, but the larger ones have not in general returned the principal and interest on capital invested. The ore deposits lie in relatively narrow fissures within which the ore shoots are irregularly distributed, and as the shoots are rarely of high grade they have not paid for the cost of finding and developing them. The Rawley ore shoot is the only large body of ore in the district that up to the present time has yielded an operating profit on moderately large mining operations. It has not yet, however, returned the large amount of capital which has been invested in the development of the property. Several of the smaller mines, such as the St. Louis, have developed ore bodies of high grade that doubtless were profitable to mine, but the bodies were not large enough to pay for intensive exploration for additional ore shoots, and consequently most of the properties in the district now lie idle.

In some properties, as, for example, the Cocomongo mine, very complex structural conditions greatly increase the cost of exploration, because of the erratic distribution of ore shoots. Ore shoots that appear promising may be abruptly cut off by premineral faults or by sudden pinching or flattening of the fault fissures. In the more persistent ore bodies like the northern ore shoot of the Rawley vein the problems to be dealt with are those relating to efficient mining methods and ore treatment rather than structural or geologic problems. But on the whole future explorations in the district must expect to encounter many difficult problems of structure. The intense fracturing to which the volcanic rocks were subjected before mineralization had a tendency to disperse the mineralizing solutions into many small fissures instead of permitting them to concentrate in a smaller number of larger veins. Partly for this reason the selection of promising veins for further development is difficult, requiring more study than is possible in a general examination of the district. It is natural to assume that the more promising veins have been prospected, and that is the impression one gets from a general study in the field. At almost any place within the more heavily mineralized areas small showings of sulphides and vein material may be detected on the surface, and many of these have been trenched or worked in a small way. Because of the dispersion of the metals into these many small fissures the chances of the existence of many ore shoots as large as the Rawley are not great. On the other hand, owing to the nature of the faulting and fissuring, it is probable that some larger fissures may be concealed at the surface, or their ore shoots may be cut off by weakly mineralized fault fissures, so that they do not crop out prominently. Thus strongly mineralized areas such as are found adjacent to the Cocomongo mine on Kerber Creek, parts of Rawley Gulch adjacent to the Rawley and Whale veins, and parts of Copper Gulch can not be said to be thoroughly prospected, even though the workings are more extensive than in some other localities.

A fairly continuous area of strong mineralization extends from the ridge near the Superior mine south of Rawley Gulch northward across Rawley Gulch and across the head of Sosthenes Gulch nearly to the south side of Round Mountain. Another area of strong alteration with some developed mineralized veins is found near the head of Alder Creek, in the region of the Joe Wheeler and Colorado Belle mines and thence westward to the northeast slope of Round Mountain. Sufficient exploration has not been done, or at least the workings are not sufficiently accessible at present, to indicate the promise of this northeasterly area. Although favorable sedimentary rocks may lie beneath the western edge of the northern part of the district, there is little assurance that conditions would be favorable here for the formation of replacement deposits. Furthermore, the depth to the basement would be very great, perhaps 2,000 feet or more. For the northern and northeastern parts of the district the presence of pre-Cambrian outcrops in Squirrel Gulch and along Alder Creek is a strong indication that the basement on which the lavas lie consists for the most part of these rocks.

The low-temperature veins of the southern part of the district present a somewhat different problem.

[83] Wuensch, C. E., Secondary enrichment at the Eagle mine, Bonanza, Colorado: Am. Inst. Min. and Met. Eng. Trans., vol. 69, pp. 96–109, 1923; reprint 1251, June, 1923.

They probably lie above a relatively shallow part of the underlying intrusive body, as is indicated by the large number of dikes occupying fissures in this part of the district. The principal minerals of value are silver minerals, with only small amounts of copper, lead, and zinc. There is no assurance that these veins will pass at great depth into veins containing abundant sulphides, like those found in the northern part of the district, but they are perhaps more likely to become slightly impoverished within moderate depths and change to low-grade veins of quartz, carbonates, and pyrite. Chalcopyrite is one of the common sulphides in these veins, though present in only small amounts. It might be persistent or even increase to moderate depths, and an increase in this mineral and in pyrite might reasonably be expected to be accompanied by an increase in gold content. The conditions for explorations to the base of the volcanic formations would appear more favorable here than in the northern part of the district. The temperatures during vein formation at the present depth of erosion were lower than in the north, to judge from the mineralogic character of the veins. As shown on page 41 and on Plate 3 it may be inferred that a synclinal area of the Paleozoic rocks extends beneath the lavas approximately along the course of Kerber Creek, although large thrust faults like those along the lower part of Kerber Creek may also be present beneath the lavas. The depth to the base of the volcanic rocks is probably at least 1,200 feet in some parts of the area, but as there may have been a relief of 500 feet on the old land surface an accurate estimate of the altitude of the basement can not be made. Also it can not be foretold what part of the strongly folded sedimentary section will be encountered in any given place. Owing to the risk involved, therefore, blind exploration to the base of the lavas is not justified.

The E. D. vein, on the east side of the road in the southern part of the district, contains dolomite, and as this mineral is an uncommon constituent in the veins of the district the magnesium may have been derived from the underlying limestones. On the other hand, magnesium is known to have been present in considerable quantities in some mineralizing solutions where it was not derived from limestones, so that its source is uncertain. Positions within or too close to intrusive bodies would be unfavorable areas in which to extend operations to great depths to reach the sediments, as the shape or extent of these intrusive bodies in depth can not be predicted. Thus veins either within the Eagle Gulch latite or within the center of the area of intrusive rocks south of this would not be favorable ones to explore in depth. Even under the most favorable conditions such exploration is likely to be very expensive and uncertain as to results. With the present state of geologic knowledge it would be more in the nature of a scientific experiment than of an economic exploration. The average gold content of the veins in the Bonanza district is only about 0.01 ounce to the ton, although in certain veins it runs much higher than this, as, for example, in several of the veins in Copper Gulch. There is also a slight but definite tendency for the ore of the Rawley vein to increase in gold content with depth. The change in gold content of the veins of the southern part of the district is not known.

The most favorable beds for replacement deposits in the underlying sedimentary rocks can not be told except by actual exploration. The conditions in similar beds in other parts of Colorado suggest that the Leadville limestone and perhaps some of the pure quartz grits or limy grits, such as the sandstone of the Chaffee formation or the coarser grits of the Kerber formation, with their intercalated layers of carbonaceous shale, might be the most favorable. In very few places in the State have the Carboniferous red beds been found to contain commercial ore bodies. The great thickness of the beds of the Maroon formation overlying the Mississippian limestone and Kerber formation would have to be penetrated unless shafts sunk happened to penetrate the basement near the edge of a synclinal area.

In conclusion, it should be said that the future production of the Bonanza district must depend to a large extent upon the existence of favorable market conditions for metals and upon the development of some custom treatment of the complex ores, as perhaps the Rawley vein is the only one so far developed which has in itself yielded an ore body of sufficient size to warrant the erection of a mill. It is not to be expected that production will be made from crude shipping ores, as shown by the failure of these ores in the history of the district. The possibility of production from the sedimentary formations beneath the lavas appears to be more favorable in the southern than in the northern part of the district, but even in the southern part deep prospecting must be exceedingly speculative.

MINES AND PROSPECTS

A large part of the mining operations in the Bonanza district have been conducted on small prospects which were abandoned as soon as the small bodies of richer shipping ores had been mined out. Few of the mines are developed to sufficient depth or length along the veins to permit detailed descriptions that would be of any general value. A number of the larger veins which furnished the bulk of the output during the early mining operations in the district are not now accessible. In 1926 and 1927 the Rawley and Cocomongo were the only mines on the larger veins that were being operated. The following descriptions are thus necessarily confined to a few typical examples. Such data and maps as are available for some of the older inaccessible operations have been included as a matter of record.

The mines are described from north to south in the order of those lying in the Kerber Creek drainage area, those lying in the Alder Creek area, and finally those in the southern part of the district. The Rawley and Cocomongo are examples of mines now accessible that are developed on veins of two rather different structural types in the northern part of the district and will be described first. These more detailed descriptions will be followed by briefer descriptions of some of the other mines.

RAWLEY MINE

The Rawley mine, owned by the Rawley Mines (Inc.), is developed on a north-south vein that crops out at an altitude of about 10,800 feet on the north side of Rawley Gulch. (See pl. 1, No. 69.) The mine workings on the vein are above a long tunnel used for drainage and haulage, the portal of which is in Squirrel Gulch 6,200 feet southwest from the outcrop of the vein. The present mill and other mine buildings are in Squirrel Gulch at the portal of this tunnel. Ore is said to have been discovered at the outcrop of the Rawley vein in 1880, and in the report of the Director of the Mint for 1881 [84] it is stated that the Rawley claim showed one of the largest ore bodies in the district. The ore, however, was of comparatively low grade for shipping and treatment at that time, and prior to 1902 the production from the vein was small. Apparently one small mill had been erected in Rawley Gulch near the outcrop of the vein before 1902, but no authentic records are available as to the amount of ore which was treated.

In 1902 a new 100-ton mill had been erected by the Rawley Mining Co. on the opposite side of Rawley Gulch from the vein. It is reported by the company that this mill was operated only two months during that year. For several years the operation of the mill was unsuccessful, partly because the flow of water in Rawley Gulch is very fluctuating and was found inadequate to run the mill at capacity for more than a short period during the year. There is no record of production during this period except for small shipments of concentrates in 1902 and 1905. (See table on p. 106.) About 1905 the company was reorganized, and between then and 1910 the work done was entirely for the purpose of developing the vein. In 1910, according to Simonds and Burns,[85] the vein had been proved to a depth of 600 feet and a large body of ore blocked out. To develop the vein below the sixth level and to cheapen the mining of the ore in the upper levels it was proposed at this time to drive a drainage tunnel about 6,200 feet in length to intersect the vein at a point 600 feet below the sixth level. Despite some adverse opinion the company started work on the tunnel May 7, 1911, and reached the vein October 23, 1912. The methods used and the data on driving the tunnel have been given in detail by Simonds and Burns.[86] Two major difficulties were encountered in driving the tunnel—the abrupt changes in character of the andesite caused by silicification and the striking of what is probably the continuation of the Paragon fault zone. The flow of water from the Paragon fault was large and was roughly estimated at 1,000 gallons a minute when it was first struck.

Between 1912 and 1915 no further work was done, but in July, 1916, work was started in preparing the mine and in completing the plans for a new 300-ton mill to be erected at the portal of the drainage tunnel. In 1916 and 1917 some small shipments of crude ore were made. An aerial tramway about 7¼ miles in length was constructed to deliver the concentrates at the Denver & Rio Grande Railroad at Shirley, due north of the mill. An electric power line was also completed to the mine, but work on the mill in Squirrel Gulch was not completed until 1923. The new mill was operated awhile in 1923 by the Colorado Corporation, and some concentrates were shipped, but the mine was again closed in this year.

Thus between 1905 and 1923 a large investment of capital was made in the development of the mine, in driving the tunnel, and in constructing the mine plant and mill, but the production of the whole period was relatively small.

The Rawley Mines (Inc.), a reorganized company, started operations in December, 1925, after remodeling the mill and providing for a 350-ton capacity. Operation of the mine and mill was continued until the later part of June, 1930, and during this time considerable development and exploratory work was done, both north and south of the Paragon fault, which bounded the original ore body on the south. The exhaustion of the ore shoot north of the Paragon fault, the faulted condition of ore-bearing fissures found south of the fault, and the unfavorable results of exploration of the Michigan vein lying east of the Rawley finally led to the closing and dismantling of the property.

[84] Burchard, H. C., Report of the Director of the Mint upon the production of the precious metals in the United States during the calendar year 1881, p. 427, 1882.

[85] Simonds, F. M., and Burns, E. Z., A problem in mining, together with some data on tunnel driving: Am. Inst. Min. Eng. Bull. 75, p. 370, 1913.

[86] Idem, pp. 369–402.

PRODUCTION

Complete data on the production of the Rawley mine prior to 1902 are not available. The reports of the Director of the Mint for 1890 and 1891[87] give $1,365 and $5,981, respectively, for these years. In reports for other years no data on the Rawley mine are given. The following table shows the production of the mine since 1902, compiled from mine records of the United States Geological Survey and the United States Bureau of Mines, supplemented by information furnished by the company. Some details of the metallurgical data from operation of the mill during 1926 and 1927 are shown in the second table, based upon data furnished by the Rawley Mines (Inc.).

Production of the Rawley mine, 1902–1930

Year	Ore (dry tons)	Concentrates produced (dry tons)	Gross content of concentrates and smelting ore				
			Gold (fine ounces)	Silver (fine ounces)	Lead (wet assay; pounds)	Copper (wet assay; pounds)	Zinc [a] (pounds)
1902		600		12,000	438,000	60,000	
1905		384		4,143	188,720		
1916	[b] 2,731		102.72	37,335	62,066	134,246	
1917	[b] 1,875		61.46	21,663	51,523	94,521	Penalized.
1923	34,170	9,032	183.80	146,329	3,267,520	567,093	1,287,066
1926	43,971	5,369	236.27	267,142	3,110,418	1,276,493	
1927	112,393	22,742	965.28	842,579	6,683,138	4,846,733	2,488,250
1928	110,595	22,238	1,123.46	903,759	5,285,710	5,391,184	2,406,152
1929	118,647	18,967	1,003.50	720,172	6,442,738	3,329,047	2,465,710
1930 [c]	56,262	7,737	456.02	328,385	2,484,756	1,520,267	765,963
	480,644	87,069	4,132.51	3,283,507	28,014,589	17,219,584	

[a] Zinc not recovered. [b] Crude ore to smelter. [c] Mine closed late in June.

Range in character of concentrates from Rawley ore in 1927, by months

Month	Assay content of concentrates							Recoveries from mill heads (per cent)			Ratio of concentration
	Gold (ounce per ton)	Silver (ounces per ton)	Lead (per cent)	Copper (per cent)	Iron (per cent)	Insoluble (per cent)	Zinc (per cent)	Silver	Lead	Copper	
January	0.050	44.0	17.1	10.8	25.9	2.4	5.43	85.7	92.5	86.1	5.36
February	.055	42.6	16.9	12.7	25.8	2.2	4.69	83.5	91.0	88.0	6.53
March	.045	45.1	16.6	11.9	26.4	2.4	4.38	90.6	93.2	91.0	6.37
April	.043	36.8	15.9	10.2	26.9	3.4	4.50	91.4	94.0	91.1	6.09
May	.039	32.8	16.6	9.70	26.6	3.7	4.70	92.5	94.1	92.6	5.39
June	.040	31.9	17.2	8.82	26.4	3.0	5.70	90.3	93.8	89.5	5.20
July	.040	32.5	14.8	9.60	25.1	4.9	7.0	88.7	92.5	88.3	4.45
August	.041	33.6	13.1	9.55	27.0	4.3	6.01	91.3	91.7	87.5	3.98
September	.040	31.6	9.91	9.06	29.5	4.8	4.92	92.1	91.0	88.1	3.75
October	.036	39.4	15.2	11.9	24.6	3.2	6.47	83.8	89.5	82.0	4.63
November	.040	38.9	13.6	12.8	25.5	3.2	5.33	82.7	90.8	82.8	4.64
December	.039	42.2	12.7	12.5	25.3	3.9	5.94	85.7	90.2	85.0	4.77

UNDERGROUND DEVELOPMENT

The writer wishes to acknowledge the cooperation of the officials of the Rawley Mines (Inc.) in facilitating the underground study of the Rawley mine and in permitting free use of maps and operating data. A. S. Winther, manager during 1926, when the mine was first visited; A. E. Ring, manager in 1927 and 1928; William Blake, mine superintendent; Ira Herbert, and other members of the engineering staff, have personally helped in the study of the mine. The geologic section of the Rawley drainage tunnel and some of the other underground observations are based upon joint examinations made by B. S. Butler and the writer.

The plan of the underground development of the Rawley mine is shown in Plate 23, and the section of the stopes in Plate 24. The general trend of the vein is N. 10° W. and the dip about 85° E. The four upper levels are adit levels, from which the mine was developed prior to driving the drainage tunnel. The second, third, and fourth levels all pass through a large fault known as the Paragon fault, which limits the productive portion of the main ore shoot on the south, so that these levels follow the vein only north of this fault. South of the Paragon fault some

[87] Smith, M. E., Report of the Director of the Mint upon the production of precious metals in the United States during the calendar year 1890, p. 139, 1891; idem for 1891, p. 184, 1892.

exploratory work has been done on the fourth adit level. In 1928 the 600-foot level was driven south through the Paragon fault zone and crosscut east about 50 feet, when a vein south of the fault was intersected. The Paragon fault was subsequently crossed, and development work was done on three other levels south of the fault. There is some development from the third level within the Paragon fault zone, which is weakly mineralized. The length of stoping on the Rawley vein proper north of the fault ranges from about 850 to 1,100 feet on levels between the 200 and 900. On the twelfth level the vein has been followed for more than 600 feet south of the shaft, but as it did not appear encouraging, the drift was not continued to intersect the Paragon fault. Between the second and ninth levels the vein has been stoped out practically to its intersection with the Paragon fault.

On the third level some development work has been done on the so-called Parallel vein, which lies north of the shaft and in the footwall of the Rawley vein. A crosscut was also driven from the fourth level to intersect the Parallel vein, but most of the work on the Parallel vein was done by lessees, and a complete survey of its development is not available. A little development work has been done on the Clark vein, one of those cut by the drainage tunnel.

An underground hoisting station, situated at the intersection of the Rawley vein and the drainage tunnel, allowed the skips to be operated in the main shaft to the fourth level. A small shaft south of the main shaft was used for raising and lowering men and materials between the sixth and third levels. The vein has been mined largely by the shrinkage-stope method. The ore was hauled from the loading bins on the twelfth level by electric locomotives to the mill, a distance of over 6,000 feet. The concentrates from the mill were delivered from the concentrate bins to an aerial tramway which ran due north of the mine plant to the Denver & Rio Grande Western Railroad at Shirley.

GEOLOGIC FEATURES

GENERAL SUMMARY

The rocks in the vicinity of the Rawley mine are the Rawley andesite and the Bonanza latite. These are much broken by north-south faults that drop the formations on the east and also by a series of northeasterly and northwesterly faults that drop the formations successively southward. The Paragon fault is the largest known of the east-west system. Practically all the faults are of premineral age, but the north-south faults are possibly older than the Paragon fault. The Rawley vein occupies a north-south fissure of comparatively small displacement and is largely the result of a filling of open spaces with minor replacement. The main gangue mineral is quartz, but barite, calcite, rhodochrosite, manganiferous calcite, and siderite are found in small quantities. The main ore minerals are pyrite, sphalerite, galena, chalcopyrite, bornite, enargite, tennantite, and stromeyerite. The vein shows a change in metal content from a lead-silver-copper ore in the upper levels to predominating copper-silver ore with a minor amount of lead in depth. A less pronounced change in the metal content is indicated from the south toward the north in the vein on several of the levels. These geologic features are discussed in more detail in the following paragraphs.

DRAINAGE AND HAULAGE TUNNEL

A geologic section from the portal of the drainage tunnel to the Rawley vein is shown in Plate 25. The geologic structure is very complex, and consequently it is not possible to make accurate correlations between the surface and underground data along the line of the tunnel. At the portal in Squirrel Gulch the tunnel starts in andesite, although the débris from the fault block of Bonanza latite that forms a high ledge above the tunnel portal completely obscures the outcrop of the underlying andesite near the portal. The Bonanza latite is encountered 70 feet from the portal and continues about 140 feet beyond this point. Two much smaller fault blocks of latite occur at about 400 and 900 feet from the portal. The remainder of the tunnel lies entirely in intricately faulted andesite. About three-quarters of its length is overlain at the surface by tilted and faulted latite. The large block of latite lying above the portal of the tunnel strikes about north and dips 45°–50° W. The latite is repeated many times at the surface along the line of the tunnel by faults which throw successive blocks downward toward the east. Although the structure appears incredibly complicated because of the steep westward dips of all the latite blocks, any doubts as to the faulting are dispelled by an examination of the tunnel. A great many fault fissures are encountered in the tunnel as may be seen from Plate 31 and the andesite is much fractured between the larger faults. Very little of the andesite is free from alteration, and the rock is either silicified, chloritized, or altered to sericite and impregnated with carbonates and pyrite. The pyritized jaspers, which are very common, are described in detail on pages 72–73. Some of these also contain traces of zinc. The distribution of the main zones of alteration is shown in the geologic section of the tunnel. Despite this extreme alteration of the rocks for nearly the whole length of tunnel, a comparatively small number of economically valuable veins are found. The Clark vein, which is described below, is the largest of these.

This vein occupies a fault zone of complex structure, most of the ore so far developed lying at the intersection of north-south and east-west faults.

About halfway from the portal of the tunnel to the Clark vein there is another small mineralized fissure of northward trend and easterly dip, but it has not been explored.

About two-thirds of the way from the portal to the Rawley vein a strong fault zone is intersected by the tunnel. At the time of driving the tunnel a large volume of water issued from this fault, considerably delaying the work. From the position of the Paragon fault at the surface and its approximate dip, it appears reasonable to assume that this fault is the continuation of the Paragon fault, and it has been so indicated on Plate 25. Evidence of strong silicification and fissuring of the andesite is noticeable in the tunnel beyond the fault, and there are a few small veins, but the immediate vicinity of the fault is largely concealed by timber.

Lack of open fissures seems to have been the main reason for the character of the mineralization revealed in the tunnel. As mentioned elsewhere in this report the kind of faulting which occurred in areas of steeply tilted formations seems to have been unfavorable to the production of open fissures.

RAWLEY VEIN AND PARAGON FAULT

General features.—The Rawley vein lies about 6,100 feet from the portal of the tunnel and occupies a fault fissure, probably of slight displacement. The country rock of the vein, except for a porphyry dike on the lower levels, consists of the lava flows of the Rawley andesite. These are too much altered near the vein to permit the recognition of individual flows and the measurement of the exact displacement along the fissure. On the third level at the north end of the drift both hanging wall and footwall consist of a conspicuously porphyritic andesite. This particular rock appears to correspond with one of the flows in the upper part of the Rawley andesite and is believed to have a thickness of about 100 feet. As it occurs in both walls of the vein, this thickness would suggest that the displacement at the north end of the vein was less than 100 feet, providing the flow has not been steeply tilted. Some small displacement has also occurred along the Parallel vein fissure on the third level, as the hanging wall there is a porphyritic andesite and the footwall a volcanic breccia. In all probability the displacement on the Rawley fissure does not exceed a few tens of feet in magnitude.

The main ore shoot of the Rawley vein is bounded south of the main shaft by the east-west Paragon fault, which cuts the Rawley vein nearly at right angles. (See pl. 24.) If the southerly dip of 55° to 60° continues below the 900-foot level its intersection with the Rawley vein would lie about 750 to 800 feet south of the shaft on the haulage-tunnel level.

The relative age of the Rawley fissure and the Paragon fault and the relations between them are problems over which opinions have differed. Simonds and Burns[88] say regarding the Paragon fault:

> Across the country from east to west, cutting the Rawley vein nearly at right angles, is a zone of faulting some 50 feet wide, dipping at an angle of about 55° S.
>
> This faulting was subsequent to the vein formation, and the zone incloses, at various places, bunches of ore detached from the veins which it intersected. The lateral throw of the fault was slight, if any, but there is reason to believe that the vertical throw must have been considerable. However, no definite data existed at the time, and only meager data have since been developed to indicate the amount of this vertical displacement. There being but little lateral throw, the alinement of vertical or nearly vertical veins was only slightly disturbed by this faulted zone.

Patton[89] concurred in this opinion.

From the character of the Paragon fault in the Rawley mine and at several other places along Rawley Gulch where it has been disclosed by mining operations the writer is of the opinion that the major part of the displacement on this fault is of premineral age, although some relatively late postmineral movement has undoubtedly occurred. The main reasons for this belief are as follows:

1. The Paragon fault is itself mineralized, not only within the Rawley mine but also in the several openings on it along Rawley Gulch east of the outcrop of the Rawley vein. Except locally the mineralization has not been greatly or at all disturbed by postmineral movement. The gouge along the Paragon fault is also strongly sericitized and pyritized, showing that it was penetrated by mineralizing solutions. The mineralization in the Paragon fault and its relation to other intersecting veins along Rawley Gulch are described on pages 131–134. This description need not be repeated here except to say that the results of mineralization within the fault and of alteration adjoining it along the Rawley Gulch east of the Rawley vein afford positive evidence of the premineral age of the faulting. If the mineralization of the Rawley vein occurred prior to the formation of the Paragon fault this would indicate two periods of similar mineralization in the veins of Rawley Gulch. There is good reason, however, to believe that this did not happen, as nearly all the veins show a mineral paragenesis that is very similar, although the proportions of different minerals may differ from vein to vein.

2. Where the relation between the Rawley vein and the Paragon fault can be seen only a slight disturbance of the Rawley vein material is evident. The relation between the fault and the vein on the fifth level

[88] Simonds, F. M., and Burns, E. Z., op. cit., p. 371.
[89] Patton, H. B., op. cit., p. 77.

south are shown in Figure 23. The displacement of the Rawley fissure in small steps as the Paragon fault is approached is quite evident, yet as the Rawley fissure narrows the mineralization follows the turns and offsets in the fissure until close to the main fault zone. Where the drift has penetrated farther into the fault the fault itself is also mineralized. The writer is informed by Mr. A. E. Ring that on the 500 and 600 foot levels, where ore in the Paragon fault was stoped, this ore was as regularly in place on the dip of the fault as in any vein. Slight postmineral movement on fault fissures is almost invariably shown in mineralized regions, and the small amount of crushed ore found at other places within the Paragon fault can not in itself be considered evidence that it was dragged in from intersecting veins. The greatest disturbance of vein material seen by the writer indicated, under a most liberal interpretation of dragging, a possible movement of about 2 feet on one of the parallel fissures shown in Figure 23. Slight postmineral movement has undoubtedly occurred, and inasmuch as ore deposited within the Paragon fault is crushed at places, some crushing of the Rawley ore close against the fault might have occurred at the same time.

3. The distribution of minerals in the Rawley vein appears to be in part related in position to the Paragon fault.

Several bodies of massive galena lie so closely under the footwall of the Paragon fault on several of the upper levels as to lead to the inference that movements on the fault produced the openings in which the ore is found. This result is like the enrichment of veins noted at other places in the district near cross faults. (See p. 95.)

Just what proportion of the movement on the Paragon fault occurred before the formation of the Rawley ore and what proportion after can not be definitely proved. But it has been pointed out in the section on the relation of mineralization and faulting (pp. 93–98) that in general the greater part of the faulting movement throughout the district is of premineral age. So far as direct evidence is available there is no indication that the Paragon fault is an exception to this general relation.

The exact amount of displacement on the Paragon fault still remains undetermined in the vicinity of the Rawley mine. About 2,000 feet west of the Rawley fissure the displacement on the Paragon where it faults Bonanza latite into contact with Rawley andesite appears to be between 500 and 1,000 feet down the dip of the fault. Because of the steep tilting of the Bonanza latite it is difficult to estimate the displacement accurately even here. Near the head of Rawley Gulch the displacement is not so readily recognizable in the surface rocks, but it appears to have considerably decreased toward the east. If this is so the movement on the fault was partly of rotational character. Lying intermediate between these positions, the fault in the Rawley mine might have an intermediate displacement, possibly 500 feet, but such an estimate is very crude at best.

At and north of the main shaft on the twelfth level a porphyry dike, with large feldspar crystals half an inch to an inch in length, lies within the Rawley fissure. This dike continues to the end of the north drift but does not appear in the drift south of the shaft. It is again exposed in the vein on the seventh level north as shown in Plate 26. The porphyry dike is clearly of premineral age, as it is much altered and partly mineralized on the twelfth level. So far as is known this dike does not appear at the surface.

Character of the vein.—The Rawley vein is fairly well defined between its walls and ranges in width from a narrow barren fissure where pinched to a maximum of about 12 feet. Its average width in the lower part of the mine is 3½ to 4½ feet. It can not be profitably stoped at most places unless the width exceeds 3 feet. Along some portions of the vein a sericitized gouge a foot or less in thickness lies against the hanging wall, and less commonly against the footwall. Although the vein material is on the whole of fairly uniform character, with no delicate banding, the vein at some places is composed of several bands of somewhat different composition. (See pl. 15, *A*, *B*.) Bodies of galena may run along either or both walls and here and there may be seen to cut diagonally across the more siliceous part of the vein.

Although replacement of portions of the wall rock has been very pronounced, it was mainly of a siliceous or pyritic nature. The greater part of the commercial ore evidently resulted from filling between the fissure walls. Some replacement of breccia material probably occurred within the fissure. The ore is not notably porous but rather massive, although very small vugs lined with quartz and sulphides are fairly common. In the vein on the 600-foot level south of the Paragon fault rhodochrosite crystals are found lining vugs, with a late coating of pyrite.

The gangue minerals are quartz, barite, calcite, rhodochrosite, or manganiferous calcite, and rarely a little siderite. Quartz is by far the predominating gangue. The sulphides are pyrite, sphalerite, galena, chalcopyrite, bornite, enargite, tennantite, chalcocite, covellite, and stromeyerite. Chalcocite, covellite, and enargite occur only in small amounts and are usually recognized only under the microscope on polished faces. It has been considered that the silver is largely or entirely in tennantite, but microscopic examination shows stromeyerite to be widely distributed in the vein in small amounts. It is associated with bornite, tennantite, and galena. Its presence probably accounts for the high silver content of some of the bornite-bearing ore. At the south end of the ore shoot stromeyerite continues to the twelfth level. It is undoubtedly a primary mineral.

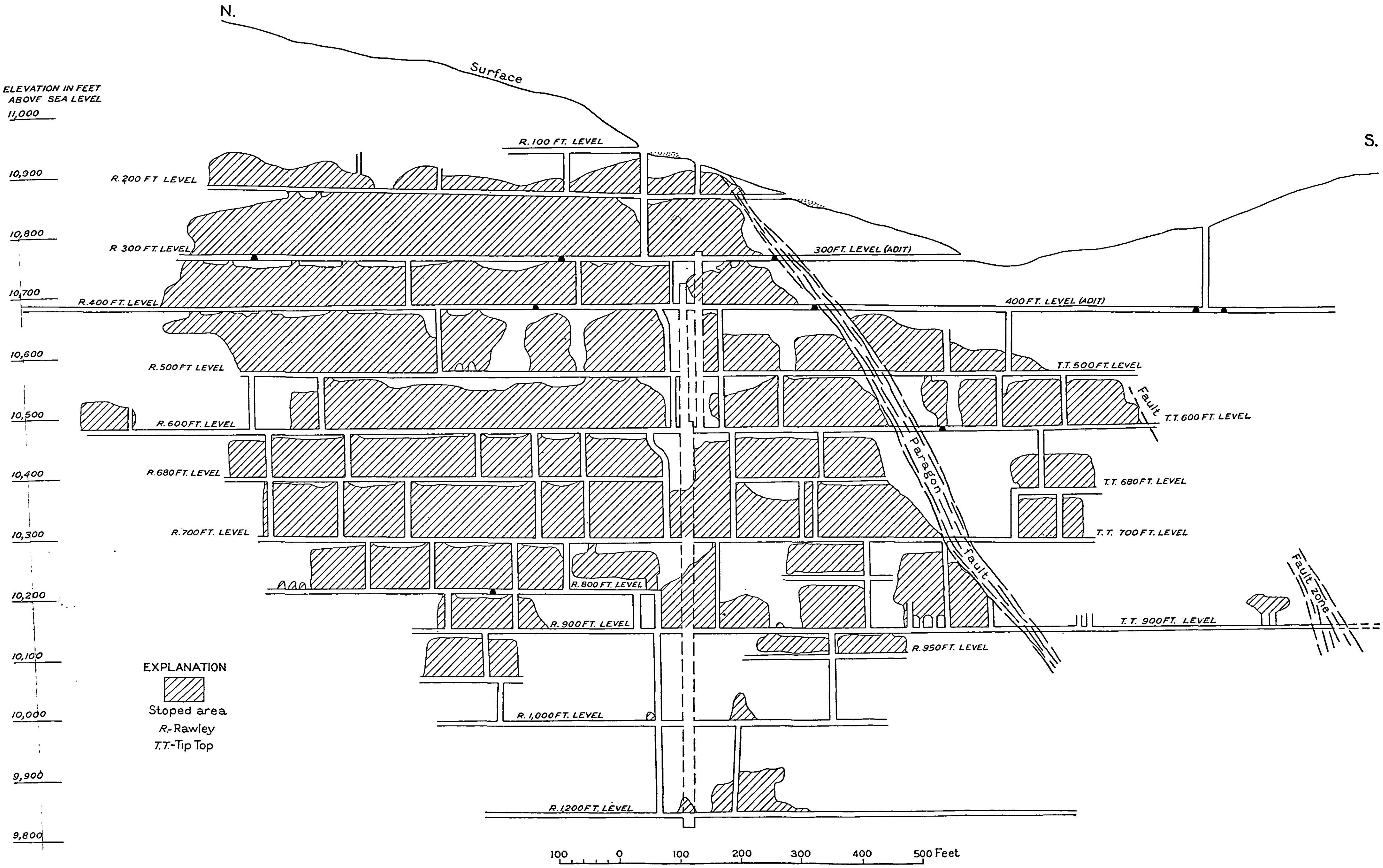
No pronounced oxidation or enrichment of the vein is evident except within 50 feet or less of the surface. Above the first and second levels near the surface some native copper occurs in small seams in the ore or in the adjacent wall rock. As the section on the paragenesis of the ores of the northern part of the district (see pp. 85–86) deals mainly with the Rawley vein, these details need only be summarized here.

The earliest effects of solutions circulating in the Rawley fissure consisted mainly in the hydrothermal alteration of the wall rock. The waters circulating in the fissure during this first stage were evidently hot or warm and perhaps contained some sulphuric acid or halogen acids. (See pp. 80–81.) These waters vigorously attacked the andesitic wall rock, dissolving out nearly all the constituents except silica and a little iron and titanium, and deposited some additional silica in place of the other constituents carried away in solution. The result of this alteration was the formation of a very siliceous rock composed largely of quartz or chalcedony and containing ferric oxide. This rock in many places along the walls of the vein is decidedly reddish or reddish brown because of its content of hematite or some finely divided form of ferric oxide, and it may appropriately be called a jasper. It is encountered in the walls of the vein on practically all levels of the mine but is much more noticeable and evidently more abundant on the lower levels. At some places it is included usually as angular fragments within the vein itself representing fragments of the wall which became detached by movement before the complete filling of the fissure. (See fig. 23.) In places where the walls were broken or cracked by additional movement along the fissure before the formation of the vein, the vein minerals have been deposited in the cracks and in small stringers in the jasper. Such occurrences in conjunction with the evidence of its general position in the walls give indisputable evidence that the alteration of the walls to a jasperlike rock preceded the filling of the Rawley fissure with vein material.

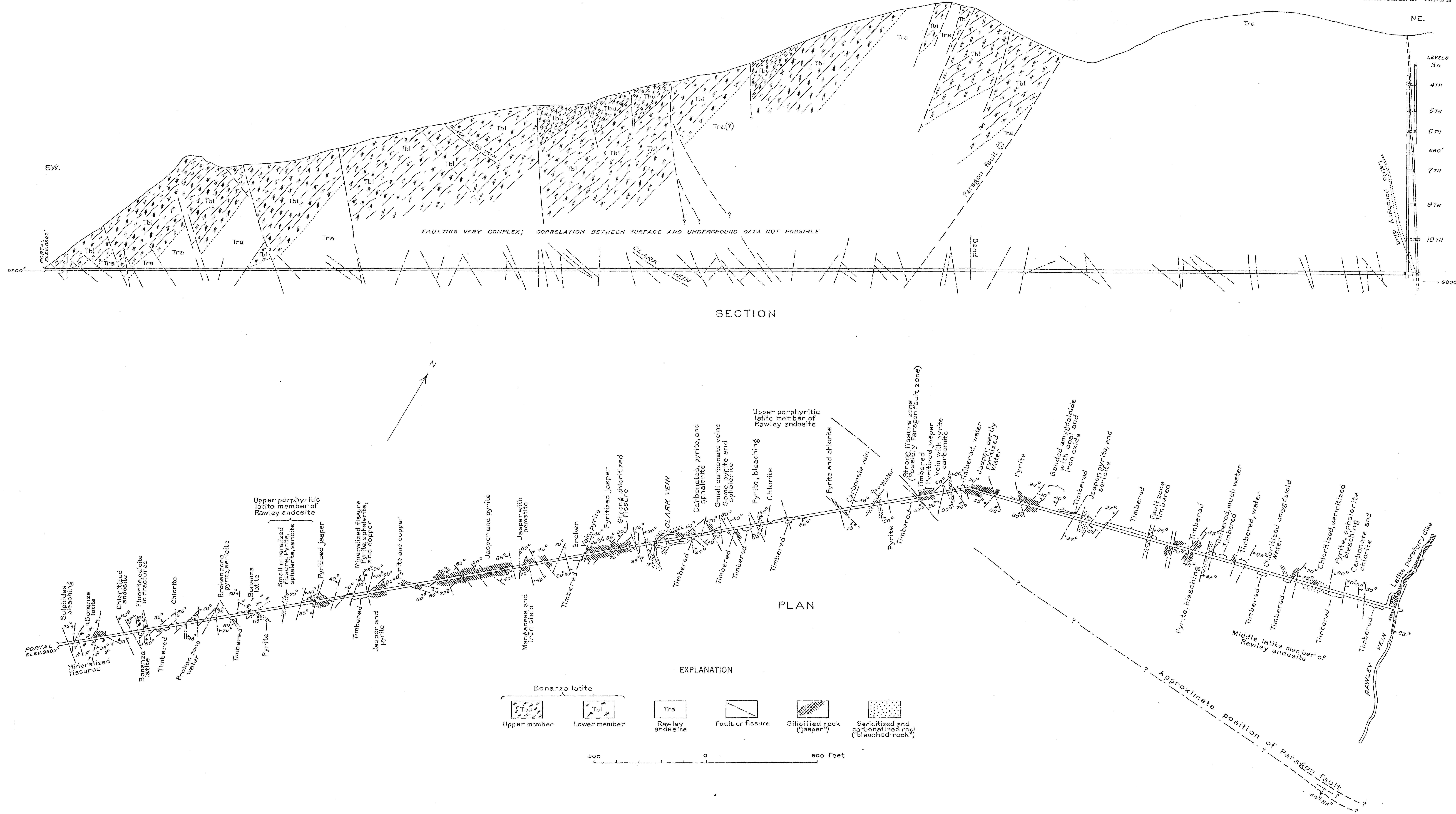
The earliest minerals to be deposited within the fissure were quartz, barite, and pyrite, followed by sphalerite, bornite, chalcopyrite, and galena and finally tennantite and small amounts of other sulphides such as stromeyerite, chalcocite, and covellite. Except for the early quartz, pyrite, and sphalerite, the other sulphides closely overlapped in their formation, and the order of deposition was not strictly uniform in all parts of the vein. Enargite where present is an early mineral, probably later than bornite but earlier than galena and tennantite. Tennantite is usually a late copper mineral, but in ore from the lower levels of the mine some of it has resulted from the breaking down or alteration of enargite. (See pl. 16, *C*.) The deposition of chalcopyrite was highly variable; it is rarely included in minute specks in sphalerite and where very abundant is an earlier mineral than galena, but its deposition in small amounts continued until very late. Stromeyerite also has a wide range of occurrence in the Rawley ore and is found in small irregular areas included in bornite and also as a later mineral replacing many of the other sulphides.

In the upper levels of the mine the deposition of pyrite appears to have been rather sharply separated from the later formation of chalcopyrite, galena, and tennantite. On the other hand, in the lower levels of the mine pyrite is more abundant and more intimately associated with the later copper minerals, such as bornite and chalcopyrite. The texture of the ore from the levels below the 600 foot, where copper and iron are the predominating metals, suggests a rapid precipitation of the pyrite in minute grains or granular masses, followed by the formation of bornite and chalcopyrite. These two copper minerals have replaced granular pyrite to a considerable extent, but the intimate association of the particles of pyrite with the copper minerals can not be explained entirely as the result of replacement of once extensive pyrite masses. The textures typical of pyritic copper ore are shown in Plate 15, *A*, *B*. Many of the smallest particles of pyrite in the bornite and chalcopyrite in ore from the 680 and 700 foot levels have an actual size of 0.0001 to 0.0002 inch. Although not all the pyrite in the ore is present in such minute subdivision, a considerable proportion of the pyritic copper ore is of the character shown in Plate 15, *A*, *B*. For the purpose of separating the pyrite and gangue from the other sulphides by flotation the practice at the Rawley is to grind the ore smaller than 100 mesh. It is evident that only partial separation can be accomplished, and it has not been found possible in practice to keep the iron in the concentrates low.

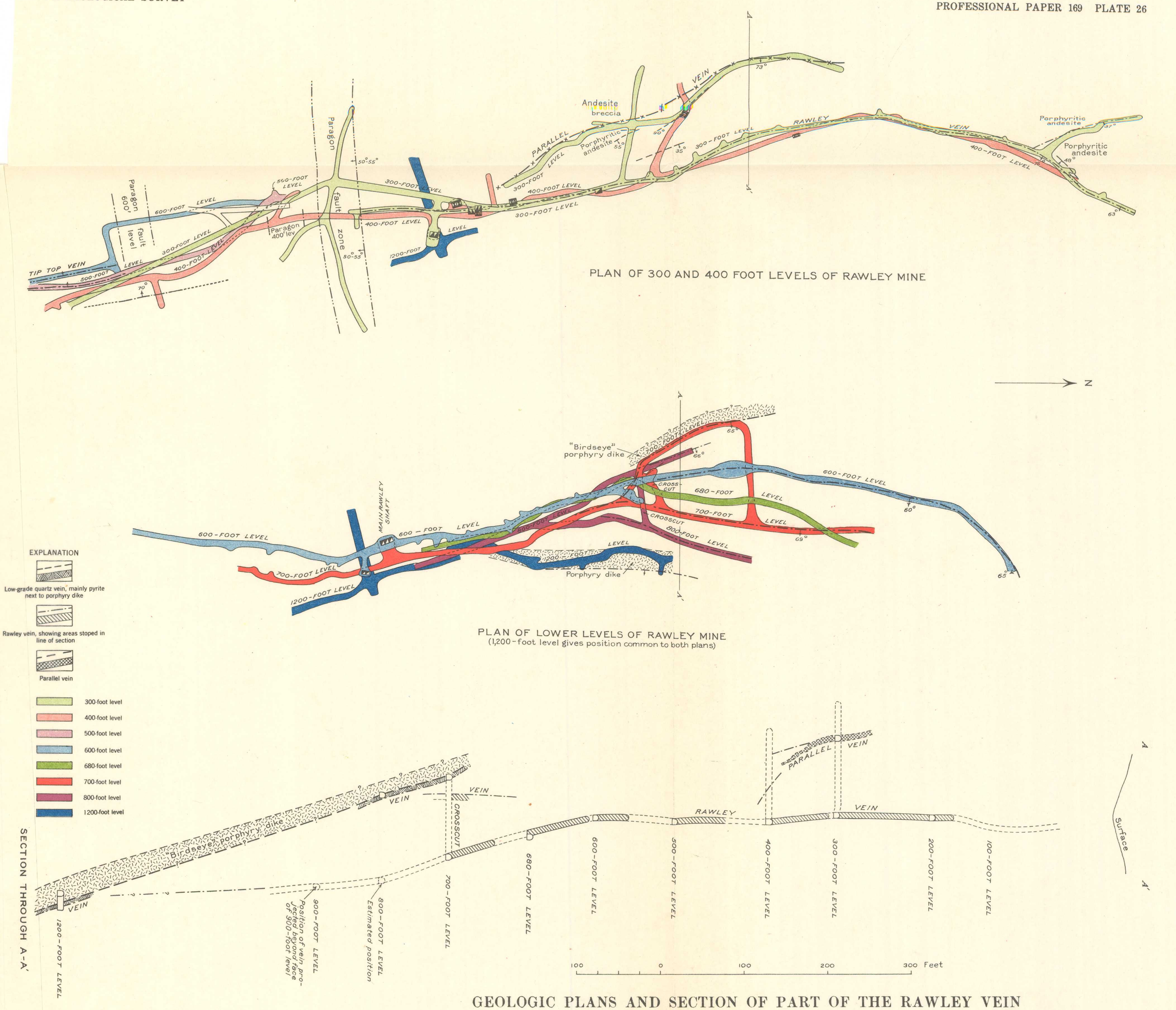
Distribution of metals in and value of the vein.—The following table shows some of the available data on the character of the ore in different parts of the Rawley vein, together with the ratios of lead to copper. The most noteworthy feature is the gradual but pronounced increase in copper content and decrease in lead content with increase in depth.



LONGITUDINAL SECTION OF RAWLEY MINE



GEOLOGIC PLAN AND SECTION OF RAWLEY DRAINAGE TUNNEL



GEOLOGIC PLANS AND SECTION OF PART OF THE RAWLEY VEIN
1931

Variation in tenor of the ore of the Rawley vein in different parts of the ore shoot

	Number of assays [a]	Ore (tons) [b]	Silver (ounces to the ton)	Lead (per cent)	Copper (per cent)	Ratio of lead to copper
200-foot level		9,415	10.0	11.6	2.11	5.47
300-foot level		6,490	9.72	12.7	1.70	7.47
400-foot level:						
South of shaft		314	12.8	18.5	1.40	13.2
	11		6.75	12.5	1.57	8.0
North of shaft		2,749	9.86	11.0	2.45	4.48
500-foot level:						
South of shaft		3,784	12.2	7.78	3.25	2.39
North of shaft		12,563	10.3	5.78	3.02	1.9
	18		6.77	3.31	2.79	1.2
600-foot level:						
South of shaft		2,423	13.4	5.6	3.54	1.58
North of shaft		6,354	9.9	1.04	3.85	.27
	26		15.1	2.06	5.07	.41
680-foot level:						
South of shaft	28		10.7	1.52	3.18	.48
North of shaft	32		12.5	.84	5.22	.17
700-foot level:						
South of shaft		3,008	11.8	2.41	3.17	.76
North of shaft		92	6.84	.69	2.25	.31
	18		16.0	1.50	6.33	.24
800-foot level, north of shaft		2,817	8.48	6.67	2.36	2.8
1,200-foot level, south of shaft		193	25.2	3.2	3.6	.89
	27		4.48	.80	.59	1.4

[a] Assays reduced to average foot percentages, representing the weighted mean of the percentages according to the widths of individual samples.
[b] Ore mined by lessees.

The horizontal change in the ratio of lead and copper toward the Paragon fault seems to be definitely shown by the data available, though it is not nearly as pronounced as the vertical change. The enrichment of the ore in lead noticeable at places near the Paragon fault is believed to be due to openings formed during the later stages of ore formation, caused presumably by contemporary movements on the Paragon fault.

The correspondence between the silver and copper content of the ore from the Rawley vein is very close in nearly all parts of the mine. The average silver content of the ore from the four upper levels mined prior to 1923 was about 5.6 ounces to the ton, or about 5 ounces of silver to 1 per cent of copper. The ratio of silver to copper in 11,820 tons of ore from the four upper levels mined by lessees in 1926 and 1927 is practically the same, 4.9 ounces of silver to 1 per cent of copper. This ratio is somewhat higher than that of the average mine-run ore of the lower levels, which ranges between 2.8 and 3.9 ounces of silver to 1 per cent of copper. There appears to be no definite relation between the silver and lead content. The minerals that probably carry most of the silver are tennantite and stromeyerite. In the Rawley ore stromeyerite is nearly always associated with bornite or tennantite and less commonly with other minerals. The bornite-bearing ore from the 700-foot level averaged about 10 ounces of silver to the ton, which is considerably higher than the average of mine-run ore from the upper levels.

The average value of ore from the Rawley vein is not fairly represented by the table on this page, as the ore was mined by lessees and the average value thus influenced by selection. The total ore mined and milled in the period from 1926 to 1930 had an average assay value of close to 8 ounces of silver to the ton, 3.2 per cent of lead, and 2 per cent of copper. Data as to the zinc content of the ore at various places in the mine are not as complete as those for lead and copper, but on the whole zinc is rather persistent. The highest content of zinc in the vein is said to have been encountered on the fourth level near the north end of the ore shoot, where it was about 4 to 5 per cent. The zinc content of the vein as a whole lies between 2 and 3 per cent. The average gold content is close to 0.01 ounce to the ton. The table on page 113 covering the mine production approximately by levels during 1927 shows the variation in value of the vein and also brings out strikingly the decrease in lead content of the ore with increasing depth of operations.

The close association of silver and copper is shown by Figure 24, based on the early production of the mine, prior to 1923, and on the monthly production of company mine ore during 1927. This chart shows that the percentage of lead in the company ore from the lower levels during November and December, 1927, was exceptionally low. The average for the lower levels is probably nearer 1 per cent, if several months' run is considered. The silver, however, shows no relation whatever to this fluctuation in the lead content but follows the copper curve very closely.

Structural relations of the ore shoot.—The north end of the Rawley ore shoot appears to be limited by the pinching of the fissure walls and by the splitting of the main Rawley fissure into flatter breaks. The split on the third level is shown in Plate 26. A northeast vein encountered in the Antoro tunnel workings is believed by local miners to correspond to the east split of the Rawley (p. 131). The correlation appears reasonable, as shown by the relative position of the workings on Plates 23 and 31. The mineralization on the east split of the Rawley fissure on the 200 and 300 foot levels does not appear to encourage further development. The west split on the 300-foot level strikes about N. 20°–25° W. and dips 35°–40° NE. It is also relatively tight and poorly mineralized. In the northern part of the 500-foot level, beginning about 250 feet north of the shaft, the vein pinches, and although it opens up in small stretches it continues narrow and for the most part too lean to stope to a point about 450 feet north of the shaft, where the drifting was stopped in 1927. The lead ore on the 400-foot level continued considerably beyond this north limit of the 500-foot level, and more recent developments (1928) on the 600-foot level encouraged further drifting toward the north on the 500-foot level. The vein was found to widen again only a short distance beyond the point where the drift had been previously abandoned. Such local pinching of the fissure walls is characteristic of the ore shoot as a whole and of many other veins in the district.

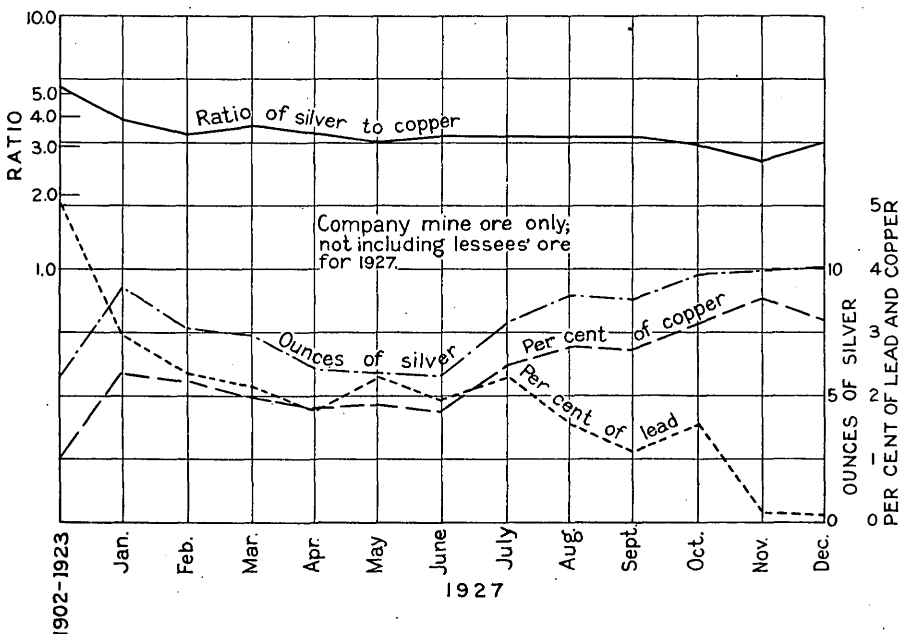


FIGURE 24.—Correspondence between silver and copper content in the ore of the Rawley vein

On the 700 and 800 foot levels a split and pronounced change in strike of the vein is encountered about 200 feet north of the shaft. This split was first recognized on the 700-foot level, where the west split of the vein was first followed, as there was no indication whatever of the east split when the level was driven. The west split soon narrowed and became barren, and later, because of the relative position of the vein in the 600 and 680 foot levels, the drift was turned, and a crosscut was driven until the east split was encountered. The east split on both 700 and 800 foot levels appears to be the main mineralized fissure and is high in copper and silver, with subordinate lead. The vein shows a strong tendency to turn to the northeast and to flatten somewhat north of the split, although the ore continues good on the 600-foot level for 600 to 700 feet north of the shaft. A plan of the lower levels and a section of the Rawley vein are shown in Plate 26.

In the west split on the 700 and 800 foot levels a porphyry dike was encountered which is similar to and very likely the upward extension of the "Birdseye porphyry" dike encountered in the north drift on the 1,200-foot level. It is noteworthy that wherever this dike has been encountered next to vein material the ore is pyritic and of low grade. The porphyry is probably a latite or quartz latite but is generally so soft and so much altered close to the vein that its exact original composition can not be determined. It is easily recognized where encountered by its large white phenocrysts of altered feldspar, in places half an inch or more in length. The cause for the low grade of the ore lying next to the dike walls is most likely the softness of the altered porphyry, which has locally choked the fissure. Pyrite commonly penetrates gouge-filled fissures much more readily than the other sulphides, which in contrast show a preference for deposition in openings.

On nearly all the north levels the Rawley fissure swings northeastward and tends to flatten in dip (see pls. 23 and 26), a change that is accompanied on many of the levels by the occurrence of splits such as those illustrated on the 300, 700, and 800 foot levels in Plate 23. On lower levels the turn in strike of the vein and the positions of the larger splits lie successively farther to the south. Although the distribution and width of the openings that formed the Rawley fissure do not vary uniformly, a gradual reduction in the total volume of these openings toward the north is in reality the cause for the limitation of the Rawley ore shoot at the north. A possible inference that may be drawn from this condition is that the forces which produced these openings had their

Production of Rawley mine in 1927, by months [a]

Month	Assay content of ore milled			Percentage of ore from different sources										Average content						Ratio of silver to copper in mine ore
				Company mine ore by levels								Lessees' ore [b]	Other sources	Mine ore			Lessees' ore [b]			
	Silver (ounces per ton)	Lead (per cent)	Copper (per cent)	300	400	500	600	700	900	1,000	1,200			Silver (ounces per ton)	Lead (per cent)	Copper (per cent)	Silver (ounces per ton)	Lead (per cent)	Copper (per cent)	
January	9.57	3.45	2.36	------	34	19.5	19.5	13.6	6	------	0.4	3.6	3.4	9.32	2.95	2.38	16.22	11.69	1.75	3.9
February	7.94	2.78	2.26	0.8	21	14	30	13	11	------	2.2	4.3	3.7	7.61	2.26	2.27	15.43	17.10	1.99	3.35
March	7.82	2.80	2.04	3	27	22	19	12	8	------	2	5.9	1.1	7.43	2.18	2.01	14.04	12.67	2.62	3.7
April	6.61	2.76	1.84	------	35	14	20	12	8	------	2	7.8	1.2	6.09	1.78	1.82	12.79	14.41	2.00	3.35
May	6.57	3.27	1.95	------	23	22	23.5	14	4	------	.5	10.4	2.6	5.87	2.37	1.86	12.65	11.06	2.66	3.15
June	6.80	3.53	1.90	------	17	21	22	19	3	------	------	16.7	1.3	5.81	1.93	1.79	11.74	10.34	2.42	3.25
July	8.25	3.61	2.44	------	17	4	16	40	3	------	------	14.8	5.2	7.88	2.30	2.43	10.39	11.15	2.48	3.4
August	9.23	3.58	2.74	------	6.5	.5	4	51	13	------	------	19.3	5.7	8.99	1.55	2.79	10.24	12.06	2.55	3.22
September	9.15	2.90	2.75	------	7	------	------	76	1	------	------	15.5	.5	8.78	1.13	2.70	11.14	12.54	3.03	3.25
October	10.16	3.67	3.13	------	13	------	------	61	7	1	------	17.6	.4	9.75	1.56	3.17	12.07	13.58	2.93	3.06
November	10.11	3.22	3.33	------	1	------	------	70	5	------	------	24	------	9.93	.15	3.58	10.68	12.64	2.53	2.77
December	10.33	2.94	3.06	------	------	------	------	68	3	------	------	29	------	10.00	.10	3.20	11.14	9.85	2.73	3.12

[a] Modification of table prepared by A. E. Ring, general manager of Rawley Mines (Inc.).
[b] About 85 to 90 per cent of lessees' ore mined from stopes above 500-foot level and other levels above this.

greatest concentration at the south end of the ore shoot—that is, near the Paragon fault. Further indirect evidence bearing on this relation is afforded by the distribution of metals in the Rawley vein as shown by the table on page 111. Attention was drawn to the fact that an enrichment of the ore shoot in galena was especially marked in close proximity to the Paragon fault. It is evident that if temporary openings were produced along the Rawley fissure by movements on the Paragon fault, the effects of this action would die out northward away from the fault, owing to dispersion of the forces along secondary splits and other minor fractures. Regardless of the origin of the Rawley fissure itself, whether it was related to stresses produced only in the footwall of the Paragon or whether it was formed before or at the same time as the Paragon, the most important structural feature is the evident relation of the ore shoot to the larger and more active fault.

Very little new evidence is afforded by the latest mining operations as to the deeper extension of the main Rawley ore shoot. There are, however, stringers of galena ore present on the 1,200-foot level north of the shaft, a body of pyritic copper ore near the shaft, and showings of mixed ores all along the level south of the shaft. The lead assays average under 1 per cent. (See table, p. 111.) However, the width and grade of the vein material found on the lower levels, such as the 1,000 and 1,200 foot levels, did not permit profitable stoping under existing conditions of the mining industry. The porphyry dike in the fissure north of the shaft on the 1,200-foot level can be considered unfavorable in the effects which it had on ore-shoot formation in the northern part of the fissure. On the other hand, it may be reasonably inferred that in a zone near the Paragon fault small bodies of pyritic copper ore with some lead, such as those partly stoped near the shaft, would exist at appreciably greater depths. This inference is based upon an assumption that movements of the Paragon fault have favored the temporary formation of open spaces, but it is stated without implication as to the profitable development and mining of such possible ore.

TIP TOP VEIN

Crosscutting and drifting on the 400-foot adit level, driven earlier in the history of the mine, had failed to reveal commercial ore south of the Paragon fault. In a search for new ore bodies in 1928 the 600-foot level was driven south through the Paragon fault, and a crosscut was driven eastward, disclosing a north-south vein in the hanging wall of the fault about 40 to 50 feet east of the strike line of the Rawley vein. (See pls. 23 and 26.) This vein, which underlies the Tip Top claim, was later developed and partly stoped from the 500, 700, and 900 foot levels. (See pl. 24.) During 1928 and 1929 about 34,000 tons of ore was mined from the Tip Top vein, and in 1930 some additional production was made, for which figures are not at hand. The following description of this vein is based upon brief examinations by the writer in 1928 and 1930 and upon personal communications from Mr. A. E. Ring.

The strike of the Tip Top vein on the 600-foot level is about N. 15°–18° W., and the average dip of the vein is about 83° W. For the first 100 feet or so south of the Paragon fault on the 600-foot level this vein was narrow, but farther south it attained a width ranging between 5 and 10 feet. The general appearance of the vein matter is much like that of the main Rawley vein, shoots of galena ore lying alongside of the siliceous part of the vein. (See fig. 25.) The mineralogy of the vein on this level differs slightly in detail from that of the Rawley vein at corresponding levels, in that it contained a greater amount of rhodochrosite occurring in small vugs in the quartz. The sulphide minerals present include pyrite, bornite (partly in small crystals), chalcopyrite, sphalerite, and galena. The proportion of galena is somewhat higher than at a corresponding altitude on the Rawley vein. On the 500, 600, and 700 foot levels of the Tip Top vein the lead probably averaged 4 to 5 per cent; it was lowest on the 700-foot level. On the 900-foot level only a few places show ore, and the lead is still lower in amount. There is probably a slight increase in copper with depth. The ore shoot that was developed had its greatest length of about 330 feet between the 500 and 600 foot levels and fingered out below irregularly, with only short bunches of ore on the 900-foot level. Only on and just above the 500-foot level did this ore shoot extend northward close to the Paragon fault. On the other levels the Tip Top fissure was generally narrow near the Paragon fault or consisted of a zone of fractures and ore stringers. In this structural feature the ore shoot differed appreciably from the Rawley ore shoot, which for some distance extends close under the footwall on the north side of the Paragon fault. As was pointed out on page 90, such a difference in the occurrence of the ore and structure of the fissure on opposite sides of a cross fault may be considered contributory evidence toward establishing the premineral origin of the fault.

On the other hand, the argument might be advanced that the higher lead content of the Tip Top ore shoot as compared with that of the Rawley shoot at the corresponding altitude indicates a late postmineral downfaulting of this ore body relative to the Rawley ore body. This argument, however, loses some of its force when it is considered that local bodies of high-grade galena ore were found on even lower levels of the Rawley vein, a feature indicating that conditions which favored deposition of galena fingered out irregularly in depth. A parallel condition was noted by Ransome in the lead-bearing ores of the Red Mountain district, Colorado. (See p. 87.) It is reasonably clear from other evidence cited above that the Paragon fault is of premineral age, and it is therefore fair to assume that physicochemical and structural conditions during mineralization would have been different on the opposite sides of the fault, owing to the sealing action of its gouge. For these reasons it would appear that the change in lead content of the shoots on the two sides of the fault does not necessarily indicate a late postmineral downthrow of the block on the south side. The writer does not consider that the change in lead content has any further direct bearing on the question of the premineral or postmineral origin of the Paragon fault, as evidence of a structural nature is believed to have independently answered this question.

The south end of the Tip Top ore shoot is delimited on the 600-foot level by cross faults of southerly dip more or less paralleling the Paragon fault. On higher and lower levels the ore shoot generally pinches out before these cross faults are reached. In Figure 25

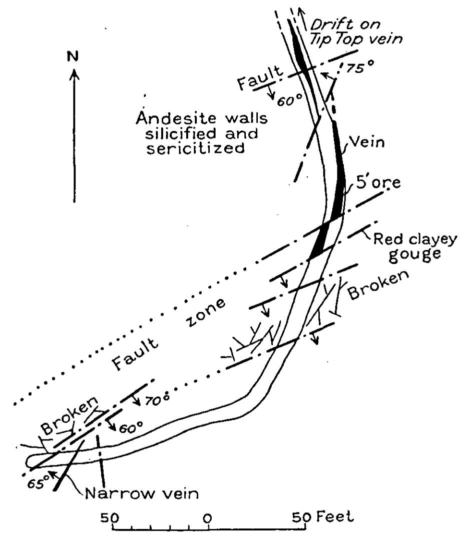


FIGURE 25.—Sketch map of south end of 900-foot level, Tip Top vein

is given a plan of the extreme south end of the 900-foot level which shows the character of this cross faulting. Many of the faults shown in the figure show alterations of their walls that include the earliest type of jaspery or siliceous alteration, as well as later stages of sericitization and pyritization. The silicification of the wall rocks shows that these faults had a premineral origin, but the jasper reveals further gougy slips of postsilicification age. These later gouges are pyritized in some of the faults. The conclusion may be stated that movements on these faults began prior to silicification and continued at least until and probably throughout the period of sulphide mineralization. Some fracturing of the rocks showing weak alteration probably indicates moderate post-mineral adjustments of the fault blocks. This broken condition discouraged explorations farther south, especially in view of the generally scattered distribution of the ore on the 900-foot level.

The nature of the structural relations between the Rawley fissure, Tip Top fissure, and Paragon fault offers no conclusive evidence regarding the question of identity of the Rawley and Tip Top fissures. It is clear, however, that both of these fissures were formed, like the Paragon fault, very early in the period of deformation of the lava beds in this region. In the discussion of the general structure of this area the belief was expressed that north-south faults were in part earlier than east-west faults. It is possible that the Rawley and Tip Top fissures represent a single comparatively minor fracture of the north-south set that was later enlarged and separated into segments by movements between adjoining fault blocks.

PARALLEL VEIN

In the years 1926 to 1929, inclusive, 12,412 tons of ore was mined from the Parallel vein, which is developed on the 300, 400, and 500 foot levels. About 70 per cent of this ore was obtained from the 300-foot level, as the vein pinches and flattens below this level. (See pl. 26.) Most of the work on this vein was done under lease, and complete maps of the drifts and stopes are not available. The ore mined by the lessees averaged about 8.6 per cent of lead, 2.55 per cent of copper, and 9.4 ounces of silver to the ton.

CLARK VEIN

The Clark fault fissure strikes a little east of north and dips 35°–40° E. Developments along it on the drainage tunnel level are shown in Figure 26. The vein matter lies within a very complex fault zone 10 or 15 feet in width in which the andesite has been greatly sheared, with the formation of thick gouges, and the ore shoots in the vein pinch and swell very irregularly. In this respect the ore bodies resemble those of the Cocomongo fault. On the tunnel level the ore shoot appears to be confined between oblique cross faults of northerly and easterly trend, both of which are mineralized, but the development is not sufficient to determine the complete length of the mineralized parts of these faults. The vein matter consists of well-crystallized sphalerite, galena, and a little pyrite and chalcopyrite in a gangue of calcite, rhodochrosite, a little quartz, and siderite. It is not nearly as siliceous as the Rawley vein. The ratio of zinc to lead is nearly 2 to 1, and copper and silver are rather low. The production from the vein has been small. The low angle of dip of the vein and its position relative to the Black Bess vein on the surface above the tunnel would suggest that the two veins may occupy the same fault zone, but definite correlation in this intricately faulted area is not possible. (See pl. 25.)

COCOMONGO MINE

The Bonanza-Cocomongo group is owned by the St. Louis Smelting & Refining Co. and is situated on Kerber Creek a little over 1¼ miles above the town

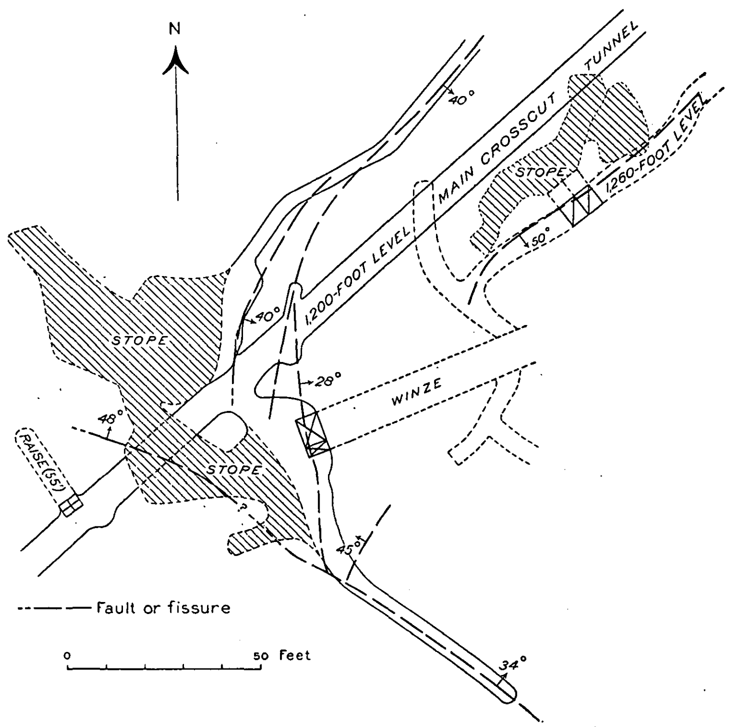


FIGURE 26.—Plan of developments on the Clark vein, Rawley drainage tunnel

of Bonanza. The mine is a consolidation of the old Bonanza and the Cocomongo mines, which develop a series of intersecting fissures, and includes the Bonanza, Bonanza No. 1, Cocomongo, Cocomongo Camp, and Hilltop claims. The consolidated group is now referred to as the Cocomongo mine.

The Bonanza claim was located in 1880, and in 1883 [90] the Bonanza mine shaft had reached a depth of 90 feet and had encountered galena and gray copper ore. The Colorado Mining Directory for 1883 [91] states that the ore was valued at $25 to $50 a ton when sorted and gives an output of 150 tons from this shaft. In 1887, 1888, 1890, and 1891 either the mine is reported as not producing or no record is given. According to an estimate by J. P. Poole [92] the Bonanza mine shipped 2,000 tons of ore between 1881 and 1900. The value of this ore is not known. Part of this ore may have

[90] Silver, Herman, Report of the Director of the Mint upon the production of the precious metals in the United States during the calendar year 1883, p. 403, 1884.
[91] Published by Colorado Mining Directory Co., Denver.
[92] Patton, H. B., op. cit., p. 68.

been treated in the old Bonanza mill, west of Kerber Creek just below the town of Bonanza. This mill was erected about the year 1900 by the Bonanza Milling Co. and was a custom mill but is said to have treated mainly ore from the Bonanza mine.

In 1902 the Bonanza mine was operated by the Hanover Mining & Milling Co. which shipped 592 tons of concentrates. (See accompanying table.) There was no production from 1903 to 1909, and the small shipment in 1910 was made by lessees. The mine was operated under sublease to the Saguache Mining Co. during 1912 and part of 1913, and the ore was treated by the Bonanza Milling Co., a subsidiary company. During the years 1913 to 1917 the mine was further subleased by the Saguache Mining & Milling Co., and small shipments of crude ore were made.

The Cocomongo claim is a later location than the Bonanza and was patented in 1910. The Cocomongo Mines Co. developed this property in 1917 to 1921 and shipped some crude ore. During the later part of this period and in subsequent years, after the properties were acquired by the St. Louis Smelting & Refining Co., the Cocomongo and Bonanza mines were operated jointly. Production was discontinued in 1926, but development work in blocking out ore and exploratory work were continued until May, 1927. The property has since remained idle, up to December, 1930.

Production of Bonanza and Cocomongo mines, 1902–1926 [a]

Year	Ore (dry tons)	Concentrates produced (dry tons)	Gross content of concentrates and smelting ore				
			Gold (fine ounces)	Silver (fine ounces)	Lead (wet assay, pounds)	Copper (wet assay, pounds)	Zinc (pounds)
1902	5, 000	592		1, 224	178, 000		93, 200
1910 [b]	115		3. 29	1, 781	85, 249	2, 948	
1911	74		. 74	1, 429	29, 250	1, 240	56, 098
1912	8, 568	1, 071	65. 91	9, 170	486, 570	8, 818	597, 652
1913 [c]	706	34	69. 07	5, 327	285, 338	9, 625	10, 444
1914 [d]	293		47. 36	5, 917	133, 995	23, 146	10, 898
1915	346		15. 15	5, 327	124, 687	22, 620	45, 963
1916	164		5. 23	2, 698	128, 474	6, 029	
1917	732		89. 70	27, 235	30, 150	47, 006	
1918	1, 285		114. 48	83, 417	54, 311	127, 585	
1919	406		34. 25	27, 995	43, 354	48, 441	
1920	4, 754	443	148. 76	60, 062	137, 590	94, 800	Over 10%
1921	1, 402	119	27. 50	22, 436	142, 473	37, 017	
1922	229		33. 40	16, 514	100, 451	34, 075	
1923	91		5. 58	2, 952	33, 874	5, 995	
1924	1, 203	231	5. 94	5, 779	91, 109	1, 309	148, 193
1925	27, 000	3, 628	64. 55	60, 248	1, 541, 070	1, 064	2, 062, 159
1926	6, 752	796	18. 75	18, 558	362, 816	2, 652	377, 784
1927 [e]							

[a] No production in years omitted from table since 1902. See text for production prior to 1902. Compiled from mine records of U. S. Geological Survey and Bureau of Mines.
[b] Mogul and Bonanza mines.
[c] Bonanza and Yellow Type mines.
[d] Ore possibly Exchequer and Yellow Type mines in large part.
[e] Mine operated Jan. 1 to May 5, 1927. No production.

UNDERGROUND WORKINGS AND MINE BUILDINGS

The underground workings on the Bonanza and Cocomongo veins are reached through two shafts—a vertical shaft 300 feet deep on the west side of Kerber Creek known as the Cocomongo shaft, and an inclined shaft on the Bonanza vein on the east side of the creek, known as the Bonanza shaft. (See pl. 27.) The present mill buildings are just below the shaft house of the Bonanza shaft, on the east side of the creek. The capacity of the present mill is 50 to 75 tons a day with nonselective flotation. It is the intention of the owners to provide for selective flotation when the mill is operated and to produce both lead and zinc concentrates. At present all of the work is done through the Bonanza shaft, which extends to a depth of about 450 feet vertically below the collar and is operated by an electric hoist. The Bonanza and Cocomongo veins are opened on five main levels and several sublevels. The greatest length of drifting is on the 300 and 350 foot levels, which extend about 1,500 feet in a northwest-southeast direction. The deepest drifts are on what is called the 500 level, which lies about 380 feet vertically below the collar of the shaft, but the shaft has been sunk about 70 feet below this level. There is somewhat more than 350 feet of drifting from the second level of the Cocomongo shaft, but this level was not examined, as it is not connected to the second level of the Bonanza shaft and is not readily accessible. The third level is the only one by which the two shafts are connected. The extreme northern part of the third level was not accessible at the time of examination, as it was partly caved and had been abandoned. The drifts in the mine amount to about 7,000 feet.

GEOLOGIC FEATURES

GENERAL RELATIONS

At the outset the writer wishes to acknowledge the assistance of the officials of the St. Louis Smelting & Refining Co., in providing facilities for the underground study of the Cocomongo mine, and particularly that of Mr. F. M. Stephens, superintendent of the mine, who has cooperated in the underground work and supplied data and mine sections which together with the writer's observations furnish the basis of the following discussion.

The Bonanza-Cocomongo vein system consists of two main mineralized faults and several related veins occupying fractures 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. At and below the fourth level of the mine the andesite which underlies the latite has been encountered and in places forms at least one wall of the veins, usually the footwall. The greatest amount of faulting appears to have occurred on the Cocomongo fault. This has an average strike of about N. 30° W. and an eastward dip which ranges from about 47° in the upper levels to about 20° in the lowest. The change in dip of the Cocomongo fault is fairly uniform, although the sharpest change occurs at or somewhat below the 300-foot level. (See section A–A′, pl. 28.)

The hanging wall of the Cocomongo fault as far down as the fifth level and the bottom of the Bonanza shaft consists of Bonanza latite. The latite has a north to N. 30° E. strike and a dip of 30°–60° W. The footwall of the Cocomongo fault at and below the 400-foot level is composed of Rawley andesite at many places in the mine. The normal dip of the Bonanza latite in both walls of the fissure has been disturbed near the fault zone. No consistent difference between the hanging wall and footwall could be detected, however, in the normal strikes and dips of the latite and andesite. The present depth of developments on the Cocomongo fault does not disclose the entire amount of displacement but indicates that it exceeds 250 feet. (See sections B–B′ and C–C′, pl. 28.) The Cocomongo fault is probably one of the series of similar faults in the vicinity of Kerber Creek that forms a zone of very large total displacement. The Cocomongo fissure is developed mostly by the mine workings northwest of the Bonanza shaft, but one drift on this fault has been extended into the footwall of the Bonanza shaft.

The geologic relations between the Bonanza and Cocomongo veins on the 300 and 350 foot levels of the mine are shown in Plate 28. The Bonanza vein has a strike of N. 45°–55° W. and so far as is known is confined entirely to the hanging wall of the Cocomongo fault. The dip of the Bonanza vein ranges from about 70° on the first and second levels south of the Bonanza shaft to about 40°–42° on the 400 and 500 foot levels. The Bonanza vein also occupies a fault, and although the amount of displacement can not be estimated, it is probably less than on the Cocomongo fault. The Bonanza fault is characterized more by fracturing and brecciation of the wall rock; the Cocomongo fault by heavy gouges and intense shearing of the wall rock.

On the 300-foot level the intersection between the two veins lies north of the Bonanza shaft but probably pitches eastward. The intersection is not simple and can not be represented by a single line. The Bonanza fault particularly has a tendency to split into a compound fracture zone near its intersection with the Cocomongo fault. The character of the termination of the Cocomongo fault at the north end of the 300-foot level could not be examined, as the drift is caved, but several cross faults or branching faults are said to have been encountered. Development work north of these cross faults appears to have been unsuccessful in locating any veins.

On the 500-foot level the irregular fracturing shown near the Bonanza shaft suggests the intersection of the two faults. The Bonanza shaft below the 500-foot level is probably on the Cocomongo fault, which at the bottom of the shaft dips only 18°–20° E. For about 100 feet south of the shaft on the 500-foot level the latite is much fractured and silicified, but no single well-defined break is evident. This zone probably represents the splitting of the Bonanza fault into a compound fracture zone similar to that shown on the map of the 300-foot level.

The termination of the Cocomongo fissure at the north end of the mine on the 400-foot level is shown in Plate 28. The fissure shows a tendency to swing into a north-south strike and appears to terminate against a strong gougy fault zone which dips northward or northeastward at angle of 47°. This fault has a strongly altered micaceous gouge and, like the Cocomongo fault, is probably of premineral origin. At the end of the 500-foot north drift on the Cocomongo fissure another premineral flat fault is encountered which strikes N. 17° E. and dips 28° E. The Cocomongo fissure as it approaches this fault shows a tendency to swing into a north-south strike. The footwalls of both the Cocomongo fissure and the N. 17° E. fissure on this level appear to be the upper latite member of the Rawley andesite.

It would appear that at the north end of the mine workings the Cocomongo fissure lost its individuality and either terminated against other premineral faults of the same general nature or was displaced by them. In either case these faults appear to limit the mineralization of the Cocomongo fissure on the north.

The Cocomongo fault passes into the footwall of the Bonanza fault on the 300-foot level and has been followed by a drift for about 250 feet, to the footwall beneath the Bonanza shaft. It shows good mineralization in parts of this drift, but at the south end of the drift it splits into several weakly mineralized fissures of steeper dip. It has not been explored farther south, and whether the conditions near the end of this drift are local is not known.

The Bonanza fissure zone has been followed by a drift southeast of the Bonanza shaft for about 480 feet on the 350-foot level and for about 300 feet on the 500-foot level. On the 350-foot level in the last 180 feet of the drift the fissure is tight and irregularly mineralized and splits into several steeper fractures. The mineralization becomes weaker in this fissure toward the southeast on all the levels.

STRUCTURAL RELATIONS OF FISSURES IN THE HANGING WALL OF THE COCOMONGO FAULT

In addition to the Bonanza vein there are also a series of so-called "vertical" veins which branch upward into the hanging walls of the Cocomongo fault. Several of these have yielded ore of good grade. Their relations to the Cocomongo fault are shown in Plates 28 and 29. The transverse "vertical" fractures were presumably the result of stresses developed in the hanging-wall blocks during the period of faulting. They are for the most part steeper than the main fault planes, but several of them were found to flatten and pinch as they were stoped upward into the hanging wall. This flattening is particularly pronounced in the "Gold vein," which occurs near the intersection of the Bonanza and Cocomongo veins. Another vertical vein, in which some ore has recently been developed, lies parallel to it and somewhat offset to the north. Still another vein lies about east of the Cocomongo shaft in the hanging wall of the Cocomongo vein. It has been explored by drifts on the 300 and 400 foot levels and stoped in some places above the 300-foot level. Its strike is S. 70°–80° E., and the dip is nearly vertical, although the vein flattens and dips northeast between the 300 and 400 foot levels near the Cocomongo fault. The greater part of the explored length of this fissure has not been productive. The intersections with the main faults at the bases of these vertical veins are not easily detected. As shown in Plate 28, the fissures appear to branch off near curves or rolls in the Cocomongo fault plane. Whether or not these rolls were instrumental in producing the fractures can not be determined, as there is insufficient evidence. These fractures appear, however, to be confined to the hanging walls of the faults.

The Bonanza vein bears a relation to the Cocomongo fault plane very similar to that of the transverse or vertical veins. Probably the Bonanza fault was incipiently formed in the same manner as these fractures, but subsequent movement on it was much greater than on the other hanging-wall fractures that have been explored. It would appear that the Cocomongo was the first fault formed, and as a result of stresses active in its hanging wall, the block on that side was fractured by several more or less parallel fissures diverging southeastward from the main fault plane. With the continuation of the downthrow of the hanging wall of the main fault, the block on the hanging-wall side of the incipient Bonanza fault participated in the movement to a greater extent than the wedge-shaped block between the Bonanza and Cocomongo faults.

This conception is illustrated in Plate 29. The presence of several vertical fractures near the intersection of the Bonanza and Cocomongo faults on the 300 and 400 foot levels, and the fractured condition of the rock near their intersection on the 500-foot level would support the contention that the Bonanza fault starts in the hanging wall of the Cocomongo and is not to be regarded as the faulted portion of some earlier continuous fracture.

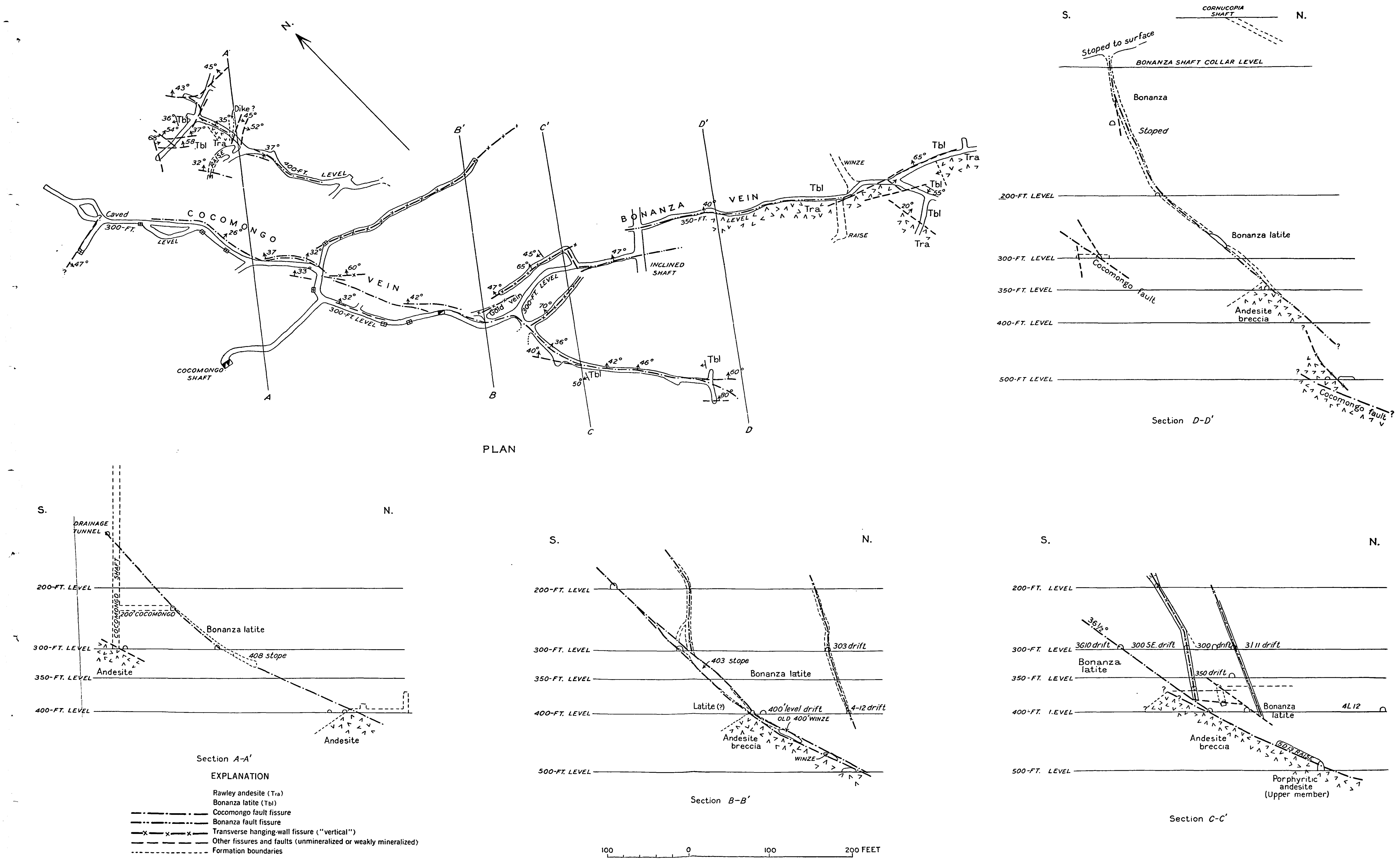
Similar transverse fractures in the hanging walls of veins that occupy faults have been found in other districts in the San Juan region. These are well illustrated by the fractures in the hanging wall of the Amethyst fault in the Creede district, described by Emmons and Larsen.[93]

DISTRIBUTION OF MINERALIZATION IN THE FISSURES

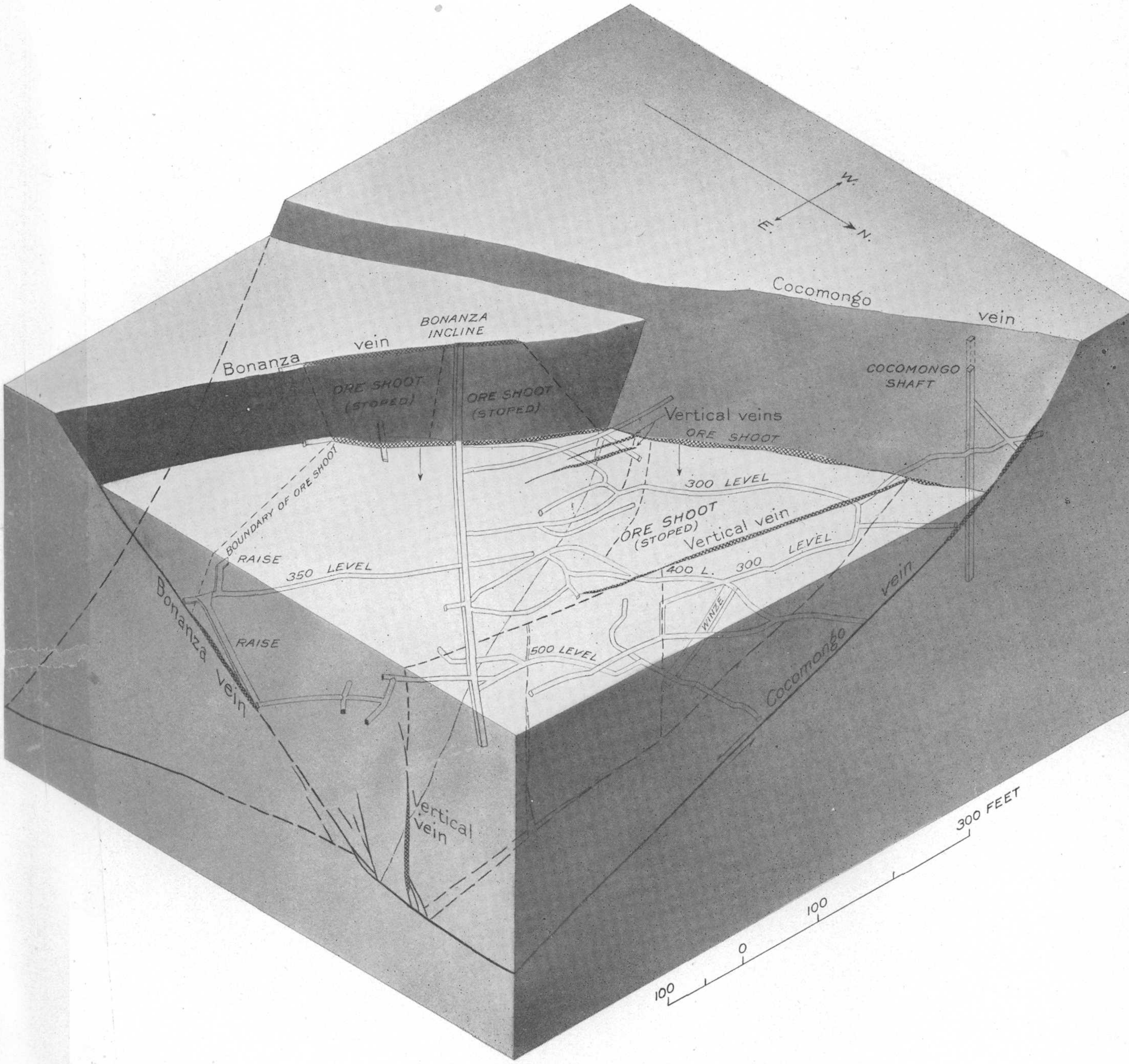
The ore bodies that have been mined from the Cocomongo and Bonanza fissures were for the most part above the 400-foot level. A wide body of high-grade lead-zinc ore was taken out of the Cocomongo fissure between the 300 and 400 foot levels, just north of its intersection with the Bonanza fissure, and is known as the 403 stope. The width stoped out amounts to 15 or 20 feet in the middle portion. The pitch length of the shoot was about 160 feet, although the shoot was not equally productive throughout this length. The stope length of the shoot was about 80 or 90 feet in its longest part. The exact character of the ore is not known, as only the open or partly caved stopes now remain. The width of this ore body, which is unusually wide for this district, may have been caused partly by the change in dip of the Cocomongo fault at this position. The differential movement between the hanging and foot walls evidently left an open space because the two adjacent walls were unconformable. (See cross section B–B′, pl. 28.) The intersection between the Bonanza and Cocomongo

[93] Emmons, W. H., and Larsen, E. S., Geology and ore deposits of the Creede district, Colorado: U. S. Geol. Survey Bull. 718, pp. 150–151, 1923.

PLAN OF THE WORKINGS OF THE COCOMONGO MINE
1931



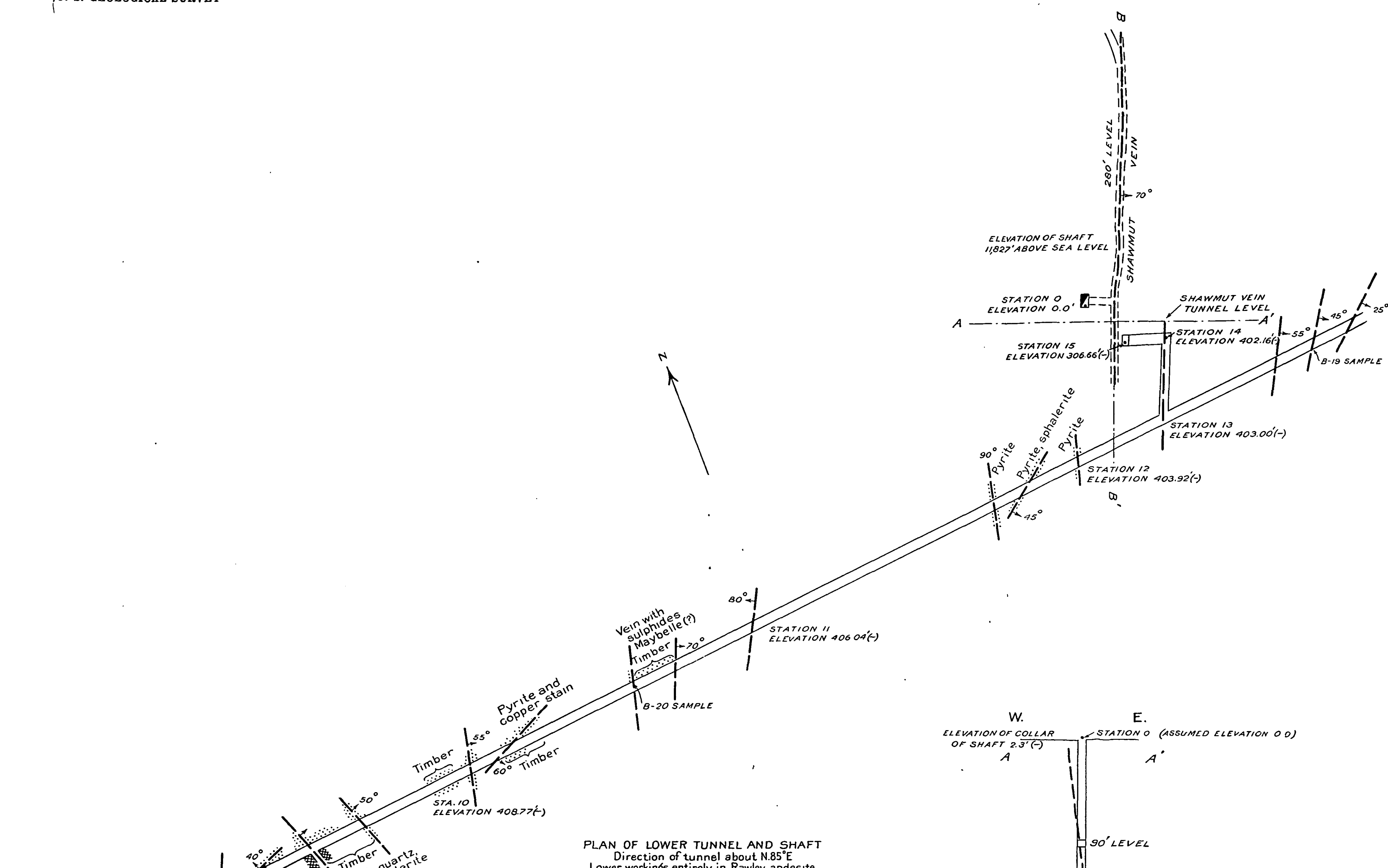
GEOLOGIC PLAN AND SECTIONS OF COCOMONGO AND BONANZA VEINS, COCOMONGO MINE

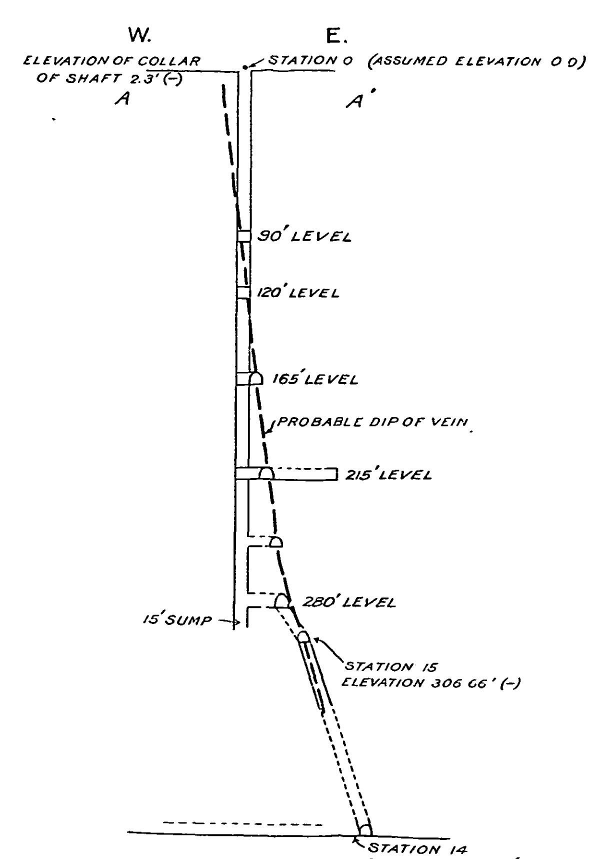


STEREOGRAPHIC PROJECTION OF PART OF COCOMONGO MINE, SHOWING RELATION BETWEEN MINERALIZED COCOMONGO AND BONANZA FAULT FISSURES

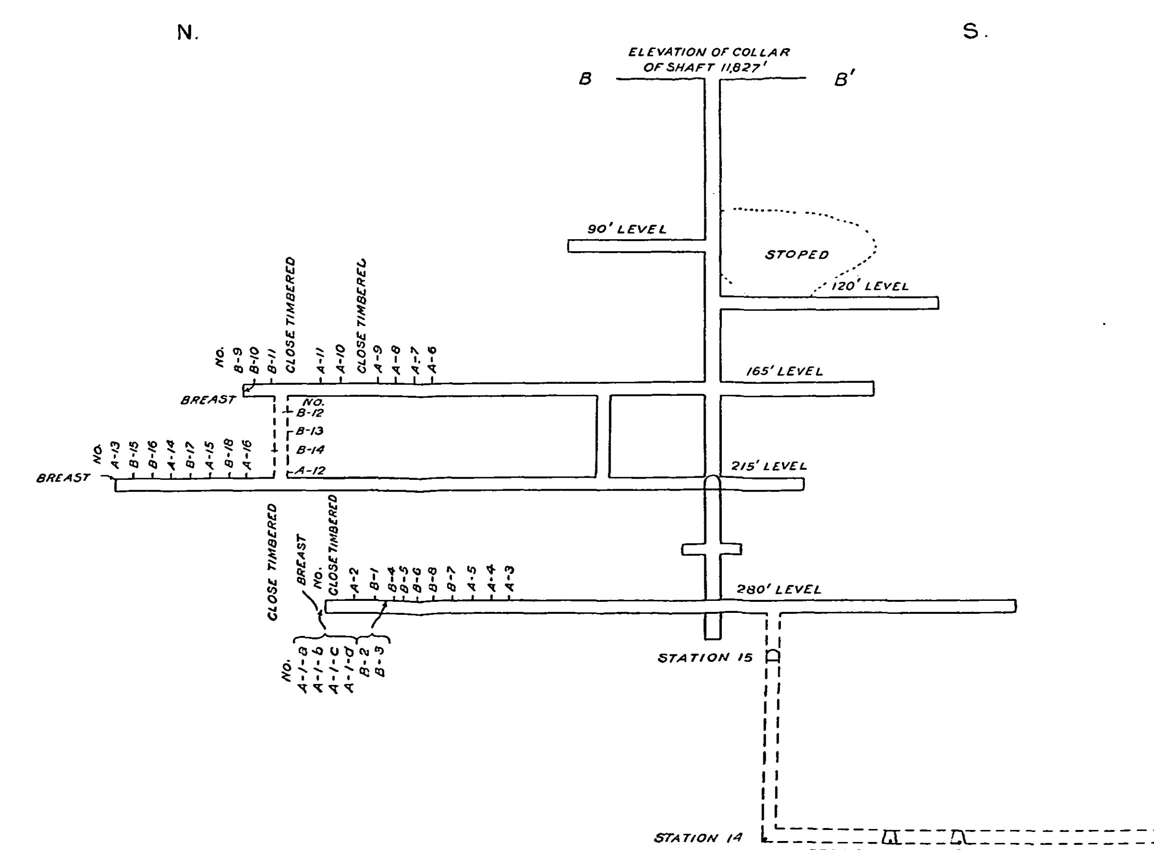
SAMPLES AND ASSAYS

No.	Width (feet)	Gold (ounces to the ton)	Silver (ounces to the ton)	Description
A-1-a	2.8	Tr.	Tr.	Altered andesite porphyry on hanging-wall pyrite.
A-1-b	1.8	0.06	4.74	Quartz with pyrite.
A-1-c	1.1	Tr.	.50	Altered andesite, quartz, and pyrite.
A-1-d	2.5	Tr.	.60	Quartz and pyrite. On footwall.
A-2	3.0	Tr.	1.40	Altered andesite and pyrite.
A-3	0.8	Tr.	3.70	Quartz and sulphides.
A-4	1.0	Tr.	Tr.	Do
A-5	2.7	Tr.	Tr.	Altered andesite, quartz, and pyrite.
A-6	1.0	Tr.	.50	Do
A-7	2.0	Tr.	5.60	Altered andesite with pyrite.
A-8	1.6	Tr.	1.00	Altered andesite, quartz, and pyrite.
A-9	1.5	Tr.	Tr.	Altered rock, quartz, and pyrite.
A-10	3.0	Tr.	Tr.	Altered andesite and pyrite.
A-11	2.8	Tr.	Tr.	Do
A-12	3.8	.03	3.80	Quartz and sulphides.
A-13	6.3	.08	5.62	Do
A-14	4.4	Tr.	1.20	Do
A-15	3.6	.12	17.88	Do
A-16	2.2	.08	5.92	Do
B-1	4.5	.04	1.60	Altered rock, quartz, and pyrite.
B-2	3.7	.01	.30	Do
B-3	1.6	Tr.	Tr.	Quartz, sulphide, and altered andesite.
B-4	4.4	Tr.	Tr.	Do
B-5	4.8	.02	Tr.	Altered andesite, little quartz, and pyrite.
B-6	4.0	.02	Tr.	Altered andesite, with pyrite.
B-7	1.5	Tr.	Tr.	Altered andesite. No sulphide or quartz.
B-8	2.0	Tr.	1.40	Altered andesite with pyrite.
B-9	2.5	.08	14.62	Footwall streak; quartz, chalcopyrite, and pyrite.
B-10	3.0	Tr.	1.00	Quartz and sulphides.
B-11	3.0	Tr.	Tr.	Quartz and 3 inches of sulphides.
B-12	2.6	Tr.	14.00	Quartz and sulphides.
B-13	3.6	Tr.	Tr.	Altered andesite, quartz, and sulphides.
B-14	2.8	.24	50.26	Quartz and sulphides.
B-15	4.2	.24	18.60	Altered rock, 1 foot; quartz, chalcopyrite, and pyrite, 2½ feet.
B-16	2.8	.08	2.92	Quartz and sulphides.
B-17	5.2	Tr.	.40	Altered rock, quartz, and sulphides.
B-18	3.0	.05	13.20	Do
B-19	.3	.06	13.44	Sulphides and chalcopyrite.
B-20	2.2	Tr	2.70	Sulphides and quartz.





SECTION ALONG LINE A–A′



SECTION ALONG LINE B–B′

PLAN AND SECTIONS OF SHAWMUT DRAINAGE TUNNEL AND MINE

Samples and assays from report by S. J. Burris, jr., on the property of the Kapi Mining & Milling Co.

fissures, which lies just at the southern boundary of this shoot, may have been a factor contributing to its formation. However, as the Cocomongo fault plane becomes flatter below the 400-foot level the shoot fails to maintain its width and does not follow the intersection of the two fissures to the 500-foot level. It is possible that the shoot was produced by the combined effect of change in dip on the Cocomongo fault and the intersection of the two fissures. A shoot of less width (the 408 stope) occurs between the 300 and 400 foot levels of the Cocomongo fault northeast of the Cocomongo shaft. (See cross section A–A′, pl. 28.)

In the Bonanza vein a large shoot of ore lay above the 200-foot level south of the Bonanza shaft. This shoot was stoped out to the surface in places. The vein is very steep above the 200-foot level, dipping 60°–70° NE. The shoot was 10 or 12 feet wide in some places, and its stope length was about 100 feet. It is said to have contained bodies of galena and quartz 2 to 3 feet in width in the midst of the vein. Between the 200 and 300 foot levels a block of ore extending about 100 feet south of the shaft still remains. It has an average width of about 3.5 feet and indicates some pinching of the fissure below the 200-foot level as the dip flattens. (See section D–D′, pl. 28.)

The amount and character of the vein material stoped out above the old 200-foot level north of the Bonanza shaft could not be determined, as these openings are not accessible. Additional bodies of unstoped ore estimated at about 25,000 tons still remain (1927) in the different veins. Above and below the 350-foot level south of the Bonanza shaft there are some bodies which have a width of a little over 4 feet, and between the 300 and 400 levels north of the Bonanza shaft there is a body 3.5 to 4 feet wide. Several other bodies of ore including those in some of the vertical fissures have average widths ranging from 3.5 to 5.5 feet.

GENERAL CHARACTER OF THE ORE

Like the other veins of the northern part of the district, the Bonanza and Cocomongo veins contain quartz as the most abundant gangue mineral. Smaller amounts of barite, rhodochrosite, manganocalcite, calcite, fluorite, and rhodonite are also found. Apatite or the carbonated apatite, dahllite, is associated with carbonates and quartz in parts of the gangue. The sulphide minerals are pyrite, sphalerite, galena, tennantite, chalcopyrite, stromeyerite, and covellite. Limonite, cerusite, anglesite, and covellite occur in small amounts as secondary minerals in the upper levels and were produced by the action of surface waters on the primary ore. Delicate banded texture is never or rarely seen in the vein matter in either the Bonanza or the Cocomongo vein. In places streaks of galena and quartz 2 to 3 feet in width are said to have been found in the wider parts of the Bonanza vein on the first level. These massive ores exhibit a rough banding due to the distribution of the coarsely crystallized galena. In addition to the streaks of massive galena ore the vein at its widest part contained some mixed zinc-lead-copper ore with pyrite, some bodies of which still remain along the hanging wall of the old stope above the 200-foot level. The footwall of the stope still shows vein matter with little or no gouge clay. In a raise above the 350-foot level south of the Bonanza shaft the lead-zinc ore occurs partly as a cement between fragmental material filling a 3 to 4 foot fissure. The included wall-rock fragments were completely silicified but not replaced to any extent by the sulphides with the possible exception of a little pyrite. This cementation of wall-rock fragments appears to be typical of the ore from some parts of the Bonanza fissure. The walls of the Bonanza vein are well defined on the 300 and 400 foot levels in this part of the mine and have small gouge streaks along them in places. On the 500-foot level south of the Bonanza shaft, in the shattered zone which perhaps marks the intersection between the Bonanza and Cocomongo veins, the vein matter is frozen to the walls of the fractures, is very siliceous, and has a massive texture.

In the large stope on the Cocomongo vein known as the 403 stope, north of the Bonanza shaft, the vein matter was 10 to 14 feet wide between walls. Remnants of the vein that are left near the edges of the stope indicate that the vein had an open vuggy texture. The large openings were probably to some extent filled with breccia and gouge clay in addition to the vein matter. At the north end of the stope, where the fissure has pinched, there remains a 2-foot vein against the hanging wall consisting of a mixture of sphalerite and galena. The sulphides form a porous intergrowth, which is not noticeably banded, however, as the open spaces are small and irregularly distributed. The sphalerite and galena show crystal faces in the openings, and carbonate crystals of a late stage line some of the openings. The texture as a whole testifies to crystallization in an open space that was incompletely filled by the sulphides. The walls of the vein are well defined by altered gouge seams.

In the northern part of the mine, in the vicinity of the Weaver winze, the Cocomongo vein shows 2 to 4 feet of sericitized gouge and brecciated material with irregularly distributed streaks of ore. Some post-mineral movement has occurred. The footwall at this end of the mine is strongly silicified. Above the 300-foot level north of the Weaver winze the vein lies against the strongly silicified footwall without much intervening gouge but is separated from the hanging wall by an altered gouge which ranges in width from a few inches to a foot or more. In the hanging wall the silicification is less intense. The main alteration products of the hanging-wall latite are sericite, carbonate, pyrite, chlorite, and quartz. Microscopic examination of the thick gouges from the Cocomongo fault in this end of the mine show them to be composed largely of finely divided muscovite (sericite). Pyrite is commonly scattered through the gouge in small crystals. Other minerals present in the gouge are quartz, carbonates, rutile, anatase, and apatite. This extreme alteration of the Cocomongo fault gouge was clearly caused by the alkaline solutions that deposited the ores and offers good mineralogic evidence of the premineral age of the gouge. However, the distribution of mineralization in the Cocomongo fault in itself substantiates a premineral origin of the faulting, even though there has been some slight postmineral movement. The vein at the north end of the mine contains more copper than is found in the south end of the mine. The copper is largely in tennantite, which is locally associated with massive quartz and also occurs as sulphide streaks in the gouge.

In the transverse vertical fractures in the hanging wall of the Cocomongo fault rhodochrosite, manganocalcite, and rhodonite are more common than in either the Bonanza or the Cocomongo vein. The vertical veins contain little or no gouge and fail to show evidence of much displacement of the two walls. The vein matter is evidently a filling of an open fracture and is at many places frozen to the altered wall rock.

DISTRIBUTION OF METALS IN THE ORE SHOOTS

The relative proportions of lead, zinc, and silver in blocked-out ore from different parts of the mine are shown in the following table:

Silver, lead, and zinc in ore from Bonanza mine

Location of ore block	Silver (ounces to the ton)	Lead (per cent)	Zinc (per cent)
Between 200 and 300 foot levels, extending about 100 feet south of Bonanza shaft	1.50	3.1	4.75
350-foot level, from about 110 to 230 feet south of Bonanza shaft	2.50	5.4	3.85
Between 350 and 400 foot levels, extending about 90 feet south of Bonanza shaft	1.12	11.6	9.60
Between 300 and 400 foot levels, from about 60 to 160 feet north of Bonanza shaft	4.40	7.1	14.10
Between 400 and 500 foot levels, from about 60 to 150 feet north of Bonanza shaft	3.40	2.6	7.10
Above 400-foot level, along raise between fourth and third levels, about 480 feet northwest of Bonanza shaft	10.60	7.3	14.93
Vertical vein in hanging wall of Bonanza vein between 300 and 400 foot levels, north of shaft	2.50	5.9	10.50
Drift at 300-foot level in footwall of Bonanza shaft on Cocomongo vein	2.00	3.7	7.50
Between 400 and 500 foot levels extending about 90 feet south of Bonanza shaft	1.30	4.4	9.90
Winze between 350 and 500 foot levels, about 250 feet south of Bonanza shaft	2.40	12.5	13.80

The figures are based on mine assays that were used for the determination of ore reserves and are given in foot percentages. No accurate data are available on the ratio of lead and zinc in the ore from the old stopes above the 200 and 100 foot levels of the Bonanza shaft. Most of this ore was taken out by lessees, but the ratio of lead to zinc was high, so far as the information available indicates. Patton[94] reports that in 1914, when he examined the vein, a galena streak was present in the midst of the main vein on the first level. This streak was 2 to 3 feet wide and "consisted of galena to the extent of 30 to 50 per cent of the bulk of the ore." Above each of the 200, 300, 350, and 400 foot levels, south of the Bonanza shaft, lead and zinc occur in about equal proportions, the average ratio of zinc to lead in the different blocks ranging from 0.71 to 1.5 to 1. In the winze between the 350 and 500 foot levels, 250 feet south of the Bonanza shaft, lead and zinc also occur in about equal amounts. On the other hand, between the 400 and 500 foot levels, just south of the Bonanza shaft the ratio of zinc to lead is slightly above 2 to 1.

The evidence of these assays would indicate an increase in the ratio of zinc to lead in depth and possibly an increase in this ratio toward the northwest. An increase in zinc is well shown by the assays of the ore shoots lying northwest of the Bonanza shaft where the average ratios of zinc to lead are all very near 2 to 1. The highest average ratio of zinc to lead, 2.7 to 1, is found between 60 and 150 feet north of the Bonanza shaft in a block of ore lying between the 400 and 500 foot levels. The mineralization in the northern section of the Cocomongo fault consisted in the deposition of zinc and lead with a larger proportion of copper than in other parts of the mine. In places large amounts of ore high in silver and containing tennantite have been taken from the stopes in the north end of the Cocomongo vein. One lot consisting of 13.8 dry tons sorted for shipment ran 1.9 per cent of lead, 4.7 per cent of zinc, 8.8 per cent of copper, and 124.6 ounces of silver and 0.038 ounce of gold to the ton. The iron content was 10.75 per cent, and the insoluble matter 50.15 per cent. Picked samples of ore of this character show as much as 374 ounces of silver to the ton and around 15 per cent of copper. This ratio of silver to copper is much higher than the normal one throughout the mine. Although part of this silver lies in the tennantite, the very high silver content may be due largely to stromeyerite. This copper-silver shoot extends below the 400-foot level to the 500-foot level, but the vein is much more siliceous on the 500-foot north level. The shoot is bounded on the south side by a barren broken zone in which the vein matter

[94] Patton, H. B., op. cit., p. 100.

is very pyritic and on the north side by the gougy faults and slips mentioned in the description of the structure.

The ore shoots as a whole, then, tend to become richer in zinc in depth and toward the northwest, and the copper tends to increase in the northwestern part of the Cocomongo vein. Data are not available as to the increase in copper with depth, but the ore highest in copper lies near the 300 and 400 foot levels in the northern part of the mine. In detail a uniform change in the character of the ore is not evident. In the shoots south of the Bonanza shaft the ratio of lead to zinc is in places as high as 4 to 1, and the ore contains from 2 to 30 per cent of lead. The individual lead shoots also do not show in detail the increasing proportion of zinc in their lower parts. For example, the raise above the 350-foot level about 120 feet south of the Bonanza shaft started in ore in which the lead was two to three times as high as the zinc. In the upper part of the raise, about 50 to 60 feet vertically above the 350-foot level, the vein was somewhat narrower and zinc was in excess of lead. The ore as a whole in all parts of the mine runs very low in copper, and only where silver is high, as in the copper-silver shoot at the north end, does the copper content reach or exceed 2 or 3 per cent.

PARAGENESIS OF THE ORES

A wide range of relations, in part contradictory, is shown between the ore minerals from different parts of the mine and as a whole indicates a closely overlapping deposition of the different minerals. Pyrite, quartz, and sphalerite are minerals of an early stage in all the ore. The quartz continued in decreasing amount after sphalerite and was at places deposited with the latest sulphides. Galena, chalcopyrite, and tennantite are later than the early abundant quartz and sphalerite. Galena occurs interstitially to sphalerite and less commonly has replaced both sphalerite and pyrite. Evidence of a brecciation of the early sulphides and cementation by later quartz and sulphides is seen in the ore from the Cocomongo and Bonanza veins. The brecciation was not uniformly distributed nor everywhere equally intense.

In general, chalcopyrite, galena, and tennantite are of nearly contemporaneous formation, but contradictory relations are exhibited in places. For example, in some ore chalcopyrite occurs with later quartz cementing brecciated pyrite, sphalerite, and galena, but in ore from the old stopes above the 200-foot south level galena has replaced tennantite to a slight extent, whereas in other parts of the same ore the two minerals appear contemporaneous. Where galena is very abundant, as in the upper levels, its crystallization has continued after the depletion of the ore-depositing solutions in copper. On the other hand, in the stopes at the north end of the Cocomongo vein, where copper is more abundant, tennantite appears to be a later mineral than galena. This apparent inconsistency in the relative ages of the lead and copper mineralization can perhaps be explained by changes in the proportions of metals in the ore solutions during the period of vein formation.

The carbonates commonly belong to a late stage and occur as veinlets together with some quartz in brecciated sulphides or fill cavities between the sulphides. Carbonates continued to be deposited after quartz and have replaced it to some extent.

SOURCE OF THE MINERALIZING SOLUTIONS

The complex nature of the fissuring in the mine makes it difficult to determine which of the fissures was the main conduit that supplied the mineralizing solutions. The increase in zinc and copper toward the northwest and in the Cocomongo fissure perhaps indicates that the direction of local circulation was outward from this part of the fissure systems. Although little development work has been done in the footwall of the Cocomongo fissure, a crosscut running from the 500-foot level about 100 feet into the footwall of the Cocomongo fissure shows only a few weak faults, which are not appreciably mineralized. At the end of the crosscut the alteration in the andesite country rock is also very weak. The crosscut to the Cocomongo shaft on the 300-foot level likewise shows only weak alteration and mineralization. To the present depth of exploration it would appear, then, that the source of the solutions was not in the footwalls of the fissures but rather down their dip. The extremely low dip of 20° or less shown by the Cocomongo fissure below the 500-foot level would appear to be unfavorable to large ore bodies at greater depth within the fissure itself, but favorable openings in the vicinity of the fissure might contain additional systems of ore shoots.

RICO MINE

The Rico vein (No. 71, pl. 1) lies in the saddle on the north side of Round Mountain. This vein is developed by a crosscut tunnel about 130 feet in length and by about 300 feet of drifts on the vein at the tunnel level. The portal of the tunnel is at an altitude of about 10,700 feet. The vein has been partly stoped above the tunnel level, and a 70-foot winze with some stoping has been sunk below the tunnel level. (See fig. 27.) The fault in which the vein lies strikes N. 45°–50° E. and dips about 25°–30° SE. In the stopes above the tunnel level it has a dip of about 29° and in the winze below about 24°. Some subsidiary fault planes dipping as low as 19° are exposed in the drift south of the crosscut tunnel. The country rock is largely altered andesite. Bleaching and silicification of the andesite have been very intense close to the vein. The vein matter occurs as lenses distributed irregularly through a sheared fault zone that is in places 30 feet or more wide. The displacement on the fault plane is not determinable, but to judge from the intensity of the shearing and the width of the sheared zone it is several hundred feet. This is probably a normal fault, the steeper part of which has been eroded. The ore occurs in pockets and lenses within the fault zone, either between layers of sericitized gouge clay or cementing siliceous breccia material. The gangue of the ore is chiefly quartz and brecciated jasper with minor amounts of barite and pinkish manganocalcite. The ore minerals are pyrite, sphalerite, galena, chalcopyrite, tennantite, and probably stromeyerite. There is a minor amount of secondary chalcocite, which forms a bluish-black sooty

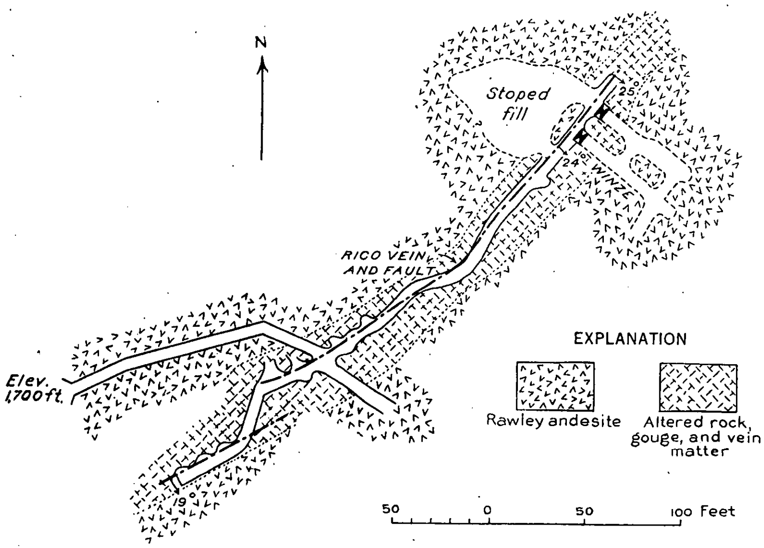


FIGURE 27.—Sketch map of the Rico tunnel

coating on some of the sulphides. As is common in the district the early silicification was very pronounced. The wall rock adjacent to parts of the vein was entirely altered to quartz, and some of it was clearly brecciated before silicification, probably by the movement on the fault. Part of the silicified and brecciated rock has been replaced by later sulphides and sericite.

Tennantite ("gray copper") is fairly abundant as a vein mineral in the sulphide pockets in the fissure. The ore is in places vuggy, and where the tennantite is associated with quartz and lines vugs it is well crystallized in modified tetrahedrons. An assay of carefully picked tennantite freed from other sulphides ran 385.4 ounces of silver to the ton. The gold content of the tennantite is small, probably less than 0.10 ounce to the ton. (See p. 66.)

The sulphide ore in the vein occurs in rather small lenses and pockets, of which those now exposed in the workings are not over a foot or two in width. Some pockets that were apparently wider have been stoped out above the tunnel level, and their dimensions could not be estimated. The very flat dip of the fissure and the width of the gougy shear zone in which the ore lies are apparently unfavorable to the existence of wide and continuous ore bodies. The vein has not been explored sufficiently to indicate its promise or to permit a search for steeper and more open fractures in the hanging wall of the fault that would be more favorable for ore deposition.

Small shipments of crude ore have ranged from 30 to 120 ounces of silver to the ton, from less than 1 to 5 per cent of lead, and from 2 to 4 per cent of copper. The gold ranged from 0.2 to nearly 0.6 ounce to the ton. One shipment of 15 tons of crude ore carried 4.9 per cent of lead, 4.25 per cent of copper, and about 63 ounces of silver and 0.6 ounce of gold to the ton. The iron content was 20 per cent, and the insoluble matter about 33 per cent. The total production has been very small, probably less than 150 tons of crude ore.

SHAWMUT MINE

The Shawmut mine (No. 76, pl. 1) is on the south slope of Round Mountain. The vein is developed by a shaft 300 feet deep, the collar of which is at an altitude of 10,827 feet, and by an adit about 1,100 feet in length, the portal of which (No. 76, pl. 1) is west of the vein on the west slope of the Round Mountain ridge at an altitude of about 11,420 feet. It intersects the vein about 400 feet below the collar of the shaft. As shown on the topographic map, the mine may be reached by unimproved wagon roads, either from Alder Creek, on the east side of the range, or by way of Rawley Gulch from the town of Bonanza. The distance from Alder Creek is about 7 miles.

The following history of the Shawmut mine is taken largely from a report on the property by W. H. Wright to the Kapi Mining & Milling Co., the present owner. The Shawmut claim was located by Peter Johnson, who received the patent in 1885. In 1893 William Bennet acquired part ownership. In 1905 a 90 per cent interest in the property was sold, and the Shawmut Gold, Silver & Copper Mining & Milling Co. was organized. This company expended $68,000 in development work after an examination of the property in March, 1906. As a result of the development of the Shawmut connecting claims as far south as the Sosthenis were purchased. A tunnel was begun with the intention of opening all claims from the Sosthenis to the Shawmut, but owing to the failure to meet large payments coming due in 1907, all the claims became forfeited to the former owners.

The Kapi Mining & Milling Co. was organized shortly afterward, and the Maybelle, Maybelle No. 1, and Maybelle No. 2 claims were located. These claims are not yet patented. In 1912 this company started an adit to intersect the Shawmut vein below the old workings. This was completed about 1918 and connected to the shaft by a raise, but no further work has been done on the vein, as it proved to be of too low grade to mine.

The Shawmut mine was one of the early producers in the Bonanza district, but complete or accurate records of its production are not available. According to Patton [95] an estimate of the production prior to 1900 gives 700 tons of ore. In the report of the Director of the Mint for 1888 [96] the Shawmut is credited with a total production of $4,006 for this year, which was divided as follows: Gold $80, silver $2,586, and copper $1,340. Details of the production are not given for other years. The old stope on the 120-foot level is said to have been mined and the ore shipped many years ago, but the records of shipment have been lost.

The geologic plan and section of the adit level (pl. 30) and the 280-foot level are based upon personal examination, but discussion of the upper levels is based upon a report prepared in 1919 for the Kapi Mining & Milling Co. by S. J. Burris, jr.

The vein on the 280-foot ("300") level and the adit level below strikes N. 15°–25° E. and dips 70°–80° E.

The country rock of the Shawmut vein on the lower levels and along the entire length of the adit level consists of lavas of the Rawley andesite. There may be some fault blocks of the Bonanza latite in the upper levels of the mine, but most if not all of the rock exposed in the broad, flat saddle between Round Mountain and Manitou Mountain is altered andesite. The Bonanza latite overlies the andesite and caps Round Mountain, and the base of the latite on the south slope of Round Mountain lies about 80 feet above the collar of the Shawmut shaft. The Shawmut ore shoot extends at least 300 feet below the base of the latite, and thus lies well within the stratigraphic range of other shoots in the district. Most of the veins cut by the drainage adit contain a high proportion of pyrite, chalcopyrite, and sphalerite, which suggests that the lower limits of the lead shoots have been reached. Although the exact position of the bottom of the lead ore in the Shawmut vein is not known, it probably is not more than 200 feet below the surface. This is about 1,000 feet vertically above the base of the lead ore in the Rawley vein and about 2,200 to 2,500 feet above the base of the lead ore in the Bonanza vein. The available evidence (see pp. 62, 92) indicates that the larger proportion of the lead shoots in the district do not extend more than 500 feet below the base of the Bonanza latite. Although it can not be considered proved that the ores of the district bear so definite a relation to the structure, this general vertical range in conjunction with the character of the mineralization in the Shawmut vein at the adit level appears to be unfavorable to the existence of commercial bodies of lead ore below the present depth of exploration on the vein.

The Shawmut fissure is probably a fault fissure, and on the fifth and adit levels it contains an altered sericitized gouge and is relatively narrow and tight. A few lenses of siliceous or pyrite vein matter from a foot to 2½ feet in width occur in the fissure on these lower levels. The fissure is said to have been well mineralized in the levels near the surface and to have carried mainly lead and silver. The lead apparently diminished rapidly in depth, as the production cited above for 1888 shows that the value of the ore was divided between silver and copper. The ore consists of pyrite, sphalerite, galena, tennantite, and chalcopyrite in a gangue consisting chiefly of quartz. Shipments of 111 tons of crude ore from the vein in 1911 and 1917 show an average content of about 1 per cent of lead, 2 per cent of copper, and 0.07 ounce of gold and 16 ounces of silver to the ton. It is not known from what part of the mine these shipments came, but the low lead content suggests some of the lower levels. No records are available to show the average content of the ore of the upper levels, but an assay of ore taken from the first level by channeling across the vein is given by Patton [97] and shows 40.2 ounces of silver and 0.2 ounce of gold to the ton.

Several mineralized fissures besides the Shawmut are cut by the drainage adit (pl. 30), but these have not been explored, and several of the larger fault fissures are timbered, so that little can be told of their character. About 200 feet from the portal an altered fault zone striking about N. 28° W. and dipping 50° E. is crossed. This zone is mostly timbered, but a short drift caved near the entrance was driven south along the footwall of this fault. The fault zone is about 50 feet wide, and the andesite in the hanging wall is considerably brecciated.

About 500 feet from the portal there is a strong vein striking about N. 20°–25° E., which is timbered but may correspond to the Maybelle vein. The fissured zone is about 40 feet in width and dips about 70° E. The mineralization produced mainly pyrite on the adit level. The Maybelle vein is said to be similar in character to the Shawmut and to be composed of galena, tennantite, chalcopyrite, and pyrite

[95] Patton, H. B., op. cit., p. 94.

[96] Munson, G. C., Report of the Director of the Mint upon the production of the precious metals in the United States, 1888, p. 133, 1889.

[97] Patton, H. B., op. cit., p. 95.

in a gangue consisting mainly of quartz with some barite. The fissure in the Maybelle tunnel is said to be about 11 feet in width.

At about 960 feet from the portal a mineralized fissure containing pyrite and sphalerite is cut, but there are no drifts on it. This fissure strikes about N. 50°-60° E. and dips 45° SE. Several other small mineralized fissures were encountered in driving the adit, and most of them show the effects of strong sericitic alteration, with some pyrite but little other vein matter.

LEGAL TENDER MINE

The Legal Tender mine is about 1,300 feet southeast of the Shawmut shaft, on the large flat area between Round Mountain and Manitou Mountain. The property includes the Legal Tender claim, which is a patented claim and is owned by the Baldwin Mining Co. The Legal Tender mine is one of the oldest mines of the district, and its production prior to 1900 has been estimated at 100 tons of $40 ore.[98] The mine plant consists of several buildings, now largely in ruins, which include a large shaft house. The underground workings are said to consist of a shaft 300 feet deep and 700 feet of drifts, but no maps of the mine are available. The collar of the shaft is at an altitude of about 11,780 feet. The mine has not been operated for many years except for about two months in 1917.

The character of the vein and its strike and dip are not known. The ore is said to be partly oxidized to a depth of 300 feet. The vein presumably carries a considerable proportion of copper. A shipment of 38 tons of crude ore carried 0.27 per cent of lead, 2.8 per cent of copper, and 9.8 ounces of silver and 0.02 ounce of gold to the ton. It is not known, however, from what part of the mine this ore came, and no records of the content of the ore shipped prior to 1900 could be obtained.

VIENNA MINE

The Vienna vein crops out on the west slope of Round Mountain and is developed by an adit whose portal is at an altitude of about 10,650 feet. This vein was not examined but is said[99] to contain galena and gray copper. A shipment of 26 tons of crude ore from this vein showed an average content of 8.8 per cent of lead, 3.1 per cent of copper, and 31.5 ounces of silver and 0.96 ounce of gold to the ton. Another lot of 2 tons assayed 3.8 per cent of lead, 1.6 per cent of copper, and 28 ounces of silver to the ton.

SOSTHENIS MINE

The Sosthenis mine (No. 77, pl. 1) is near the head of Sosthenes Gulch, on the west slope of Manitou Mountain, at an altitude of about 11,300 feet. The mine is developed by four tunnels, all but one of which are now caved near the portals. The mine was worked mainly between 1887 and 1893 and during this period produced over $40,000 mainly in silver and gold. The production records given by the Director of the Mint are shown in the accompanying table. These records are incomplete, no details being available as to the production of mines in the district in 1889, but they are probably close to the total production of the property. The total output of crude ore is not known but is probably at least 400 tons.

Value of metals produced at the Sosthenis mine [a]

Year	Gold	Silver	Lead	Total
1888 [b]	$2, 500	$29, 080		$31, 580
1890 [c]	750	4, 202	$283	5, 235
1891	557	4, 287		4, 844
	3, 807	37, 569	283	41, 659

[a] No production in 1887 (Munson, G. C., Report of the Director of the Mint upon the production of the precious metals in the United States, 1887, p. 181, 1888) and no record of production in 1889. Value of gold used, $20 an ounce; silver (coinage value), $1.29 an ounce; lead, $87 a ton.
[b] Munson, G. C., op. cit. for 1888, p. 121, 1889.
[c] Smith, M. E., idem for 1890, p. 187, 1891.

The original mine plant, now in a ruined condition, consisted of boiler and compressor house, besides several other buildings. A geologic sketch plan of the lowest adit level, the portal of which is at an altitude of 10,238 feet, is shown in Figure 28. The other adit levels are caved near the portals. Most of the ore that was mined presumably came from one or more of the upper adit levels, as there are no stopes from the lowest level. The total length of drifts and crosscuts on the lowest level is about 1,280 feet. Three principal veins, all in andesite, are exposed by the lowest tunnel, which follows the first one for 300 feet or more from a point about 180 feet in from the portal. The fissure is clearly a fault fissure with slickensided walls and altered micaceous gouge and consists of a series of branching and parallel fault planes. Its direction changes gradually from N. 20° W. where first encountered to about N. 20° E. near the end of the drift. The fault planes near the portal dip 70° or more westward, but near the end of the drift the dip is 75°-80° E. The vein is timbered in parts of the drift, but no strongly mineralized rock is exposed. Near the end of the drift, about 450 to 500 feet from the portal, the fissure zone consists of several parallel fault planes exposed by a short west crosscut, one of which contains 1½ to 2 feet of siliceous vein matter which has in part replaced brecciated wall rock and is in part a filling between the fragments, and which is accompanied by pyrite and tennantite, with some galena and sphalerite. This northerly series of veins is presumably the Sosthenis vein. The mineralization shown on this level was not sufficiently strong to

[98] Patton, H. B., op. cit., p. 68.
[99] Idem, pp. 96-97.

encourage stoping. Drifts were also run along several parallel fractures to the east. (See fig. 28.)

According to information cited by Patton [1] the Sosthenis vein in the upper adit levels was oxidized and yielded silver and gold. This statement is borne out by the record of production given above, in which the gold content is relatively high in proportion to the silver in comparison with the ratio in most of the unoxidized veins in the district. On the assumption that estimates of the total ore are approximately correct at 400 to 600 tons, the gold content of the ore would have been between 0.04 and 0.05 ounce to the ton. Patton publishes an estimate of the grade of the shipping ore at 0.04 ounce of gold and 35 ounces of silver to the ton, with 15 per cent of lead and 12 to 15 per cent of zinc. The average content of the unoxidized sulphide ore is not known, but a few tons of crude ore for which a record is available assayed 9 ounces of silver to the ton, with 11.4 per cent of lead and about 1 per cent of copper. The character of the vein in the lowest adit level indicates that iron and copper have increased in depth and the lead has decreased considerably.

In the crosscut from the drift two other veins are intersected—one about 150 feet east of the adit tunnel and another about 200 feet east. There is a drift about 120 feet long on the first vein and a raise near the crosscut. This vein strikes N. 5° E. and dips about 55° E. The second vein strikes N. 20° E. and dips about 65° E. It shows about 2 feet of vein matter in places of rather low sulphide content. Beyond this vein in the crosscut several other fissures are cut but have not been explored by drifting. Bad air near the end of the crosscut and in the short drifts prevented very detailed observations.

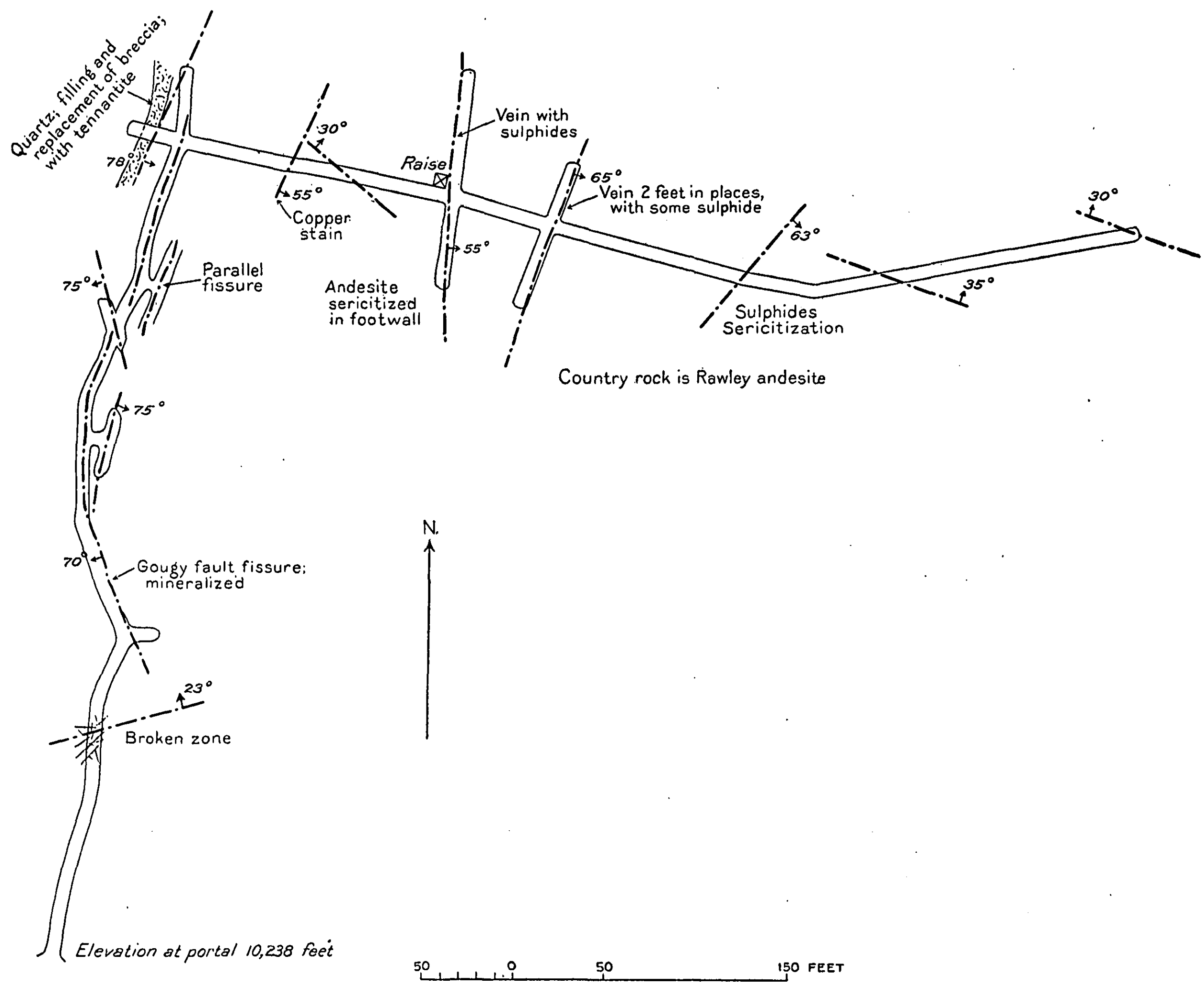


FIGURE 28.—Sketch map of the workings of the Sosthenis mine

[1] Patton, H. B., op. cit., p. 97.

LITTLE JENNIE MINE

DEVELOPMENT AND PRODUCTION

The Little Jennie mine (No. 45, pl. 1) is 11,300 feet above sea level on the south side of the gulch a few hundred feet south of the workings of the Sosthenis mine. The adit (fig. 29) is about 550 feet in length and for about 350 feet from the portal is driven on a fissure zone striking south to S. 15° E. and standing nearly vertical or dipping steeply westward. At a point about 350 feet from the portal the vein splits, and thence for about 200 feet the adit follows the east split, which strikes about S. 45°–50° E. and dips about 70° NE.

The Little Jennie claim lies on the hillside a few hundred feet east of the adit, on a different vein from those developed by the accessible part of the workings. The Little Jennie workings were started early in the history of the district. Burchard [2] states

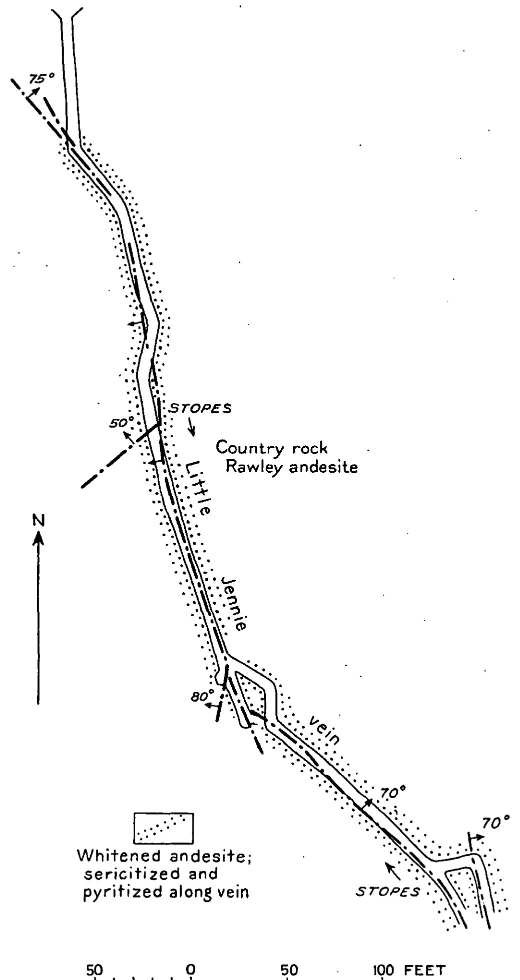


FIGURE 29.—Sketch map of the Little Jennie tunnel

that the vein on the Little Jennie claim was opened by a shaft, but in driving a tunnel 200 feet below the shaft, in order to cut the vein, a blind lode was encountered. This lode had an ore streak about 18 inches wide, consisting of quartz impregnated with gray copper and chalcopyrite, with some galena. This rapidly widened out to about 6 feet. Burchard states that the ore was not of high grade but occurred in large quantity. This vein is evidently the one shown in Figure 29 and will be referred to in this description as the Little Jennie vein. Apparently the production accorded to the Little Jennie came from stopes in this adit, as there are no extensive workings on the Little Jennie claim, so far as is known. Silver [3] states that in 1883 the Little Jennie was being developed and that some ore had been shipped. There was a 30-inch vein with chalcopyrite and gray copper, running 30 ounces of silver to the ton. Details of the production of the Little Jennie are not known, but Patton [4] gives an estimate of 500 tons valued at $25 a ton.

GEOLOGIC FEATURES

The country rock is entirely andesite, most of which is of the porphyritic type. The fissures that the veins occupy are evidently fault fissures, which show a tendency to split into parallel or diverging fractures. Along the veins the andesite is strongly decomposed and bleached, owing to the formation of sericite, quartz, and carbonates. The fault gouge is likewise strongly decomposed and consists largely of sericite, as is common in the altered premineral gouges of the district. Apparently because of the steep dip of the fissures the vein matter is fairly continuous and ranges from 1 to 4 feet in width.

The paragenesis of the minerals in the vein is particularly interesting, as it illustrates rather clearly several steps that are common in the formation of ore bodies in this part of the district. The earliest stage in the formation of the ore after the rupturing of the andesite was the intense siliceous alteration of the wall rocks of the fissures. This was caused presumably by solutions containing sulphuric or halogen acids. The attack of these siliceous mineralizing solutions converted the fractured and partly brecciated andesite into a rock consisting largely of silica with a little amorphous ferric oxide and hematite. There was an additional movement on the fault fissures after this stage of silicification. The vein filling followed, consisting of four stages—(1) early pyrite, quartz, and manganese silicate (rhodonite), (2) continued deposition of quartz and pyrite followed by sphalerite, (3) formation of galena and chalcopyrite with the beginning of deposition of rhodochrosite, and a little vein apatite, (4) deposition of rhodochrosite or manganocalcite with some late chalcopyrite and tennantite. During the period of vein formation the early jaspers and less silicified bodies of wall rock adjoining the fissures were attacked, pyrite, carbonates, and sericite were formed in them, and the jaspers were further recrystallized and impregnated with pyrite. The first stage, in which rhodonite and quartz were precipitated, was clearly early and distinct, but

[2] Burchard, H. C., Report of the Director of the Mint upon the production of the precious metals, 1882, p. 541, 1883.

[3] Silver, Herman, idem for 1883, p. 403, 1884.

[4] Patton, H. B., op. cit., p. 68.

the other stages overlapped considerably. The later carbonates have replaced the early quartz and rhodonite (pl. 13, *B*) and chalcopyrite has replaced pyrite to some extent. Where fragments of the reddish jaspers have been included within the later vein deposits they are completely recrystallized, with the partial loss of some of their red color. Ghostlike outlines of these reddish jasper fragments are seen in the vein filling in some material on the mine dump.

ORES

The ore minerals recognized in the Little Jennie vein are pyrite, sphalerite, galena, chalcopyrite, tennantite, and small specks of a gray mineral that is possibly stromeyerite. The gangue is mainly quartz, with rhodonite, rhodochrosite, carbonated apatite (dahllite or podolite), and manganocalcite. The general character and the paragenesis of the Jennie vein suggest that it belongs to the lower part of the epithermal or low-temperature vein zone. The vein has more of a tendency to be banded and vuggy and has a higher proportion of manganese carbonates than the lower parts of such veins as the Rawley.

Some samples of the Little Jennie vein over widths of 16 to 48 inches give assays of 4 to 18 per cent of lead, 2.5 to 19 per cent of zinc, 1 to 1.5 per cent of copper, and 3 to 10 ounces of silver to the ton. In the north-south vein the zinc content exceeds that of lead, and in an average of five assays to which the writer had access the ore showed a width of 2.1 feet with 7.4 per cent of lead, 14.1 per cent of zinc, and 4.3 ounces of silver to the ton. Siliceous vein matter, due partly to replacement and partly to filling on the hanging wall and footwall of the ore streaks, showed from a trace to 5 per cent of lead, from 0.2 to 8 per cent of zinc, and a few ounces of silver to the ton, over a width of 1 to 2 feet.

The southeast vein beyond the split showed a higher content of lead than of zinc and in two samples averaged 15.5 per cent of lead, 5.3 per cent of zinc, and 7.7 ounces of silver to the ton, over a width of 2.3 feet. The Little Jennie is said to have produced a small tonnage of shipping ore, but smelter returns on this ore are not available. One small lot of a little over 7 tons, presumably from the Little Jennie dump, showed a content of 10.66 per cent of lead, 0.88 per cent of copper, and 4.42 ounces of silver to the ton.

Although the explored part of the Little Jennie vein is narrow and the development work done is small, the steepness of the fissures and the intense alteration of the adjacent rock give some promise of the vein holding its width and mineral content to greater depth, as is also indicated by the kinds and proportions of the vein minerals.

OTHER MINES AND PROSPECTS IN SOSTHENES GULCH

Other veins developed by small workings adjacent to the gulch near the Sosthenis mine are the Merrimac, May Queen, Gypsy Queen, Vallejo, and Wisconsin.

Merrimac and May Queen.—The Merrimac and May Queen claims (No. 52, pl. 1) are evidently on the same vein and were worked through the same crosscut adit, but none of the old workings are now accessible. Burchard [5] states that the Merrimac lode where cut by the tunnel is 14 feet wide and carries galena and tennantite. There are some small discovery shafts and pits on the vein south of the portal of the adit. The country rock is andesite.

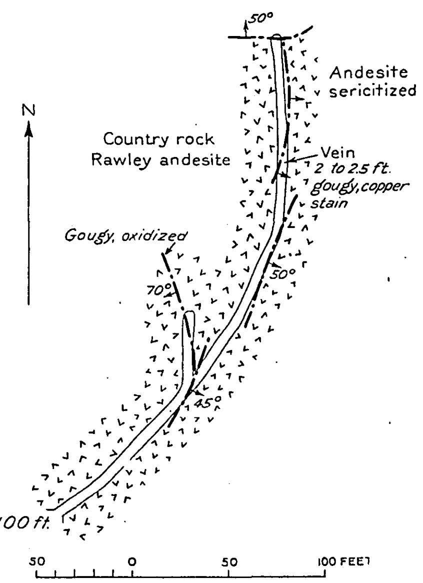


FIGURE 30.—Sketch map of the Gypsy Queen tunnel

Gypsy Queen.—A sketch map of the Gypsy Queen adit (No. 33, pl. 1) is shown in Figure 30. The workings are partly caved at several places, and a considerable part of the drift is timbered. The main fissure seems to have been encountered about 150 feet from the portal. The fissure strikes about N. 30° E. and dips 50°–60° SE. The andesite country rock is altered to a white soft rock adjacent to the vein, and there is a soft micaceous gouge along many of the slip planes. The general direction of the mineralized fractures is northeast, but the drift gradually turns northward in following the vein. Timbering and caved ground prevented detailed study of the faults, but it appears that the fissure has been displaced toward the west at several places. The vein matter where it could be seen was from 1 foot or less to 2.5 feet in width. As the workings are shallow, surface water has deposited limonite, manganese oxides, and green copper salts along the fracture planes. The gangue of the vein is mainly quartz, with some man-

[5] Burchard, H. C., op. cit. for 1882, p. 541, 1883.

ganese-bearing carbonates. The ore minerals seen on the dump are pyrite and tennantite with some galena and sphalerite. Burchard[6] states that some high-grade gray copper ore had been taken from this prospect.

Vallejo.—A sketch map of the accessible parts of the Vallejo workings (No. 80, pl. 1) is shown in Figure 31. The main vein prospected occurs in a fault fissure striking N. 70°–75° E. and dipping 45°–50° S. As the strike and dip of the Merrimac (May Queen) vein is not known, it can not be positively stated that the Vallejo drift is on the same vein, but from the alinement of the claims this appears likely. There is a wide zone of bleached, decomposed andesite and gouge along the fissure, but where it could be seen the vein material is narrow and siliceous. Several cross fissures are cut by the workings, and nearly all of them show altered walls and small amounts of quartz, pyrite, and other sulphides. Most of the fissures appear to be of premineral age.

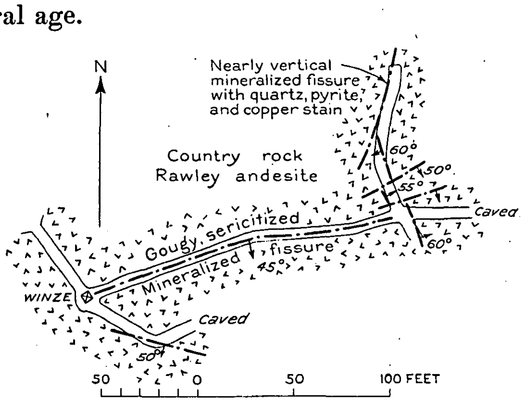


FIGURE 31.—Sketch map of the Vallejo tunnel

Wisconsin.—The Wisconsin adit (No. 87, pl. 1) is on the slope northeast of the mines in Sosthenes Gulch, at an altitude of 11,540 feet. The adit is apparently crosscut to the vein, which from surface indications appears to have a strike of about N. 20° E. The workings could not be entered, as the portal had caved. In contrast to the gangue of the Little Jennie and other veins near it, that of the Wisconsin vein, seen on the dump, is entirely quartz. The sulphides are mainly pyrite and sphalerite, with smaller amounts of galena and chalcopyrite. Quartz and pyrite were deposited early in the vein-forming stage and were followed by chalcopyrite and galena, deposited interstitially to the quartz. Under the microscope the sphalerite is seen to contain minute specks of chalcopyrite, which were apparently deposited with it. The later chalcopyrite has replaced pyrite to some extent. The texture of the siliceous ore is somewhat vuggy or banded, but none of the vugs were seen to contain carbonates.

[6] Burchard, H. C., op. cit. for 1882, p. 541, 1883.

ANTORO MINE

HISTORY AND PRODUCTION

The Antoro mine, owned by the Antoro Mines Co., lies north of Rawley Gulch adjacent to the property of the Rawley mine. The company controls 14 claims in the vicinity of the Antoro tunnel. Including the Antoro tunnel there are about 4,200 feet of drifts and crosscuts, with a shaft 550 feet in depth and a winze of 125 feet. Several veins are developed by the workings, including the Antoro vein proper.

The Antoro vein itself was discovered early in the history of the district. Burchard[7] states that in 1882 the Antoro vein was developed by four shafts from 20 to 60 feet in depth. Pockets in the walls of the vein near the surface are said to have been impregnated with native silver. The only year before 1900 for which data of the production are given is 1891.[8] During that year the Antoro produced $1,680 in silver and $522 in lead. In 1887 and 1888 the mine is reported as not producing. The early production was evidently intermittent, although Patton[9] gives an estimate of 1,000 tons of ore between 1881 and 1900. The production since 1900 has also been intermittent. The long Antoro adit was completed to the Antoro vein about 1910 or 1911 and was connected to the surface by an inclined raise. Between 1908 and 1927 about 1,400 tons of ore was produced from the several veins. There is some zinc-lead ore suitable for milling on the Antoro dump, which lies at the portal of the tunnel.

MINE DEVELOPMENT

The portal of the Antoro adit is at an altitude of 11,267 feet on the slope about 1,300 feet north of Rawley Gulch. There are about 4,000 feet of crosscuts and drifts on this adit level. (See pl. 31.) About 170 feet from the portal a winze 125 feet deep has been put down on a nearly vertical vein. At least three other veins and possibly several more smaller ones are cut by the workings. The Antoro vein, the Poverty vein, and the Zinc vein have received the most development. Another vein has been followed at a position about 400 feet from the portal. These workings have caved, but one drift is about in line with the Northeast vein developed by the winze. On the adit level the Poverty vein is the only one that has been stoped to any extent. The adit level is connected through to the surface by a 550-foot raise. (See fig. 32.) The Antoro vein is developed for about 500 feet on the adit level and for about 350 feet on the "114 level," which is about 114 feet above the adit level. The "200" level is 200 feet above the adit level and

[7] Burchard, H. C., op. cit. for 1882, p. 542, 1883.
[8] Smith, M. E., op. cit. for 1891, p. 184, 1892.
[9] Patton, H. B., op. cit. 68.

approximately 320 feet below the surface but has only about 30 to 40 feet of drifts.

GEOLOGIC FEATURES

All the workings of the Antoro mine are in the Rawley andesite, the upper levels and outcrop of the Antoro vein being in the upper latite member. The lava flows on the surface appear to have a strike somewhat west of north and a dip of 15°–20° W. The dips of the flows are much less steep here than 2,000 or 3,000 feet west of the mine. By allowing for the intervening lavas which have been eroded from above the vein outcrop but which overlay the andesite during the time of ore deposition, the present workings on the Antoro vein may be estimated as ranging within 200 to 600 feet below the base of the Bonanza latite.

On the main Antoro adit level the Rawley andesite is very much broken by faults, and it is in several of these fault fissures that the larger veins occur. Practically all the faults show some effects of mineralization, either by their altered gouge or by the presence of small amounts of sulphides, particularly pyrite or sphalerite. No postmineral faults of any consequence were found. The fault of greatest displacement is apparently the Poverty fault, in which the Poverty vein occurs. This fault has an average strike of N. 65° W., but the fault plane is somewhat curved and concave toward the north and dips 28°–35° N. The fault is accompanied by heavy gouge and some strong breccia zones, but, as is typical of all the low-angle faults in the district, the mineralization was very irregularly distributed.

The Antoro vein also occupies a fault fissure, as is shown by the different bodies of andesite that form the hanging wall and footwall at the south end of the "114 level." The Antoro fissure has an average strike of N. 25° W. and dips 65°–85° E. The average dip is probably 80°–85°, although the fault plane is warped irregularly, and both the strike and dip have a moderate range. At the surface near the Antoro shaft the vein crops out in the upper latite member of the Rawley andesite.

ANTORO VEIN

The Antoro vein proper is exposed at the north end of the mine workings. It strikes north and dips about 70° E. The gangue in the vein is largely quartz

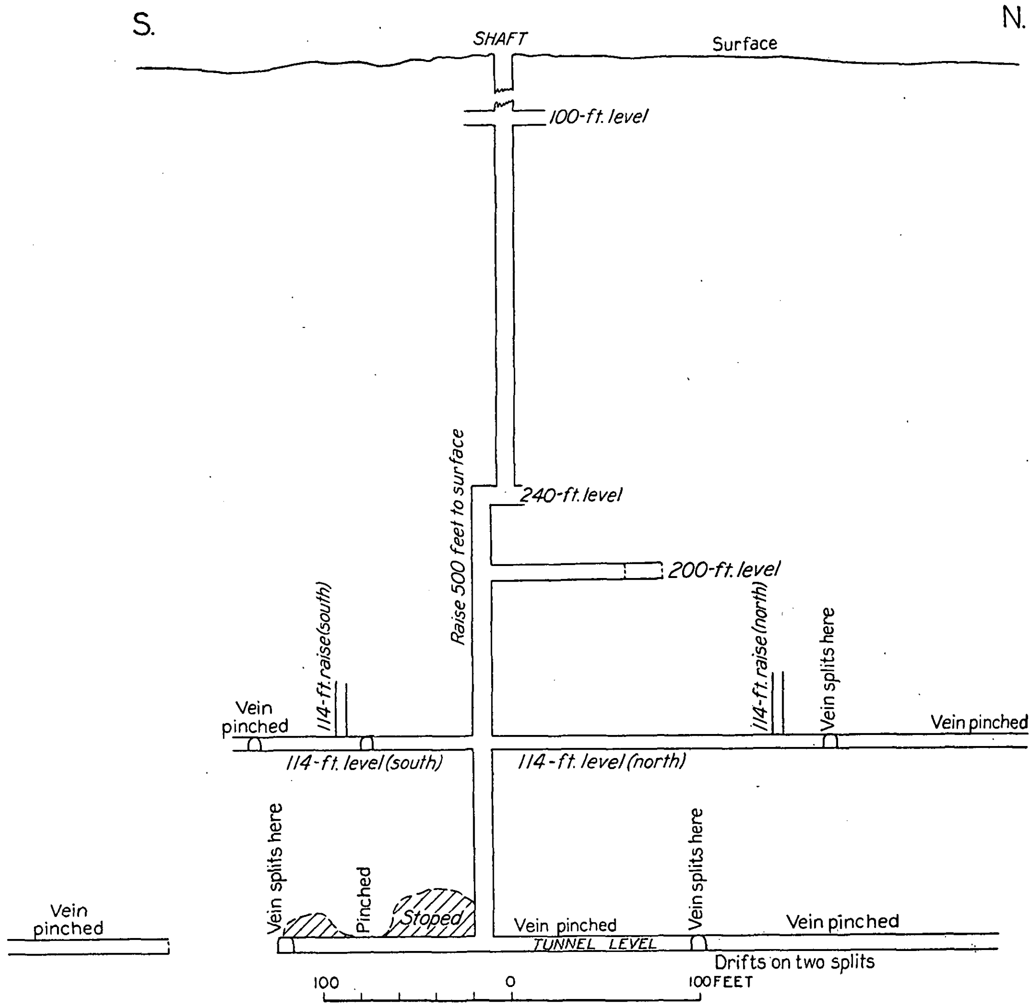


FIGURE 32.—Longitudinal section of drifts on the Antoro vein, Antoro mine

but is composed partly of barite and calcite. The sulphides that have been recognized in the ore are pyrite, sphalerite, galena, chalcopyrite, and tennantite. Some secondary chalcocite was present in the small vertical vein in the hanging wall near the adit level. This was probably of local distribution near some watercourse. The vein in the raises 25 feet above the "114 level" shows no evidence of alteration by surface water. Oxidized ore is said to extend from 75 to 120 feet below the outcrop of the vein.

For a distance of about 240 feet on the "114 level" the vein has an average width between 2 and 2.5 feet and carries about 5.5 ounces of silver to the ton, 8 per cent of lead, and 8 per cent of zinc, as indicated by mine assays. Copper is low, assays showing from a trace to 1.8 per cent. The gold content of the vein is also low, ranging from negligible amounts to 0.02 ounce to the ton. In the 114 north raise the vein for about 25 feet above the drift level averages 3½ feet in width and as indicated by samples carries about 6.5 ounces of silver to the ton, 18 per cent of lead, and 8.3 per cent of zinc.

The vein has been followed by drifts for only about 60 feet on the 200 level north. It has an average width here of about 1.6 feet and carries 4 ounces of silver to the ton, about 9 per cent of lead, 9 per cent of zinc, and 0.5 per cent of copper.

Along the main adit level the Antoro fissure is filled with a strongly sericitized gouge and is relatively tight and weakly mineralized. The vein could be examined for only about 100 feet north of the main raise, as the adit level was partly caved and filled with water. The Antoro vein is also exposed in a drift about 100 feet in length which branches north from the east-west drift on the Poverty fissure. The vein is also weakly mineralized in this drift and dips about 65° E. The relation between the Antoro fault and the Poverty fault could not be determined, as the Poverty fault passes into the south wall of the east-west drift where the two fissures meet.

About 100 feet south of the main raise, near the turn in the adit level, a small fracture in the hanging wall of the Antoro fissure has been explored. This fracture strikes N. 50° W. and dips 70° E. and presumably is a small transverse tension fracture formed in the hanging wall of the Antoro fissure. A narrow body of black sulphide ore has been stoped along this branch vein for about 20 feet upward. (See fig. 32.) The ore is partly enriched by secondary chalcocite.

On the "114 level" north of the main raise the Antoro fissure splits into two fissures, which appear to terminate against a premineral cross fault striking N. 40°–50° W. and dipping 75°–85° SW. Too little exploration has been done beyond this cross fault to determine whether this is the limit of the Antoro ore shoot. Conditions similar to those revealed on the main adit level north of the raise were probably found here but could not be examined because of a cave in the level. At the north end of the "114 level" the Antoro vein is better mineralized than on the main adit level but pinches down somewhat near the cross fault. Near the split the vein is about 18 inches in width and carries 8 ounces in silver to the ton, 15 per cent of lead, and about 7.5 per cent of zinc. About 150 feet north of the main Antoro raise there is a 30-foot raise on the vein which exposes about 30 inches of good-grade ore at the top. The vein in this raise is about 3 feet wide and has an altered gouge on its handling wall. The structure of the vein in the raise is vuggy, with quartz and galena crystals lining the vugs. The gangue consists mainly of quartz but partly of barite and carbonate. About 30 inches of the vein at the top of the 30-foot raise shows a content of 22.5 per cent of lead, 4.4 per cent of zinc, and 9.5 ounces of silver to the ton. Both walls of the vein are much altered; sericitization is evident in both, but the footwall is the more strongly silicified. At the foot of the raise in the drift the vein matter is more massive and less vuggy, but there is about 1 to 1½ feet of loose altered gouge on the hanging wall. This gouge extends all along the north drift and has a tendency to slump into the drift, necessitating timbering most of the way.

In the "114 drift" south of the main raise the vein lies between pyritized walls and is well mineralized for a distance of 70 feet, to a small raise. The vein in the upper end of this raise appears similar in character to that in the north raise and is about 2 feet thick. Beyond this raise to the south the vein becomes nearly vertical and pinches to a narrow barren fissure filled with altered gouge. The fissure continues barren to the end of the south drift. There are several parallel fractures in both walls, but they are not mineralized.

As far as present developments show the ore body is about 240 feet in length, extending possibly 50 feet below the "114 level" and an undetermined distance above. How much of this body has been mined above the "114 level" is not known, as the old workings are not accessible, but the early production was small. Although the fissure is tight on the main adit level, the mineralogic character of the ore just above the level does not indicate that the bottom of mineralization has been reached. Should the vein widen below the adit level within the next few hundred feet, there might be additional bodies of zinc-lead ore or of copper-silver ore. The intersection with the Poverty fissure should also be reached within a vertical depth of 200 feet in the vicinity of the shaft, providing the two fissures hold their dip as exposed on the adit level. Although the ore body developed by the present workings is small, the amount of work done is insufficient to show its full extent. It is presumably limited, however, on the north and south by the cross fissures mentioned.

POVERTY VEIN

The Poverty vein occupies a low-angle fault dipping northeastward toward the Antoro fissure. The two veins intersect east of the main adit level, but the intersection is not exposed in the drift. Near the intersection both veins are only weakly mineralized. The strongest mineralization in the Poverty fault occurred near the end of the west drift. A small body of high-grade lead-silver ore has been mined from the stope shown on the map. Shipments direct to the smelter amounting to 730 tons showed an average content of 32.3 per cent of lead, 0.6 per cent of copper, and 8.9 ounces of silver and 0.012 ounce of gold to the ton. The zinc is said to have averaged 4 per cent or less in the ore that was shipped. The stope pinched at the east end but at the top showed 10 to 26 inches of ore which assayed from 3 to 7 ounces of silver to the ton, 8.5 to 25 per cent of lead, 0.2 to 5.0 per cent of copper, 2.4 to 6.0 per cent of zinc, and 7 to 11 per cent of iron. The data regarding the stope are based upon assay maps, as the stope could not be entered because of bad air. In the relatively high lead content and the low copper content this ore agrees with the ore of the Antoro vein as indicating that the bottom of the zone favorable to ore has not been reached. Ore bodies in flat veins such as the Poverty are likely to be very irregularly distributed, however.

ZINC VEIN

The Zinc vein is a north-south vein exposed by a crosscut east of the main adit level. It can be traced for about 160 feet in the drifts. It dips about 65° E., and the strike turns somewhat to the northeast in the north drift. It can not be definitely stated whether or not this is the continuation of the Antoro vein until more development work has been done. The vein runs much higher in iron and zinc than either the Antoro or the Poverty vein, and this mineralogic difference, in conjunction with its strike in the north drift, suggests that it is not a direct continuation of the Antoro vein. It may, however, be another part of the Antoro fissure which has been displaced by premineral movement on the Poverty fault. The vein is from 1 to 4 feet thick, averaging around 2 feet, and contains about 8 per cent of lead, 13 per cent of zinc, a trace of copper, and about 19 per cent of iron. The silver assays range from less than 1 ounce to 9 ounces and average a little over 2 ounces to the ton.

At the south end of the drift the vein pinches and terminates against a fault plane striking N. 85° E. and dipping about 70° S. In the north drift the vein is only a foot or a little more thick and pinches near the breast of the drift. The gangue of the vein is siliceous, and it appears too narrow and too high in iron and zinc to encourage stoping.

NORTHEAST VEIN

About 170 feet from the portal of the main adit level a winze has been sunk 125 feet on a steep vein. The winze was filled with water, but from what could be seen near the adit level the vein strikes about N. 30° E. The winze is said to be nearly vertical. The gangue consists of hard, dense quartz containing pyrite and chalcopyrite,[10] and the vein matter is said to be 18 inches wide at the bottom of the winze. This vein is in line with and about 300 feet northeast of the split in the Rawley vein on the 300-foot north level of the Rawley mine. Mr. John E. Ashley, superintendent of the Antoro property, very reasonably considers the fissure in the winze to be a continuation of the east split of the Rawley fissure. According to him, the northeast vein carries about 2 per cent of copper and has a good silver content. A vein of similar strike was apparently drifted on about 400 feet from the portal of the main adit, but these drifts were caved and could not be examined.

MICHIGAN AND PARAGON MINES

DEVELOPMENT AND PRODUCTION

The Michigan and Paragon properties (Nos. 54, 61, 62, and 63, pl. 1), which are owned by the Antoro Mines Co., have been developed on two veins on the north side of Rawley Gulch above the Rawley mine. The Paragon vein is in a fault that follows approximately the course of Rawley Gulch and is the large fault that is encountered in the Rawley mine. It has an average strike of N. 80°–85° E. and dips 55°–60° S. The Michigan vein has been found only north of the Paragon. It strikes N. 20°–25° E. and dips 45°–58° SE. The Michigan and Paragon veins intersect on the north side of Rawley Gulch, where the Michigan vein apparently terminates—at least it has never been recognized in the south or hanging wall of the Paragon fault.

The Michigan vein workings, which include a shaft on the vein at an altitude of 11,460 feet and two tunnels below the shaft, were operated during the early history of the district, and all are now inacessible. The known extent of the Michigan tunnels is shown on Plate 1. It is estimated that about 700 tons of ore was taken from this vein.[11] In 1888[12] the Michigan produced $5,337 in silver and $8,253 in lead, and in 1890 $1,337 in silver and $2,471 in lead, making a total for these two years of $17,398. The production between 1881 and 1900 given by Patton[13] is $24,500. The production of $17,398 represents about 5,170 ounces of silver and 246,000 pounds of lead and would indicate on 500 to 700 tons of ore that the ore averaged from 8 to 10 ounces of silver to the ton and 20 to 25 per cent of lead. The early shipping ore is said to have been oxidized and to have contained lead carbonate. There has been little or no production from

[10] Patton, H. B., op. cit., p. 89.
[11] Idem, p. 90.
[12] Munson, G. C., Report of the Director of the Mint upon the production of the precious metals in the United States, 1888, pp. 120, 121, 1889.
[13] Patton, H. B., op. cit., p. 68.

the Michigan vein since 1900 except for a few tons of ore shipped from the vein where it is exposed in the Paragon No. 2 tunnel.

The Paragon vein was also developed to a slight extent in the early eighties. In 1884 [14] the Paragon had shipped a small quantity of ore which was concentrated by hand jigs in use at the Empress Josephine. This ore was apparently unoxidized sulphide containing pyrite, sphalerite, and galena and was valued at $35 to $45 a ton. In 1887 [15] the Paragon produced $625 in gold and $2,000 in silver, presumably from enriched ore. No other records of production prior to 1900 are known. There are also no records of production between 1900 and 1916, but from 1916 to 1927 about 500 tons of ore was taken from the Paragon tunnels in Rawley Gulch. About 30 tons of this ore came from the Michigan vein.

GEOLOGIC FEATURES

A geologic plan of the Paragon No. 2 tunnel giving the extent of development in October, 1926, is shown in Figure 33. The Paragon fault zone in the No. 2 tunnel consists of a series of mineralized fractures which have a general easterly strike and a southerly dip. Near the portal of the tunnel the Paragon fault zone consists of three nearly parallel fault planes with about 30 to 50 feet of broken and silicified or bleached andesite between them. They strike N. 50°–70° E. and dip 50°–55° SE. A small stope was being worked in the northwestern vein in 1926. The stope was up about 20 feet above the drift, on a narrow body of black sulphide ore containing some secondary copper sulphides. Altered gouge lay between the altered sulphide ore and the hanging wall. The hanging wall consisted of bleached and pyritized porphyritic andesite, which was partly crushed. There were also a small stope and two inaccessible winzes along the main Paragon fault in the drift. The crosscut southeast of the drift exposes an altered and broken zone beyond which there is a third fault plane. About 250 feet from the portal these fault planes appear to be displaced by an east-west fault dipping 55°–70° S. The east-west fissure is irregularly mineralized, but a few small lenses of tennantite (gray copper) ore have been uncovered. The drift continues on the east-west vein for about 150 feet from the intersection and then encounters a northeasterly fault which may be part of the Paragon fault. It appears that the east-west fissure has caused a horizontal displacement of about 150 feet. The N. 60° E. fissure contains an 8-foot vein mainly of quartz, manganocalcite, pyrite, and sphalerite just under the footwall of the east-west fault. The vein is not of high grade, however, and has a very low lead content. For the remainder of the tunnel the Paragon fissure is only weakly mineralized and turns into a nearly east-west strike.

On the whole the mineralization in the Paragon fault zone was scattered, and only one small shoot has been stoped to any extent. The position and approximate limits of this stope, which was not accessible, are shown in the section, Figure 33. The Paragon vein where exposed for about 150 feet in the No. 2 adit shows a width ranging from 12 to 48 inches and averaging about 30 inches. Assays show from 1 to 6 per cent of lead, 1 to 8 per cent of copper, and 13 ounces of silver, and 0.05 ounce of gold to the ton. The assays average about 3 per cent of copper and 2 per cent of lead. Data on the zinc content are not available, but the vein, as a whole, probably contains at least one and one-half times as much zinc as lead. An average of about 375 tons of crude ore shipped from the Paragon mine gives 7.2 per cent of lead, 2.3 per cent of copper, and 12.2 ounces of silver and 0.08 ounce of gold to the ton. The N. 80° W. vein contains from 8 to 30 inches of vein matter in streaks. This assays about 1.0 per cent of lead, 1.0 per cent of copper, and 6.8 ounces of silver and 0.016 ounce of gold to the ton. Small pockets and streaks of ore from 8 to 12 inches in width containing considerable tennantite (gray copper) gave very high silver assays. This ore consists of pyrite, tennantite, and chalcopyrite with some quartz, galena, and sphalerite. The tennantite and chalcopyrite are in part very intimately intergrown, as shown by the microscope.

Small shipments of siliceous silver ores from the Paragon vein ran about 3 per cent of lead, 1 per cent of copper, and 18 ounces of silver and 0.20 ounce of gold to the ton. The iron content ranged from 8 to 18 per cent and the silica from 48 to 60 per cent.

The Michigan vein is encountered in the footwall of the Paragon fault about 550 feet from the portal of the tunnel. It has been explored by a drift for about 150 feet. Near its intersection with the Paragon the Michigan vein is in a complex fissure zone 30 feet or more in width. Several parallel veins are shown by one crosscut. The gangue of the veins is made up of vuggy quartz, pinkish manganocalcite, and some jasper. The jaspery material is of earlier formation than the vein quartz and sulphides and represents a replacement of the original andesitic wall rock by silica. On the whole this part of the Michigan vein is essentially a zinc vein with a minor amount of lead. The sulphides recognized are pyrite, sphalerite, tennantite, and galena. There is an altered gouge on the hanging wall of part of the vein. At its intersection with the Paragon the min-

[14] Silver, Herman, Report of the Director of the Mint for 1884, p. 239, 1885.

[15] Munson, G. C., idem for 1887, p. 181, 1888.

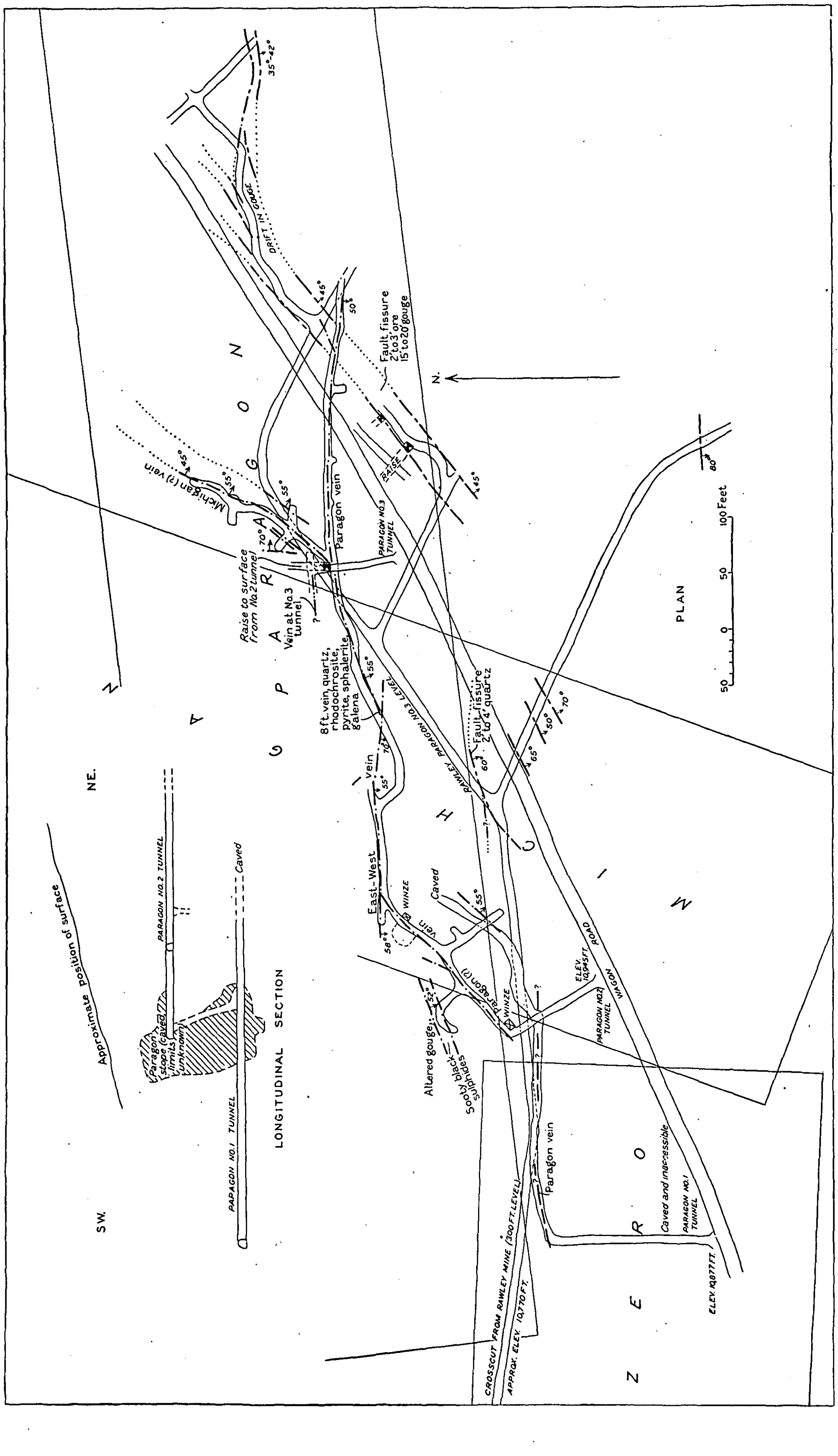
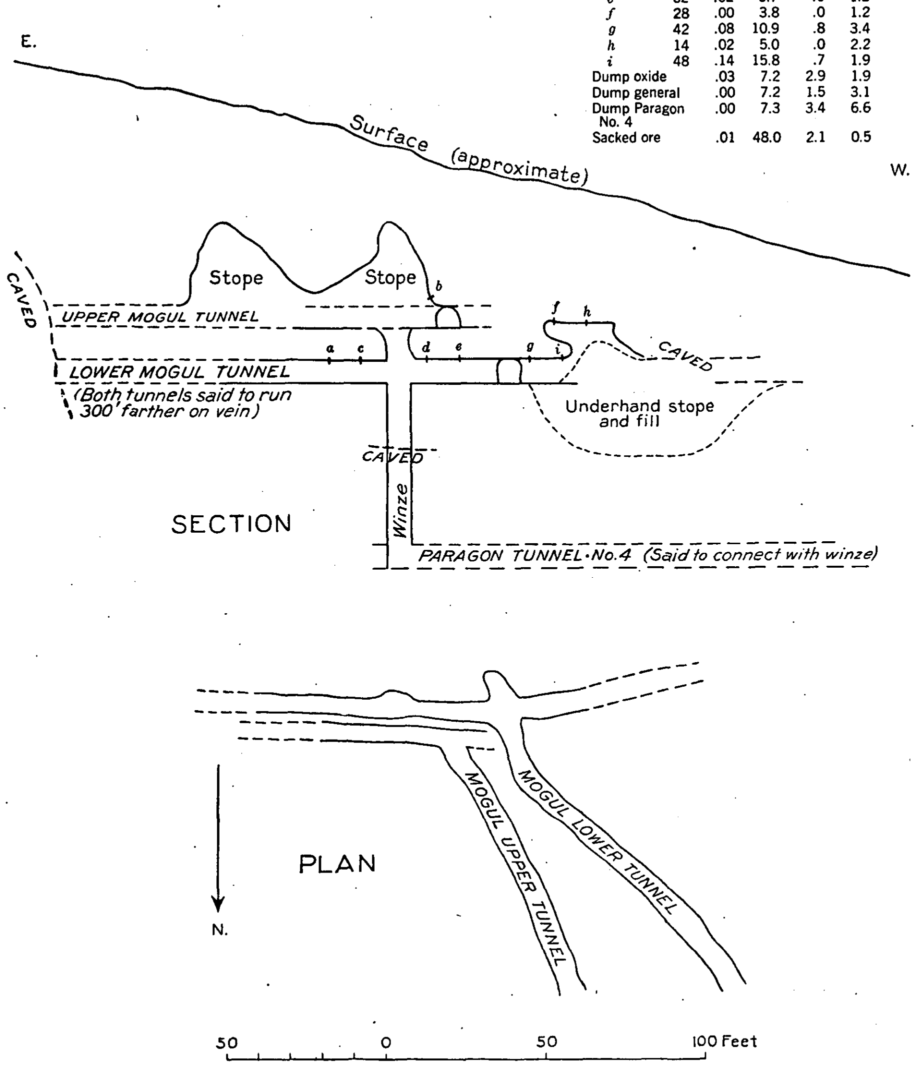


FIGURE 33.—Plan and longitudinal section of workings of the Paragon mine

eralized part of the Michigan fissure turns sharply, paralleling the strike of the Paragon, but shows little evidence of being faulted by the movement on the Paragon fault. The evidence indicates that both fissures are of premineral age. The amount of displacement on the Paragon fault could not be accurately determined at any position along its outcrop, but about 2,000 feet west of the Rawley fissure, where it faults down a block of the Bonanza latite, the displacement down the fault plane (dip slip) is certainly in excess of 500 feet and may possibly be 1,000 feet. The displacement probably decreases toward the east, so that the movement on the fault plane has been in part one of rotation. The amount of displacement at the point where the Michigan vein joins the Paragon can not be stated, but it is possibly less than 500 feet. Because of its dip the Michigan fissure, if it is present in the hanging wall, would probably have been displaced toward the west in the hanging wall of the Paragon, but it has not been definitely recognized in any of the workings. The deeper exploration of the Rawley mine also failed to find any vein corresponding to the Michigan in the hanging wall of the Paragon fault. Very little ore has been mined from this part of the Michigan vein, but one small shipment contained 8.9 per cent of lead, 2.9 per cent of copper, and 9.1 ounces of silver and 0.03 ounce of gold to the ton.



	Width (inches)	Au	Ag	Cu	Pb
a	30	0.08	14.2	2.3	2.9
b	18	.01	5.0	.0	1.2
c	48	.01	9.0	.0	2.9
d	42	.02	8.2	.0	1.6
e	62	.02	5.7	.0	1.2
f	28	.00	3.8	.0	1.2
g	42	.08	10.9	.8	3.4
h	14	.02	5.0	.0	2.2
i	48	.14	15.8	.7	1.9
Dump oxide		.03	7.2	2.9	1.9
Dump general		.00	7.2	1.5	3.1
Dump Paragon No. 4		.00	7.3	3.4	6.6
Sacked ore		.01	48.0	2.1	0.5

FIGURE 34.—Plan and longitudinal section of the Mogul tunnel levels

OTHER WORKINGS ON THE PARAGON VEIN

There are numerous other small workings and prospect tunnels on the Paragon vein, above the Paragon mine along Rawley Gulch. The largest of these are the Ashley tunnel, the Great Mogul tunnel, and the Rainbow tunnel. All the data that are available regarding the length and direction of these workings are shown in Plate 1 and Figure 34. The Ashley tunnel was driven on the Paragon fissure, but the first part of the Great Mogul tunnel is a crosscut. The two tunnels are connected by a winze, the position of which is not known, as neither tunnel was accessible. The Rainbow tunnel was open as far as the Paragon fissure, but the drift on this fissure was not accessible. There is said to be 450 feet of drift from this tunnel in a direction about N. 85° E. from the end of the crosscut. The fissure contains parallel stringers of quartz and dips 60° S.[16]

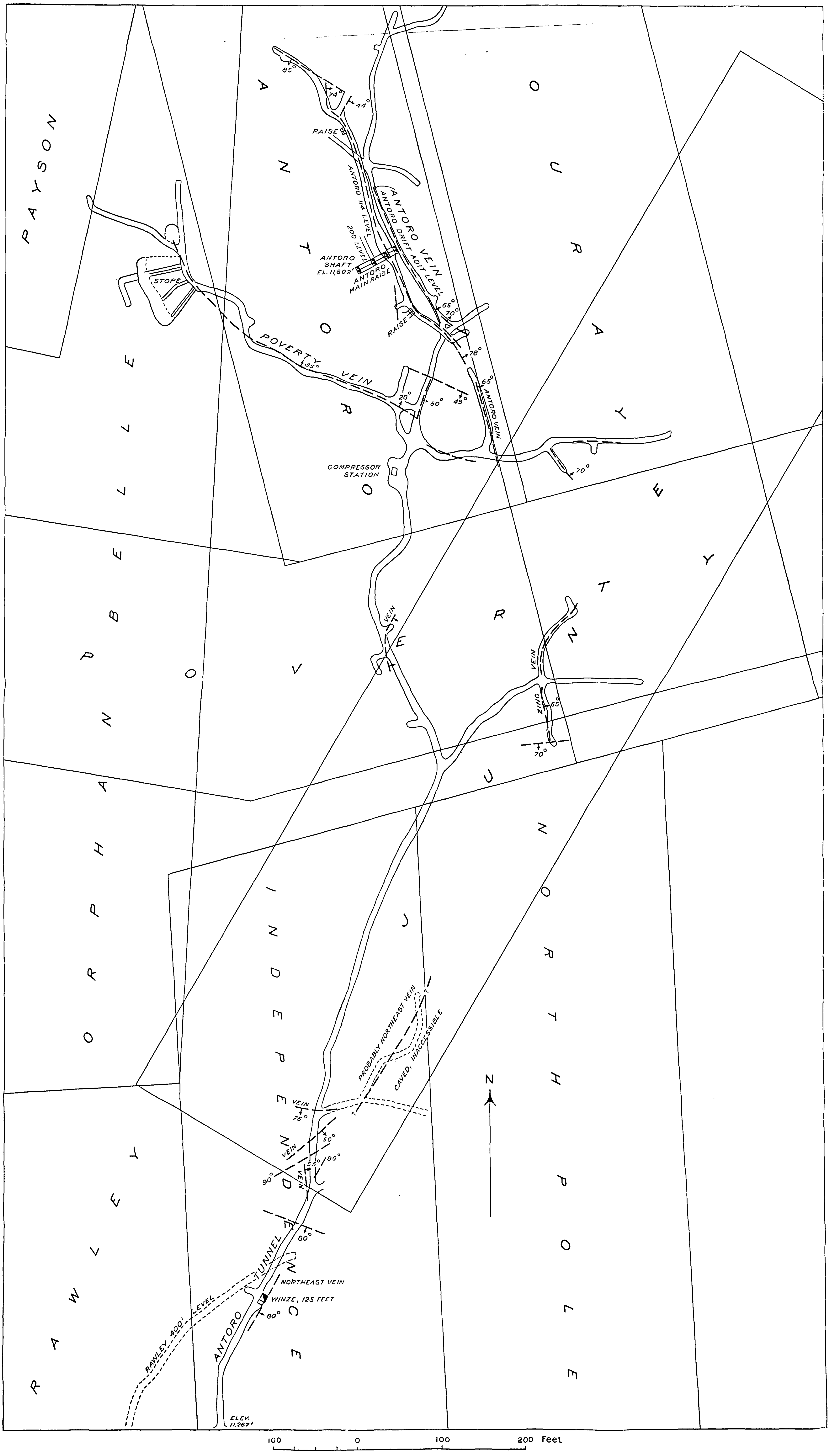
According to Patton [17] there has been some slight production from the Great Mogul (First Chance), but there has been no production from the Rainbow so far as is known.

WHALE MINE

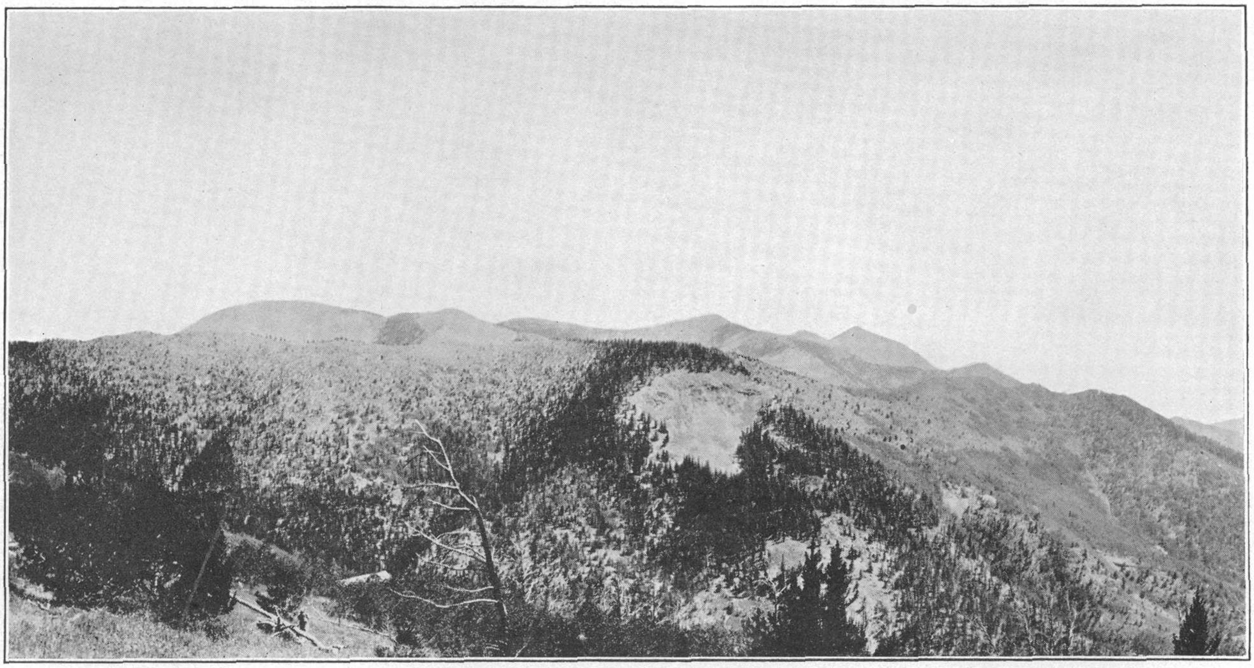
The Whale mine (No. 82, pl. 1) is on the slope south of Rawley Gulch nearly opposite the Rawley mine. The mine was worked through several adits and shafts, which were all inaccessible in 1926 and 1927.

[16] Patton, H. B., op. cit., p. 92.

[17] Idem, p. 91.

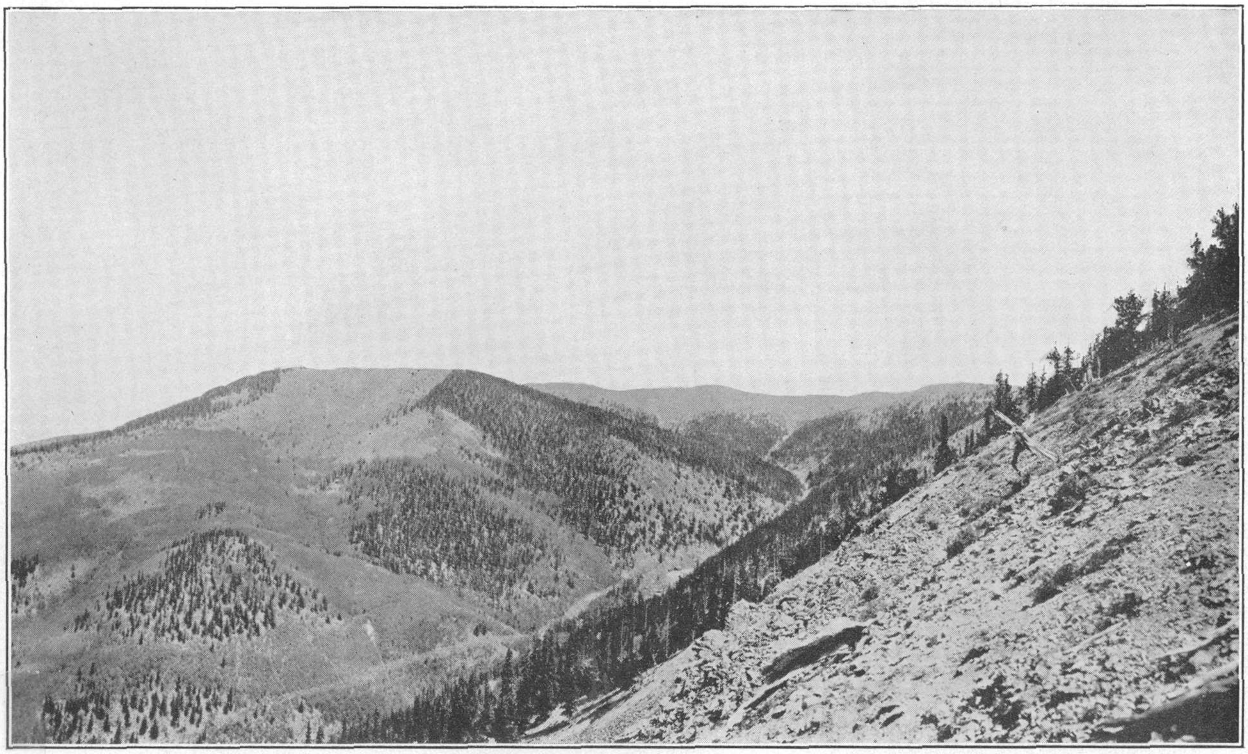


PLAN OF WORKINGS OF ANTORO MINE



A. VIEW ACROSS COPPER GULCH FROM POINT ABOVE SENATOR MINE

Looking southward. The pyramidal peak at right is Hayden Peak and the round-topped high summit at left is Elkhorn Peak. There is a small landslide scar on the ridge south of the gulch.



B. VIEW FROM SOUTH SIDE OF COPPER GULCH NORTHEASTWARD TOWARD ITS HEAD

The talus slope in foreground is composed of Bonanza latite.

The production for four years according to mint reports is shown in the accompanying table. The value of the ore during these years lay mainly in silver and copper. According to an estimate by Patton[18] the mine had produced 2,000 tons of $50 ore up to 1893, but authentic records of the total production are not now available. It is evident, however, that the production is considerably greater than that shown by the records of only four years given by the mint reports, as the mine was one of the larger early producers in the district. In his report for 1881[19] Burchard says: "The Whale has been a regular producer of ore, and the returns have been satisfactory to the owners." In the report for 1882[20] he says:

The Whale has been a large producer of ore. The shaft is down 100 feet and drifts run in both directions. The south drift is 35 feet, and the north 45 feet, and in this drift the mineral streak shows a body of ore 5 feet in width that has milled 149 ounces of silver and 10 per cent copper. A tunnel is being run that when completed will cut the vein at a depth of 250 feet.

The lowest adit to the Whale vein is about 10,900 feet above sea level and about 100 feet west of the old road from Rawley Gulch to the Superior-Erie mine. It was bulkheaded and filled with water at the time of examination and so could not be entered. Above it on the road is another caved adit which probably crosscuts about 300 feet to the vein. The Whale vein strikes a little east of north and is probably almost vertical. In the patent records on the Whale claim, No. 7228, the vein is said to have been stoped for about 300 feet north of a crosscut adit at the time the survey was made, in 1891, although the drift was then inaccessible. This old adit is said to have crosscut 151 feet to the vein, but its portal is now entirely caved in and covered. The discovery shaft was said to be 150 feet deep in 1891, but it is believed to have been connected later to the 300-foot level by a raise.

Partial record of value of metals produced at the Whale mine, 1887–1891[a]

Year	Gold	Silver	Lead	Copper	Total
1887		$2, 727	$678		$3, 405
1888	$100	3, 233		$1, 508	4, 841
1890		2, 068		278	2, 346
1891		16, 161	2, 175	3, 300	21, 636
	100	24, 189	2, 853	5, 086	32, 228

[a] From reports of the Director of the Mint. No individual records of the production given for the district for 1889. Gold value, $20 an ounce; silver (coinage value), $1.29 an ounce; lead, $87 a ton; copper, $240 a ton.

No data as to the average metal content of the Whale vein could be obtained. According to Patton,[21] most of the valuable ore was shipped from the upper workings, in which the metal content of the vein was mainly lead and silver. According to Mr. L. W. Sharpe, of Bonanza, the upper 50 to 100 feet of the Whale vein was an oxidized and enriched copper-silver ore, containing green copper carbonate. This ore assayed 100 to 140 ounces of silver to the ton and 8 to 12 per cent of copper, with a little gold. Toward the north and on the lower levels (300 foot±) the vein split and became very wide. In these lower workings the metal content according to Mr. Sharpe was a complex zinc-copper-lead ore of low grade. It is not known how much stoping was done from the lower adit levels, but the output of 1888, 1890, and 1891 presumably came from the upper part of the vein, to judge from the relative values of lead and copper. Data as to the character and width of the vein in the lower workings are meager, but the vein appears to be worthy of consideration in explorations for additional bodies of low-grade ores in the district.

HANOVER MINE

The Hanover mine is west of the Whale, on the mountain slope south of Rawley Gulch. The Hanover vein is developed through an adit and an inclined shaft (Nos. 34 and 35, pl. 1). The Hanover property includes the Erie and Hanover claims, which are at present owned by Messrs. Buck & Sharpe, of Bonanza. In the mint report for 1891[22] the Hanover is credited with a production of $581 in silver and $696 in lead. Details of the production for other years are not known. A production of a few tons was made under lease in 1921. An estimate of 700 tons of ore produced prior to 1900 is given in the report by Patton.[23]

The Hanover tunnel is about 10,860 feet above sea level, and according to the patent survey made in 1900 runs due south for 250 feet. At a point 200 feet from the portal there is a winze sunk 140 feet to the east at a pitch of 35° and a 100-foot raise west of the tunnel and on the same pitch. There may have been a small amount of additional work in this tunnel since the patent survey was made. The Hanover vein apparently has a strike of south to S. 25° E. and a dip of 28°–35° E. The Hanover inclined shaft is about 300 feet south of the portal of the tunnel at an altitude of 10,880 feet. A plan of this incline taken from an assay map is shown in Figure 35. This plan perhaps does not represent the full extent of the workings, as the date of the map is not known.

The country rock of the Hanover mine is entirely andesite. The ore consists of pyrite, sphalerite, ga-

[18] Patton, H. B., op. cit., pp. 68, 92.
[19] Burchard, H. C., Report of the Director of the Mint upon the production of the precious metals in the United States, 1881, p. 427, 1882.
[20] Burchard, H. C., idem for 1882, p. 543, 1883.
[21] Patton, H. B., op. cit., p. 92.
[22] Smith, M. E., Report of the Director of the Mint upon the production of the precious metals in the United States, 1891, p. 184, 1892.
[23] Patton, H. B., op. cit., p. 93.

lena, chalcopyrite, and tennantite in a gangue of quartz and barite. Copper is subordinate to zinc and lead in the ore seen on the dump. The formation of the vein was preceded, as in many other fissures in the district, by silicification of the wall rock. Red jasper is included in some of the vein material and is fractured and veined with quartz and sulphides and partly impregnated with pyrite. The jasper has replaced the andesite country rock, as microscopic examination reveals faint but unmistakable relicts of the original porphyritic texture.

The only record obtained of the metal content of the ores is on a small shipment of 17 tons, which showed a gross content of about 3 per cent of lead and 15 ounces of silver and 0.018 ounce of gold to the ton. The zinc content was sufficiently high to be penalized. Several assays of the vein in the Hanover incline show a width of 16 to 26 inches, with 5 to 13 per cent of lead, from a trace to 2 per cent of copper, 1.5 to 16 per cent of zinc, and 3 to 5 ounces of silver and a trace of gold to the ton. The iron content ranges from 12 to 16 per cent.

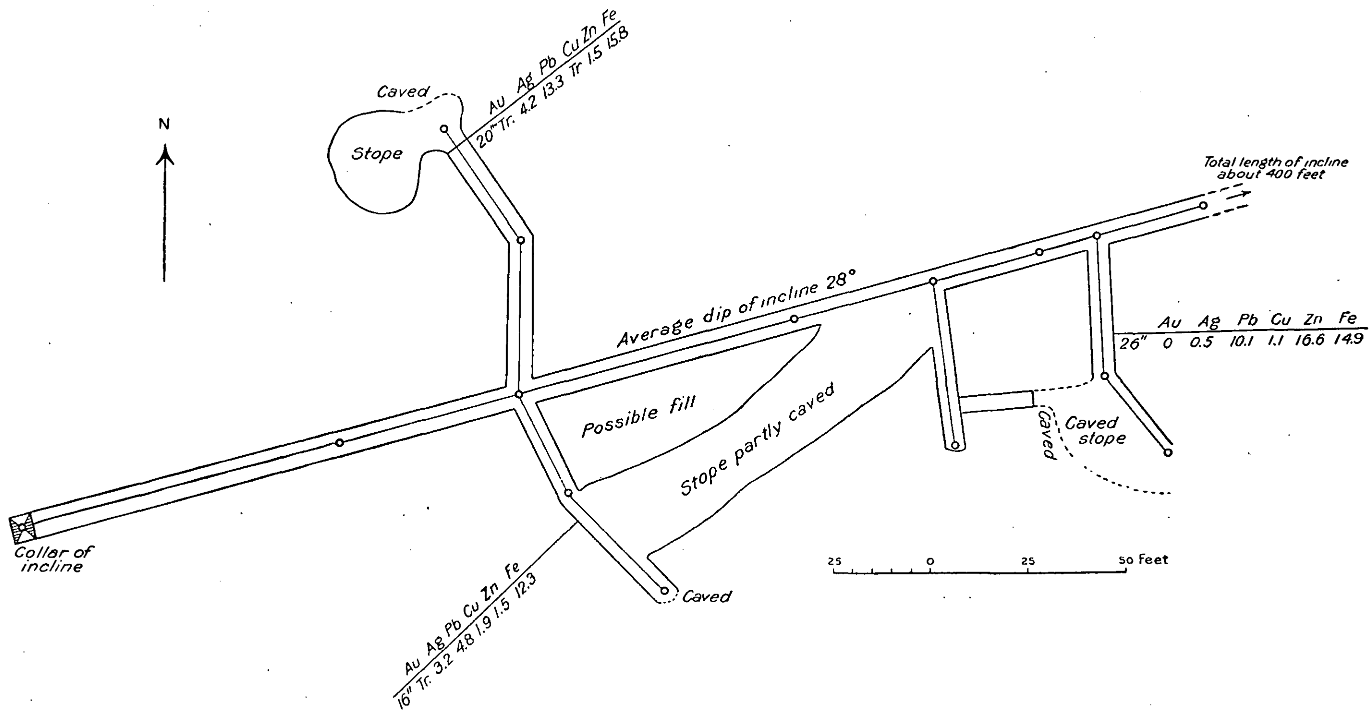


FIGURE 35.—Plan of the Hanover incline

ERIE AND SUPERIOR MINES

The Erie and Superior mines are on the same vein and have been developed jointly for a number of years. The Superior shaft is on a spur of the ridge south of Rawley Gulch at an altitude of 11,184 feet. There are several adits on the Erie claim below and west of the Superior shaft (Nos. 23 and 79, pl. 1). The mine is accessible by wagon road from Rawley Gulch. The Superior claim is not patented but is apparently excluded from the patent applications of several later conflicting claims. The Superior is an old property and in 1881 [24] was being actively developed. In 1882 [25] the shaft had been sunk to a depth of 100 feet, disclosing a 7-foot vein with 3 feet of ore on the footwall. In this year some lead and copper ore were taken from the vein and treated at the Bonanza smelter. In 1883 [26] levels driven at depths of 70 and 140 feet showed a 5-foot vein with 22 inches of ore containing galena, gray copper, and pyrite, running 20 to 60 ounces of silver to the ton. In 1890 [27] the production of the Superior is given as $1,202 in silver and $522 in lead. There is no record of the production for other years prior to 1902. An estimate of 700 tons of $40 ore between 1881 and 1900 is given for the Erie and Superior together in Patton's report,[28] but most of this tonnage is credited to the Erie mine. Between 1902 and 1927, ore known to be produced from the Erie and Superior properties is given in the accompanying table.

There are two main adit tunnels on the Erie—the lower Erie tunnel, at an altitude of 10,882 feet, and an upper tunnel, at an altitude of 11,000 feet. Both are drifts on the vein. Only part of the lower tunnel was accessible in 1926. A geologic sketch of this part based upon a compass and pacing survey is shown in Figure 36. The Superior shaft is said to be dry and to require no pumping. It is vertical for the first

[24] Burchard, H. C., op. cit. for 1881, p. 427, 1882.
[25] Idem for 1882, p. 543, 1883.
[26] Silver, Herman, op. cit. for 1883, p. 404, 1884.
[27] Smith, M. E., op. cit. for 1890, p. 139, 1891.
[28] Patton, H. B., op. cit., p. 68.

Production of the Erie and Superior mines, 1902–1927 [a]

Year	Ore mined (dry tons)	Concentrates produced (dry tons)	Gross content of concentrates and smelting ore				
			Gold (fine ounces)	Silver (fine ounces)	Lead (wet assay, pounds)	Copper (wet assay, pounds)	Zinc (pounds)
1902	100	----------	5. 00	3, 000	35, 300	4, 800	----------
1903	80	----------	----------	2, 960	2, 100	70	----------
1904	60	----------	3. 00	2, 400	21, 200	2, 800	21, 200
1905	(b)	----------	----------	----------	----------	----------	----------
1912	90	11	1. 19	247	15, 100	1, 180	----------
1917	114	----------	2. 57	1, 473	22, 095	1, 348	----------
1918	69	----------	1. 26	843	9, 685	1, 203	----------
1924	18	----------	. 36	110	2, 508	----------	3, 688
1927	[c] 10	----------	----------	59	1, 308	----------	250

[a] No production in years omitted from table since 1902. See text for production prior to 1902. Compiled from mine records of U. S. Geological Survey and Bureau of Mines.
[b] May be some ore included in Rawley mine production.
[c] To Rawley mill, probably from dumps.

20 to 25 feet and dips about 60° below. It could not be entered, as the air was bad. A plan of the workings on the Superior shaft is shown in Figure 37, taken from an undated assay map.

The Erie and Superior vein lies entirely in Rawley andesite. The vein occupies a fault fissure that strikes about N. 60°–65° E. and dips 40°–60° S. and has brought the Superior member in the hanging wall opposite an amygdaloidal member in the footwall; but it is uncertain whether the fault is normal or reverse. Along parts of the lower tunnel the walls of the fissure have been intensely silicified and consist of reddish or white jaspery quartz partly impregnated with pyrite. The vein material is of later age than the silicification. An altered micaceous gouge occurs in places along the hanging wall, and next to this the hanging-wall andesite has been strongly decomposed and bleached to a whitish rock consisting of sericite, carbonates, chlorite, and quartz with some pyrite. Oxidation has affected the vein near the surface, and limonite and black manganese oxides have been deposited. In specimens of oxidized ore on the dump galena was the most abundant sulphide that remained partly unaltered, although it was largely altered to anglesite and cerusite. The primary ore minerals are pyrite, sphalerite, galena, chalcopyrite, and tennantite, which occur in a gangue of quartz, barite, and pinkish manganese-bearing carbonates.

Shipments of crude ore from the Erie and Superior show a gross content of 7 to 18 per cent of lead, 0.6 to 3 per cent of copper, 5 to 20 per cent of zinc, and 5 to 40 ounces of silver and 0.017 to 0.05 ounce of gold to

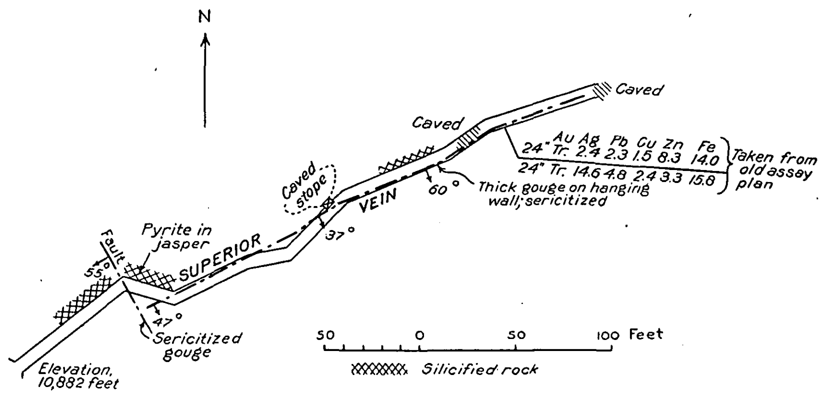


FIGURE 36.—Sketch map of the lower Superior tunnel

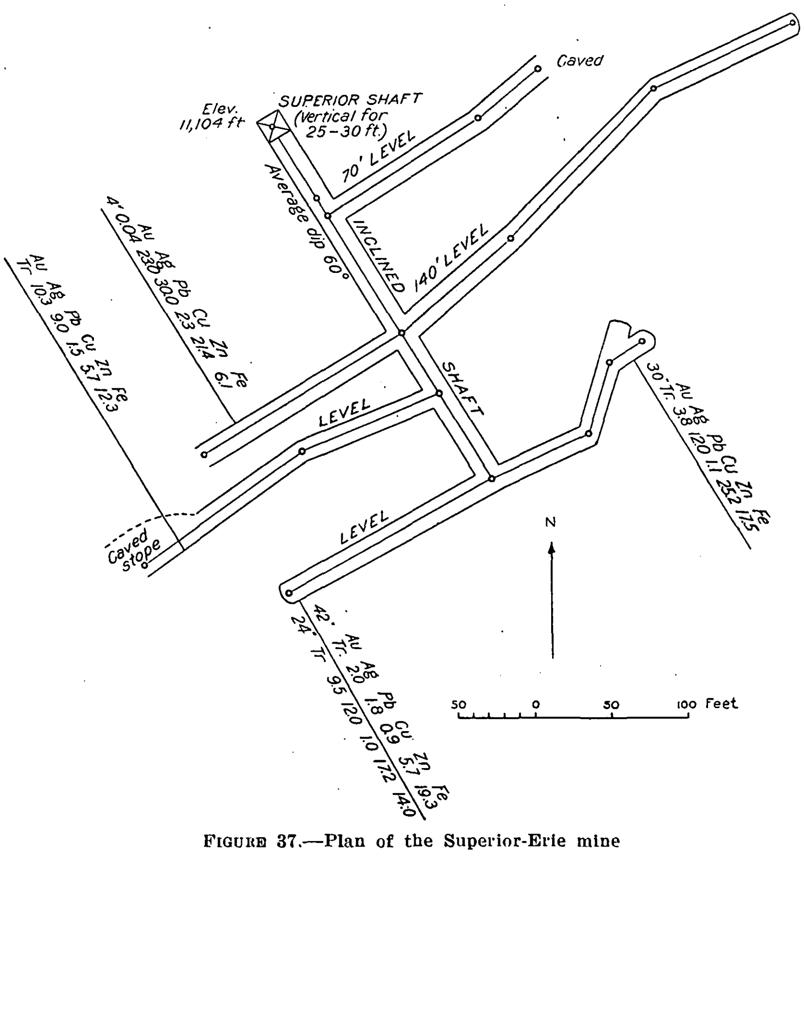


FIGURE 37.—Plan of the Superior-Erie mine

the ton. The average content was about 10 per cent of lead, 1.5 per cent of copper, and 21 ounces of silver and 0.025 ounce of gold to the ton. Mine samples of the vein show from 6 to 19 per cent of iron, the average being about 15 per cent.

MINES ON THE MINNIE LYNCH VEIN

The Minnie Lynch vein crops out on the ridge south of Rawley Gulch about a mile east of Kerber Creek. It is developed by three or four main tunnels and several shafts and cuts. The two upper adits at altitudes of 10,830 and 10,736 feet (No. 56, pl. 1) are on the Minnie Lynch property. The Paddy Doyle mine (No. 60, pl. 1), at an altitude of about 10,650 feet, is also on the Minnie Lynch vein but is a separate property. The production from this vein has been small.

The adits belonging to the Minnie Lynch mine were caved near the portals. The ore on the dumps is siliceous and contains considerable sphalerite. The other sulphides are pyrite, tennantite, and galena. Tennantite is fairly abundant and occurs in parts of the ore in a massive fine-grained aggregate of quartz, pyrite, and tennantite. Besides quartz the gangue contains some pinkish manganese-bearing carbonate. Very little of this, if any, contains sufficient manganese to be classed as rhodochrosite. According to Patton[29] the vein is from 3 to 5 feet wide, strikes N. 85° W., and dips 73° N. Small shipments of crude ore, from which the zincky material was apparently sorted out, to judge from the large proportion of sphalerite on the dump, showed a gross content of about 17 per cent of lead, 1 per cent of copper, and 0.091 ounce of gold and 33.8 ounces of silver to the ton.

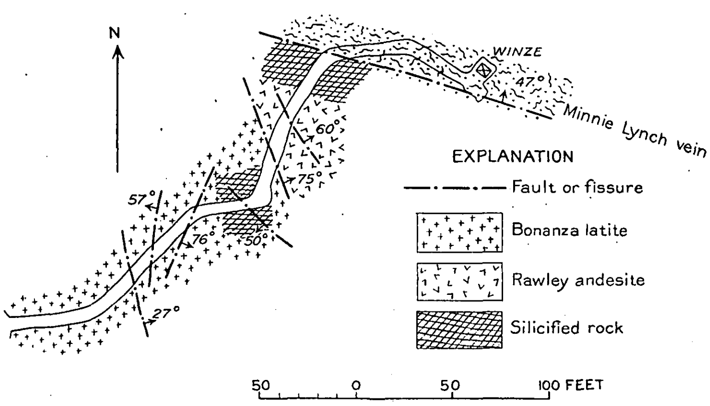


FIGURE 38.—Sketch map of the Paddy Doyle tunnel on the Minnie Lynch vein

A geologic sketch map of the Paddy Doyle adit on the Minnie Lynch vein is shown in Figure 38. The first 160 to 170 feet of the tunnel lies in broken Bonanza latite, which in this vicinity has an average northerly strike and a dip of 32°–40° W., which essentially coincides with the local surface of the hill slope. Underlying the latite in the tunnel are some breccias and fine-grained flows of the Rawley andesite. The contact between the andesite and the latite is practically a normal contact, as shown where the basal part of the latite is clearly exposed in the crosscut. The actual contact, however, has been slightly faulted by small breaks and is somewhat obscured by alteration. A similar condition is encountered in several other small tunnels on the slope to the north and west, as the tunnels start in latite at the surface but soon penetrate the underlying andesite.

The Minnie Lynch vein is cut about 60 or 70 feet beyond the andesite-latite contact. In 1927 the vein was explored by a drift for about 90 feet, and a small winze was sunk 25 feet on the vein. Here the vein strikes N. 80° W. and dips about 45°–50° N. The character of the rock in the hanging wall could not be determined because of insufficient exploration and the decomposition of the wall rock near the fissure. The vein material occurs in a zone of shearing and alteration about 15 feet in width, which suggests that the fissure is a fault fissure. Mr. Dan Mahoney, who was working the property when it was examined, said that some assays of the vein material taken where the vein was first struck by the tunnel ran 100 to 150 ounces of silver to the ton. Where the winze was sunk the vein material was 2 feet wide, and the average content of the rock broken was about 8 ounces of silver to the ton. The silver is associated with gray copper (tennantite) ore. The volcanic rocks near the vein are altered to hard white silicified rocks or to a bleached greenish rock containing sericite, chlorite, and carbonates. Small shipments of crude ore from the Paddy Doyle show from 5 to 12 per cent of lead and 9 to 30 ounces of silver and 0.02 ounce of gold to the ton. The copper content runs from 1 to 2 per cent.

MINES ALONG COPPER GULCH

The mines along Copper Gulch (pl. 32) lie in a mineralized zone extending from the vicinity of the town of Bonanza northeastward for a little over 2 miles, although the greatest amount of development has been done in the lower part of the gulch. The veins of this area are similar mineralogically to those north of them, but several have a higher gold content than is common to other mines in the district, and in some of them small pockets of gold and silver tellurides have been found. The gold content of the ore shipped from the mines in this gulch averages from 0.02 to 1.2 ounces to the ton, but it is not at all consistent. The average gold content of the ores of the Bonanza district, not including those from Copper Gulch, is close to 0.01 ounce to the ton, as indicated by smelter recoveries since 1902.

[29] Patton, H. B., op. cit., p. 93.

Nearly all the workings in Copper Gulch are in andesite. For about a mile east of the town of Bonanza the andesite on both sides of the gulch is intensely silicified. Alteration of this type occurred commonly throughout the district but was particularly intense in this area, and in many places has made the determination of the character of the country rock a matter of some difficulty. Both reddish or brownish jaspers containing ferric oxide and white or gray jaspers are common. The jaspers are of earlier formation than the veins but are related in their distribution to the faults and fissures. Pyrite crystals are thickly embedded in some of the jaspers, but at the surface the pyrite has commonly been destroyed, leaving cavities in its place.

Most of the production from Copper Gulch has come from the Empress Josephine mine, although a small quantity of high-grade ore has been taken from the St. Louis mine. Other properties in this gulch are the Liberty, Glennbrook, Mariposa, Now What, Hortense, Cliff, and Queen City. Plate 1 shows the relative positions of some of the larger operations.

EMPRESS JOSEPHINE MINE

LOCATION

The Empress Josephine mine is on the north side of Copper Gulch a short distance northeast of the town of Bonanza, at an altitude of about 9,780 feet. It is accessible by a road up the gulch. The mine is owned by S. G. Everett, of Cleveland, Ohio. During 1926 and 1927 it was not being operated, and in the following discussion of the development and nature of the vein the writer has had to draw from the report of the Colorado Geological Survey and from information furnished by those familiar with the mine. The writer is especially indebted to Dr. R. D. George, of the State Geological Survey, and to Mr. Frank Leavitt, of Bonanza, for specimens of the telluride ores from this mine. Some data regarding the nature of the vein and the geologic occurrence of the tellurides were given by Mr. Leavitt and Mr. Dan Mahoney, of Bonanza.

HISTORY AND PRODUCTION

The Empress Josephine mine was developed early in the history of the district. Burchard [30] states that the Empress Josephine was perhaps the best-developed mine in 1881. About 150 feet of levels had been run from the shaft, which was 180 feet deep. The daily output was 5 or 6 tons of ore, although no stoping had been done. Burchard states that the ore shipped yielded an average of $100 per ton. In his report for 1882,[31] he says:

> The Empress Josephine is one of the most valuable properties in the county. It is opened by a shaft of 210 feet in depth and three levels. The first level is now in 200 feet and is in a solid body of high-grade ore that will bear shipping without sorting. The second level is in 160 feet, also in high-grade ore. * * * Some of the richest ore yet encountered has been taken out of the 140-foot level, 100 feet east of the shaft. The ore in this level has shown a steady improvement, the streak on the footwall varying from 16 to 18 inches, consisting of galena of a high grade, with a 2-inch streak of antimonial silver on the hanging wall. Recently a marked change took place in the footwall streak, gray copper coming in with a 2-inch streak of silver glance, carrying native gold, which runs 36 ounces in gold and 22,000 ounces in silver per ton.

In 1883, according to Silver: [32]

> The Empress Josephine mine is probably the largest producer in Saguache County. Machinery was erected during the summer, and the shaft, which is about 250 feet deep, will be sunk to a depth of 500 feet. From the shaft four levels run that aggregate 500 feet. The ore is a very high grade of gray copper and galena. The vein averages 10 feet wide; the pay streak 25 inches.

Up to 1884 [33] the mine had produced more mineral than any other mine in the county. In the mint report for 1884 [34] the following statements were made regarding the vein and the mine development:

> In the deep workings of the claim the ore is said to have changed from silver to gold bearing. The ore encountered was a form of telluride and was found near cross vein No. 2 in the second level. It lies in the casing immediately adjacent to the main pay streak and is 5 inches in thickness, associated with quartz. The telluride occurs in streaks through the quartz, varying from one-fourth to 1 inch in thickness, and is also scattered in pockets through the vein in crystallized form. The work now being done consists almost entirely in extending the east drifts at the different levels. * * *
>
> Work has again been resumed in the first level. A streak of nearly 14 inches is exposed which carries large quantities of antimonial silver. The second level has reached a distance of 335 feet from the shaft. The rich telluride streak still continues, associated with 5 inches of quartz. In the third level the most favorable showing is at present disclosed. The pay streak, about 15 feet back from the breast, shows nearly 4 feet of ore, principally galena, associated with gray copper, assays of the best running from $150 to $300 per ton. The breast now carries a large streak of iron pyrites associated with brittle silver, yielding good returns.

The production for the three years for which data are given in the mint reports is shown in the accompanying table. Patton [35] estimates the production between the years 1881 and 1900 at 5,000 tons of $60 ore. Since 1909 77 tons of ore has been shipped by

[30] Burchard, H. C., op. cit. for 1881, p. 426, 1882.

[31] Burchard, H. C., op. cit. for 1882, p. 540, 1883.

[32] Silver, Herman, op. cit. for 1883, p. 404, 1884.

[33] Idem, pp. 238, 239.

[34] Idem for 1884, pp. 238, 239, 1885.

[35] Patton, H. B., op. cit., p. 68.

lessees. (See table, p. 142, for some shipments of ore in 1908 and 1912.)

Value of metals produced at Empress Josephine mine, 1887, 1890, and 1891 [a]

Year	Gold	Silver	Lead	Total
1887	$287	$2, 181		$2, 469
1888	1, 500	11, 636		13, 136
1891	124	923	$71	1, 118
	1, 911	14, 740	71	16, 723

[a] Value of gold, $20 an ounce; silver (coinage value), $1.29 an ounce; lead, $87 a ton; copper $240 a ton. No data on individual mines given for this district for 1889. Apparently no production in 1890.

DEVELOPMENT

The Empress Josephine shaft is about 500 feet deep and follows the vein with a dip of about 85½° N. There are seven levels in the mine, but the length of drifts on some of them is not known. Regarding the condition of the upper levels in 1914 Patton [36] says:

The first level has been apparently worked out and abandoned. Stopes from the second level have been broken through the floor of this level. * * *

The second level is developed east of the shaft only. It has not been completely worked out. A winze connects with the third level at about 270 feet from the shaft. At 350 feet the drift is blocked by a cave-in. At this point acid water enters the drift and attacks steel so vigorously as to require the laying of wooden rails. No timbering is required of the first two levels.

On the third level, which is developed on both sides of the shaft, some timbering is required. Stoping on this and on the fourth level has not been developed very systematically.

An incomplete stope map and section of the shaft and a plan of the third, fourth, fifth, and sixth levels is shown in Plate 33. Plans of the upper levels are not available. There has been no stoping on the third level beyond a point about 300 feet east of the shaft, where the Empress Josephine vein is sharply cut off by a fault.

GEOLOGIC FEATURES

Although the mine could not be entered, it is probable that the workings are largely, if not entirely, in the Rawley andesite. This is the rock which crops out in the vicinity of the shaft, and altered andesite flows and breccias are the only wall rocks that are found on the mine dump. A fault block of Bonanza latite crops out approximately along the strike of the vein about 200 to 250 feet west of the shaft, but this may not be reached by the west drifts.

The andesite and latite on the slopes bordering Copper Gulch in this vicinity are broken into a complicated series of block faults. Two predominating sets of faults can be recognized—a northeasterly set and a northwesterly set. A smaller number of faults strike nearly due east. Silicification and bleaching of the lavas along these fault planes have been very intense and in places have made the tracing of formation boundaries difficult. Because the jaspery rocks resist disintegration into soil the slopes bordering the gulch are strewn with their débris. Another type of decomposition of the lavas has resulted in soft bleached rock containing sericite and carbonates. As such altered rock disintegrates readily, the zones of sericitic alteration are in many places obscured by the heavy mantle of talus and soil on the slopes. The outcrops of andesite west and immediately east of the mine have been intensely silicified and partly bleached. These types of alteration are described in a general way for the whole district on pages 71–80, where it is shown that the alteration which consisted in the formation of a soft rock containing sericite, chlorite, and carbonates was in most places, if not everywhere, later than that which produced the jaspery siliceous rock. The economic interest in these alterations lies in the fact that the siliceous type has preceded ore deposition, whereas the micaceous type has invariably accompanied it. As all the definitely recognized faults in the vicinity of this mine show one or both types of alteration, it is probable that the major faulting occurred either before or during the period of ore formation. It could not be determined from the distribution of rocks at the surface whether there had been any fault movement on the Empress Josephine fissure, but it seems very probable that the vein occupies one of the east-west series of fault fissures. The vein strikes about N. 75°–80° E. and dips about 85° N. According to Patton [37] the strike and dip of the vein have a considerable range in the workings. He states that the vein is cut by several faults, most of which are marked by a strong clay gouge, but that only one of these displaces the vein more than a few feet.

Although the writer has not seen these cross fissures in the Empress Josephine mine, the Now What and Hortense mines are both developed on similar east-west mineralized fissures. Most of the cross faults in the Now What mine cut obliquely across the Now What fissure and have displaced it a few feet at several crossings. The vein matter, however, has not been much disturbed by the formation of the cross fissures and at some crossings is noticeably wider, usually in the footwall of the cross fissure. The writer was informed by Mr. Leavitt that the Empress Josephine vein was richer in the vicinity of these cross faults, which cut across obliquely and displace the main fissure from a few feet to 15 or 20 feet. The vein was not only wider but yielded higher assays in the parts underlying the fault planes. Regarding the ore shoots Patton [37] says:

[36] Patton, H. B., op. cit., p. 106.

[37] Patton, H. B., op. cit., p. 107.

The ore values in the Josephine vein are very unevenly distributed. The ore occurs in shoots that are about 25 to 30 feet in breadth (in one case 100 feet) and that run from at or near the surface down to the 400-foot level and probably farther. These ore shoots have a pitch to the east, in conformity with a series of faults that also pitch to the east. The shoots are often bounded on one or both sides by these faults.

The relation of silicification to the fissuring in the Josephine mine is not known, but along the Now What fissure there was an early period of siliceous alteration, whereas most of the cross fissures are characterized by altered micaceous gouge and bleached wall rock. These relations may be interpreted to show that the east-west fissures, such as the Empress Josephine, Now What, and Hortense were first formed and that the earliest mineralizing solutions silicified their walls. Continued adjustments of the fault blocks during the period of alteration and mineralization caused these fissures to be displaced slightly by the formation of a series of oblique fractures. If these fault fractures were formed just before or even during the period of vein formation, they would undoubtedly have had an important control on the course of the ore-depositing solutions that rose along the larger fissures. Those cross faults which happened to be formed during the deposition of ore would have sericitized and bleached walls rather than silicified walls as the solutions depositing the later sulphides were incapable of producing silicification of the jaspery type.

Regarding the eastward continuation of the Josephine vein Patton[89] says:

Only one of these faults displaces the vein more than a few feet. This is located several hundred feet east of the shaft on the third level. The fault plane has a strike of N. 10° W. and a dip of 50° E. It cuts the vein off sharply. Between the shaft and this fault the drift on the third level follows the vein, but beyond the fault no trace of the vein has been found. The drift was continued in the same general direction and at 450 feet east of the fault strikes the Hortense vein, which is a vein of the same general character as the Josephine vein, with about the same strike and dip, and is known to lie to the south of the Josephine vein. From this it would appear that the above-mentioned fault must throw the Josephine vein to the left—that is, to the north on the east side of the fault.

Patton makes no mention of the evidence upon which he bases the statement that the Hortense vein is known to lie south of the Josephine vein, but it appears very probable because of their same strike and the direction of fault displacements that the two veins occupy faulted portions of the same fissure.

CHARACTER OF THE ORES

The ore minerals of the Empress Josephine mine are galena, sphalerite, pyrite, chalcopyrite, tennantite, covellite, empressite, hessite, sylvanite (or krennerite), petzite, rickardite, altaite, and native tellurium. The gangue is mainly or almost entirely quartz but contains some barite and carbonates. Galena, sphalerite, and pyrite are by far the most abundant ore minerals. The tellurides were found only locally in small pockets. Limonite, cerusite, probably anglesite, native copper, and some basic hydrous aluminum phosphates of doubtful identity (p. 71) are of supergene or secondary origin. Native tellurium is perhaps secondary, but its geologic occurrence is not known, and the only specimen of it seen was not associated with other tellurides.

The vein quartz is massive and irregularly crystallized, either white or gray, and impregnated with finely divided sulphide. Some small cavities are present and are commonly lined with quartz crystals or small amounts of sulphides. Carbonates are uncommon but were seen in some cavities in ore on the dump. Some late veinlets of calcite were also seen. The ore is not appreciably crustified or banded except in relation to irregularly distributed cavities. The texture of the Josephine vein as a whole is not known, but to judge from material on the dump and from other veins in the vicinity, it is not at all different from the common type of siliceous veins in the district.

The material on the dump contains some brick-red jasper in which pyrite crystals 2 to 4 millimeters in diameter are thickly embedded. It is not known from what part of the mine this came, but it is similar to jaspers that crop out along Copper Gulch above the mine. Some of the ore includes fragments of white or gray fine-grained siliceous material formed by the replacement of wall rock and containing very small grains of pyrite.

The ore shoots in the Empress Josephine vein pitch eastward, as is shown to some extent by the stope map. The ore is said to have been oxidized to a depth of 60 to 80 feet below the surface. In this oxidized ore the lead was present partly at least as cerusite and probably also as anglesite. Early shipments from the mine show the value of the ore to be mainly in silver and gold. How large the bodies of oxidized lead ore were is not known, but even complete oxidation to 60 or 80 feet could not account for a very large tonnage of ore of this type. The richest ore from the mine was obtained between the 70 and 140 levels east of the shaft.

The conditions on these levels in 1882 and 1884 are indicated by the quotations from the mint reports given above. The ore was apparently not oxidized, but there may have been a little enrichment in silver. A study of some polished sections of specimens from the telluride lenses (pl. 19, *C*, *D*) indicates that nearly all of these are primary or hypogene minerals, although the presence of native tellurium and some reported free gold suggests the possibility that some of

[89] Patton, H. B., op. cit., p. 107.

the tellurides in the oxidized zone may have been decomposed, with the precipitation of free gold and some transportation of the tellurium to greater depth. Appreciable transportation of gold is not to be expected, however, as it is brought into solution with difficulty, except possibly in veins containing considerable manganese.

Regarding the decomposition of tellurides of gold Lindgren[40] says:

> They decompose easily above the water level; the tellurium is in part carried away as soluble compounds, in part fixed as tellurite (TeO_2) or tellurates of iron like emmonsite and durdenite. The gold remains in minute brownish grains (mustard gold). In most cases there is little evidence of solution and transportation of this gold.

Under these conditions an apparent enrichment in gold might be expected in the oxidized ore, due largely, however, to the reduction in volume of the original ore and the carrying away of other constituents rather than to actual transportation of the gold itself. A zone of silver enrichment may have existed in the mine just below the oxidized ore, but unless the conditions were much different from those shown in other veins in the northern part of the district the zone was probably very shallow. The ground-water level in the mine probably stands at about the third level, but in scarcely any veins in the district, with the possible exception of some of the wide manganese veins in the southern part, does complete oxidation extend as deep as the water level.

The primary telluride ore which lay between the 70 and 140 foot levels is said to have been a lenslike body between faces of the normal lead-zinc ore. As only a few specimens of the telluride ore were available for microscopic examination, a comprehensive study of the paragenesis of these minerals could not be made. Some of the tellurides formed distinct crystals in the pockets in the ore, a mode of occurrence which shows them to be of late origin. Although considerable search was made for other lenses of telluride ore, only a few very small pockets were found. A similar condition occurs in the Hortense vein.

Microscopic study of a few sections shows the ordinary vein minerals to have the succession normal to the district. Silicification of the wall rock was the first process after the formation of the fissures. Barite was one of the earliest if not the earliest vein mineral. It is apparently not abundant, but one specimen taken from the dump shows platy white crystals of barite about which later pyrite and sphalerite are molded. Galena, tennantite, and a little chalcopyrite were later. The tellurides were distinctly later than the main deposition of galena, and between them and the galena there is in many places a narrow rim of lead telluride, altaite. (See pl. 19, *C*, *D*.) The tellurides themselves, such as hessite and empressite (AgTe), are intergrown irregularly, suggesting contemporaneous formation. Small amounts of altaite, sphalerite, galena, and chalcopyrite occur in microscopic particles distributed along certain zones or streaks in the hessite and empressite. Their presence in the tellurides suggests that the late solutions depositing the tellurides either dissolved and reprecipitated small amounts of copper, zinc, and lead, or that the late solutions originally contained small amounts of these metals. The gold tellurides, sylvanite (or krennerite) and petzite, in the specimens examined are not associated with the massive intergrowths of hessite and empressite but form small streaks in quartz containing some sphalerite, galena, and altaite. In the mint report for 1884 it is stated that these quartz veins containing gold telluride were 5 inches or so in thickness and lay immediately adjacent to the main lead-zinc ores. Quartz apparently continued deposition to a late stage in the Empress Josephine vein, as nearly all the small vugs in the siliceous lead-zinc ore are lined with small quartz crystals rather than with sulphides or carbonates.

The value of the ore taken from the mine is not known other than as given in the quotations from the mint reports. Because of the very irregular distribution of the gold and silver tellurides there was probably a wide range in the value of the early shipments. Small shipments of the normal type of lead-zinc and siliceous ores made since 1908 or 1909 show an average gross content of about 10 per cent of lead, 1.1 per cent of copper, and 38.4 ounces of silver and 0.66 ounce of gold to the ton. Assays and analyses of shipping ore taken from Patton's report[41] are shown in the following table.

[40] Lindgren, Waldemar, Mineral deposits, 3d ed., p. 965, New York, 1928.

[41] Patton, H. B., op. cit., p. 111.

Assays and analysis of ore shipped from the Empress Josephine mine

Date	Gross weight (pounds)	Gold (ounces per ton)	Silver (ounces per ton)	Lead (per cent)	Copper (per cent)	Zinc (per cent)	Sulphur (per cent)	Iron (per cent)	Silica (per cent)	Net value (per ton)	Cost of treatment (per ton)
April, 1908	6, 300	0. 17	26. 7	11. 15	--------	9. 2	23. 5	15. 5	34. 5	$7. 96	$12. 00
Do	18, 040	1. 67	12. 6	--------	--------	4. 5	8. 1	6. 1	73. 0	26. 10	13. 00
Do	4, 720	. 055	54. 6	23. 9	0. 7	4. 0	29. 1	22. 7	15. 6	29. 49	9. 00
Do	305	2. 0	21. 6	3. 8	--------	9. 0	10. 4	5. 0	61. 4	56. 71	13. 00
April, 1912	3, 257	1. 225	46. 9	25. 4	--------	7. 9	12. 0	7. 8	36. 0	60. 00	12. 85

LIBERTY MINE

The Liberty mine is just east of the town of Bonanza and about 1,000 feet south of the Empress Josephine mine, on the south side of Copper Gulch. The portal of the adit is 9,619 feet above sea level. The Liberty vein strikes about N. 55°–60° W. and dips 70°–75° S. It is developed by an inclined shaft 125 feet in depth, the collar of which is in an adit about 70 feet from the portal. A compressor and hoist with electric power is installed at a station opposite the shaft on the adit level. The levels below the adit, except the 60-foot level, were under water at the time of examination.

Both walls of the vein to the 60-foot level were composed of Bonanza latite. A small amount of stoping has been done on the vein at the two upper levels. In a small stope below the adit level, which could be entered by a winze about 20 feet east of the shaft, a lenslike body of ore had been taken out. This stope was 6 to 8 feet wide in places, but the vein material remaining around its borders was from 6 to 18 inches wide. The latite has been bleached, sericitized, and partly silicified near the fissure. An altered micaceous gouge occurs on the hanging wall of parts of the vein. The gangue is mainly quartz with some barite and a little carbonate, probably calcite. The ore minerals found in specimens of the ore taken from the ore bins and from the small stope below the first level are pyrite, sphalerite, galena, tennantite, chalcopyrite, covellite, and probably stromeyerite. Mr. Theodore Eck, part owner of the property, states that some telluride ore was encountered in driving the adit level. The ore near the surface is partly oxidized and coated or stained with orange-yellow or yellowish-brown crusts. Chemical tests of this material show that it is probably a hydrated phosphate and sulphate of ferric iron (p. 71). It is associated with a soft fibrous mineral, possibly beidellite. In the less oxidized ore some of the cavities are filled with a pure-white soft mineral that resembles kaolin but proved to be a basic hydrous phosphate of aluminum. None of these products of oxidation could be definitely identified, however, without chemical analysis. They are commonly found throughout the northern part of the district in partly oxidized ores.

Small shipments of ore from this mine showed a gross content of 4 to 11 per cent of lead, 4 per cent or less of zinc, a trace to 0.25 per cent of copper, and 55 to 145 ounces of silver and 0.01 to 0.03 ounce of gold to the ton. It is said by the owners that some of the oxidized ore ran $4 to $5 in gold to the ton. The production of the mine has been small.

NOW WHAT MINE

The Now What mine is on the opposite side of Copper Gulch from the Empress Josephine. The vein runs nearly due east and is developed by two adits—one near the bottom of the gulch at an altitude of about 9,690 feet and the other above on the slope at about 9,760 feet. A plan of the two tunnels is shown in Figure 39, taken from a map made by transit survey and furnished by Mr. William Burkhardt, owner of the property. The mine was under lease by the Bonanza Mining & Milling Co. when it was examined in June, 1927.

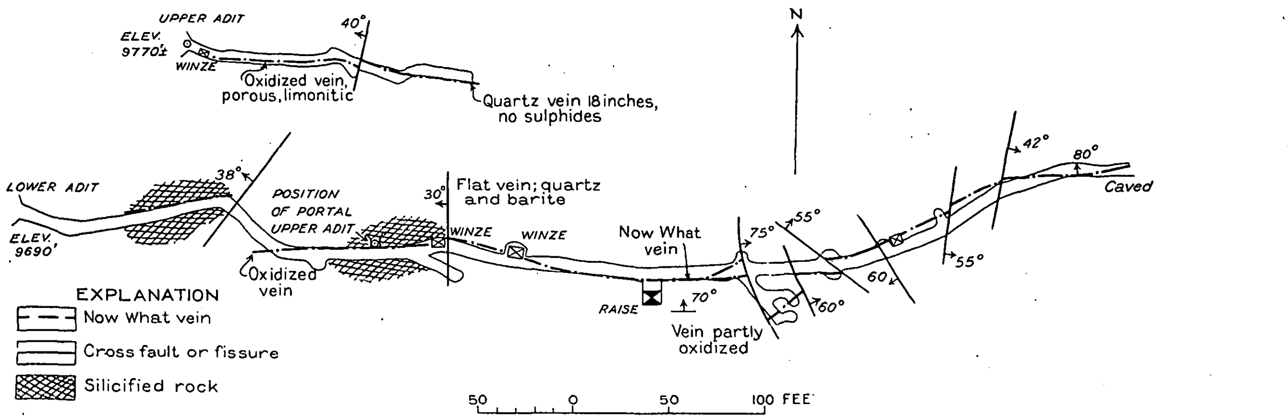


FIGURE 39.—Plan of the Now What mine

The country rock of the mine is entirely Rawley andesite. The texture of the flows suggests that they belong to the middle part of the formation. The strike of the Now What vein ranges from due east to about N. 65° E. locally and the dip ranges from 75° N. to vertical. The fissure is displaced from a few feet to as much as 25 feet by five or six cross faults, which cut it somewhat obliquely or nearly at right angles. Some of the movement on these cross faults was postmineral, but at several of the crossings nearer the face of the tunnel, 400 to 500 feet from the portal, the vein material is not noticeably disturbed by the faults but ends abruptly against them. At some of the cross faults the Now What vein is wider and has a higher sulphide content in the footwall of the fault. It is apparent that some of these faults have influenced and localized the ore deposition, and hence they must have been of premineral origin with movement continuing intermittently until postmineral time. The cross faults contain an altered gouge, and some show a weak mineralization, although most of them are tight. The Now What vein ranges in width from 6 inches to a little over 3 feet but averages about 1½ feet.

The gangue of the vein is almost entirely quartz but includes a little barite and carbonates. The quartz is usually massive or jaspery, but some milky-white colloform quartz is present. The ore minerals are pyrite, sphalerite, galena, and small amounts of copper minerals.

Samples of the vein show an average content of about 5.1 per cent of lead, 5.8 per cent of zinc, 1.0 per cent of copper, and 8.5 ounces of silver and 0.025 ounce of gold to the ton. About 46 tons of ore mined from the vein averaged a gross content of 5.5 per cent of lead, 0.6 per cent of copper, and 8 ounces of silver and 0.026 ounce of gold to the ton.

HORTENSE MINE

The Hortense mine is on the south side near the bottom of Copper Gulch, at an altitude of 9,807 feet. The vein has been developed by an adit and by a shaft on the hill slope above. In the adit the vein has been followed for about 500 feet. The shaft is probably about 100 feet in depth, but only short drifts have been run from it. The production of the mine has been small.

A plan of the Hortense tunnel showing its relation to the Empress Josephine workings is given in Plate 33. The vein strikes N. 70°–85° E. and dips 60°–90° N. The fissure is cut by several cross fissures, one of which is mineralized and has been explored in the adit level. The vein material in the upper 80 feet of the shaft is said to have been of low grade,[41] but the quality of the ore improved below this. In the adit the vein is narrow, ranging in width from 6 inches to 2 feet or a little more. There are several small stopes in the tunnel, both overhead and underhand. The fact that the vein contained small pockets of tellurides probably encouraged the development on it despite its narrowness. Its strike and dip are about the same as those of the Empress Josephine vein, and it very likely lies in a faulted portion of the same fissure. The country rock of the mine is entirely andesite.

The gangue of the vein is chiefly quartz, and the ore minerals include pyrite, sphalerite, galena, tennantite, and some tellurides. The tellurides are said to have contained both silver and gold and to have occurred in part as small cubic crystals. None of these were seen, and their identity is not known, but they are presumably of the same species that were found in the Empress Josephine vein. The average value of the ore from the mine is not known, but a shipment of several tons averaged in gross content about 21 per cent of lead, 1 per cent of copper, and 36.6 ounces of silver and 0.60 ounce of gold to the ton.

[41] Burchard, H. C., op. cit. for 1882, p. 544, 1883.

MARIPOSA TUNNEL

The Mariposa tunnel is on the north side of Copper Gulch at the east side of the town of Bonanza, at an altitude of about 9,660 feet. A geologic sketch map of that part of the workings which was accessible in 1927 is shown in Figure 40. The country rock includes andesite and Bonanza latite in fault contact and much broken and altered along a series of northeast and northwest fractures. In the part of the tunnel that was accessible two fissures have been followed by drifts, but they show only weak mineralization. Beyond the second fissure the tunnel is caved. The rocks have been bleached and silicified and contain some pyrite, and some of the fissures show siliceous vein material with a little sulphide.

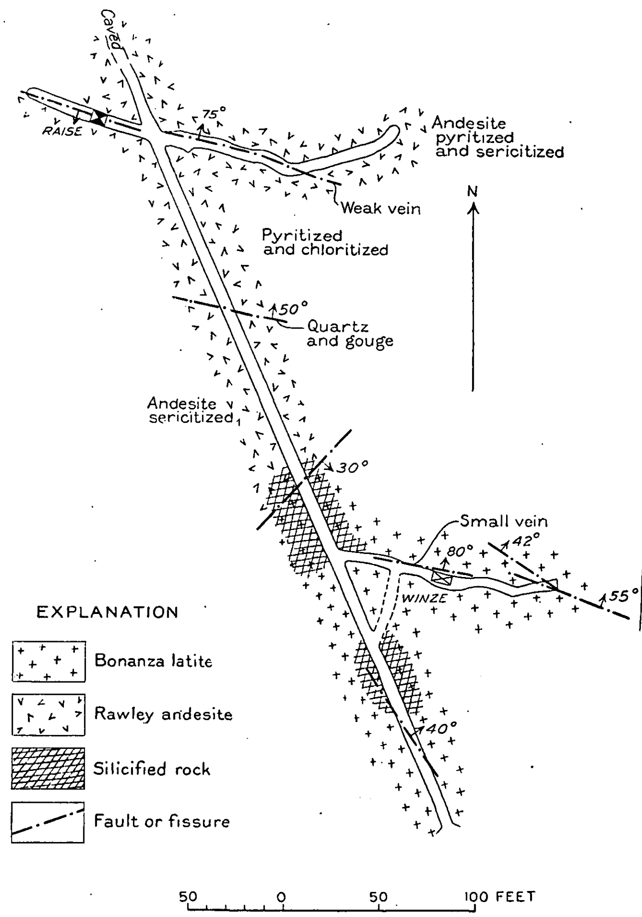


FIGURE 40.—Sketch map of the Mariposa tunnel

As far as is known, there has been no production of any importance from this property.

ST. LOUIS MINE

The St. Louis mine is on the south side of Copper Gulch about a mile above the town of Bonanza. The shaft is at an altitude of 10,045 feet. The property is at present owned by the Antoro Mines Co.

In the mint report for 1890 [43] the production of the St. Louis is given as $840 in gold, $679 in silver, and $183 in lead. In 1891 [44] the production was $413 in gold, $646 in silver, and $174 in lead, making the total for these two years $2,935. The mine was reported as not producing in 1887 and 1888, but data on the production for other years prior to 1900 could not be obtained. An estimate of the production by J. M. Poole, of Bonanza,[45] credits the St. Louis with a total production of about $3,600 between 1881 and 1900. Between 1913 and 1926 the mine produced about 1,200 tons of ore, the content of which is shown in accompanying table.

Production of the St. Louis and other mines, 1914–1926 [a]

Year	Ore (dry tons)	Gross content of concentrates and smelting ore				
		Gold (fine ounces)	Silver (fine ounces)	Lead (wet assay, pounds)	Copper (wet assay, pounds)	Zinc (pounds)
1914	512	734. 81	6, 090	88, 456	12, 601	([b])
1915	223	230. 05	3, 649	48, 047	6, 035	--------
1916	66	253. 36	1, 314	12, 402	1, 445	--------
1917	336	268. 24	6, 670	35, 028	21, 311	--------
1923	[c] 57	13. 60	2, 922	11, 837	1, 334	--------
1924	[d] 22	. 94	322	7, 071	--------	7, 721
1925	[d] 35	14. 14	212	4, 505	--------	6, 450
1926	22	1. 10	480	3, 517	483	--------

[a] No production in years omitted since 1902. Compiled from mine records of U. S. Geological Survey and Bureau of Mines.
[b] 6 to 12 per cent.
[c] Recorded as Rico and St. Louis mines.
[d] Possibly not St. Louis mine, but other mines of St. Louis group.

The geologic conditions in the vicinity of the mine are similar to those existing along the lower part of Copper Gulch. There are two major sets of fissures along this part of the gulch—one set striking northeast to nearly east and the other striking northwest. A definite age relation between the two sets could not be determined, but nearly everywhere on the slope southeast of the St. Louis the northwest set appears to be the younger. There probably was not, however, any great lapse of time between the different sets. Both sets are mineralized in places, but in general the northeasterly fissures are characterized by more intense silicification of the adjoining lavas. The St. Louis vein occupies a fissure or fault zone belonging to the northeasterly system. The country rock of the mine, so far as could be determined from observations in the adit level and at the surface, is entirely Rawley andesite, but the andesite flows and breccias in the vicinity do not lie stratigraphically much below the base of the Bonanza latite. Fault blocks of latite on the opposite side of the gulch have about the same altitude as the workings, and latite is exposed several hundred feet above the mine on the slope southeast of the shaft.

[43] Smith, M. E., op. cit. for 1890, p. 139, 1891.
[44] Idem for 1891, p. 184, 1892.
[45] Patton, H. B., op. cit., p. 68.

In proximity to faults and fissures on both sides of the gulch near the mine the lavas have been intensely silicified. Reddish-brown or white jaspery rocks form a large proportion of the débris on the slopes. Some of the dark-reddish jaspers are thickly crowded with crystals of pyrite.

The St. Louis shaft is about 340 feet in depth, and there are five main levels from it, mosly east of the shaft. At the 80-foot level there is a crosscut adit to the north which drains the upper part of the mine. Below this level the mine was filled with water in 1927. The following discussion is based upon information given to the writer by Mr. John Ashley, of Bonanza, who was in charge of the property, and upon information obtained from the map and an examination of the 80-foot level. A longitudinal section of the mine is shown in Figure 41. At and above the 80-foot level there are two nearly parallel fissures that strike N. 50°–70° E. and at the level are about 10 to 15 feet apart. The north fissure dips 75°–80° SE. and the south fissure 55°–60° NW., so that the two fissures converge in depth and are said to come together about 15 feet below the 80-foot level. This junction was under water, but the relations seen suggest that the south fissure is a split or hanging-wall fracture of the north fissure. The shaft follows approximately the course of the north vein to a point between the 180 and 230 foot levels, about 200 feet below the collar. At this point the vein is said to be cut off by a nearly horizontal fault, and in the rest of the shaft no vein is exposed. A drift east on the 230-foot level intersects the fault and vein about 120 to 150 feet from the shaft. Beyond this the vein is exposed in the drift. The ore shoot in the north vein has a pitch of about 50° E. and is apparently limited laterally both by cross fissures and by pinching of the fissure walls. Within the main shoot on the north vein there is a narrow shoot of ore of high gold content which grades laterally in each direction into lower-grade lead-zinc ore. Some local shoots or bodies of copper ore containing bornite are also found in the mine. The vein material ranges in width from less than 1 foot to 3 or 4 feet. In the south vein the stopes are less extensive and largely above the 80-foot level. The largest stope shows a tendency for the ore to pitch steeply toward the east. The south vein has about the same range in width at the 80-foot level as the north vein.

The gangue is chiefly quartz, which is in part coarse grained and in part dense and jaspery. There has been a considerable silicification of the walls of the veins. The ore minerals include pyrite, sphalerite, galena, chalcopyrite, bornite, and tennantite. The form in which the gold occurs in the vein is not known, and apparently no tellurides have been recognized. It is said that even in the highest-grade ore, which the writer has not seen, no gold was visible.

Both veins are considerably oxidized on the 80-foot level, and the ore occurs in irregular streaks, of which the larger ones have apparently been stoped. The most thoroughly oxidized material is soft and crumbly and contains considerable limonite. This is said to have a high gold content, and some relative enrichment in gold might be accounted for by reduction in volume or specific gravity of this material during oxidation. In less oxidized portions of the veins the sulphides are partly altered to or coated with bluish-black secondary sooty chalcocite. Some enrichment of silver may have occurred in this material, as is common in the district. It is said that in the south vein the gold content was less consistent than in the north vein.

In the north vein the gold shoot, which extended from a position west of the shaft on the 50-foot level down to the 180 level, had an eastward pitch of about 58°. The stope length of this shoot ranged from about 15 to 30 feet, to judge from Mr. Ashley's indication of it on the map. The pitch length was about 160 to 180 feet. The gold content apparently decreased on each side of the axis of the shoot, which was bounded by lower-grade lead-zinc ore of the normal type. About 40 narrow-gage carload shipments of approximately 20 to 25 tons each, mined from this shoot and near its borders, had gold contents ranging from 0.03 to over 7 ounces to the ton and averaging between 1.3 and 1.4 ounces. Two small shipments of 4 or 5 tons each contained about 27 and 35 ounces of gold to the ton. The ore averaged 12 to 15 ounces of silver to the ton, 8 to 9 per cent of lead, and 1.5 to 2 per cent of copper and contained as much as 12 per cent of zinc.

A small body of bornite ore was stoped on the 180-foot level between 85 and 110 feet east of the shaft, just east of the lower part of the gold shoot. One carload shipment from this shoot had a content of 7.55 per cent of copper and 55.3 ounces of silver and 0.15 ounce of gold to the ton.

Some shipments of the normal type of lower-grade lead-zinc ore had gross contents of 6.5 to 16 per cent of lead, from several per cent to 12 per cent of zinc, about 1 per cent of copper, and 6 to 22 ounces of silver and 0.03 to 0.07 ounce of gold to the ton.

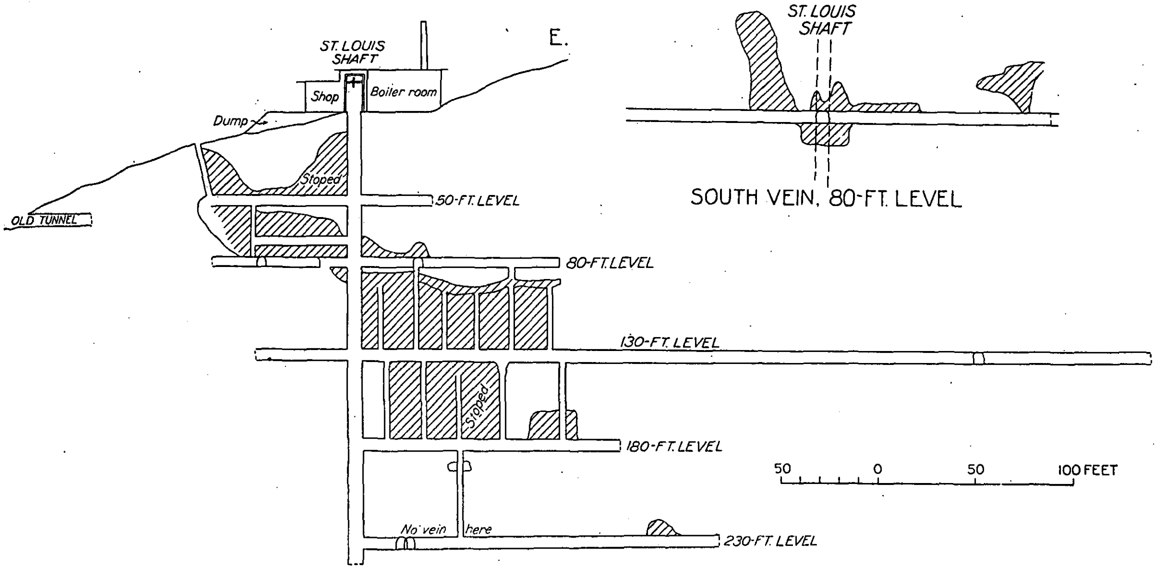


FIGURE 41.—Longitudinal section of the St. Louis mine

OTHER MINES AND PROSPECTS OF THE ST. LOUIS GROUP

Besides the St. Louis there are several other claims and prospects adjoining Copper Gulch which are the property of the owners of the St. Louis mine. These include the Boston, Philadelphia, Coin, St. Louis No. 2, Chicago, Cronje, Botha, Joubert, Kruger, Chief, Summit, Bay State, Cliff, and some other claims that have not been surveyed for patent. The most extensive workings on these are the Cliff and Cronje tunnels, shown in Plate 1. The Cronje tunnel was not examined. The Cliff tunnel (fig. 42) was examined only hastily, but it is of some interest, as it penetrates one of the strong northeasterly fault zones along which the Bonanza latite is faulted down toward the southeast. The Cliff tunnel runs in a direction averaging S. 65° E. for about 420 feet. Within this distance it intersects several cross faults striking N. 30°–50° E. and dipping 50°–60° SE. Although the tunnel starts in andesite it penetrates altered latite not far from the portal. The Cliff vein occupies one of the faults. It strikes about N. 50° E. and dips 60°–70° SE. In the hanging wall of the Cliff vein the country rock has been completely silicified for a distance of about 200 feet along the crosscut. Some pyrite is present in the jasper. Beyond the jasper zone another gougy fault plane is cut near the end of the tunnel. Most of the silicified rock is of a reddish-brown color and is much veined and impregnated with pyrite. The alteration has been so complete that the original character of the country rock has been largely destroyed; consequently the details of the geologic relations could be worked out only by careful examination and microscopic study of the altered rock.

The Cliff vein, which is from 1 foot to 4 or 5 feet in width, has a metal content consisting largely of iron and zinc. The writer was informed by Mr. Ashley that some shipments of zinc ore had been made from this vein, and also that several hundred tons of ore had been treated in the Bonanza mill. Some of the ore is said to have run 18 to 22 per cent of zinc. The gold, silver, copper, and lead content of the vein is low. Assays of the vein taken from an assay map show from 0.7 to 8 ounces of silver and a trace to 0.2 ounce of gold to the ton, a trace to 1 per cent of copper, and 0.5 to about 5 per cent of lead.

QUEEN CITY MINE

The Queen City mine is near the head of Copper Gulch, about 2 miles northeast of the town of Bonanza, at an altitude of 10,754 feet. Although apparently considerable work had been done on this prospect, to judge from the dump and mine buildings, most of it evidently was of an exploratory character. The dump consists largely of unaltered andesite and contains little vein material. A small pile of ore in the ore bin shows some galena intimately intergrown with quartz in a peculiar graphic manner. Superficially some of this material resembles steel galena, but microscopic examination shows that the separate grains of galena are in parallel crystallographic orientation with one another and are graphically intergrown with quartz and some sphalerite. The texture suggests contemporaneous deposition of galena, quartz, and sphalerite. There is a little manganiferous calcite in some of the cavities in the quartz.

The production of this mine is not known, but it was probably small.

MINES ALONG KERBER CREEK

BALTIMORE MINE

The Baltimore mine is just below the Cocomongo mine on the west side of Kerber Creek, about 1¼

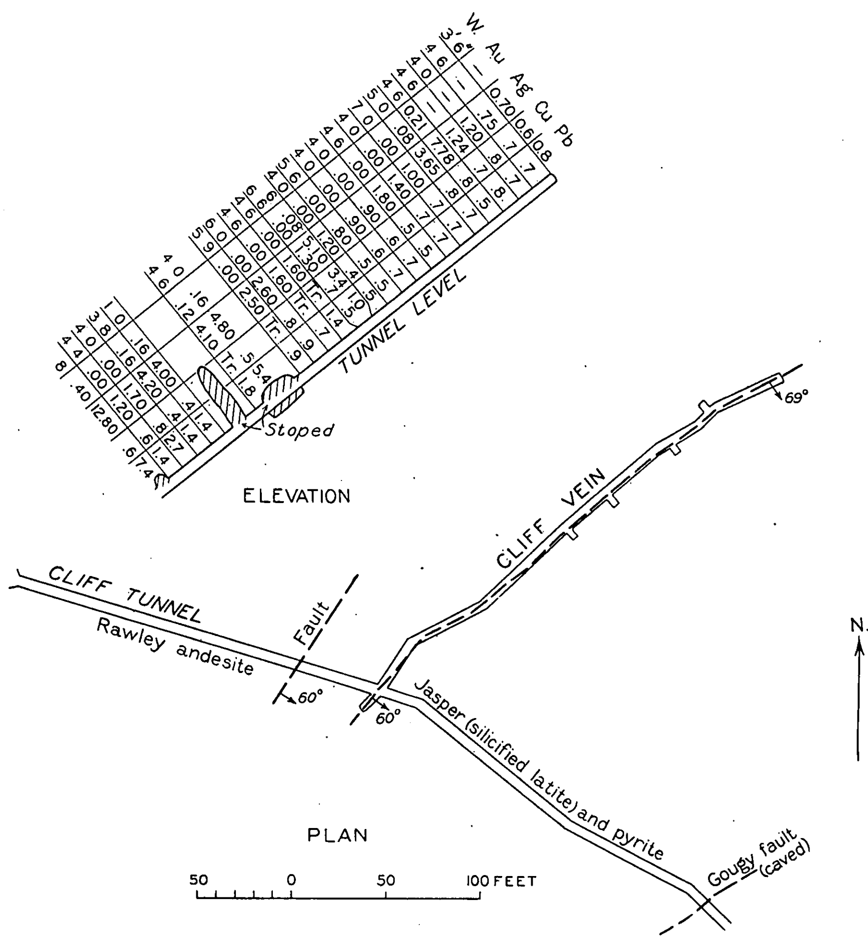


FIGURE 42.—Sketch map of the Cliff tunnel

miles above the town of Bonanza. The collar of the shaft is a little over 100 feet west of the main road up Kerber Creek, at an altitude of about 9,685 feet. The mine was being operated in 1927, and a compressor and hoist had been installed. When it was examined only about 120 feet of drifting had been done on the 100-foot level of the main Baltimore vein and several small stopes 15 to 25 feet in height had been opened along the drift.

The country rock of the mine is Bonanza latite to the present depth of development. The Baltimore vein strikes from about N. 75° W. to nearly west and dips 65°–70° S. It apparently occupies a fault of small throw. A short crosscut to the south on the

100-foot level near the shaft reveals a parallel fissure about 25 feet away on the hanging-wall side of the Baltimore fissure. This crosscut had not been driven far enough to show whether or not the parallel fissure is mineralized, but the alteration became less intense in the crosscut away from the main vein. The latite is silicified near the Baltimore vein. The vein showed a tendency to pinch and swell owing to irregularities in the walls and a small horse of altered country rock occurs in the fissure about 100 feet from the shaft. Where it widens out the vein material is 3 to 4 feet in width, exclusive of the silicified and fractured country rock, but it pinches down to a foot or less in other places, where it is too narrow and of too low grade to stope. When examined the drifts were insufficient to indicate the promise of the vein, but at least it occupies a fairly strong and steep fracture. The shaft is said to have been in some ore practically all the way.

The new shaft is about 180 to 190 feet S. 80° E. of an old shaft believed to be on the Baltimore vein. The west drift had been started with the purpose of driving below or connecting with these old workings, the extent of which is not known. Several northeast faults crop out on the ridge 1,500 feet southwest of the Baltimore. Their strike indicates that they might intersect the Baltimore fissure near or somewhat west of the old shaft. It is not known whether the northeast fissures are mineralized, although in the saddle where they cross the ridge there has been some alteration of the latite near them. The Baltimore fissure is said to be traceable across Kerber Creek for some distance to the east, where there are some small prospects on it. It must, however, in its eastward extension intersect the northwestward-trending fault zone of the Bonanza and Cocomongo veins or of the Exchequer fault. Its age relations to these fault systems can not be determined from surface indications, at least without considerable detailed work.

The gangue of the vein is chiefly quartz, usually somewhat massive, and the sulphides are mainly pyrite, galena, and sphalerite. There is a little copper in the vein, probably as chalcopyrite or tennantite or both. The ore that was stoped in 1927 averaged about 13 per cent of lead, 0.3 per cent of copper, and 6 to 7 ounces of silver and 0.01 to 0.02 ounce of gold to the ton. The iron content ranges from 8 to 12 per cent, and the silica from 40 to 60 per cent.

EXCHEQUER MINE

The Exchequer mine is on the east side of Kerber Creek a little over a mile above the town of Bonanza. The portal of the Exchequer adit is about 9,660 feet above sea level, at the side of the Kerber Creek road. Between 1881 and 1900 this mine produced considerable ore,[46] but since 1900 there has apparently been little production or development. In the mint report for 1882 it is stated that the mine was opened on an incline and that 3 to 10 feet of ore was exposed. In his report for 1883 Silver [47] states:

> The Exchequer, near the town of Exchequer, possesses one of the largest ore bodies in the county. It is a true fissure from 25 to 30 feet in width, with a pay streak of from 2 to 8 feet wide. A great deal of the Exchequer ore is free milling, carrying from 50 to 90 ounces of silver. The development consists of an incline about 175 feet long.

Regarding the development and production in 1884, Silver [48] says:

> The Exchequer * * * began work in June, since which time shipments have been quite regular of large quantities of fine concentrating ore. The mineral is largely associated with gray copper.

The only record of production is in the mint report for 1890,[49] which credits the Exchequer with a production of $724 in silver.

The mine was apparently worked mainly through an inclined shaft and a tunnel, shown in Plates 1 and 34. The inclined shaft is at present caved but is said to have been timbered and 400 feet in depth with a dip of 26° 30′. The tunnel trends northeast for 170 feet, and at 130 feet from the portal a crosscut extends east-northeast for 340 feet to the Exchequer fault (or vein). A drift follows the vein northward for more than 700 feet, but only the first 150 feet from the crosscut remained accessible.

The country rocks of the mine are andesite and Bonanza latite. The Exchequer vein, from which most of the ore was presumably mined, strikes about N. 10°–15° W. and dips 20°–30° E. The first part of the drift reveals a fault dipping at a very small angle and mostly filled with a soft altered gouge from 20 inches to 3 feet in thickness. (See pl. 7, *D*.) Although the latite and gouge have been very strongly altered, there is little or no vein material. About 100 feet north of the crosscut the drift apparently turns into the hanging wall, where the latite is broken by a series of steeper hanging-wall fractures striking north to N. 45° E. and dipping 45°–55° E. There is considerably less gouge in the larger fractures, and in joints in the rock parallel to them and to the flow planes of the latite there are small seams containing quartz, pyrite, some copper minerals, and a little rhodochrosite and calcite. Some of these seams show a delicate banding of the minerals in which quartz, pyrite, rhodochrosite, and calcite were deposited in order toward the middle of the seams. The main fault or vein could not be reached beyond this point, and

[46] Patton, H. B., op. cit., p. 68.
[47] Silver, Herman, op. cit. for 1883, p. 403, 1884.
[48] Idem, for 1884, p. 238, 1885.
[49] Smith, M. E., op. cit. for 1890, p. 139, 1891.

nothing more could be determined concerning the character of the mineralization.

The early mint reports on the character of the vein material and silver content indicate that parts of the Exchequer fault contained bodies of gray copper ore similar to those found in parts of the Cocomongo fault. These two faults are alike in some respects, except that the Exchequer fault has a considerably flatter dip at the outcrop and is not as well mineralized where it can be seen. In the Cocomongo mine the fault displacement on the fissure zone was fairly large. It is possible that toward the south this displacement was taken up by movement on the Exchequer fault. That the displacement on the Exchequer fault was large is suggested by the intense fracturing and disturbance of the Bonanza latite in the immediate footwall of the fault. The flow planes dip very irregularly both toward the east and toward the west. This is one of very few places in the district where the Bonanza latite flow planes are seen to dip eastward. The dip ranges from horizontal to 55°. On the surface of the ridge above the mine the latite has a normal westward dip of 45° to 50°, so that the eastward dips would appear to be caused by the rotation of small blocks adjacent to the Exchequer fault plane.

The average grade of ore taken from this mine is not known, but probably some of the early shipments were of very good grade compared with ores from the district as a whole. The fissure probably has too gentle a dip to be of great promise for deeper exploration, as with increasing depth it is likely to become tighter and the ore bodies to be narrow and irregularly distributed. There may be some hanging-wall veins that were overlooked during the early development, but this appears unlikely.

MEMPHIS MINE

The Memphis mine is on the west side of Kerber Creek opposite the Exchequer tunnel, a little over a mile above the town of Bonanza. It is developed on a vein that was known in the early days of mining as the Arkansas vein. The location and extent of all the old Arkansas workings are not known, and some of them may have been on the east side of Kerber Creek. In the mint report for 1882 Burchard[60] says:

> The Arkansas, below the Revenue and near the town of Exchequer, is developed by a tunnel 175 feet long, from which a shaft has been sunk 75 feet and a level run from the shaft for 25 feet. The vein is 7 feet wide, with a pay streak of galena and gray copper 26 inches in width, assaying 75 ounces of silver per ton.

In 1883 there was no development on this property, but in his report for 1884 Silver[61] states:

> Among the most promising prospects in this vicinity are the Bonanza, Revenue, Keystone, Rawley, Antoro, and Arkansas mines. The latter is being opened by an adit tunnel now 161 feet in length. A shaft 75 feet deep connects with a tunnel at a point where an incline has been commenced, which will be driven for 100 feet. The vein is 6 feet wide, showing an ore streak of 16 inches, composed of gray copper and copper pyrites, with an average value of $125 per ton. Irregular shipments were made during 1884.

For 1885 and 1886 there are no detailed records of the production and development of individual mines, but in 1887 and 1888 the Arkansas is reported as not producing. The mint report for 1890[52] credits it with a production of $840 in silver and $165 in lead. In 1914, when the district was examined by the State Geological Survey, the mine was being worked in a small way. In 1915 and 1916 there was no production from the mine, but in 1917 and 1918 development work was carried on and a small amount of ore was shipped.

The location of the Memphis mine and part of the drifts on the Arkansas vein are shown in Plate 34. In 1918, when the last work was done, the total development was reported as comprising a vertical shaft 135 feet in depth and 300 feet of drifts. There is an adit on the property 50 feet in length. According to Patton[53] there were levels at 20 feet and 100 feet from the collar in 1914. In 1918 it was reported that 40 feet of stoping had been done on the first and second levels.

The main shaft was entirely caved near the collar in 1927, but a short part of an inclined winze or raise along the strike of the vein was accessible from the bottom of a shallow shaft about 40 feet east of the main shaft. In these shallow workings two fissures had been developed—one striking about N. 70° E. and the other about N. 80° W. These fissures are nearly vertical and close together and probably are caused by a splitting of the Arkansas fissure. The N. 80° W. fissure contained some small lenses a foot or so in width of siliceous ore containing pyrite, sphalerite, galena, and tennantite. The N. 70° E. fissure was tight and poorly mineralized. The country rock is Bonanza latite, which strikes about north and dips 30°–35° W. Regarding the workings from the main shaft in 1914 Patton[53] says:

> The mine was worked through a shaft 100 feet deep. There are two levels—one at 20 feet, from which most of the ore has come, and inaccessible at the time the mine was visited, and one at 100 feet depth. In the second level is a vein with east and west strike and dip 80° N. The ore is mostly galena and sphalerite in a quartz gangue. The vein appears to be a replacement of the country rock along a line of brecciation. The mine is said to have produced ore to the value of $5,000, but the values are very irregularly distributed.

[60] Burchard, H. C., op. cit. for 1882, p. 541, 1883.
[61] Silver, Herman, op. cit. for 1884, p. 238, 1885.
[52] Smith M. E., op. cit. for 1890, p. 139, 1891.
[53] Patton, H. B., op. cit., p. 104.

The ore mined since 1914 has showed a gross content ranging from 5.5 to 13 per cent of lead, 1 to 4 per cent of copper, and 19 to 31 ounces of silver and 0.025 to 0.044 ounce of gold to the ton. The average content, based upon total shipments of less than 200 tons, is about 12.7 per cent of lead, 1.2 per cent of copper, and 30 ounces of silver and 0.034 ounce of gold to the ton.

WHEEL OF FORTUNE MINE

The Wheel of Fortune tunnel is just above the town of Bonanza on the east side of Kerber Creek near the valley bottom, at an altitude of about 9,525 feet. The old Wheel of Fortune shaft, which was sunk on the Wheel of Fortune vein proper, is on the ridge northeast of the town at an altitude of a little over 9,900 feet. The vein developed by the shaft appears to strike northwest, but workings on the vein were inaccessible. The lower adit was apparently driven to intersect the vein at a lower level, but a blind vein striking about N. 80° E. was intersected and drifted

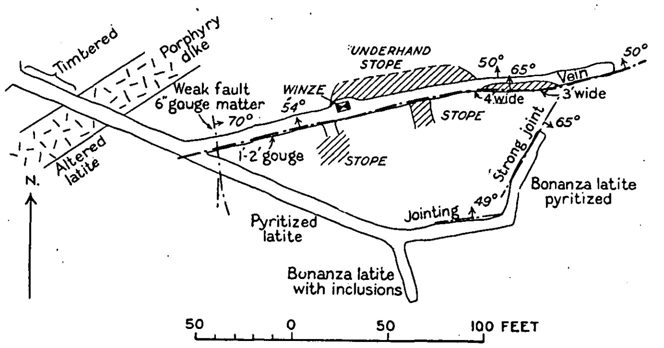


FIGURE 43.—Sketch map of the Wheel of Fortune tunnel

on, and the old Wheel of Fortune vein does not appear to have been cut by the tunnel.

The development work in the adit (fig. 43) is in Bonanza latite except for a porphyry dike crossed near the portal. The vein has an average strike of about N. 80° E. and dips 50°–60° N. A heavy gouge from 2 to 3 feet thick is present in parts of the vein, and the ore is in part contained within this gouge in local shoots. A small shipment of ore containing considerable gougy vein material ran about 12 per cent of lead, 0.7 per cent of copper, and 22 ounces of silver to the ton. Zinc is present in the vein, but the proportion of this metal is not known.

The Wheel of Fortune vein, which is developed by a shaft about 100 feet in depth (see pl. 1, No. 84), strikes about N. 60° W., as nearly as can be determined by the outcrops. The country rock is the Bonanza latite. The vein material on the shaft dump contains pyrite, sphalerite, galena, chalcopyrite, and tennantite (gray copper) in a gangue consisting mainly of quartz with some calcite. Fine granular intergrowths of sphalerite and galena were noted, and in most of the material on the dump zinc is in excess of lead, partly perhaps owing to the discarding of zinc at the time of operation. The total production of this property is not known, although it was probably not large. An estimate made by J. P. Poole[55] gives a production of 100 tons of silver-lead ore from this property from 1881 to 1900. Since 1900 about 140 tons of ore produced from the district is credited to the Wheel of Fortune.

ST. JOSEPH MINE

The St. Joseph property is on the east side of Kerber Creek about half a mile above the town of Bonanza. The vein has been worked through two adits, and there are some shafts and pits on it at the surface. The portal of the lower adit is at an altitude of about 9,560 feet. The underground workings were not examined by the writer, but the outcrop of the vein can be traced and has a trend of about N. 78° W. In this vicinity, as along the lower part of Copper Gulch, there appear to be two sets of fissures, a northeast and a northwest set. The dip of the vein is not known. Patton[56] states that the ore carries lead, zinc, and silver and in certain parts of the vein has a gold content as high as 1 ounce to the ton. The lower adit is said to be over 560 feet in length and is probably entirely in andesite.

MINES OF THE SOUTHERN PART OF THE DISTRICT

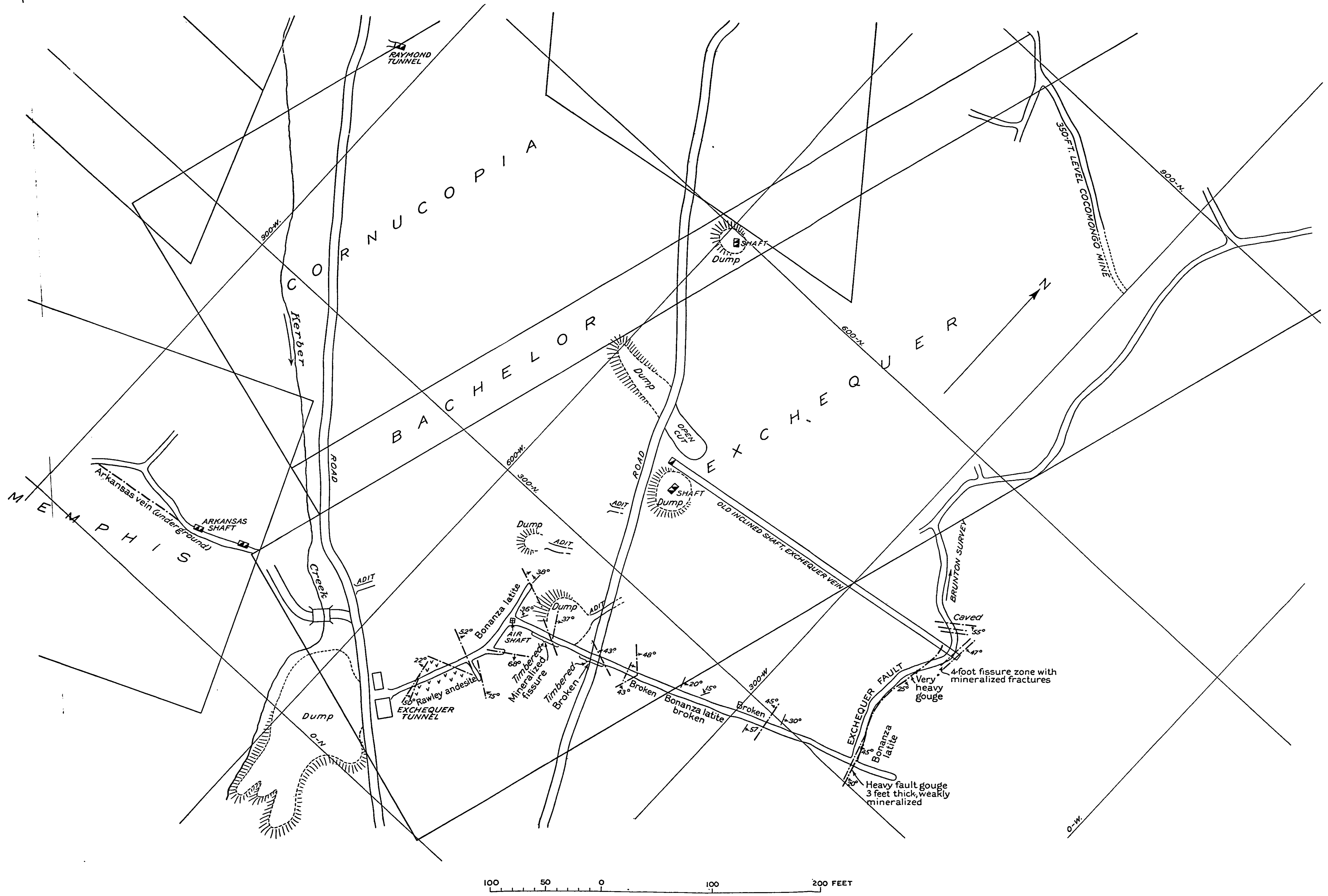
EAGLE MINE

HISTORY AND PRODUCTION

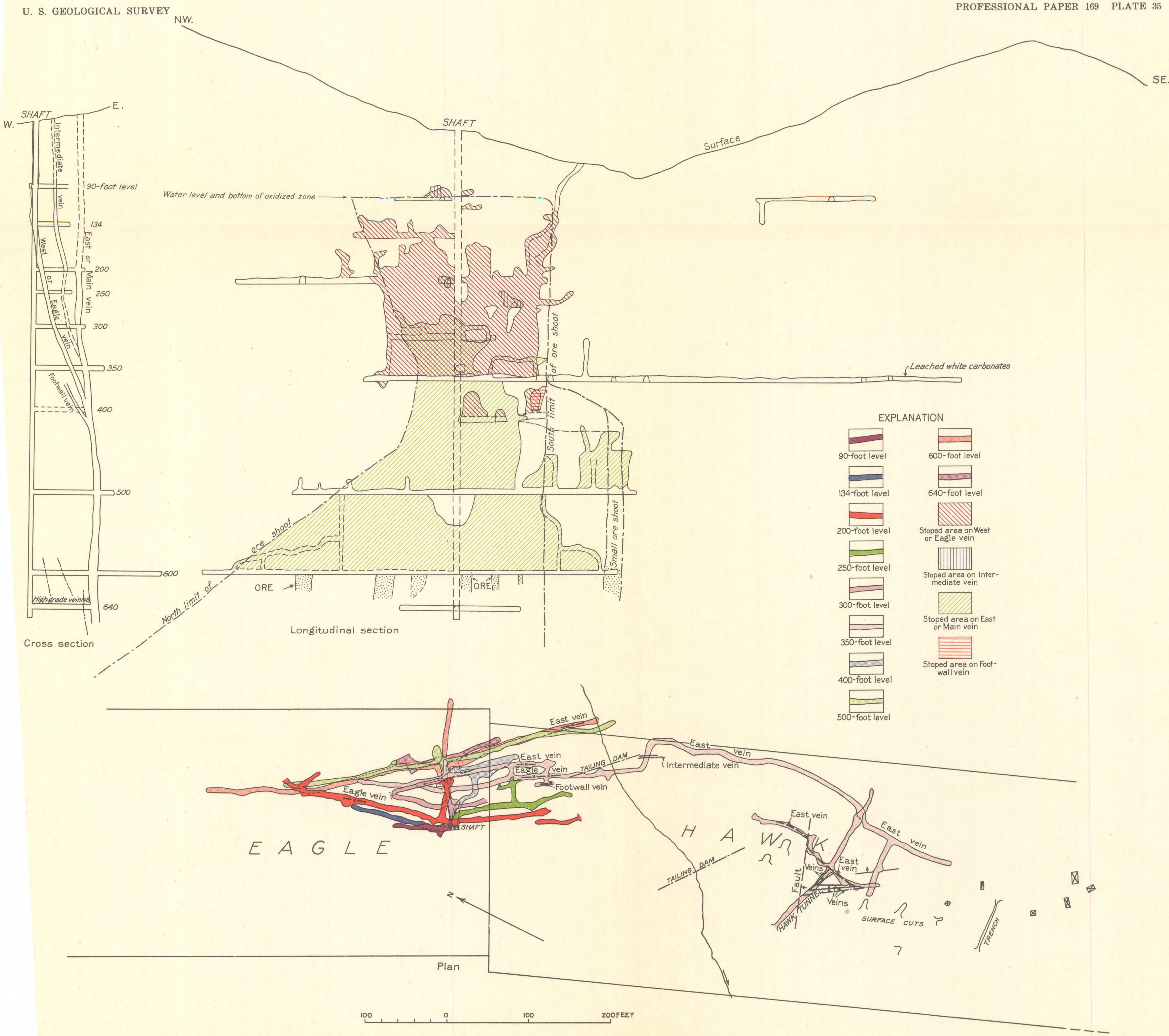
The Eagle mine is in the southern part of the Bonanza district, in Eagle Gulch, about three-quarters of a mile east of Kerber Creek. It is the only mine in the district from which there has been appreciable production from a vein of the rhodochrosite-fluorite type. The underground workings were not accessible in 1926 and 1927, and the following discussion of this property is based upon information furnished to the writer by Mr. C. N. Glascow, upon published accounts of the mine,[57] and upon microscopic examination of specimens obtained from the dump and other sources. The writer is especially indebted to Mr. Glascow, who furnished specimens of ore from the 600-foot level and gave other information concerning the character of the vein. A part of the following description is drawn from the published report of Wuensch.

Regarding the early history of the property Wuensch[58] says:

[55] Patton, H. B., op. cit., p. 68.
[56] Idem, p. 105.
[57] Idem, pp. 114–117. Wuensch, C. E., Secondary enrichment at the Eagle mine, Bonanza, Colo.: Am. Inst. Min. and Met. Eng. Trans., vol. 69, pp. 96–109, 1923.
[58] Wuensch, C. E., op. cit., pp. 96, 97.



MAP OF EXCHEQUER AND MEMPHIS MINES AND VICINITY



PLAN AND LONGITUDINAL SECTION OF THE EAGLE MINE

1931

It was discovered in the fall of 1882, but little more than assessment work was done on the property for a number of years. **A prominent lens of quartz containing an abundance of** manganese oxides outcropped, but its silver and gold content were practically nil. At a depth of about 40 feet a small pocket of native and horn silver ore was found which netted $1,200 from approximately 1,200 pounds. This stimulated development, and at a depth of 90 feet the water level was reached without finding any more ore. Desultory operations were conducted by various lessees for several years, and on the 134-foot level a few small "bunches" of residual primary ore, which had escaped leaching, were found; because of their low grade (average 12 ounces silver and 0.02 ounce gold) operations proved unprofitable. In 1898 the owner, a local merchant, sank a shaft to a depth of 200 feet, where the top of the zone of secondary enrichment was encountered. The rich sulphide streaks were carefully sorted out and the low-grade vein material used to fill the stopes. The ore shipped averaged about 130 ounces of silver and 0.30 ounce in gold. Occasionally the gold content was as high as 2 to 3 ounces.

The production for the years 1902–1926 is shown in the accompanying table.

Production of the Eagle mine, 1902–1926 [a]

Year	Ore (dry tons)	Concentrates produced (dry tons)	Gross content of concentrates and smelting ore			
			Gold (fine ounces)	Silver (fine ounces)	Lead (wet assay, pounds)	Copper (wet assay, pounds)
1902	20	------	5.00	2,000	--------	------
1903	90	------	21.77	8,189	--------	------
1904	224	------	56.00	44,800	--------	------
1915	50	6	.60	385	60	------
1917	[b] 117	------	2.11	1,735	1,576	133
1920	[c] 4,000	102	44.50	16,620	4,957	212
1921	[d] 4,500	98	17.68	22,805	8,446	141
	175	------	21.00	34,908	14,717	354
1922	[e] 9,200	184	18.50	31,564	11,183	238
	5	------	.30	1,208	401	------

[a] No production in years omitted from table since 1902. See text for production prior to 1902. Compiled from mine records of U. S. Geological Survey and Bureau of Mines.
[b] Includes 7 tons from Eagle dump.
[c] Ore from Eagle dump.
[d] Largely old fillings from stopes between 400 and 500 foot levels.
[e] Ore from 500 and 600 foot levels.

Between 1904 and 1916 the mine was not worked, but in 1916 and 1917 some small shipments of ore were made. About 1917 the operation of the mine was undertaken on a larger scale by the Saguache-Eagle Mining Co. A 50-ton flotation mill was erected, and from 1920 to 1922 it treated 17,700 tons of ore. Smelting ore amounting to 180 tons was also shipped to the smelter.

The mill was closed in June, 1922, as the primary ore of the lower levels with the mining methods employed had proved of too low average grade to treat profitably. Up to 1930 it had not been operated since that time. The total production of the Eagle mine is not known, as there are no detailed accounts of production prior to 1902.

DEVELOPMENT

The Eagle property embraces two abutting patented claims, the Eagle and the Hawk, and three other unpatented claims known as the West Eagle, South Eagle, and East Eagle. A shaft 650 feet in depth has been sunk near the common end line of the Hawk and Eagle claims at an altitude of about 9,620 feet. The drifts and stopes at the time when the mine was last closed are shown in Plate 35. An adit known as the Hawk tunnel has been driven on the south side of Eagle Gulch opposite to the shaft at an altitude of about 9,535 feet. The Eagle shaft follows the west or Eagle vein to a point between the 134 and 200 foot levels, but below this it is in the footwall of the veins and connected to the drifts by crosscuts. In all there is nearly 4,000 feet of drifts and crosscuts, including the Hawk tunnel.

GEOLOGIC FEATURES

The Eagle vein so far as is known lies entirely in the Eagle Gulch latite, an intrusive volcanic rock. The veins in the Eagle mine occupy a system of nearly parallel branching fissures which strike N. 12°–37° W. and dip 75°–90° E. In the upper levels the fissured zone is 60 to 70 feet wide and three principal veins are developed—the Eagle vein, the intermediate vein, and the east vein. Their relative positions are shown on the vertical cross section of the shaft in Plate 35. Regarding the structural features of these veins Wuensch[59] says:

The first, the Eagle, outcrops prominently in two places and contains an abundance of manganese oxides in a quartz gangue; small amounts of limonite and fluorite are also present. The outcrops of the other two, the intermediate and east veins, are scarcely discernible. The outcrop of the east vein consists of a mixture of barren quartz, silicified, and kaolinized porphyry with only a slight manganese stain. The intermediate vein does not seem to outcrop; only a small manganese-stained fracture is found on the surface.

The oxidized ore is very porous; the sulphide zone not so much, but both are of such an open texture as to permit rapid and deep circulation of the surface waters.

The Eagle and east veins are well defined. They vary from 2.5 to 17 feet in width, with an average of 4 to 5 feet. The intermediate vein is very erratic; it pinches and swells both laterally and vertically. Numerous other small feeders and fractures extend into the hanging wall, and some into the footwall. These terminate in relatively short distances and join either of the two major veins. The veins occupy well-defined fracture planes, as well as erratic fractures suggestive of shearing. The footwall is especially well developed in all the veins, the hanging wall not so well.

Between the fifth and sixth levels a false footwall is found in addition to the real footwall. This has proved most disastrous to the mining of the ore body by the shrinkage system between these levels. It was wholly unexpected because, ex-

[59] Wuensch, C. E., op. cit., p. 98.

cept for two small lenses of latite found lying along the footwall of the vein in the upper parts of the mine, the walls were very firm and well adapted to this system of mining. However, this false footwall material, which is from 2 to 8 feet in width (with an average of perhaps 3 feet), is uniformly present between these levels, and because of its highly altered and propylitic condition it sloughed off and seriously diluted the grade of the ore. The false footwall appears to be the downward extension of the footwall of the Eagle vein, whereas the real footwall is the downward extension of the east vein. In general, the wall rock is comparatively fresh and unaltered, except for a few feet next to the vein, where it frequently is partly silicified and pyritized.

The intersection of the Eagle (west) vein and the east vein is exposed on the 350 and 400 foot levels. This intersection pitches to the south, as indicated on the longitudinal section of the vein given in Plate 35. The intermediate vein branches off from the east vein somewhat higher. The writer was informed by Mr. Glascow that the intermediate vein is not much more than 6 inches wide in places but contained some small bodies of good ore. Most of the older workings of the upper levels are on the Eagle vein. Below the 400-foot level and the junction of the east and Eagle veins only one main vein is known to be present. Between the 500 and 600 foot levels this vein averages about 4½ feet in width, and there is a definite slip or fault plane along the footwall. The hanging wall is indefinite, grading into altered and silicified country rock. The vein has a tendency to widen in depth, and at the 600-foot level there is a broken fissured zone about 17 feet in width. Below the 600-foot level the vein material is in a wide, much broken fissure zone. On the lower levels there are in both walls small branch veinlets which run very high in silver, particularly those in the footwall.

On the 350-foot level the east vein has been developed by a drift south beneath Eagle Gulch. Below the center of the gulch the vein changes in strike. According to Mr. Glascow the vein walls at this position are broken and there is no definite footwall slip, such as is found along the vein north of the gulch. Farther south, both in the Hawk tunnel and on the 350-foot level, the east vein is displaced slightly by an east-west postmineral fault. At the extreme south end of the drift on the Hawk tunnel level the east vein is accompanied by a series of diverging mineralized fault fractures which form the footwall of the vein and against which it appears to terminate, at least locally. Explorations have not been continued beyond the intersection with these fractures because of the lean character of the mineralization in this part of the mine.

ORES

The unoxidized vein material consists largely of quartz, rhodochrosite, and fluorite with relatively small amounts of sulphides—an association that appears to be characteristic of the mineralization as a whole in the southern part of the district. (See pl. 21, *B*.) In the great bulk of the vein material left on the dump the sulphides occur in very scattered grains in the gangue and consist largely of sphalerite, pyrite, and galena, with smaller amounts of chalcopyrite and tennantite. In the lower levels of the mine, where the primary silver minerals are found, the ore is not of uniform grade, but the silver-bearing ores are said to occur in a series of high-grade lenses or chimneylike shoots separated by stretches of nearly barren gangue. These silver shoots occupy a series of late fissures which lie in and along the early low-grade vein matter and which are both oblique and parallel to the original vein walls. In a specimen of ore from one of these shoots on the 600-foot level given to the writer by Mr. Glascow the sulphides consist of pyrite, sphalerite, galena, chalcopyrite, pyrargyrite, and an unknown mineral, possibly pearceite. The gangue consists of rhodochrosite, fluorite, and manganocalcite. In this ore pyrite and sphalerite are the minerals of earliest formation and were followed by galena intimately intergrown with manganese-bearing carbonate. (See pl. 19, *B*.) The pyrargyrite and the pearceite(?) are found in smooth rounded areas in galena, suggesting that they were in the earlier stages deposited together with the galena and so of primary or hypogene origin. Pyrargyrite and chalcopyrite of a still later stage replace galena and occur intergrown with carbonate and in well-crystallized form lining and projecting into small cavities in the ore. (See pl. 22, *A*, *B*.) In one cavity associated with pyrargyrite there were also a few small crystals of a lead-gray soft mineral of high metallic luster and irregular fracture, containing bismuth. This mineral could not be definitely identified, and none of it was seen in a number of polished sections made of the ore. It contains no silver nor copper, so far as could be determined by microchemical tests, and may possibly be a rare sulphobismuthite of lead. The small cavities in the ore contain many small prismatic crystals of scarlet ruby silver perched on rhodochrosite, manganocalcite, or other earlier sulphides. Small greenish-yellow crystals of chalcopyrite have a similar mode of occurrence. The bases of the larger crystals are partly intergrown with carbonates. The early pyrargyrite occurring in galena is without much doubt of primary or hypogene origin, but the origin of the later pyrargyrite is more problematic. Because these minerals are in part intergrown with carbonates and earlier sulphides and because of their association with the bismuth-bearing mineral they probably represent a late stage of primary or hypogene silver enrichment. The low sulphide content of the vein as a whole and the occurrence of the silver ore in small shoots appear to be unfavorable to a deep or pronounced zone of supergene sulphide enrichment.

In vein material obtained from the Eagle dump in which no ruby silver was found the order of mineral formation was quartz, pyrite, sphalerite, galena, and chalcopyrite, followed by an intergrowth of tennantite and carbonates. The carbonate overlapped the galena slightly but not to the extent shown in the specimen containing pyrargyrite from the 600-foot level. Fluorite is an early mineral that was formed largely before the manganese-bearing carbonates and rhodochrosite. (See pl. 21, *B*.) It was partly deposited with and partly replaced early vein quartz. The later rhodochrosite replaced early quartz extensively in some parts of the vein and produced a fine-grained tough rock of pale pinkish color which resembles some intergrowths of quartz, rhodonite, and rhodochrosite seen in other veins in the district. Microscopic examination shows this material to consist almost entirely of quartz and rhodochrosite with traces of fluorite. (See pl. 21, *A*.)

As is common throughout the district, a period of silicification of the wall rock preceded the deposition of vein material. The underground relations were not seen by the writer, but surface relations and fragments of silicified rock seen in the ore confirm this conclusion as to the general relations. Regarding the condition of the wall rock Wuensch [60] says, "In general, the wall rock is comparatively fresh and unaltered, except for a few feet next to the vein, where it frequently is partly silicified and pyritized."

The writer selected some of the freshest-appearing wall rock that could be obtained from the dump. Microscopic examination shows it to be considerably altered, however, with the formation of carbonates, sericite, and pyrite. Wuensch [61] says:

In certain parts of the vein brecciated and partly silicified fragments of country rock (latite) are found. In these instances the vein is invariably nonproductive and rhodochrosite conspicuously lacking or present in very small quantity.

On the same page, in summarizing his views of the general order of mineralization, he says:

Two distinct periods of mineralization are evident. The first is characterized by an abundance of barren quartz with subordinate amounts of fluorite containing a small amount of pyrite. Later, along the same lines of fracturing, or roughly parallel fractures, the second period of mineralization is found. This was characterized by an abundance of quartz, rhodochrosite, and subordinate amounts of fluorite; the amounts vary considerably in different parts of the vein. It was with these mineralizing solutions that the argentiferous sulphides were introduced into the vein by ascending solutions. Invariably these sulphides are absent if there is no rhodochrosite, although in parts of the vein where rhodochrosite predominates but little or no sulphides are found.

The microscopic study of the ore confirms the close association of the silver sulphides with manganese-bearing carbonates. Although pyrite and sphalerite appear to have formed earlier than the vein carbonates, the carbonates in several specimens are intimately intergrown with galena, tennantite, and polybasite in such a way as to suggest their essentially contemporaneous formation.

The results of oxidation and enrichment could not be studied at first hand, and no specimens of the enriched sulphide ore of the intermediate levels of the mine could be obtained. With regard to these features Wuensch [62] states:

Roughly, the upper 100 feet of the various veins are completely oxidized, although local oxidation may extend to between 250 and 300 feet. The vein material consists of quartz, psilomelane, wad, limonite, and fluorite. The fluorite usually is completely decolorized or has a black to purplish-black tint—a decided difference from the deep green in the primary ore. Even though quartz predominates, the vein is so thoroughly stained by the manganese oxides as to give the appearance that it is the most abundant mineral. This part of the vein is practically devoid of precious metal content. It contains from a trace to 0.01 ounce gold and from 0.3 to 6 ounces silver. The higher content is found only in small residual portions where sulphides are sparingly disseminated. In these instances the rhodochrosite can usually be observed in the last stages of alteration to psilomelane. * * * In the upper part of the sulphide zone argentite coats the sphalerite and to a less extent the galena. This is unusual, because galena is usually the more effective precipitant of silver from secondary solutions. There is some evidence that chalcopyrite, which is visible in intimate association with the sphalerite, may account for this irregularity. The sphalerite is mostly of the resinous variety, although some marmatite is found. Most of the sphalerite, however, has the appearance of being of the blackjack variety, because of the sooty coating of secondary argentite. In places native silver is found in the form of delicate wires in vug holes perched on the base sulphides. Doctor Patton says wire silver is the predominating ore mineral in the Eagle. This is not the case, however. At the time of his visit to the district the mine was full of water, so that he probably derived his information from sources other than observation. Below this argentite zone the ruby silver minerals, proustite and pyrargyrite, are found in association with the other sulphides. The former appears to be slightly in excess of the latter. Occasional crystals of polybasite are found.

The zone of secondary black or sooty sulphides mentioned by Wuensch is found in many veins in all parts of the district. In the northern part of the district it has a very short vertical range, however, compared with that in the Eagle mine. The black sooty coating commonly found on sphalerite is not believed to consist entirely of argentite, as is implied by Wuensch's description. This coating, which in some places is hardly more than a film, consists primarily of chal-

[60] Wuensch, C. E., op. cit., pp. 98, 99.
[61] Idem, p. 100.
[62] Idem, p. 99.

cocite or covellite, but the somewhat enriched silver content of some black friable ore of this nature indicates that silver is also present in some invisible secondary form. This coating of secondary copper and silver sulphides is said to have been found in the ore at least to the depth of the 350-foot level and perhaps is present to some extent on the 400-foot level. On the 600-foot level at least, as mentioned above, there is no convincing evidence of extensive supergene enrichment, and sooty coatings or films are absent. Wuensch [63] further states.

Because the original ore shoot increased in length with each successive level in depth, the volume of vein material leached must have been small compared with the volume of material subjected to enrichment; hence though the enrichment was important in increasing the grade of the secondary ore, the secondary ore was not enriched as much as is usual in such enrichments.

LIMITS OF THE ORE SHOOT

As brought out in the preceding description, the ore shoot in the upper levels was narrow and consisted apparently of local bodies of enriched or partly leached ore. At the north end of the mine there is a gradual transition from the normal rhodochrosite-fluorite-quartz vein material into barren quartz with small amounts of fluorite and scarcely any rhodochrosite. The wall rock is partly silicified in this portion of the mine. The northern limit of the shoot is indicated on Plate 35, and in the lower levels pitches about 45° N. The southern limit of the shoot is nearly vertical, however, and is bounded by a zone of barren, bleached rhodochrosite in which, except for a few scattered bodies, the sulphides are entirely absent. This change to barren altered rhodochrosite is said to be abrupt and occurs on all levels at about the limit indicated by the nearly vertical line in Plate 35. In this barren part of the vein the rhodochrosite is soft and bleached and is partly replaced by a claylike earthy material resembling kaolin. From a commercial analysis of a mixture of rhodochrosite and this claylike mineral Wuensch [64] concluded that this mineral is nontronite, a hydrated ferric silicate of variable composition but similar to kaolin in that the alumina of kaolin is replaced in nontronite by ferric iron. Wuensch's conclusion appears to be supported by the very low alumina content of the material analyzed. A number of specimens of yellowish-white bleached material which the writer obtained from the Eagle dump were examined microscopically for the purpose of determining the occurrence of this mineral. Most of this material was found, however, to consist of a mixture of granular iron-manganese-calcium carbonate, quartz grains, and kaolinite, named in the order of abundance. The kaolinite occurs as minute colorless fibers or scales with a moderately large extinction angle ranging between 10° and 20°. The birefringence of this mineral is low, and the indices of refraction lie entirely between 1.56 and 1.57. The mineral shows no color or pleochroism such as is characteristic of the varieties of nontronite listed by Larsen.[65]

This mineral is undoubtedly kaolinite, and no minerals corresponding to nontronite were identified in specimens which the writer obtained. This statement is not intended to imply, however, that nontronite may not be present in parts of the vein, as described by Wuensch, for only a few specimens were examined by the writer. The quartz in the recrystallized carbonate consists of small irregular grains and many minute terminated crystals. The kaolinite also occurs in nearly pure-white form, filling small pockets in the carbonate and quartz. Whether or not this claylike material in the southern part of the vein is largely nontronite or kaolinite, the particular interest attached to it lies in the fact that where it is present in the vein the sulphides are practically absent. Wuensch concluded that this absence was caused by the action of surface waters which had leached the primary sulphides from the vein, and therefore he suggested that an enriched zone might be encountered at greater depths. Regarding the condition encountered on the 350-foot level south he says: [66]

Out of about 500 feet of drifting on the vein only three or four daily face samples contained more than 2 ounces of silver and a trace in gold, although the gold content of these was much higher in all samples than from the same grade of silver ore from other parts of the mine. The average of the whole vein would not contain as much as did the average on the Hawk tunnel level, 220 feet vertically above.

Where the cross vein joins the east vein rhodochrosite containing a few disseminated crystals of the sulphide minerals characteristic of the deposit is found. The rhodochrosite shows various stages of the conversion into nontronite. The sulphide particles are rather sooty and give the appearance that they too are in the incipient stages of solution. This seems to indicate that a selective solution may have taken place—that is, that the character of the downward-circulating waters was such as to have effected the solution of the sulphides before the rhodochrosite. If this is so, there is a possibility of finding an important secondary enrichment in depth. On the other hand, there is the contradictory evidence that no important amounts of sulphides were ever present. In a few isolated parts of the veins small areas of rather fresh rhodochrosite, with an abundance of quartz and some fluorite, are found in which little or no nontronite is present, but the sulphides are absent.

It has recently come to be recognized that the formation of kaolin in nature requires a certain limited range in the acidity of the solutions causing its forma-

[63] Wuensch, C. E., op. cit., p. 103.
[64] Idem, pp. 104–106.

[65] Larsen, E. S., Microscopic determination of the nonopaque minerals: U. S. Geol. Survey Bull. 679, pp. 217, 251, 252, 255, 258, and 259, 1921.
[66] Wuensch, C. E., op. cit., p. 105.

tion. Boydell[67] has emphasized the importance of this feature with regard to the enrichment of disseminated copper deposits. He says:

At Tyrone, N. Mex., in an ore body which occurs entirely in monzonite, the ore is comparatively hard and silicified, whilst outside the ore body, where concentration has been slight, the altered rock is highly kaolinized, soft, and only slightly silicified. The contrast is very pronounced; examination of the ore shows that it contains much unaltered pyrite largely as residual kernels, as evidence that the primary mineralization was strong. Outside the ore body, in the soft kaolinized rock, pyrite is sparsely disseminated, showing that the primary mineralization was weak.

This difference is attributed by Boydell to the more acid condition of the downward percolating waters in the neighborhood of the ore body because of the oxidation of the abundant pyrite there. In such solutions the acidity was too high for the formation of kaolin. Solutions percolating through a relatively barren gangue, as in the rhodochrosite and quartz lying south of the Eagle ore shoot, would have a low acidity, and conditions might be favorable for the formation of kaolin. The formation of nontronite is not so well understood as that of kaolin, but it is evidently, at least in some occurrences, a product of weakly acid surface solutions. Although the vein could not be studied underground at the Eagle mine, the possibility that the portion lying south of the main ore shoot was originally barren is an alternative hypothesis that appears to have support both from the general character of the veins of the southern part of the district and from consideration of the conditions under which kaolin may form.

GRADE OF THE ORE

The accompanying table, taken from Wuensch's paper, gives a series of assays from different levels of the mine. Wuensch[68] says of these samples:

These samples are quite representative of the vein material on the respective levels, with the exception of the 200 foot, 300 foot, and 400 foot, which were so largely stoped out that an average could not be obtained, although the samples give an average of what remains. Samples from the 500-foot and 600-foot levels were obtained from the floors of the respective levels, samples being taken every 10 feet. If the samples of the residual lens of primary ore are omitted from the samples taken on the 134-foot level, the average silver content will be about the same as on the 90-foot level.

Shipping ore that was mined and sorted from the upper levels of the mine between 1902 and 1904 showed a content ranging between 90 and 200 ounces of silver and about 0.25 ounce of gold to the ton. The ore that was treated in the mill between 1920 and 1922 failed to show the average silver content that had been expected from the dump and mine samples. The occurrence of the rich ore in narrow shoots rendered accurate sampling of the mine very difficult and required more careful selection of stoping ground than was practiced under the mining methods actually used. The average recovery from the 17,700 tons of ore treated in the mill was between 4 and 5 ounces of silver and less than 0.1 ounce of gold to the ton. The lead content was near 0.01 per cent, and the copper content practically negligible. The sources of this ore are indicated in the table on page 151. The mill recovery is said to have averaged about 72 per cent, and dilution of the ore in the shrinkage stopes ranged between 10 and 15 per cent.

Assays of ore from different levels of the Eagle mine [a]

Level	Au	Ag	Mn	Fe	Pb
90-foot	0. 01	2. 4	9. 6	3. 4	0. 15
134-foot	. 01	[b] 9. 8	4. 8	2. 4	. 09
200-foot		7. 0		2. 0	. 10
300-foot		22. 7			
400-foot		15. 2			
500-foot	. 02	15. 5	7. 6	3. 1	. 50
600-foot	. 02	10. 6	13. 6	3. 0	. 10

Level	Zn	SiO_2	Al_2O_3	S	CO_2
90-foot	Tr.	62. 4		0. 4	
134-foot	0. 10				
200-foot	. 09				
500-foot	. 20	46. 6	1. 7	1. 7	
600-foot	. 20	48. 8	1. 2	1. 1	15. 5

[a] Wuensch, C. E., op. cit., p. 101.
[b] 2.5 ounces excluding lens of residual primary ore.

OREGON VEIN

Near the upper end of Eagle Gulch, about 4,000 feet northeast of the Eagle mine, there is a group of claims with several exploratory tunnels and shafts known as the Oregon group. The main Oregon tunnel and shaft are at an altitude of about 10,200 feet on the north side of the gulch. (See pl. 1 and fig. 44.) The vein has also been prospected by a shaft and several tunnels on the south side of the gulch.

The Oregon vein occupies a fault zone having a strike of about N. 55° W. and a nearly vertical or steep northeasterly dip. The oxidized vein matter and altered rock crop out from a point near the crest of the ridge south of Eagle Gulch in a northwesterly direction across the gulch for a distance of 1,000 to 1,500 feet. The country rock along the outcrop consists of a complex of Rawley andesite, Hayden Peak latite, and intrusive Eagle Gulch latite, with several latitic dikes. The structural relations between these different rocks are necessarily much generalized on Plate 1.

Where exposed in the Oregon tunnel the vein matter occupies a fissured zone having a width of 60 to 65

[67] Boydell, H. C., Operative causes in ore deposition: Inst. Mining and Metallurgy Bull., pp. 64–66, 1927.
[68] Wuensch, C. E., op. cit., p. 102.

feet, but this width includes much altered rock, and the mineralization has formed parallel veins that range from a few inches to 5 feet in width. The principal vein minerals are quartz, fluorite, a little barite, and manganese and iron oxides (psilomelane and wad). The walls and rock bodies included within the vein zone are silicified and sericitized, and away from the oxidized fissures they contain pyrite. The country rock exposed in the Oregon tunnel crosscut consists of latite and quartz latite porphyry. The rocks are

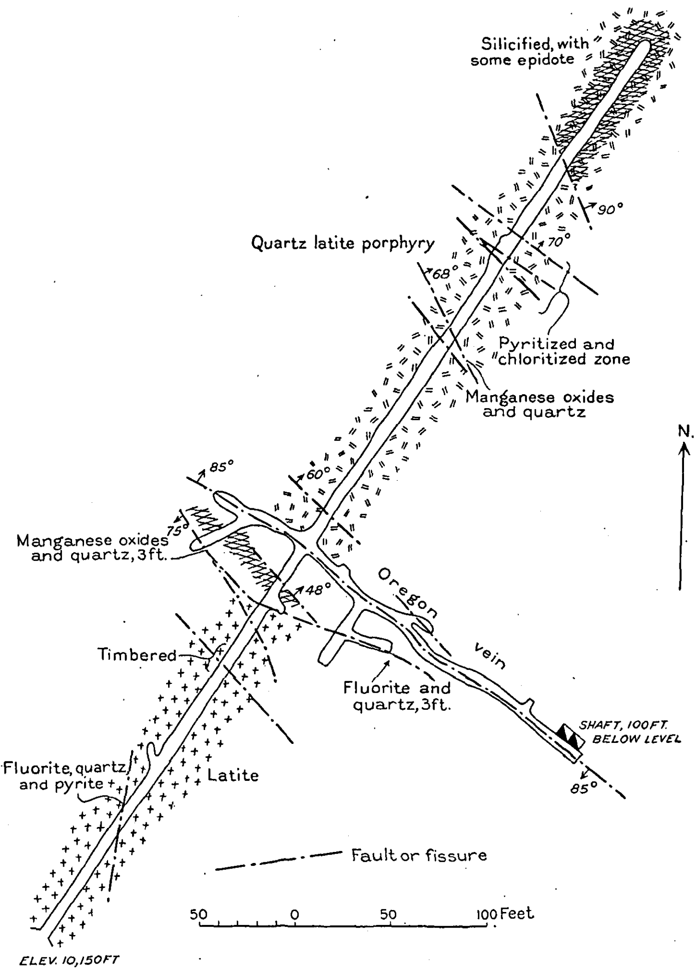


FIGURE 44.—Sketch map of the Oregon tunnel

considerably fissured on both the north and south sides of the Oregon vein and are silicified and sericitized near the other fissures intersected by the tunnel. Other alteration products are chlorite, epidote, and pyrite. A shaft 195 feet deep has been sunk from the surface to a depth of 100 feet below the level of the southeast drift. (See fig. 44.) According to Mr. Emil Keserich, part owner, this shaft was sunk by lessees and did not expose the vein fully at depth, owing to the position of the shaft bottom in the wall of the main vein.

The assays of the vein given below were obtained from reports by C. E. Wuensch and J. H. Farrel and from the description of the vein given by Patton.[69]

[69] Patton, H. B., op. cit., pp. 117, 118.

In a number of assays from several different sources the silver content ranges from 0.3 to 3 ounces and the gold from 0.005 to 0.02 ounce to the ton. The manganese content ranges from several to 19 per cent. An average sample across 50 feet of the vein at the Oregon tunnel level assayed 3.2 per cent of manganese, 0.15 per cent of lead, a trace of zinc, and 0.3 ounce of silver and 0.005 ounce of gold to the ton. Massive streaks of ore from veins 2 to 8 feet in width assayed 0.005 ounce of gold and 1.1 ounces of silver to the ton, 0.09 per cent of lead, 0.13 per cent of zinc, 10.2 per cent of manganese, 1.03 per cent of sulphur, 3.1 per cent of calcium oxide, and 3 per cent of iron. The silica content of the vein in several samples ranged between 40 and 80 per cent. A sample of 6 feet of vein material from the 100-foot shaft on the ridge southeast of Eagle Gulch assayed 19.1 per cent of manganese, 10.1 per cent of iron, and 3.2 ounces of silver and 0.01 ounce of gold to the ton. The low grade and oxidized nature of the vein near the surface are characteristic of the veins in this part of the district. In the description of the Eagle mine (p. 153) attention is called to the fact that the richer silver ores have been found only where the vein contained considerable rhodochrosite, but that the presence of rhodochrosite does not always indicate silver shoots. Present explorations on the Oregon vein fail to indicate definitely the position of possible rhodochrosite-silver shoots, but the work done is too shallow and does not include sufficient drifting along the exposed length of the vein to be conclusive.

VEINS OF CHLORIDE AND GREENBACK GULCHES

In Chloride and Greenback Gulches, which parallel Eagle Gulch on the southeast, there are many small prospect shafts and tunnels, but production from this area has been negligible. Along Chloride Gulch the only prospecting work of interest is that of the Chloride group, and among those tributary to Greenback Gulch are the Whitney group (No. 85, pl. 1), the Enterprise, the Crown Point (No. 19, pl. 1), the Exchange, and the Mount Hayden and Schoville groups of unpatented claims (Nos. 37 and 74, pl. 1), but this list is far from complete.

The most extensive work done in this area is that on the Chloride group of patented claims, about half a mile above the mouth of Chloride Gulch. These claims lie along the continuation of the strike of the Eagle and Hawk veins, but it is not certain that they belong to the same vein system because of intervening faults and splitting of the fissures. The principal development tunnel of the Chloride group is at an altitude of about 9,375 feet on the south side of Chloride Gulch. This is chiefly a crosscut tunnel, but there are several drifts and winzes on the veins intersected. The tunnel has a direction of S. 88° E. for at least 440 feet, but when examined in 1927 it could be entered for only 240 feet because of caved ground. At about 200 feet from the portal the tunnel intersects a northwesterly fissure on which a winze had been sunk, but the nature of the ore in place could not be seen. Other veins are said to have been cut near the breast of the tunnel and a winze sunk on one of them. One of the winzes is said to have been continued to a depth of 100 feet below the tunnel level. Vein material from the dump at the portal of the tunnel shows the gangue to consist of early quartz and fluorite, with later quartz and adularia, and a final stage of rhodochrosite. A shaft on the ridge about 900 feet southeast of the tunnel at an altitude of 9,714 feet is 240 feet in depth, and from this about 280 feet of drifting has been done, probably on a N. 45° W. vein. Vein matter from the shaft dump contains pyrite, chalcopyrite, sphalerite, and galena in a gangue of quartz, fluorite, adularia, and altered carbonate. (See pl. 20, *A*.) There are also some chalcocite, covellite, limonite, manganese oxides, and kaolin due to superficial alteration. The material of these veins, to judge from the dumps, consists chiefly of gangue. No data were obtained on the metal content of the veins, nor on the production of this group, but it is probable that no production of consequence was made.

The other veins of Chloride and Greenback Gulches consist chiefly of quartz with small amounts of carbonates, other gangue minerals, and sulphides. The extreme alteration of the volcanic rocks in this area is described on pages 73–74. Evidences of silicification, pyritization, and sericitization are common in the vein walls, but the concentration of sulphides in the vein matter of later age has been very weak. Figures on the average gold and silver content of the different veins were not obtainable, but the relative concentration of these metals is presumably comparable to that shown by such veins as the Eagle, Oregon, Express, and Pershing (pp. 158–159). According to Mr. Schoville, of Bonanza, some of the veins of the Mount Hayden and Schoville groups assay near the surface about $1 in gold and from several to 10 ounces of silver to the ton. These veins occur along the upper parts of Greenback and Schoville Gulches (Nos. 37 and 74, pl. 1) and are just outside of the area of most intense solfataric alteration that centers near the lower part of Greenback Gulch.

EXPRESS MINE

The Express mine is on the northwest side of Express Gulch about 4,000 feet northeast of the junction of Express and Kerber Creeks and is accessible by a road up Express Gulch. The Express shaft is at an altitude of 9,275 feet and is 240 feet in depth; levels are driven 96, 150, and 224 feet below the collar. The drifts were not completely accessible on all levels because of caves, but a sketch of part of the 224-foot level is shown in Figure 45. There are about 150 feet of drifts on the 96-foot level and 300 feet on the 224-foot level.

The Express vein strikes N. 50°–80° W., with an average of about N. 70° W., and dips 75° SW. on the upper level and as much as 75° NE. on the 224-foot level. To the depth explored the average dip of the vein is nearly vertical. The country rock of the mine consists of altered latite breccia, andesite, and latite or quartz latite porphyry. On the 224-foot level most of the wall rock is altered latite breccia, probably a part of the large volcanic neck on the edge of which the mine is situated. (See pl. 2 and pp. 34–36.) A small block of andesite is cut on the 224-foot level on the south side of the drift about 100 feet east of the crosscut from the shaft. Owing to the intense alteration near the vein the relations of this body could not be determined during the short examination that was

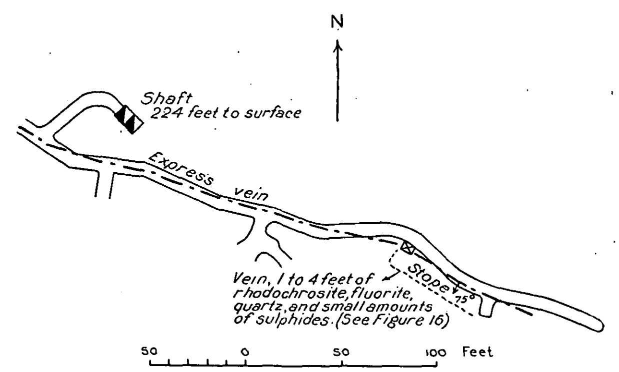


FIGURE 45.—Sketch map of the 224-foot level of the Express mine

made. This body is locally referred to as a "basalt dike," although it is possibly a fault block of one of the andesite flows of the Rawley formation. At the bottom of the shaft a conspicuous porphyry is present, presumably an intrusive body associated with the latite breccias of the volcanic neck. The structural relations of the different wall rocks are probably complex, as is typical of the relations seen at the surface in this vicinity, but the wall rocks including the porphyry have been silicified and sericitized along the fissure, and hence all are older than the mineralization.

The Express vein ranges from 1 to 4 feet in width and has a conspicuous banded texture (fig. 13) of a type practically absent in the veins of the northern part of the district. This texture is one more typical of low-temperature (epithermal) veins, and the mineralogy of the vein further supports the classification of this vein, along with others in the southern part of the district, as of a lower-temperature type than those of the northern part. The ore minerals, which are in small proportion to the gangue, are chiefly pyrite, sphalerite, galena, and chalcopyrite, with small amounts of enargite, tennantite, pyrargyrite, covellite, and possibly bornite and stromeyerite. The gangue consists of quartz and fluorite, with some rhodochrosite and calcite. In addition to the pyrargyrite, which occurs in small blebs in the galena in a manner similar to its occurrence in the Eagle vein (p. 152), there are also closely associated with it small amounts of an unidentified gray mineral, possibly another silver mineral. A similar mineral is seen intergrown with pyrargyrite in the Eagle vein (p. 152). Minute amounts of a brownish-gray mineral associated with tennantite and resembling stromeyerite, a copper-silver sulphide, which is common in the ores of the district, was seen under the microscope in a specimen taken from the dump. Although to judge from the specimens collected by the writer, pyrargyrite is not as common in the developed parts of the Express vein as in the Eagle vein, Mr. John McKenzie, owner of the property, reports the occurrence of shoots in which the silver content is high.

The mineralization in the vein, as judged from the banded texture shown in Figure 13 and from the microscopic study of sections of the ore, began with the deposition of quartz with only small amounts of fluorite. Pyrite, chalcopyrite, sphalerite, and galena, with small amounts of silver minerals, accompanied the quartz filling, but chalcopyrite is the most common mineral in the quartz. A fluorite-quartz stage appears to have followed the early quartz, carrying only very small amounts of sulphides, largely sphalerite and galena. Rhodochrosite in the main followed the major deposition of fluorite, and barren calcite was last. The metal sulphide content of the vein, like that of the Eagle vein, is very low, and the only metals occurring in sufficient amount to be of value are silver and traces of gold. The silver content of the vein as a whole is low, however, the richer ore lying in small shoots, as in the Eagle vein.

There has been no production from the Express vein, all the work up to 1928 being done for the purpose of development. Ore shoots of sufficient size or grade for mining had not up to that time been developed. Although the more extensive explorations of the Eagle vein and other properties in the southern part of the district have not yet yielded large bodies of primary ore, the amount of development work done in this part of the district does not completely exclude the possibility of finding such bodies. The oxidized and enriched tops of such ore shoots, as at the Eagle, have proved of some value, but the primary ores below have not yet been profitably mined. Exploration should be confined to the upper parts of these veins until enriched shoots of sufficient size and silver content have been discovered. The primary ore below can probably be expected to hold its average tenor to depths greater than any present explorations in this part of the district. In the Express vein exploration eastward in the andesite would probably be in more favorable country than westward toward the center of volcanic activity, where silicification and kaolinization were the dominant and usually barren types of alteration. A bleaching and softening of the rhodochrosite similar to that found in the Eagle vein is seen in the Express vein. This is usually erroneously interpreted as an indication that the metal content of the vein has been leached. This alteration was of a weak nature and was due to the formation of small amounts of kaolinite in the relatively barren gangue; the adjacent sulphide grains appear to be entirely unaffected. Whether this alteration was caused by a late circulation of warm waters of hot springs or by descending cold meteoric waters is problematic, but the second alternative is more likely. The Express vein is partly oxidized on the 96-foot level, indicating strong action of surface waters to at least this depth. On the 224-foot level there is little or no indication of oxidation, but the rhodochrosite has been bleached and softened.

PERSHING MINE

The Pershing mine is near the head of Manganese Gulch, a short gulch paralleling Express Gulch and about 1,000 to 1,400 feet southeast of it. Development work on the vein was first done during the World War for the purpose of obtaining manganese ore, but this work was of minor extent. In 1927 and 1928 the property, which is owned by the Express-Headlight Mining & Development Co., was under lease to the Texas-Colorado Mining Co.

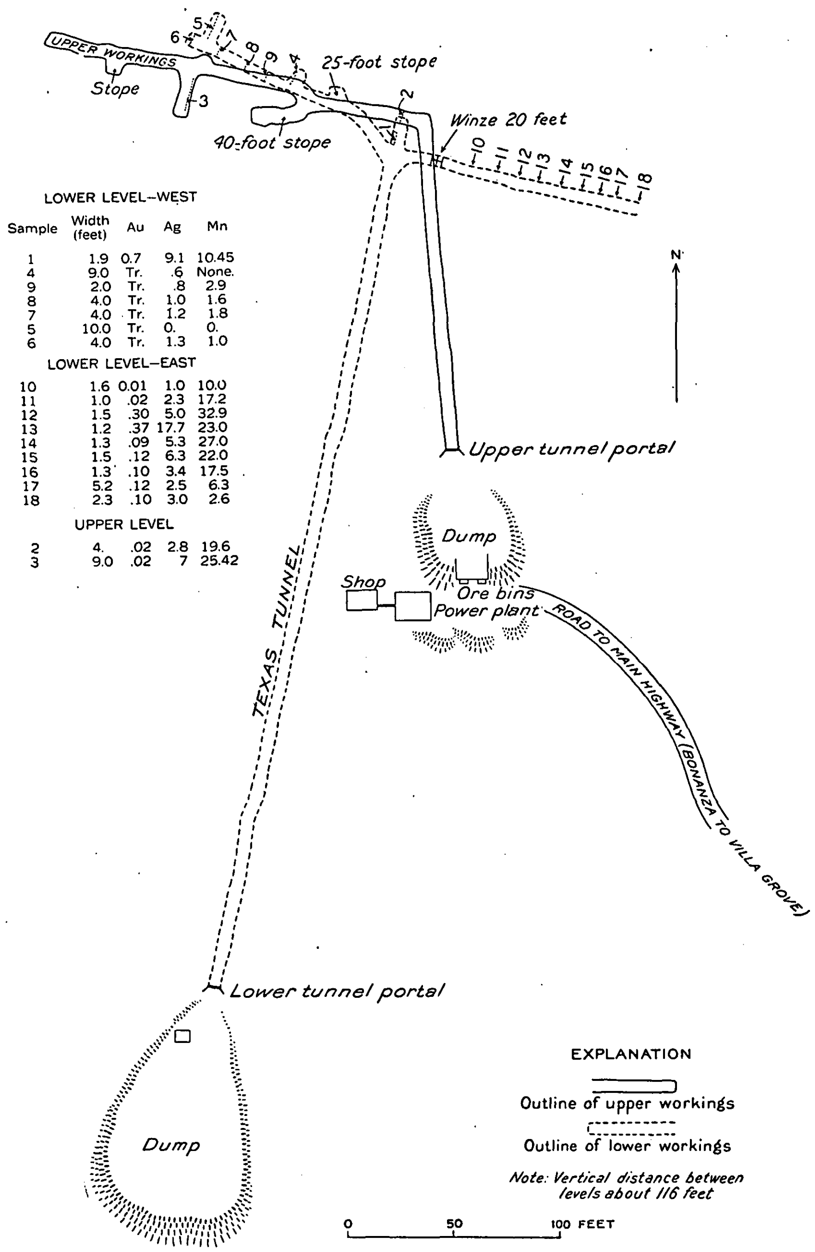
The Pershing or Headlight vein strikes nearly west to N. 80° W. and has a nearly vertical dip. It is developed by two crosscut tunnels and a few hundred feet of drifts. (See fig. 46.) The upper tunnel is at an altitude of 9,625 feet, and a lower tunnel, called the Texas tunnel, was driven in 1927 and 1928 and intersects the vein about 116 feet below the upper workings.

The principal country rock is the Rawley andesite, but it is much shattered and fissured and is intruded by a complicated network of rhyolite and quartz latite dikes. A large part of the rock penetrated in the Texas tunnel consists of rhyolite intrusions, the shapes of which are not definitely known because of débris on the surface which obscures their outcrop in this vicinity. The Texas tunnel was driven about 75 feet before bedrock was encountered, indicating a thickness of 30 feet or more of soil and slumped rock. The vein where cut by the upper tunnel is 3 to 4 feet in width, but it widens rapidly westward along the drift, and a shoot of manganese oxides approximately 100 feet in length and 10 to 25 feet in width had been developed in 1928. The ore in this shoot consists of mixed manganese oxides, quartz, and fragments of altered country rock.

Pyrolusite and psilomelane are the principal manganese oxides, with some admixed earthy and siliceous material and limonite. The pyrolusite occurs in massive form, in sheaflike groups of prisms, and as striated crystals lining cavities in the more siliceous ore. It may possibly represent a pseudomorphic replacement of manganite, although no unaltered manganite was recognized in the upper level. The psilomelane is in part intimately associated with the pyrolusite but in part appears to have been deposited later. In the siliceous ore the quartz is intimately associated with the oxides, preventing easy mechanical separation. Some late quartz veinlets cut through the pyrolusite, and quartz crystals incrust some of the prismatic growths of pyrolusite. The limonite is usually intergrown with the psilomelane or earthy manganese oxides. A few large and small masses of vein quartz were encountered in developing the upper tunnel, which contained a little pyrite, chalcopyrite, and sphalerite. Mr. William Heim, manager of the property, reported that some of this vein matter ran from 4 to 10 ounces in silver to the ton. Texturally and mineralogically it resembles the siliceous vein material from the Express and Eagle veins.

The vein is in part siliceous, and as the silica is intimately intergrown with the oxides good mechanical concentration would require rather fine crushing. There are, however, narrow shoots of practically clean pyrolusite, ranging from small veinlets up to some 1.5 feet in width. The fissured zone where cut in the lower tunnel is about 10 feet in width and consists of a series of small parallel veins with quartz and pyrolusite. According to Mr. Heim a sample across the vein at this point assayed for 8 feet 0.25 ounce of gold and 9 ounces of silver to the ton and for the additional 2 feet about $2.50 in gold and 27½ ounces of silver to the ton. The west drift from the lower tunnel failed to expose an oxide ore shoot comparable to that in the tunnel above, probably showing that these bodies are of lenticular shape. The gulch in the vicinity of the property is very dry, and attempts to obtain water in the gulch bottom below the mine were not successful. For this reason it is possible that oxidized ore may extend several hundred feet below the outcrop. The manganese oxides are presumably derived largely if not entirely from rhodochrosite.

The small amount of iron in the oxidized vein probably indicates a low percentage of primary pyrite, and in the manganese oxide shoots the complete loss of the original structure of the vein indicates a small



Sample	Width (feet)	Au	Ag	Mn
LOWER LEVEL—WEST				
1	1.9	0.7	9.1	10.45
4	9.0	Tr.	.6	None.
9	2.0	Tr.	.8	2.9
8	4.0	Tr.	1.0	1.6
7	4.0	Tr.	1.2	1.8
5	10.0	Tr.	0.	0.
6	4.0	Tr.	1.3	1.0
LOWER LEVEL—EAST				
10	1.6	0.01	1.0	10.0
11	1.0	.02	2.3	17.2
12	1.5	.30	5.0	32.9
13	1.2	.37	17.7	23.0
14	1.3	.09	5.3	27.0
15	1.5	.12	6.3	22.0
16	1.3	.10	3.4	17.5
17	5.2	.12	2.5	6.3
18	2.3	.10	3.0	2.6
UPPER LEVEL				
2	4.	.02	2.8	19.6
3	9.0	.02	7	25.42

FIGURE 46.—Map of the Pershing mine

amount of original vein quartz. The vein presumably was a quartz-rhodochrosite vein, with lenses or shoots of purer rhodochrosite, and with a comparatively low average content of sulphides.

Over 600,000 pounds of ore shipped in 1926 and 1927, which consisted largely of lumps or coarse material, roughly hand sorted as it was mined, contained from 39.7 to 44 per cent of manganese, 14 to 19 per cent of silica, about 8 per cent of water, and 0.03 per cent of phosphorus. The iron content was low, being 6 per cent in the largest shipment, and there was no sulphur. Sample assays of the siliceous vein in the drifts are given in Figure 46.

MINES OF ALDER CREEK

The Alder Creek district adjoins the Bonanza district on the northeast, across the high divide between Round Mountain and Manitou Mountain. Alder Creek drains the district northeastward into the San Luis Valley. The nearest town in the San Luis Valley is Alder, on the narrow-gage branch of the Denver & Rio Grande Western Railroad. (See fig. 1.) The region adjoining the upper part of Alder Creek and shown on Plate 1 is one of steep northward or eastward-facing slopes, many of which are heavily covered with timber. Access to the mines of the upper part of Alder Creek is gained by wagon road along the creek from Alder, a distance of 4 to 5 miles. This road formerly afforded a connection with the Kerber Creek mines by way of the Colorado Belle mine and along the east and south slope of Round Mountain. In 1927 the road was passable by automobile for about 2½ miles west of Alder, but it has since been opened to permit the shipment of ore from the Joe Wheeler mine. When the road has been in good condition automobiles have also been driven almost to the end of the road, in the bottom of the valley near the head of the creek.

The general relation between the geologic features and mineralization in the Alder Creek area is discussed on pages 101–102. The production from the mines of this area has undoubtedly been small, and the activity has not revived much since the earliest discoveries and prospecting. Of recent years there has been intermittent production by lessees from the Golden Wave (Joe Wheeler) and Silver Queen claims and possibly a few others. There are also several prospects that lie east of the area mapped and were not examined.

JOE WHEELER MINE

The Joe Wheeler mine (No. 39, pl. 1) is on the slope north of Alder Creek at an altitude of 10,700 feet. It consists of several tunnels and shafts, the present main working tunnel being on the Golden Wave claim (unpatented). The property is owned by the Joe Wheeler Mining & Milling Co. The Joe Wheeler vein where exposed in the main tunnel (fig. 47) has a strike of N. 10°–15° W. and a nearly vertical dip. When examined in 1927 the vein had been opened for a length of about 50 feet by a manway and stope from 30 to 35 feet above the tunnel level. In the northern and upper part of this stope the vein had a dip of 70° W., but in the lower 20 feet the vein reversed its dip to 73°–75° E. The vein occupies a fault zone about 6 to 8 feet in width but consisted where exposed of two parts—a lenticular body of ore from 1 to 4 feet wide against the east wall of the fault, and another vein 1 to 2 feet wide against the west wall—separated by a horse of altered rock and low-grade vein matter. The hanging or east branch of the vein consisted of a quartz-barite gangue carrying chalcopyrite, bornite, and gray copper, with some pyrite, sphalerite, and galena. The mineralized rock on the west wall contained a higher proportion of galena, and the writer was told that it was of lower silver content. At the north the Joe Wheeler vein is cut off by a N. 10°–20° E. gougy fault, which contained lenses of ore consisting chiefly of sphalerite and galena. A small stope 3 to 4 feet in width had been mined out above the tunnel level on this fault. The tunnel also crosscut through the fault, but it was caved, and whether a vein corresponding in strike to the Joe Wheeler had been discovered in the west wall could not be determined. The only country rock exposed adjacent to the Joe Wheeler vein and in other parts of the tunnel was the Rawley andesite, which is considerably sericitized and pyritized near the fissures and veins and locally replaced by quartz.

There are several other tunnels and shafts on the hill above the Joe Wheeler tunnel, and these extend in a northwesterly direction to the saddle on the ridge about 375 feet higher than the tunnel. (See pl. 1.) The dump material and leached vein from the surface show that mineralization along this zone above the tunnel consisted chiefly in the formation of quartz, barite, rhodochrosite, sphalerite, and galena, with some pyrite and other sulphides. On the other hand, tunnels farther down the gulch in line with and below the Joe Wheeler vein show chiefly quartz, barite, chalcopyrite, and pyrite, with lesser amounts of galena and sphalerite. It would appear, therefore, that there was a pronounced decrease in lead content of the veins of this fissure system in depth.

The mineralogy of the Joe Wheeler vein is not greatly different from that of the veins in the Kerber Creek mines, except that barite is more abundant than in the greater number of the veins in Rawley Gulch. The order of crystallization in any particular piece of vein matter is essentially quartz, barite, pyrite, sphalerite, and an intergrowth of galena, bornite, chalcopyrite, and tennantite. The relations of galena and the copper minerals are variable. Chalcopyrite occurs in microscopic particles in sphalerite, and bornite and chalcopyrite of an early stage have replaced crackled grains of pyrite, but the deposition of chalcopyrite seems to have continued intermittently until most of the galena was deposited. Photomicrographs of the ores showing relations of the common minerals of the Joe Wheeler vein are reproduced in Plates 14, *A*, *B*, and 16, *D*. In addition to the more common minerals mentioned above there are small amounts of an unidentified lead and bismuth bearing mineral, probably a sulphobismuthite of lead such as cosalite, and some chalcocite, covellite, and stromeyerite. Chalcocite and stromeyerite are late minerals but may belong to a late period of the primary (hypogene) mineralization. The lead-bismuth mineral is clearly primary and where seen is associated with galena and stromeyerite. (See pl. 17, *C*, *D*.)

Shipments of crude smelting ore made from the Golden Wave claim in 1917, 1919, 1926, 1927, and 1928 amounted to a total of 138 tons. The gross metal content was 0.35 ounce of gold, 1,210 ounces of silver, 39,653 pounds of lead, 840 pounds of copper, and some zinc of which the records are incomplete. One shipment of 23 tons of lead-zinc ore assayed 8.4 per cent of lead and 5.7 per cent of zinc. Another shipment of 16.4 tons, which is said to have been broken for the full width of the vein without sorting, assayed 6.9 ounces of silver to the ton, 11.7 per cent of lead, 9.7 per cent of zinc, 55.9 per cent of insoluble matter, and 11.4 per cent of sulphur.

COLORADO BELLE MINE

The Colorado Belle (No. 14, pl. 1), located as the Belle of Colorado, is one of the very old claims of the district, having been located in 1881 and patented in 1887. The workings are near the first saddle of the ridge extending northeastward from Round Mountain, at an altitude of about 10,290 feet. In 1883 the Director of the Mint[70] made the following statement:

> On the opposite side of Round Mountain at the Alder Gulch are situated a number of fine prospects of which the Belle of Colorado is the principal. Near the surface the ore was galena, but as depth was attained the mineral gave out, and nothing was uncovered until the shaft was down about 80 feet, when the vein was found, and at the bottom of the shaft, 90 feet in depth, nearly 3 feet of mineral is exposed. The large percentage of gray copper which the ore carries in the lower workings renders it of a much higher grade than that encountered near the surface.

When the patent survey was made in 1884 the depth of the shaft was given as 130 feet. It is not known whether there was any production from this property.

The Colorado Belle shaft was entirely inaccessible when examined in 1927, and the vein could not be studied underground. Surface exposures, although poor, indicate that the vein has a roughly east-west strike and a southerly dip, possibly as low as 60°. Vein material on the dump has a gangue of quartz, barite, and a manganese-bearing carbonate of salmon-pink color, and the sulphides consist chiefly of pyrite, sphalerite, and galena. Rock of the dump shows that silicification of the wall rock occurred before mineralization. The rocks exposed in the vicinity of the mine comprise flows in the Bonanza latite and Rawley andesite. (See pl. 1.)

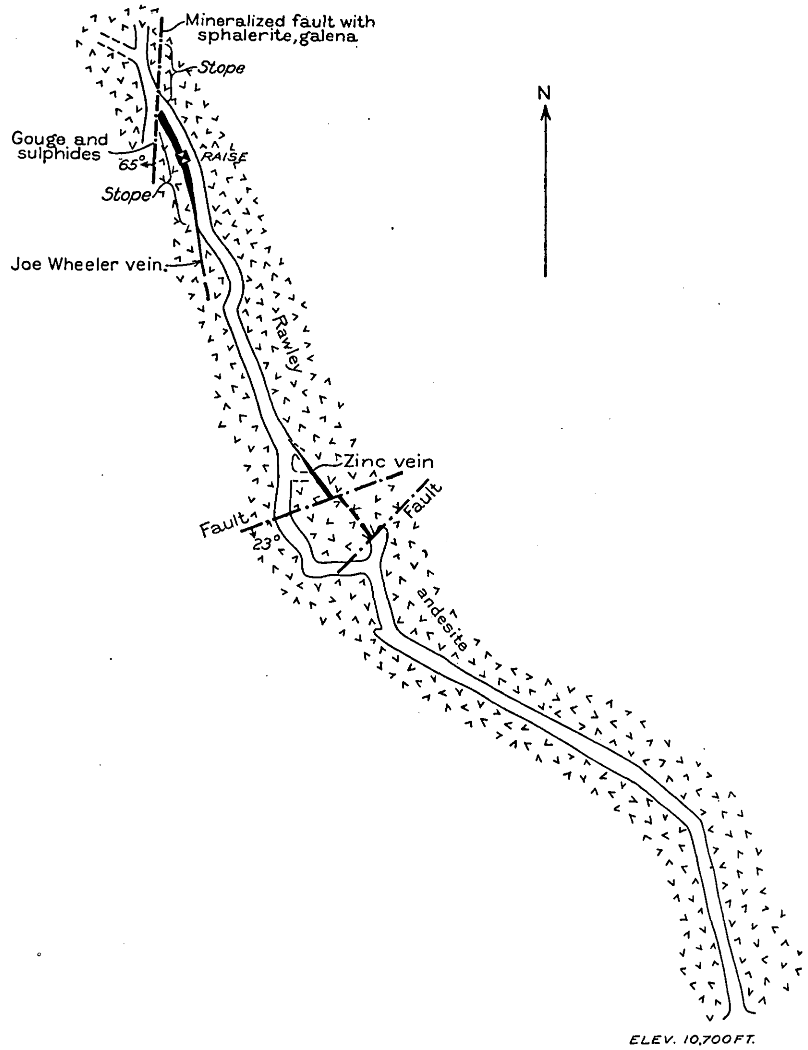


FIGURE 47.—Sketch map of the Joe Wheeler tunnel. Scale 1 inch=100 feet

OTHER MINES AND PROSPECTS

There are many other prospect tunnels and shafts on the slopes of the gulches tributary to the head of Alder Creek, some of which are shown on Plate 1. Sufficient accurate data on these openings were not obtained to permit their individual description without the possibility of giving misleading impressions. Many of the larger prospecting tunnels were driven early in the mining history of the region and therefore are now inaccessible, but attention may be called to two of them.

[70] Burchard, H. C., Report of the Director of the Mint upon the production of the precious metals in the United States, 1882, p. 540, 1883.

One of these older active properties is the Manitou, comprising a group of claims developed largely by a common improvement tunnel on the Green Bay claim (No. 49, pl. 1) and situated at an altitude of 11,519 feet on the steep northeasterly slope of the divide between Alder and Rawley Gulches. In 1883 [71] the Manitou is reported as continuing development work, a crosscut tunnel 650 feet in length having been driven to intersect the Little Manitou vein. In this same year the Big Manitou is reported to have shipped a small amount of ore.

In 1888 [72] the Emma, possibly the Emma lode of the Manitou group, is credited with a production of $9,381.40, consisting of $40 in gold, $7,757.40 in silver (at $1.29 an ounce), and $1,584 in lead (at $87 a ton).

Another of the larger common development tunnels is that on the Great Depth claim (No. 30, pl. 1), but this tunnel was inaccessible in 1927.

[71] Burchard, H. C., Report of the Director of the Mint upon the production of the precious metals in the United States, 1883, p. 404, 1884.

[72] Munson, G. C. (agent for Colorado), in Kimball, J. P., Report of the Director of the Mint upon the production of the precious metals in the United States, 1888, p. 121, 1889.

INDEX

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