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GEOLOGY AND ORE DEPOSITS OF THE BAYARD AREA, CENTRAL MINING DISTRICT, NEW MEXICO

BY

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Prepared in cooperation with the
STATE BUREAU OF MINES AND MINERAL RESOURCES
NEW MEXICO SCHOOL OF MINES

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GEOLOGY AND ORE DEPOSITS OF THE BAYARD AREA, CENTRAL MINING DISTRICT, NEW MEXICO

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ABSTRACT

This report has been prepared in cooperation with the State Bureau of Mines and Mineral Resources of the New Mexico School of Mines. The area described, which has been named the "Bayard area" for convenience, covers 8.75 square miles near Bayard station, in the southwestern part of the Central mining district, Grant County, N. Mex. Practically the entire production of this area has come from only two mines, the Ground Hog and the Lucky Bill, which are on the same vein. Up to January 1, 1933, these two mines had produced 270,229 tons of ore from which lead, zinc, copper, silver, and gold valued at $6,791,823 were recovered; the Ground Hog mine alone since late in 1928 has had an average annual production of over 44,000 tons of argentiferous zinc-lead-copper ore containing 25 to 35 percent of the valuable metals.

The exposed rocks include Pennsylvanian and Cretaceous sedimentary rocks; late Cretaceous (?) sills and dikes; Tertiary (Miocene?) gravel, tuff, and volcanic sand that lie upon the eroded surface of the Cretaceous rocks and cover the oxidized vein outcrops; and Tertiary quartz latite flows and dikes later than the sediments. The mineral comparison of the flows and associated dikes indicates that these two rocks are closely akin. Older rocks, representing the pre-Cambrian and every system of the Paleozoic era, crop out in the surrounding territory and dip under the Bayard area. Including sills and flows, the maximum thickness of all rocks above the pre-Cambrian in this area is 6,926 feet. In vertical section the sills, which are quartz diorite, constitute as much as 32 percent of the post-Cambrian rocks. They have been observed in formations from the Devonian up and have an aggregate thickness ranging from 750 to over 2,200 feet. Individual sills attain a thickness of 750 feet or more. The three largest are in the Colorado formation and crop out in the Bayard area, where the lower and middle of the three are the principal host rocks for the known ore deposits. The sills represent two ages of intrusion, but all have a marked petrographic similarity, and they are considered as having been injected by closely spaced pulsations of the same magma.

The sills were injected prior to a regional synclinal warping and were folded with the enclosing rocks; the Bayard area lies on the eastern flank and near the trough of the syncline. Granodiorite stocks at Santa Rita, Hanover, and elsewhere were injected after the regional folding and further deformed the rocks. Numerous faults traverse the region, and the fault assemblage in the Bayard area consists of several strong members linked together by a multitude of subordinate ones and covering a zone about 2 miles wide. This zone

is part of a northeastward-trending system that is complementary to a set of stronger regional faults trending northwestward. All faults of the Bayard area are normal, and most of them dip southeastward. Many of them die out within the area, either by gradually splitting and fraying out or by simply decreasing in throw, the rate of decrease lying consistently between 95 and 120 feet per 1,000 feet of strike length. Fault throws show a wide range, the greatest being well over 1,300 feet. The total displacement of the faults is the sum of many recurrent movements, the first of which occurred in the interval between sill and stock injections. The earliest faults became faintly mineralized, and many of the mineralized fissures were later filled by granodiorite porphyry dikes, the odd shapes of which reflect the fracture patterns they occupy. The next faulting that can be definitely recognized took place along the earlier zones and tended to follow the dike walls. The known commercially important ore deposits of the area are in faults of this period. The region was then eroded to a rolling surface, and the ore deposits were oxidized and truncated. This erosion interval was followed by a period of explosive volcanic activity during which the Tertiary sediments were deposited; the end of the explosive stage was marked by a minor recurrence of faulting along some of the earlier breaks. The quartz latite dikes, some of which penetrated into reopened veins, were injected probably shortly thereafter, marking the beginning of more quiet volcanic activity, and a third period of mineralization succeeded their injection. Faulting recurred after extrusion of the lavas but seems to have been restricted to the major zones of earlier faulting. The current cycle of erosion has stripped away the Tertiary rocks from most of the area.

All the intrusive rocks have been hydrothermally altered, the alteration minerals including albite, chlorite, epidote, quartz, calcite, and sericite. Study of the details of alteration and of the age relationships between the different altered rocks and the three periods of mineralization mentioned above leads to the conclusion that each general period of intrusion was followed by a period of rock alteration that passed as a continuous process into vein formation. Only quartz and pyrite accompanied by a trace of gold were deposited during the first of these periods of vein formation. The fault fissures were largely sealed by this material and some of them also by granodiorite porphyry dikes injected into them later. The solutions of the second period—those that brought in the ores—managed to penetrate here and there along the sealed faults, but only where these faults had been reopened by post-dike faulting were deposits of commercial importance formed. These deposits consist of massive, varitextured argentiferous mixtures of sphalerite, chalcopyrite, galena, and pyrite accompanied by quartz and calcite. Calculations show that in the average sulphide ore mined to date (February 1933), 47 percent of the silver content is associated with the chalcopyrite, 35 percent with the galena, and 18 percent with the sphalerite; nearly half the silver content in this ore, however, seems to be supergene and to be locked up in a chalcocitic tarnish on the sphalerite and chalcopyrite.

The veins in the western part of the area differ in several respects from those to the east, and the differences are believed due to a gradual change in the mineral content of the solutions as they traveled westward from their source. Rich bodies of lead carbonate ore, chalcocite ore with native silver, and a little vanadium ore have been formed by supergene modifications of the original ore. A small tonnage of gold ore, also of supergene origin, has been mined from two of the veins, and minor amounts of placer gold have accumulated in the arroyos.

A little quartz and pyrite were deposited along some of the oxidized veins during the third period of mineralization, causing the interesting anomaly of hypogene minerals later than supergene minerals in the same vein.

Over 20 mines and prospects are described. The Lucky Bill, Ground Hog, and San Jose mines, which are on the same vein and continuous, are described together. In these mines the known ore bodies lie in a narrow, gently pitching band that has been explored thus far for a pitch length of 3,500 feet; there is a suggestion that the shoots are regularly spaced in this band. Many of the other properties of the area have had a moderate production, chiefly of cerusite ores, but none have been sufficiently prospected to prove their value.

Several specific economic conclusions and recommendations for future prospecting are presented at different places in the report, and these are summarized and collated in the final chapter.

INTRODUCTION

SCOPE OF THE REPORT

In the spring of 1928 a promising ore shoot was discovered in the Ground Hog mine, in the southwestern part of the Central mining district, Grant County, N. Mex., and early development work showed that it would prove to be fully as large as the mined-out main shoot of the adjacent Lucky Bill mine, which had contained the only commercially important ore bodies of the vein type that had been developed in the district up to that time. The Lucky Bill and Ground Hog mines are on the same vein, and a geologic study of the area was decided upon in view of the possibility that other veins also might contain commercially valuable deposits. The study was made under a cooperative agreement between the United States Geological Survey and the State Bureau of Mines and Mineral Resources of the New Mexico School of Mines.

The area studied is referred to herein as the " Bayard area ", after Bayard station, the term " Central district " being used to indicate the entire district officially known by that name.

FIELD WORK AND ACKNOWLEDGMENTS

The Central mining district was visited by L. C. Graton in 1905, during a geologic reconnaissance of New Mexico, and his report was published in 1910.[1] Sidney Paige studied the district more in detail in 1910, as part of his study of the Silver City quadrangle, and presented his report in the Silver City folio, published in 1916.[2] His geologic map is on a scale of 1:125,000. Subsequently A. C. Spencer, assisted for a while by Paige, began a detailed study for the United States Geological Survey of that part of the Central district around Hanover and Santa Rita, mapping on a scale of 1:24,000.

[1] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 305–318, 1919.

[2] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (no. 199), 1916.

This area includes the vicinity of the Ground Hog mine, but Spencer concentrated on the deposits at Hanover and Santa Rita and completed his field work before the Ground Hog ore shoot had been exposed sufficiently for study. I was able to visit the Ground Hog mine for a few days in October 1930, in anticipation of the detailed study that was to be made later, and my observations during that brief visit have been recorded.[3] Field work for the present report was started April 14, 1931, and continued without interruption until September 11 of the same year. Headquarters were then established with the New Mexico Bureau of Mines and Mineral Resources at Socorro, through the courtesy of E. H. Wells, director of the bureau, and short visits were made to the field whenever it became desirable to do so; one of these was for the purpose of a field consultation with Spencer and Paige, from which I profited considerably.

I am glad of this opportunity to express my indebtedness to S. G. Lundy and A. W. Thomas, of the topographic branch of the United States Geological Survey, who prepared a special topographic base map of the Bayard area on a scale of 1:12,000. The remarkable accuracy of this map facilitated geologic mapping to a notable degree. The cooperation tendered by interested parties has been cordial and complete; the management of the Chino branch of the Nevada Consolidated Copper Co. offered blanket permission to investigate and use any information in its possession and placed office space and equipment at my disposal, and the officials of the Ground Hog unit of the Asarco Mining Co. were equally liberal. Special acknowledgments should be made to the late John M. Sully, general manager, G. J. Ballmer, chief geologist, and W. L. Emerick, assistant geologist, of the Chino mines; to B. M. Hatcher, manager, the late F. W. Richard, superintendent, M. N. Hawkins, engineer, and C. Elayer, foreman, of the Ground Hog mine; to Ira Wright, manager, and W. Wright, engineer, of the Black Hawk Consolidated Mines Co.; to A. P. Mracek, owner of the Three Brothers Mining Co.; and to C. R. Altman of Silver City, part owner of the Betty-Jo group of claims.

I am indebted to geologists of the New Mexico Bureau of Mines and Mineral Resources, particularly to Prof. Sterling B. Talmage, for critical discussion of parts of the manuscript.

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The following list contains the names of all published reports and of the larger private reports on the Bayard area that have come to my attention.

[3] Lasky, S. G., Geology and ore deposits of the Ground Hog mine, Central district, Grant County, N. Mex.: New Mexico School of Mines, State Bur. Mines and Min. Res., Circ. 2, 1930.

1870. Raymond, R. W., Statistics of mines and minerals west of the Rocky Mountains (2d report), p. 404, U. S. Treasury Department. Contains notes on a few of the mines in operation at the time.

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1930. Lasky, S. G., Geology and ore deposits of the Ground Hog mine, Central district, Grant County, N. Mex.: New Mexico School of Mines, State Bur. Mines and Min. Res., Circ. 2. Observations prefatory to the present report.

1933. Schmitt, Harrison, The Central mining district, N. Mex.: Am. Inst. Min. Met. Eng. Contr. 39. Deals chiefly with correlation of geologic phenomena in the three subdistricts, Fierro, Hanover, and Santa Rita.

1935. Spencer, A. C., and Paige, Sidney, Geology of the Santa Rita mining area, New Mexico: U. S. Geol. Survey Bull. 859.

GEOGRAPHY

LOCATION

The Central mining district is in eastern Grant County, N. Mex., and officially includes the subdistricts of Hanover, Fierro, and Santa Rita, as well as the claim locations near the town of Central. Central is 7½ miles due east of Silver City, the county seat, and about midway along the 18-mile highway between Silver City and Santa Rita. Fort Bayard, a Federal hospital, is a mile north of Central.

The Bayard area covers 8.75 square miles in the southwest corner of the Central mining district and is contiguous on the east to the town of Central. Figure 1 shows the relation of this area to the area covered by the Santa Rita special map and its position within the Silver City quadrangle. The district is reached by the Santa Rita-Hanover branch of the Atchison, Topeka & Santa Fe Railway, which leaves the Deming-Silver City branch at Whitewater. Highway 180 crosses the district from Santa Rita to Central and continues through Silver City to a junction at Lordsburg with the southern United States transcontinental highway 80. State highway 11, which starts at Deming, also on the transcontinental route, joins highway 180 at Bayard station.

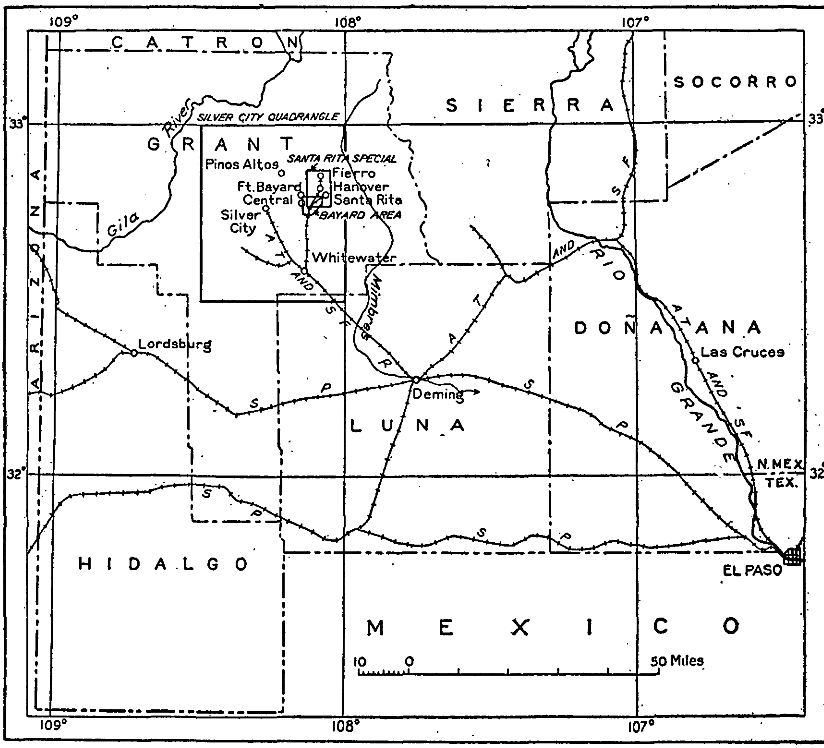


FIGURE 1.—Map showing location of the Bayard area of the Central mining district, N. Mex.

SURFACE FEATURES

The Central mining district is in the transitional fringe of disordered structure and mountainous surface between the Mexican Highland of the Basin and Range province and the southern volcanic lobe of the Colorado Plateaus.[4] The Bayard area lies in the foothills of this fringe, at their junction with the featureless desert flat that spreads for many miles southward, the southernmost boundary of the area being almost at the edge of the desert alluvium, tongues of which penetrate along Whitewater and Cameron Creeks.

Whitewater Creek is the principal drainageway for most of the Central district. Tributary to it are Santa Rita and Hanover

[4] Fenneman, N. M., Physiography of western United States, pp. 317–328, 379–393, New York, 1931.

Creeks and Gold Gulch. Cameron Creek flows along the west edge of the mapped area and drains the vicinity of Central and Fort Bayard. Both Whitewater and Cameron Creeks, extending southward, become lost in the desert fill before reaching the Mimbres River, which is the major drainage outlet for this part of the eastern slope of the Continental Divide.

The most marked surface feature of the locality is the difference between the topography of the area of volcanic rocks and that of the area in which these rocks have been eroded away. Whitewater Creek is roughly the dividing line between these naturally distinct areas. The volcanic flows cap a group of rugged hills along the southeastern border of the area mapped. (See pl. 1.) The average altitude of these hills, which are at the western edge of a volcanic range extending southward from Santa Rita, is about 6,400 feet. San Jose Mountain is a detached mass cut off by Bayard Canyon along the line of the Ground Hog fault. The hills rise on moderate lower slopes to high, rough, jointed cliffs and are cut by many steep, bare canyons. (See pl. 3, *A*.) Where the canyons have cut through to the underlying softer tuffs and sands they have widened out into open valleys by ragged retreat of the cliffs. Retreat by landsliding is a common feature, and three of the landslides are shown on the geologic map. A few outliers of the volcanic hills, almost destroyed by nearly complete removal of the lava blanket, lie in the southwest corner of the district, which is covered chiefly by the tuffaceous sand and gravel that lie between the lava and the pre-Tertiary rocks.

The area from which the Tertiary rocks have been stripped occupies roughly the north half of the district and is underlain chiefly by quartz diorite sills. The surface is gently rolling, having a maximum relief of only 150 feet, and gradually rises toward higher hills in Pennsylvanian and Cretaceous sediments to the north. (See pl. 3, *B*.) This rolling surface cannot be much different, in either altitude or contour, from the prevolcanic surface, which where exposed shows the same gentle character. The prevolcanic surface was one from which topographic expression of structure had been essentially removed, and the present erosion cycle has not yet been able to modify it greatly. Plate 4, *A*, shows the absence of topographic expression along the Copper Glance fault, which at that place has shale of the Colorado formation in one wall and quartz diorite in the other. Paige [5] states that the broad features of the present relief of the entire Cretaceous area of the Silver City quadrangle were probably well developed before they were covered by the flood of lava. The present surface in the Bayard area is

[5] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (no. 199), p. 13, 1916.

scratched by numerous minor arroyos and is sharply trenched along the main creeks and their tributaries, but the arroyos are only partly guided by structure, and the trenching appears to have been geologically recent, as shown by patches of cemented stream conglomerate along many of the arroyos tributary to Santa Rita and Hanover Creeks. The base of the conglomerate averages about 10 feet above the present arroyo bottoms, but at the south end of the Cashier claim a patch of this rock is perched on top of a hill about 40 feet above the adjacent creek bed.

Small areas of loose gravel were found on the low noses and hills on each side of Santa Rita Creek at the east edge of the area mapped. The material consists chiefly of fragments of the Colorado formation, but mingled with them are also fragments of Beartooth quartzite, of limestone, and of the stream conglomerate just mentioned. Rounded pebbles of magnetite that must have been transported from the area of metamorphosed limestone several miles to the north are abundant. These accumulations of loose gravel are about 40 feet above the present bed of Santa Rita Creek. The bench on the west bank of Hanover Creek at the north edge of the area mapped is covered with a similar skin of gravel, and the flat west of the Hanover highway on the Fort Bayard Reservation is covered with a thin layer of gravel that contains considerable basalt. Paige[6] believes that an early Quaternary gravel sheet at one time covered the region and that these gravel deposits are remnants of it. What appears to be an old stream channel related to the gravel sheet is situated in a saddle in the lava at the south end of the Morrison homestead, on the drainage divide between Whitewater and Cameron Creeks. Rounded pebbles and cobblestones of magnetite have been sorted from the loose debris there and, it is reported, shipped for iron ore.

None of the Quaternary gravel is shown on the geologic map.

CLIMATE AND VEGETATION

The Bayard area has the climate of the semiarid section of the Southwest. A Federal hospital for the care and treatment of tubercular war veterans is located at Fort Bayard. The average annual temperature is 54.7°, practically the same as the average for the State. The mean minimum temperature is 41.4°, and the mean maximum temperature 68°. Cloudless days are the rule throughout the year. In the summer the days are brilliant and hot, sometimes scorchingly hot, but the nights are cool and comfortable. Torrential downpours and daily afternoon showers occur during a part of the summer and relieve the intense heat. The wet season begins early

[6] Paige, Sidney, oral communication.

in July and continues through August, the precipitation gradually declining thereafter until November. Over 40 percent of the annual precipitation falls in July and August, and as much as 10 percent may fall in a single downpour. Records for Santa Rita show a minor wet season in the spring that is lacking at Fort Bayard, and the average precipitation at Santa Rita is about 20 percent greater than at Fort Bayard. The average annual snowfall amounts to about 16 inches. The following table of climatic data has been compiled from official records for Fort Bayard[7] and Santa Rita.[8]

Climatic data for the Central mining district, N. Mex.

	Precipitation (inches)		Average number of days with precipitation	Average evaporation[1] (inches)	Temperature (° F.)					
	Average	Snowfall			Mean	Mean maximum	Mean minimum	Mean range	Highest[2]	Lowest[2]
January	0.79	3.4	4	2.83	38.4	50.7	26.0	24.7	76	−12
February	1.00	3.1	4	3.96	41.3	53.9	28.6	25.3	80	5
March	.92	3.1	5	6.89	45.7	59.0	32.3	26.7	85	9
April	.52	.5	3	9.68	52.7	66.8	38.5	28.3	87	19
May	.50	Tr.	3	12.86	60.8	75.4	46.1	29.3	93	25
June	.82	0	4	13.85	70.6	85.5	55.6	29.9	103	35
July	3.74	0	12	13.85	72.1	84.7	59.5	25.2	100	46
August	3.70	0	12	9.05	70.4	83.1	57.7	25.4	98	45
September	2.05	0	7	7.98	65.4	78.4	52.5	25.9	100	31
October	1.38	.2	4	7.30	56.0	69.8	42.2	27.6	85	19
November	.83	1.2	3	4.20	45.9	59.2	32.5	26.7	78	−1
December	1.08	4.4	5	3.06	36.9	48.6	25.3	23.3	72	4
Annual	17.23	15.9	66	92.3	54.7	68.0	41.4	26.6	103	−12

[1] At Santa Rita. [2] At Fort Bayard.

The rocks of the district are usually free of soil and debris, and vegetation of all kinds is scanty. The plants consist chiefly of short-root grasses and low woodland brush, and the area is generally regarded as range land. Sagebrush, several varieties of cactus, the higher-mesa range grasses, perennial weeds, and beargrass are the common growths. The few scattered trees consist of scrub oak and mountain mahogany, which seem to occur more abundantly on the tuffaceous rocks at the base of the lavas than elsewhere in this vicinity. Good stands of timber, which include aspen, oak, and several varieties of coniferous trees, grow on the higher slopes to the north, where precipitation is somewhat greater and where the snow melts more slowly.

WATER

All streams of the area are intermittent except for a few stretches fed by springs. They flow only during periods of melting snows

[7] Linney, C. E., Garcia, Fabian, and Hollinger, E. C., Climate as it affects crops and ranges in New Mexico: New Mexico Coll. Agr. and Mech. Arts, Agr. Exper. Sta., Bull. 182, pp. 25–26, 1930.

[8] Furnished by New Mexico State engineer's office; records kept by Chino Copper Co.

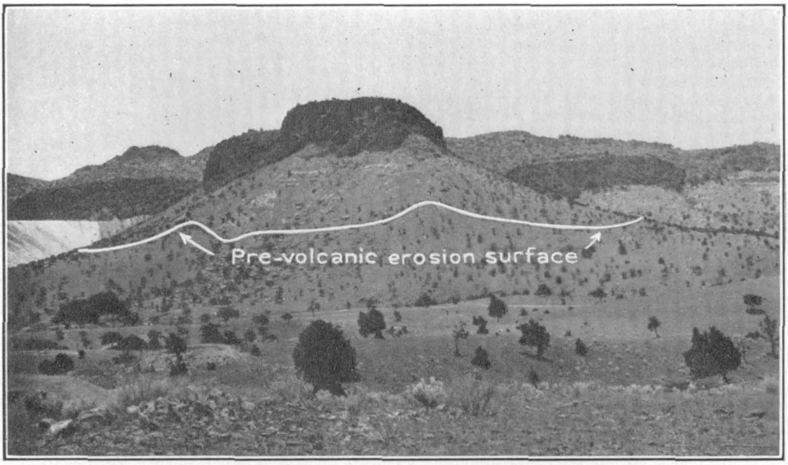
and during the summer rains but may become temporary torrents immediately after a summer cloudburst. Nearly all the springs occur along fault lines, and a few of them furnish a local water supply for domestic use. Water is generally obtained from wells, which must be drilled to depths of several hundred feet if a large supply is needed. Santa Rita procures its water from wells 600 to 2,000 feet deep; this water has an average hardness [9] of 27.34 parts per 100,000, of which 18.04 parts is permanent and 9.3 parts temporary. The water supply for Fort Bayard is obtained from a group of 21 springs 3 to 6 miles north of the post.

Ground-water level lies nearly at the same altitude as the present stream level, the water in shafts and wells throughout the area rising approximately to the altitude of the nearest large arroyo. Mine workings will therefore remain dry to a maximum depth of 150 feet. Only in the western part of the area, where an appreciable thickness of sandstone dips under the surface, may water be expected to handicap mining operations. (See pl. 2.) Elsewhere, except in the Ground Hog zone, only shale, quartzite, limestone, and igneous rocks will be penetrated, and any water that these rocks may yield should be readily controlled.

A well about 750 feet northwest of the Three Brothers shaft had to be drilled to a depth of 440 feet before the moderate supply of water needed for domestic purposes could be obtained. Three water-bearing zones were cut—the first in a quartz diorite sill at a depth of 240 feet, the second in Magdalena limestone at a depth of 398 feet, and the third also in Magdalena limestone at a depth of 440 feet. The main flow comes from the third zone. At the Johney shaft water stands 85 feet below the collar; the shaft is 200 feet deep, and it was necessary to pump about 10 gallons a minute to keep it dry. A well at the highway Y southwest of Bayard station is said to have passed through 20 feet of tuffaceous gravel and 222 feet of intrusive igneous rock before more than a scanty seepage of water was obtained. At a depth of 242 feet the well penetrated shale of the Colorado formation and encountered a strong flow of water that rose within 30 feet of the surface. The drillers estimated, by bailing, that the well furnished 15 gallons a minute.

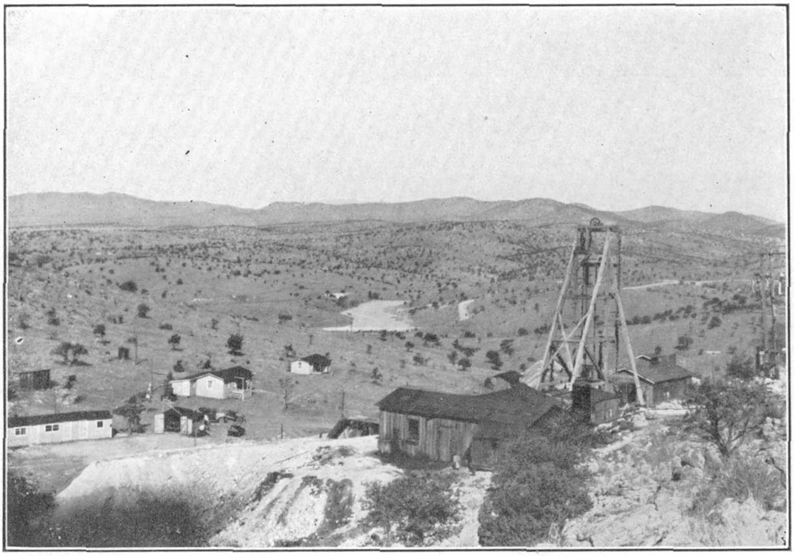
The Ground Hog mine and the other mines along the Ground Hog fault zone will probably always have more water to handle than may be encountered elsewhere in the area. Much of the water of those mines is derived from the porous Tertiary sediments in the hanging wall of the Ground Hog fault and may represent the underground drainage of a large area east of the mines. In 1924,

[9] Thorne, H. A., Mining practice at the Chino mines, Nevada Consolidated Copper Co., Santa Rita, N. Mex.: U. S. Bur. Mines Inf. Circ. 6412, p. 24, 1931.



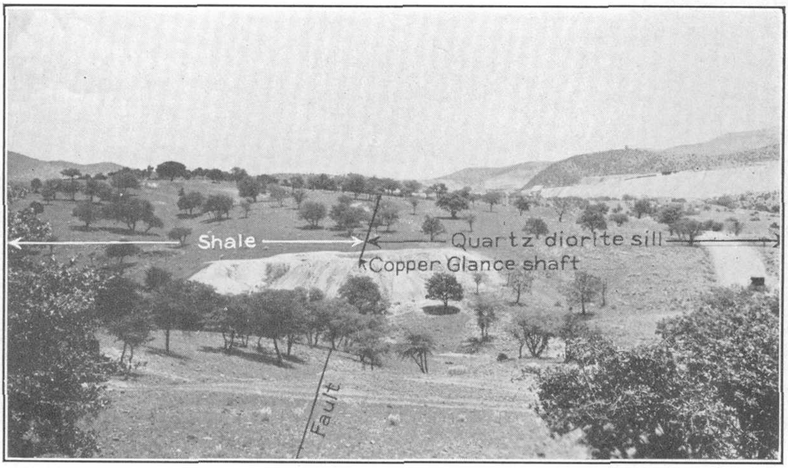
A. VOLCANIC HILLS ON THE SOUTH BANK OF SANTA RITA CREEK.

Showing quartz latite cliffs resting on bedded volcanic sediments. Note the gentle character of the prevolcanic erosion surface. White area to the left is the edge of the Chino mines waste dump. Looking nearly due south.



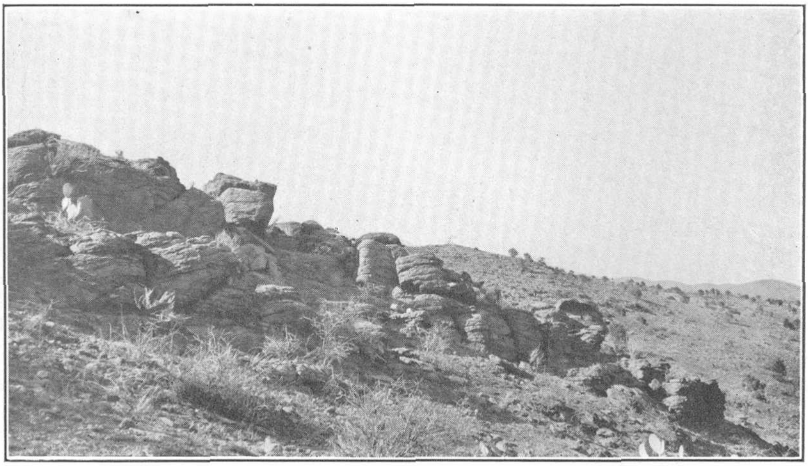
B. ROLLING TOPOGRAPHY OF THE NORTH HALF OF THE BAYARD AREA.

Showing the gradual rise toward the higher hills to the north. Looking north from Ground Hog shaft No. 1; Hanover Creek in the middle foreground. Courtesy of the Asarco Mining Co.



A. VIEW LOOKING EASTWARD ALONG THE COPPER GLANCE FAULT AT THE COPPER GLANCE MINE

Showing absence of topographic expression. Chino mines waste dump to the right.



B. BASAL SHEETING OF MIDDLE SILL, LOST MINE CLAIM.

Contact is at base of scarp.

after the Ground Hog mine had been idle for nearly 4 years, water stood about 300 feet below the collar of shaft 1, at an altitude of 5,820 feet. At the same time it stood 200 feet below the collar of the San Jose shaft, about 1,300 feet to the northeast, or at an altitude of 5,900 feet. The Ground Hog mine pumped steadily 5 gallons a minute when the bottom workings were 310 feet below the surface (altitude 5,750 feet) and after the overlying ground had been drained; about 10 gallons a minute from 410 feet below the surface under the same conditions; and in the spring of 1932 before the overlying 100-foot block of ground had been drained, about 20 gallons a minute from 510 feet below the surface. Presumably about one-fourth of the 20 gallons a minute represented water from local pockets.

GEOLOGY

GENERAL CHARACTER AND DISTRIBUTION OF THE ROCKS

The rocks exposed in the Bayard area include Pennsylvanian, Cretaceous, Tertiary, and Quaternary sedimentary formations; late Cretaceous or early Tertiary intrusive rocks; and Tertiary (Miocene?) dikes and lava flows. Older rocks have been cut by drill holes in the area and crop out in the surrounding territory, particularly east and north of Santa Rita, where every system of the Paleozoic era is represented. These rest on pre-Cambrian rocks and dip southwestward under the Bayard area; some of them are host rocks for large ore deposits in the adjoining parts of the Central district, and there are strong possibilities that these favorable formations may contain ore deposits where cut by the veins of the Bayard area. For that reason a short description of the unexposed rocks is given in the following pages.

The Paleozoic rocks have been studied in detail by Paige,[10] Wells,[11] Schmitt,[12] Landon,[13] and Spencer,[14] and the descriptions and measurements of the formations that do not crop out in the Bayard area are based mainly on their work. The exposed sedimentary rocks consist primarily of Colorado sandstone and shale and of a series of Tertiary (Miocene?) gravel, sand, and tuff that preceded the extrusion of the lavas and were deposited on the eroded surface of the earlier rocks. Bands of Upper(?) Cretaceous Beartooth quartzite and Pennsylvanian Syrena formation that dip under the Colorado formation fringe the mapped area on the north.

[10] Paige, Sidney, op. cit. (Folio 199), pp. 3–6.
[11] Wells, E. H., private report for the Chino Copper Co.
[12] Schmitt, Harrison, unpublished manuscripts.
[13] Landon, R. E., dissertation, University of Chicago, 1929.
[14] Spencer, A. C., and Paige, Sidney, Geology of the Santa Rita mining area, N. Mex.: U. S. Geol. Survey Bull. 859, pp. 12–28, 1935.

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The igneous rocks include quartz diorite sills of two ages; granodiorite porphyry dikes, the parent rock of which is represented by granodiorite stocks at Santa Rita and Hanover; quartz latite dikes; and quartz latite flows. They constitute about three-fourths of all rocks exposed in the Bayard area, and of this portion nearly four-fifths consists of the quartz diorite sills. In vertical section the sills make up 32 percent of all rocks above the pre-Cambrian. They have been observed in formations from the Devonian up and have an aggregate thickness ranging from about 750 to over 2,200 feet. The three largest sills are in the Colorado formation and crop out in the Bayard area, where the lower and middle of the three are the principal host rocks for the known ore deposits. Spencer and Paige [15] describe these three sills as a single intrusive, which they call the "Fort Bayard laccolith", but later field observations show that the "Fort Bayard laccolith" is made up of three distinct sills and that the middle sill is later than the others.

The quartz latite dikes and porphyry flows seem to be closely related, though to the unaided eye they appear to be decidedly different rocks. The dikes are believed to be subsurface representatives of the flows, though not necessarily feeders to them; the main feeders were probably a group of stocks, lithologically similar to the dikes, that crop out elsewhere in the Silver City quadrangle.

The igneous rocks may be classified in several ways—according to geologic age, origin, form, alteration, or age relations to mineralization and to economic metallization. The subjoined table is a summary of these classifications. It will be noted that each classification contains a group that coincides with one of the mineralization groups, and thus the whole table may be considered a single classification that shows the age relations between the different rocks and the mineralization of the area. In the economic aspect the chart shows two broad groups—one of plutonic origin and late Cretaceous or early Tertiary age, the members of which were intruded before the period of economic metallization—that is, before the period of ore formation; and a second group consisting of Tertiary (Miocene?) lava flows and associated dikes that were emplaced after that period. A long period of erosion uncovered the ore deposits and exposed them to oxidation before any of the Miocene (?) volcanic rocks were deposited. For convenience, the rocks of the plutonic group are referred to hereafter in this report as of Cretaceous (?) age. They are described in the section entitled "Cretaceous rocks."

[15] Spencer, A. C., and Paige, Sidney, Geology of the Santa Rita mining area, N. Mex.: U. S. Geol. Survey Bull. 859, pp. 33–34, 1935.

Classification of the igneous rocks of the Bayard area

<table>
<tr><th>Petrographic name</th><th>Geologic age</th><th>Origin</th><th>Form</th><th>Age relation to mineralization</th><th>Age relation to economic metallization</th><th colspan="2">Hydrothermal alteration</th></tr>
<tr><td rowspan="2">Quartz latite.</td><td rowspan="2">Tertiary (Miocene ?).</td><td rowspan="2">Volcanic.</td><td>Surface flows.</td><td>Later.</td><td rowspan="2">Later.</td><td colspan="2">None.</td></tr>
<tr><td rowspan="2">Dikes.</td><td rowspan="3">Broadly contemporaneous.</td><td>Without epidote.</td><td rowspan="5">Sericite, calcite, quartz, chlorite, albite.</td></tr>
<tr><td>Granodiorite porphyry.</td><td rowspan="4">Early Tertiary or late Cretaceous.</td><td rowspan="4">Plutonic.</td><td rowspan="4">Earlier.</td><td rowspan="4">Epidote.</td></tr>
<tr><td>Granodiorite.</td><td>Stocks.[1]</td></tr>
<tr><td>Later quartz diorite.</td><td rowspan="2">Sills.</td><td rowspan="2">Earlier.</td></tr>
<tr><td>Earlier quartz diorite.</td></tr>
</table>

[1] At Santa Rita, half a mile east of the Bayard area, and at Hanover and Copper Flat.

The following table shows the sequence and thickness of the formations in the Bayard area:

Sequence of geologic units and mineralization in the Bayard area of the Central mining district, New Mexico

<table>
<tr><th>Age</th><th>Subdivision</th><th>Character and economic value</th><th>Thickness (feet)</th></tr>
<tr><td rowspan="4">Quaternary.</td><td>Alluvium.</td><td>Unconsolidated sand, gravel, and clay, filling desert flat south of and encroaching upon the Bayard area.</td><td></td></tr>
<tr><td>Formation of placer deposits.</td><td>Noncommercial gold placer deposits derived from the veins.</td><td></td></tr>
<tr><td>Gravel.</td><td>Cemented gravel along some arroyos and streams, generally trenched. Loose gravel on low hills and benches.</td><td></td></tr>
<tr><td>Basalt.</td><td>One short dike noted.</td><td></td></tr>
<tr><td>Unconformity—</td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Tertiary (Miocene?).</td><td>Quartz latite flows.</td><td>Pseudobedded brown porphyry. Lower few feet is white and dull and grades downward into tuff.</td><td>0–600.</td></tr>
<tr><td>Mineralization.</td><td>Sericite-quartz-pyrite alteration of quartz latite dikes; noncommercial.</td><td></td></tr>
<tr><td>Quartz latite dikes.</td><td>Gray fine-grained porphyry. Approximately contemporaneous with "brown sand."</td><td></td></tr>
<tr><td>Brown sand.</td><td>Lenses of nonvolcanic, roughly sorted angular conglomerate in cross-bedded impure brown volcanic sand.</td><td>0–20.</td></tr>
<tr><td>Gravel, sand, and tuff.</td><td>Thin-bedded water-sorted pure volcanic sand; tuffaceous gravel, locally bedded and sorted; and subordinate layers of massive tuff.</td><td>10–400.</td></tr>
<tr><td>Unconformity—</td><td></td><td></td><td></td></tr>
</table>

Sequence of geologic units and mineralization in the Bayard area of the Central mining district, New Mexico—Continued

Age	Subdivision	Character and economic value	Thickness (feet)
Early Tertiary or Late Cretaceous.	Economic metallization.	Quartz-sulphide and quartz-calcite-sulphide veins carrying gold, silver, copper, lead, and zinc. Include the important ore deposits of the Bayard area.	
	Granodiorite porphyry dikes.	Varitextured porphyry characterized by thick books of biotite and phenocrysts of titanite.	
	Mineralization.	Auriferous quartz-pyrite veins; noncommercial.	
	Quartz diorite sills.	Of two ages. Most prominent in the Colorado formation but occur in all formations from the Percha shale up. The later quartz diorite is medium-grained and nearly granitic in texture. The earlier quartz diorite is characterized by large doubly terminated quartz phenocrysts and by the presence of biotite. The large sills are markedly crosscutting. Principal host rock for the known ore deposits of the Bayard area.	0–1,675± (in Colorado formation).
Unconformity—			
Upper Cretaceous.	Colorado formation.	Upper or sandstone member. Lower beds are thin-bedded sandstone and include several limy fossiliferous layers; upper beds are more massive, in part quartzitic sandstone interbedded with subordinate shale. Contains the major sill of the area, which ranges in thickness from about 375 to about 750 feet.	130± –450+ (130± –1650+ including sills).
		Lower or shale member. Light to dark-colored shale, rough-grained to slaty and slabby; locally sandy or calcareous. Contains a sill as much as 450 or 475 feet thick.	190–220 (190–695± including sills).
Upper (?) Cretaceous.	Beartooth quartzite.	In general, dominantly massive vitreous quartzite; inludes sandstone and limy and shaly beds that locally are predominant.	66–142.
Unconformity—			
Permian.	Abo redbeds.	Mostly red shale, but includes several limestone beds. Crops out at Santa Rita, and unexposed remnants may be present in Bayard area.	0–207.
Pennsylvanian.	Magdalena group. Syrena formation.	Alternating limestone, in part shaly, and shale, in part limy; shale in excess in lower 130 feet (Mountain Home shale of local geologists); limestone in excess in upper part. Contains several quartz diorite sills, the aggregate thickness of which ranges from 90 to 290 feet. Contains the ore deposits of the Three Brothers mine.	170–390 (170–680 including sills).
	Magdalena group. Oswaldo formation.	Thick-bedded shaly fossiliferous limestone containing 20 to 30 feet of basal shale ("parting shale"). In the northern part of the Central district contains a persistent thin sill of quartz diorite about 110 feet above the base. Host rock for some of the zinc ores near Hanover.	400–430 (400–475 including sill).
Unconformity—			
Mississippian.	Lake Valley limestone.	Lower part massive slate-gray limestone, slightly cherty; upper part white crystalline crinoidal limestone. *Principal host rock for the zinc ores at Hanover.*	240–450.
Upper Devonian.	Percha shale.	Lower part soft black fissile shale, upper part gray calcareous shale containing numerous lime nodules. Near Fierro contains several quartz diorite sills ranging up to 400 feet in thickness.	100–300 (100–700 including sills).
Unconformity—			

Sequence of geologic units and mineralization in the Bayard area of the Central mining district, New Mexico—Continued

Age	Subdivision	Character and economic value	Thickness (feet)
Silurian.	Fusselman limestone.	Nearly identical with the Montoya limestone but contains characteristic fossils. Contains the silver deposits at Georgetown.	40±.
Upper Ordovician.	Montoya limestone.	Massive cherty dolomitic limestone.	180–410±.
Unconformity——			
Lower Ordovician.	El Paso limestone.	Gray limestone, in part dolomitic. Sandy and slabby in lower part, cherty and more massive in upper part. Important host rock for iron ore at Fierro.	216–478.
Upper Cambrian.	Bliss sandstone.	Chiefly glauconitic and hematitic cross-bedded sandstone and quartzite above a basal conglomerate; alternating beds of dolomite and dolomitic limestone in upper part. Contains a little iron ore at Fierro.	145–186.
Unconformity——			
Pre-Cambrian		Granite, gneiss, and schist.	
Approximate thickness of sedimentary rocks above pre-Cambrian [1]			1,892–4,123.
Approximate thickness of all rocks above pre-Cambrian, including sills and flow rocks.[1]			1,892–6,926+.

[1] The rocks below the upper part of the Syrena formation are not exposed in the Bayard area, and the thicknesses of these rocks as given in the table refer to exposures in neighboring areas. The totals derived from the figures in the table are therefore only approximate for the Bayard area.

UNEXPOSED ROCKS

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks of this area are similar to the pre-Cambrian elsewhere in New Mexico. The nearest exposures are at Fierro, where schist and gneiss are exposed at several places in the mines and around the border of the Cretaceous stock,[16] and near and along the San Lorenzo road, 6 miles east of Santa Rita, where gabbro (?), granite gneiss, and schist are exposed.

CAMBRIAN SYSTEM

BLISS SANDSTONE

The Bliss sandstone, of Upper Cambrian age, overlies the pre-Cambrian rocks throughout southern New Mexico.[17] In the Central district the formation crops out at a few places around the border of the Hanover stock and is well exposed along the San Lorenzo road east of Santa Rita. At Fierro, where it is the host rock for a small amount of ore, it has been squeezed and metamorphosed, and

[16] Kniffin, L. M., Mining and engineering methods and costs at the Hanover Bessemer Iron & Copper Co., Fierro, N. Mex.: U. S. Bur. Mines Inf. Circ. 6361, pp. 2–3, 1930.

[17] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 4, 1928.

its thickness ranges from 150 to 186 feet. It is 164 feet thick along the San Lorenzo road where measured by Wells and 145 feet where measured by Landon. In that vicinity, where examined by me, the lower 20 feet consists of conglomerate and conglomeratic sandstone containing pebbles and large boulders of the underlying pre-Cambrian rocks. Discontinuous layers of hematite several inches thick are prominent. The remainder of the section consists of layers of gray to green, brown, and maroon cross-bedded sandstone and quartzite 4 to 20 feet thick, separated by thin layers of dolomite and dolomitic limestone. Glauconite is a conspicuous constituent of most of the sandy beds.

The top of the Bliss formation is not well defined in the Silver City quadrangle but is taken at the horizon where the strata cease to be dominantly arenaceous, generally at the top of a thin glauconitic or quartzitic sandstone.

ORDOVICIAN SYSTEM

The Ordovician system is represented by the El Paso limestone (Lower Ordovician) and Montoya limestone (Upper Ordovician). No Middle Ordovician rocks are present. These formations are roughly coextensive with the Bliss sandstone in southern New Mexico and apparently are conformable with it. In the Silver City region the basal beds of the Montoya limestone are not generally distinguishable from the upper beds of the underlying El Paso limestone.

EL PASO LIMESTONE

The El Paso formation consists dominantly of thin-bedded limestone but includes subordinate dolomitic beds. In its lower part the formation is sandy and the bedding planes are mottled with impurities that weather out in irregular narrow bands; these markings help to distinguish the El Paso limestone from the upper part of the Bliss sandstone. The upper part of the formation is more massive than the lower part, and some beds are very cherty.

The thickness of the El Paso limestone varies widely in the Silver City quadrangle. Paige[18] gives the probable maximum as 900 feet. It is 478 feet along the San Lorenzo road as measured by Wells, but according to Landon and Schmitt the thickness is as little as 216 feet near the Hanover-Fierro stock, where the beds have been stretched and thinned.

The El Paso limestone is the main host rock for the contact-metamorphic iron ores at Fierro.

[18] Paige, Sidney, op. cit., p. 4.

MONTOYA LIMESTONE

In the vicinity of Santa Rita and Hanover the basal member of the Montoya limestone is a 10-foot bed of white cross-bedded quartzitic sandstone. Above this the formation consists of massive beds of gray to pink and white dolomite. Nodules and layers of white and pink chert are found throughout the formation and are prominent near the top.

The Montoya limestone is between 300 and 330 feet thick in the vicinity of Silver City. This is about the same as the thickness measured by Schmitt near Fierro, but Wells gives a generalized section to apply at Santa Rita that totals about 410 feet. According to Spencer,[19] the combined thickness of the Montoya and overlying Silurian Fusselman limestone at Fierro may be as low as 220 feet; Landon measured the combined thickness of the two formations along the San Lorenzo road as more than 225 feet.

SILURIAN SYSTEM

FUSSELMAN LIMESTONE

The Fusselman limestone can be distinguished from the underlying massive dolomitic and cherty Montoya limestone only by means of fossils. It is about 40 feet thick. The silver deposits at Georgetown, about 5 miles northeast of Santa Rita, are in the Fusselman limestone just below the overlying Devonian Percha shale.

DEVONIAN SYSTEM

PERCHA SHALE

The Upper Devonian Percha shale is widespread over southern New Mexico. It attains its greatest thickness—500 feet—in the Silver City quadrangle, where it rests unconformably on the Fusselman limestone. Good exposures crop out east of the Central district from Georgetown southward, and at those places the formation consists of 100 feet of black fissile shale overlain by about 80 feet of gray shale containing calcareous nodules, and by 20 feet of limy shale and fossiliferous shaly limestone, a total thickness of about 200 feet. There is a complete gradation from the noncalcareous shale of the lower part through the calcareous upper part and into the massive limestone of the overlying Lake Valley formation. In the Central district, where the Percha shale is exposed only in the Hanover Basin, the observed thickness ranges from 100 to 300 feet. The formation contains several sills, the largest of which is as much

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[19] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 342, 1928.

as 400 feet thick, that are similar to the quartz diorite sills of the Bayard area.

On the Nellie Patterson no. 5 claim, in the northern part of the Bayard area, a drill hole 200 feet south of the township line cuts the Percha shale at a vertical depth of 1,280 feet (altitude 4,995 feet).

CARBONIFEROUS SYSTEM

LAKE VALLEY LIMESTONE

The Lake Valley limestone (of lower Mississippian age) grades from the underlying Percha shale through an argillaceous transition zone 10 to 40 feet thick. Above the transition zone is about 200 feet of massive slate-gray varitextured limestone that weathers to pale drab gray. This is known in the Hanover-Santa Rita area as the "lower blue limestone." According to Schmitt, this member as a whole contains about 85 percent of $CaCO_3$ and about 1 percent of chert. The chert lenses are generally gray but may be black in the upper few feet of the member. The lower blue limestone is overlain by 80 to 175 feet of white crinoidal limestone containing about 15 percent of white chert in lenses 2 to 5 inches thick.

The thickness of the Lake Valley formation ranges from 245 to 450 feet; this wide range is the result of plastic deformation incident to igneous intrusion.

The Lake Valley limestone, particularly the crinoidal limestone member, carries most of the zinc ore in the Hanover district.

MAGDALENA GROUP

The Magdalena group, of lower Pennsylvanian age, has been divided by local geologists into an upper and a lower division, called by Spencer[20] the "Syrena" and "Oswaldo" formations respectively. At the base of the Oswaldo formation is a 20- to 30-foot bed of shale carrying abundant plant remains and known as the "parting shale." The remainder of the Oswaldo formation consists of 380 to 400 feet of thick-bedded fossiliferous limestone containing a few beds of shale. At 90 feet above the parting shale is a quartz diorite sill 40 to 45 feet thick, called the "marker sill", which is rather consistent in thickness and position over most of the district and which forms a very convenient horizon marker. The drill hole on the Nellie Patterson No. 5 claim in the Bayard area cuts the top of the marker sill at a vertical depth of 995 feet (altitude 5,280 feet). At that place the marker sill is only about 12 feet thick, and probably it thins out altogether to the south.

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[20] Spencer, A. C., and Paige, Sidney, op. cit., pp. 22–26.

The dividing plane between the Syrena and Oswaldo formations is at the base of a body of shale 100 to 130 feet thick, which is known locally as the "Mountain Home shale", from the Mountain Home claim of the Empire Zinc Co., where it is well exposed. This member contains 10 to 25 percent of limestone in thin beds and irregular lenses. The remainder of the Syrena formation contains alternating beds of limestone and shale in the proportion of 60 percent of limestone and 40 percent of shale. This part of the formation, variously referred to by local geologists as the "Humbolt formation" and the "Don limestone", contains several discontinuous quartz diorite sills.

The maximum thickness of the Syrena formation is 390 feet. The formation is about 300 feet thick where cut in diamond-drill holes on the Rio Grande and Bull Frog claims, in Gold Gulch, in the Bayard area. In the drill holes on the Nellie Patterson No. 5 claim the thickness, as adjusted for dip of beds and pitch of holes, is only 170 feet; Ballmer[21] obtained a thickness of 185 feet by measurement a few hundred feet to the north. A well just within the Fort Bayard military reservation west of the Three Brothers mine passes through 295 feet of Syrena formation and stops with the bottom still in that formation.

The total thickness of the entire Magdalena group in the Central district, exclusive of all sills, ranges from 570 to 820 feet. The several sills have an average aggregate thickness of at least 250 feet.

ABO REDBEDS

In the Bayard area the Cretaceous rocks rest directly upon the Syrena formation, but north and east of this area are several exposures of rocks that have been correlated with the Abo redbeds, of Permian age. Wells measured a section 207 feet thick half a mile east of the San Juan road and about 5 miles southeast of Santa Rita. The formation there consists of red shale and subordinate limestone and sandy shale and covers an area of several square miles. Spencer[22] found the Abo at several other places also, some of it in the mine pits at Santa Rita.

EXPOSED ROCKS

CARBONIFEROUS SYSTEM

SYRENA FORMATION

The Syrena formation, the upper formation of the Magdelena group, is the oldest rock exposed in the Bayard area. It crops out

[21] Ballmer, G. J., personal communication.
[22] Spencer, A. C., and Paige, Sidney, op. cit., pp. 26-28.

at only two localities. One of these is in the vicinity of the Three Brothers mine and Gold Gulch, where the southern edge of the exposure east of Fort Bayard extends for about 1,000 feet into the area shown on plate 1. The upper part of the formation in that vicinity consists of slabby, thin-bedded fossiliferous gray limestone having partings at intervals of 1 to 12 inches. Several quartz diorite sills crop out in the limestone in that vicinity.

White to buff sandy shale of the Syrena formation crops out in a thin slice along Lovers Lane. Intervening between the shale and the overlying Beartooth quartzite is a thin bed of blue-gray limestone spotted on the weathered surface with brown impure patches. Near the south end of the exposure, on the Fifty-six, Door Key, and Ivanhoe claims, the shale beds adjacent to the Ivanhoe Dike have been metamorphosed to a dense green to black indurated rock, here and there saturated with magnetite and including layers of knotty shale likewise impregnated with magnetite.

The following sections, compiled from logs of drill holes in the Bayard area, are descriptive of the Syrena formation. Thicknesses are adjusted for dip of beds and pitch of holes. In the first section the lower 129 feet seems to correspond to the Mountain Home shale of local geologists, but in the other section there seems to be no logical dividing plane.

Composite section of Syrena formation as cut in diamond-drill hole on the Nellie Patterson No. 5 claim

Beartooth quartzite.	
Syrena formation:	*Feet*
Gray crystalline limestone, slightly shaly	6
Greenish-gray cherty limy shale	5
Blue-gray fossiliferous limestone, slightly shaly	7
Greenish-gray shaly cherty limestone	2
Gray crystalline limestone	21
Gray shaly limestone	15
Gray to black limy shale, highly fossiliferous	16
Greenish-gray, very shaly limestone containing a little chert	14
Gray crystalline limestone, locally shaly	24
Brownish-gray shale	1
Light- to dark-gray shaly limestone, locally crystalline and containing a little chert	14
Sill	90
Greenish-gray shaly limestone, crinoidal for the most part	18
Gray, nearly pure crystalline limestone	1
Gray crystalline limestone, locally shaly, cherty and fossiliferous	26
Total (including sill)	260
Oswald formation.	

Section of Syrena formation as cut in diamond-drill hole on the Rio Grande No. 2 claim, Gold Gulch

	Feet
Beartooth quartzite.	
Syrena formation:	
Silicified green shaly limestone	6
Mottled green to gray limestone, locally shaly	21
Light-gray to buff limestone	11
Silicified gray shaly limestone with 2-foot bed of silicified shale at the base	15
Green to gray limy shale	18
Gray limestone with shaly streaks	4
Dull-gray limestone	13
Gray limy shale; includes two sills, 6 inches and 2 feet thick, and a 1-foot bed of gray limestone	19
Alternating thin beds of limy sandstone and limy silicified shale	5
Gray finely crystalline limestone containing chert nodules; slightly shaly near the top	26
Gray limy shale	1
Gray crystalline limestone	6
Gray to green cherty shale	21
Mottled green to gray cherty limestone	5
Sill	176
Dark-gray cherty shale	14
Gray crystalline limestone	6
Greenish-gray shaly, cherty limestone containing alternating cherty and noncherty shale layers in the lower part	40
Black shale	3
White crystalline limestone	4
Black limy shale	4
White crystalline limestone	5
Greenish-gray limy shale	4
Grayish-white limestone with thin shaly streaks	7
Gray silicified cherty shale	25
Greenish-gray shaly limestone	2
Gray crystalline limestone	16
Total (including sills)	480
Oswaldo formation.	

CRETACEOUS ROCKS

BEARTOOTH QUARTZITE

The Beartooth quartzite was named by Paige[23] from Beartooth Creek, a tributary to Cameron Creek north of Fort Bayard. It lies unconformably on the Syrena formation in the Bayard area, but without notable discordance in dip. No fossils have been found in the Beartooth quartzite. Paige tentatively classified it as Upper

[23] Paige, Sidney, op. cit. (Folio 199), p. 5.

Cretaceous, but Darton[24] considers it to be the same as the Sarten sandstone of the Deming quadrangle, in which he found fossils of the Washita group of the Comanche (Lower Cretaceous) series.

The character of the Beartooth quartzite is variable. Throughout the Bayard area the lower part is chiefly quartzite, but the upper part differs from place to place. In the eastern part of the area and to the north the formation is dominantly massive vitreous quartzite containing a few sandstone and shaly beds in the central part. A pebbly to conglomeratic layer as much as 3 feet thick, consisting of rounded quartzite and chert pebbles in a quartzite matrix, generally lies at or near the top of the formation in this part of the area and may be used as a horizon marker. In the vicinity of the Three Brothers mine and Yellowdog Gulch the upper part of the formation consists essentially of varicolored sandstone in beds several inches to a foot or two thick. Some beds are shaly, and a few beds of black shale are present also. Conglomeratic layers are present near the top of the formation, but they are thin and not extensive.

The thickness of the Beartooth quartzite ranges from 66 to about 140 feet. The following sections are descriptive of this formation in the Bayard area:

Section of Beartooth quartzite on Door Key claim, in gulch north of Ivanhoe mine

Colorado formation.	
Beartooth quartzite:	*Feet*
Fine-grained pink quartzite. Marblelike concretions at upper contact. The lower half of this bed is the conglomeratic quartzite	5
White, bleached shaly sandstone	6
Medium-grained gray quartzitic sandstone, with a little iron oxide cement	4
Light-gray shaly sandstone	13
Light-gray quartzitic sandstone	11
Medium-grained white quartzite, weathering pink	27
Total	66
Syrena formation.	

Section of Beartooth quartzite in Yellowdog Gulch, Fort Bayard Reservation

Colorado formation.		
Beartooth quartzite:	*Ft.*	*in.*
Black quartzitic sandstone	1	3
Soft brown sandstone, locally quartzitic. Lower 8 inches is a pebbly conglomerate	1	6
Black quartzitic sandstone similar to top member		6–12
Dark-gray shaly sandstone with thin shale partings	17	

[24] Darton, N. H., op. cit. (Bull. 794), pp. 38, 342.

Section of Beartooth quartzite in Yellowdog Gulch, Fort Bayard Reservation—Continued

	Ft.	in.
Beartooth quartzite—Continued.		
Soft greenish-brown sandstone	5	
Greenish-brown quartzitic sandstone, locally conglomeratic	1	4
Gray fissile shale		6
Greenish-gray sandstone	1	8
Greenish-gray sandy shale	9	4
Black shale	3	
Unexposed	19	
Fine-grained grayish-white quartzite	2	
Black shale	1	3
Greenish-brown shaly sandstone	1	6
Pink fine- to medium-grained quartzite, bedding planes 1 to 3 feet apart	48	
Light grayish-yellow bleached siliceous shale	20	
Fine-grained white vitreous quartzite	9	
Total	142±	
Syrena formation.		

COLORADO FORMATION

The Colorado formation rests upon the Beartooth quartzite with apparent depositional conformity. The upper limit of the formation in general is either the present land surface or an older erosion surface buried under the volcanic rocks of the region, so that the full thickness is not present. At some places, particularly in the Bayard area, what is left of the formation is covered by one or more of three thick sills that have been intruded into it. Its distribution in the area under discussion is extremely irregular, owing to the presence of the sills and of numerous faults. It forms three fairly continuous belts—one extending from a point near the extreme northwest corner of the area eastward to Hanover Gulch; a second belt extending discontinuously from the extreme northeast corner southwestward to the Ground Hog mine; and a third belt, the base of which is not exposed, extending southwestward from Gold Gulch nearly to Bayard station. In addition, numerous inclusions in the sills crop out at several places.

It has been possible to separate the Colorado formation in the Bayard area into two mappable units—an upper sandstone member and a lower shale member. Fossils that J. B. Reeside, Jr., identified as *Inoceramus labiatus* Schlotheim, *Cardium pauperculum* Meek, and *Mactra utahensis* Meek were collected from a limy bed in the sandstone, and a fossiliferous layer near the middle of the shale contains numerous *Gryphaea newberryi* Stanton and less abundant *Exogyra columbella* Meek, *Plicatula hydrotheca* White, and species of

Astarte, *Ostrea*, and *Gyrodes*. Of the fossils from the shale some were collected by Spencer and identified by T. W. Stanton, and the others were collected by me and identified by Mr. Reeside. These fossils, according to Reeside, are of lower Benton age (Graneros shale and Greenhorn limestone). Darton [25] states that the fossil *Inoceramus labiatus* is highly characteristic of the Greenhorn limestone of eastern Colorado and parts of northern New Mexico, so that the sandstone member of the Colorado formation in the Bayard area may be considered equivalent in age to the Greenhorn limestone and the underlying shale member equivalent to the Graneros shale, which underlies the Greenhorn and is the base of the Colorado group to the north.

It is doubtful if the separation into the lower shale and the upper sandstone can be extended much beyond the limits of the small area under discussion, and the two members are therefore not given geographic names but are referred to in this report simply as the shale member and the sandstone member of the Colorado formation.

Shale member.—The lower member of the Colorado formation consists of gray and black shale, in places very sandy or limy. At 105 to 115 feet above the base there is a persistent sandy, limy layer several inches thick that contains abundant fossil *Gryphaea newberryi* and in places consists almost wholly of these and associated fossils. This layer is an excellent horizon marker. Although very thin, it has a peculiar worm-eaten appearance where weathered that makes it easy to recognize. (See pl. 5.) Directly below the *Gryphaea*-bearing layer is a 25-foot bed of sandstone that seems equally persistent, though in places it is rather shaly and hardly distinguishable from other parts of the shale member. This bed is well exposed directly above the lower sill north of Bayard station.

The thickness of the shale member ranges from 190 to 220 feet. Below is a generalized section of this member.

Generalized section of the shale member of the Colorado formation

Sandstone member.	
Shale member:	*Feet*
Shale, dark gray to black, calcareous and very sandy; parting planes wavy and imperfect and a fraction of an inch to several inches apart; breaks to rough surfaces, a characteristic feature. Not everywhere present	8–10
Shale, dark gray to slate gray, in part sandy; straight-grained and slabby	80–105
Gryphaea horizon.	

[25] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, pp. 40–41, 1928.

Generalized section of the shale member of the Colorado formation—Continued

	Feet
Shale member—Continued.	
Sandstone, buff, fine-grained and calcareous, loosely cemented locally; grades to dark-gray and black shaly sandstone not everywhere distinguishable from the overlying sandy beds	25
Shale, black to gray, generally fissile and straight-grained; includes a few thin sandy layers	80–85
Total	190–220
Beartooth quartzite.	

Sandstone member.—The sandstone member consists primarily of that part of the Colorado formation lying between the shale member and the middle sill. This part has a maximum thickness of about 130 feet and pinches out altogether where the sill crosscuts to the shale. It consists mainly of soft thin-bedded white to gray sandstone and includes several limy beds. The thin, slabby layers of the sandstone weather in such a way as to present a distinctive wavy appearance.

The following section was measured:

Section of sandstone member of Colorado formation in Gold Gulch

	Feet
Middle sill.	
Sandstone member:	
Interbedded fissile shale and thin-bedded shaly sandstone, dark green; includes thin bed of sandy limestone near middle	40
Quartzitic sandstone, white to gray and buff	20
Sandstone, white to gray, soft, fine- to medium-grained; much of it wavy	16
Sandy limestone, dark gray, locally fossiliferous	14
Sandstone, white to gray, fine- to medium-grained, mostly thin-bedded and slabby	34
Limestone, light to dark gray, in places very sandy; weathers to warty convex surfaces 3 inches or less in diameter; locally fossiliferous; *Inoceramus* horizon	1–2
Sandstone, thin-bedded and wavy	9
Sandstone, gray, fine-grained, partings 1 to 18 inches apart	6
Total	130
Shale member.	

That part of the sandstone member overlying the middle sill crops out at a few places, and in the extreme northeast corner of the area are sandstone beds above the upper sill. These higher beds are more massive than the lower ones and consist of sandstone layers separated by shale partings a few inches to a foot or so thick. Several of the beds are quartzitic and somewhat similar to parts of the Beartooth quartzite.

The total thickness of the sandstone member of the Colorado formation present in the area is at least 450 feet.

QUARTZ DIORITE SILLS

The quartz diorite sills represent rocks of two ages, an earlier medium-grained porphyritic rock characterized particularly by large, corroded, doubly terminated quartz phenocrysts, and a later finer-grained, nearly equigranular rock in which these phenocrysts are absent. The differences are not generally outstanding, however, and without definite field evidence to the contrary, the two rocks would be classed confidently as contemporaneous phases of the same rock. No critical evidence bearing upon the relative age of the two rocks was noted in the Bayard area, but northeast of the Kneeling Nun and about 1½ miles east of Santa Rita two dikes of the typical finer-grained rock cut a sill that contains an exceptionally large proportion of the diagnostic doubly terminated quartz phenocrysts. Figure 2 illustrates the field relations at that place. Although the age difference indicated by these relations is undeniable, it cannot be great. The two rocks are so nearly identical in mineral and chemical composition that they may be considered as having been injected by closely spaced pulsations of the same magmatic differentiate. The rock injected by the earlier pulsation carried numerous partly resorbed quartz crystals, and the second pulsation presumably took place at a time when resorption of those crystals had been nearly completed.

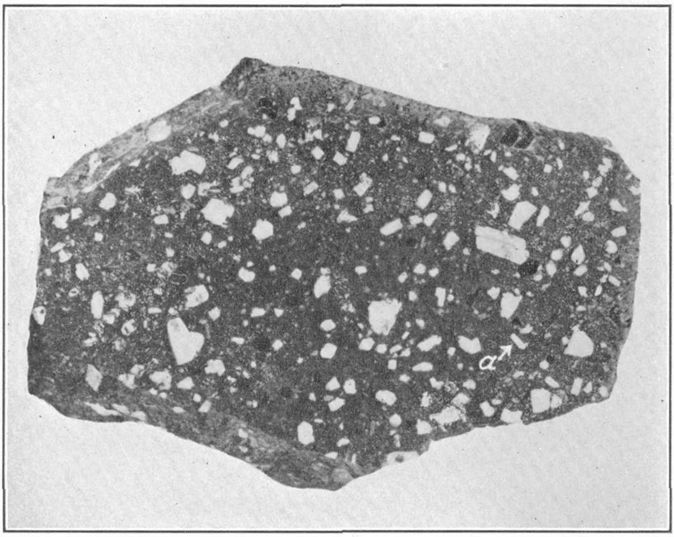
The sills tend to follow the contacts between shale and more competent rock, but they are broadly discordant and at many places crosscut from one shale contact to another. Discordance increases with the thickness of the sills and ranges from practically nothing in the 40-foot "marker sill" near the bottom of the Oswaldo formation to a maximum of about 350 feet in the large middle sill in the Colorado formation. The sills are generally sheeted parallel to their contacts, and this is particularly true of the base of the middle sill and of the upper sill on the south bank of Whitewater Creek. (See pl. 4, *B*.) Well-developed jointing may extend up to about 225 feet, measured normal to the contact, and as a result the sills generally weather to slabby pieces; where the inner parts of the sill are exposed, the rock weathers to large rounded boulders.

EARLIER QUARTZ DIORITE

General features.—The earlier quartz diorite is the rock of the upper and lower of the three sills in the Colorado formation and

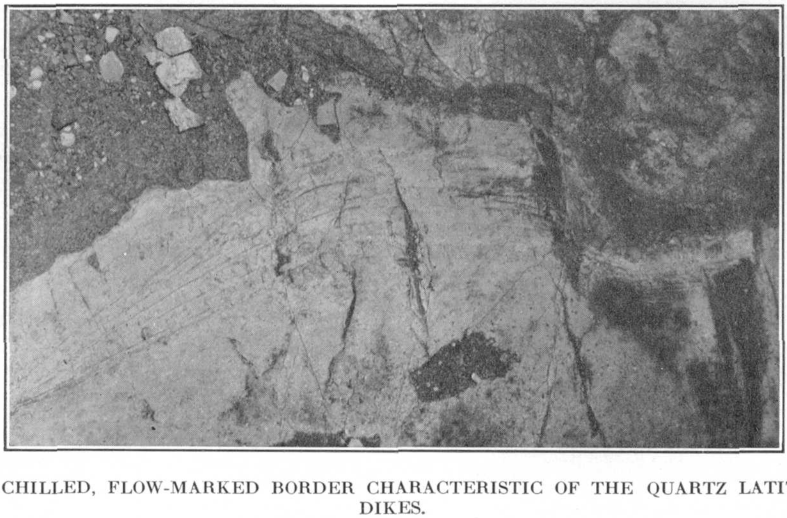
WEATHERED SPECIMEN OF THE *GRYPHAEA*-BEARING LAYER OF THE SHALE MEMBER OF THE COLORADO FORMATION.

Showing characteristic worm-eaten appearance. Natural size.



A. POLISHED SPECIMEN OF GRANODIORITE PORPHYRY

Natural size. Crystal marked *a* is phenocryst of apatite.



B. CHILLED, FLOW-MARKED BORDER CHARACTERISTIC OF THE QUARTZ LATITE DIKES.

Bed of Gold Gulch, on the Joseph mill site.

apparently also of the sills in the Syrena formation that crop out in the northern part of the mapped area. It was the first rock to be intruded into the sediments of the Central district, although earlier and related igneous activity ocurred nearby in the vicinity of Pinos Altos.[26]

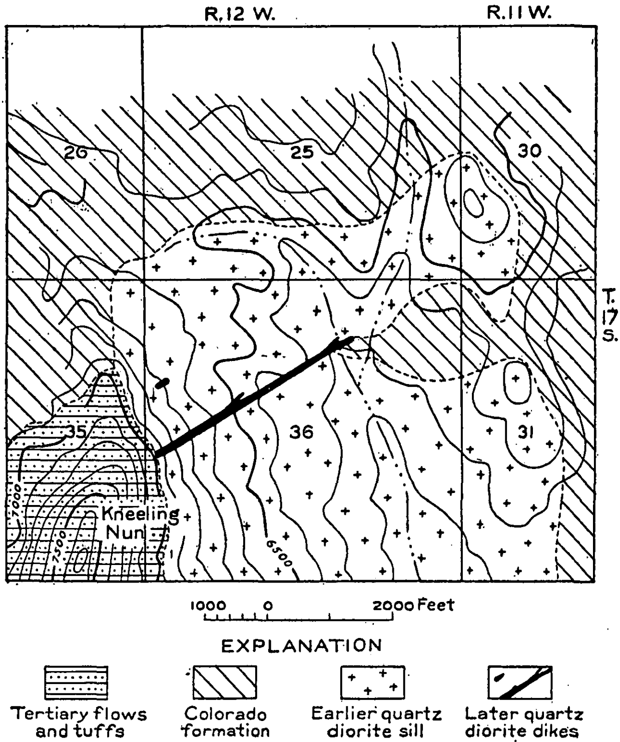


FIGURE 2.—Sketch map of the area northeast of the Kneeling Nun, showing dikes of later quartz diorite cutting a sill of earlier quartz diorite.

The lower sill in the Colorado formation crops out at only two places, and its distribution and thickness must be inferred largely from two drill-hole logs and from exposures in the Ground Hog mine. One prong crops out near the Three Brothers mine, and thence the sill extends southeastward, mostly beneath the surface, as a strip 2½ miles or more wide. The southwestern limit of this strip lies beneath the Tertiary or Quaternary rocks somewhere beyond the highway Y near Bayard station, where a drill hole cuts the sill beneath a thin mantle of Tertiary sediments. The northeastern limit corresponds approximately with a line extending southeastward from the Old Rake claim through a point between the Ivanhoe and Ground Hog mines. The workings of the Ground Hog mine cut the lower sill, but this rock does not appear in any of the sedi-

[26] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (no. 199), p. 7, 1916.

mentary sections between the middle sill and the Syrena formation that crop out north of the Ivanhoe mine and on the Nellie Patterson group of claims. The line must pass well northeast of the Owl mine, because a drill hole at that mine cuts through a considerable thickness of lower sill.

The lower sill is strongly warped. North of Bayard station, where it is exposed for about 2,500 feet along the highway, it lies directly beneath the 25-foot sandstone bed of the shale member of the Colorado formation—that is, about 85 feet above the Beartooth quartzite, but at the Ground Hog mine, a mile to the east, it lies above the 25-foot sandstone bed. The south end of the other exposure crops out on the Fort Bayard Military Reservation a mile to the north, and within that mile the sill has crossed to the contact between the shale and sandstone members of the Colorado formation, about 200 feet above the Beartooth quartzite. From that place the outcrop extends northeastward for about 4,500 feet, gradually cutting downward across the shale member, and at the north end the sill lies between the shale member and the Beartooth quartzite, sending subsidiary fingers well down into the quartzite. The stratigraphic discordance thus shown is the full thickness of the shale member, which is about 200 feet, and this seems to be about the maximum discordance of the lower sill. The lower sill lies on top of the Beartooth quartzite at the Owl mine also, as shown by a diamond-drill hole on the Rio Grande No. 2 claim.

The thickness of the lower sill, except at the edges, seems to be between 425 and 475 feet, as disclosed by mine workings and diamond-drill exploration at the Ground Hog mine and by the diamond-drill hole at the Owl mine. (See fig. 16.) The mass north of Bayard station is faulted on the east side against the middle sill and against Tertiary sediments, and no estimate of the thickness at that place can be made. The drill hole at the highway Y to the southwest cuts through 222 feet of lower sill and into shale below, but because of the discordant nature of the sill and the unknown position of the Bayard fault in that vicinity, it is inadvisable to project the upper contact of the Bayard station mass to that place in order to estimate the full thickness.

The upper sill in the Colorado formation crops out between the Ivanhoe mine and the waste dump of the Chino mines, at the east edge of the area mapped. All other parts of this sill in the Bayard area have been removed by erosion, and this mass owes its preservation only to the great throw of the Ivanhoe-Lovers Lane fault. Inasmuch as the rock is earlier quartz diorite, there is a suggestion that it may be part of the lower sill, but a glance at the geologic map will show that this could be true only if the throw of the Copper Glance fault were greater than that of the Ivanhoe-Lovers

Lane fault, whereas in truth the throw of the Ivanhoe-Lovers Lane fault is much the greater. The top of the sill is exposed for most of the distance from the south end of the Ivanhoe claim to the Keystone mine; the Colorado sediments that overlie it differ from the typical beds of the shale member and from the lower beds of the upper or sandstone member and must be high up in the sandstone member, but there is no evidence to indicate just how far above the base of this member the sill may be.

The earlier quartz diorite on the North Star and adjacent claims, on Whitewater Creek, is bounded largely by dikes and faults and is evidently a basal segment of the upper sill faulted in between forks of the Ivanhoe-Lovers Lane fault. What appears to be the base of this segment is exposed in the railroad embankment at the western edge of the mass, which is strongly sheeted parallel to the apparent base. The joint planes are remarkably close together in the lower part of the sheeted zone, the rock breaking into slabs only 2 inches thick.

The thickness of the upper sill is not known. The only available evidence consists of topographic relief and the log of a churn-drill (Chino hole 711) on the Vulcan claim that penetrated the sill for 268 feet. The minimum possible thickness is about 450 feet.

Of the sills in the Syrena formation northeast of the Three Brothers mine, the two small upper ones are at about the same horizon and are presumably parts of the same mass. The lower sill, of which only a corner is shown on the map, extends for a considerable distance beyond the mapped area. What is presumably the same sill was cut in the diamond-drill hole on the Nellie Patterson No. 5 claim, a mile to the east, and in the drill hole on the Rio Grande No. 2 claim, a mile to the south. The thickness of this sill ranges from about 90 to about 175 feet.

Petrography.—The earlier quartz diorite is a highly altered greenish-gray porphyritic rock containing 30 to 50 percent of phenocrysts in a chloritic granular groundmass in which crystalline grains and clusters of magnetite are commonly visible. Alteration has everywhere profoundly changed the composition of the rock and in places has destroyed the general texture. Many parts of the rock consist chiefly of alteration minerals, the only original constituents being quartz and the resistant accessory minerals apatite, zircon, and magnetite.

The phenocrysts range from less than a millimeter to nearly a centimeter in length and include white feldspar, less abundant quartz, hornblende, and biotite, and a few apatite crystals. The quartz phenocrysts, which consist of medium- to coarse-grained, strongly embayed individuals and clusters, constitute in general the most characteristic megascopic feature of the rock, though in places they are sparsely distributed. The crystalline shape of many of them can be recognized as the double pyramid. The feldspar phenocrysts, as seen in the hand specimen, consist of corroded patches and stubby, sharp-cornered crystals with pitted faces and range from 0.5 to about 7 millimeters in length. Microscopic examination shows that they include sodic labradorite and very subordinate amounts of orthoclase and albite. The labradorite is variably albitized, and albite is the only feldspar present in the faulted-in basal segment of the upper sill on Whitewater Creek, on the North Star and adjacent claims. A few zoned phenocrysts of labradorite were noted, and combined albite-pericline twinning is common in both labradorite and albite. Hornblende and biotite, the hornblende completely altered and the biotite nearly so, are everywhere present and locally prominent, though in places either or both are decidedly scarce. Hornblende is generally the more abundant and forms stout to long prisms, generally medium-grained, some of which are perfectly developed crystals having typical elongated, six-sided cross sections; the biotite consists of shapeless to subhedral flakes and of thin pseudohexagonal books. Apatite phenocrysts as much as 2.5 millimeters in length have been seen. Both stubby and needlelike crystals are present, the stubby variety having a ratio of length to breadth of 3½ to 1 and the needlelike variety 6 to 1. They are most common near the base of the sill and are very abundant in the albitic mass of the upper sill on Whitewater Creek. Microscopic individuals of both varieties are abundant.

The rock is chloritized to an extreme degree, and epidote also is wide-spread. All specimens of the rock will effervesce if weak acid is placed upon them, and in some of them calcite can be recognized with the unaided eye. Minute crystalline grains of pyrite occur at many places and impregnate large masses of the rock, and sericite is prominent along most fracture zones. Alteration of the earlier quartz diorite is described in detail in the section entitled "Rock alteration."

The following analysis was furnished by the geologic department of the Chino mines:

Analysis of earlier quartz diorite from the Vulcan claim

[Analyst, J. J. Jones, chief chemist, Nevada Consolidated Copper Co., Chino branch. Sample was dried before being analyzed]

SiO_2	62.37	MgO	1.75	TiO_2	0.66
Al_2O_3	18.06	CaO	5.99	P_2O_5	.27
Fe_2O_3	4.41	Na_2O	.91	MnO	.41
FeO	1.69	K_2O	2.57		99.09

LATER QUARTZ DIORITE

General features.—In the Bayard area the later quartz diorite is confined to the large middle sill in the Colorado formation, though many of the sills that crop out in the Paleozoic rocks near Hanover and Fierro are composed of this rock. The base of the middle sill is well exposed near the northern edge of the area, and thence southward to the overlapping Tertiary and Quaternary rocks this sill forms almost all the present land surface. It is only a thin skin over much of the area, and the breaking of this skin by numerous faults has exposed the base of the sill and the underlying rocks, notably in the footwall of the Copper Glance fault and west of Whitewater Creek from Gold Gulch southward. The top surface of the sill has been preserved in the Bayard area only in the deeply depressed hanging-wall blocks of the Copper Glance and Hanover Creek faults. The middle sill extends westward and northwestward beyond the Bayard area for about a mile, the nose of the sill being exposed due north of Fort Bayard, near the junction of Cameron and Beartooth Creeks; it extends northeastward on the east side of Hanover Creek nearly to Hanover and southward for an unknown distance under the Tertiary and Quaternary sediments.

The middle sill commonly lies either at or just above the top of the lower or shale member of the Colorado formation or near the contacts of the 40-foot shaly bed of the sandstone member. On the Copper Bell and Gybbon claims the base of the sill crosscuts to the Beartooth quartzite, and accordingly it has a stratigraphic discordance of about 350 feet, which is the maximum distance from the quartzite to the top of the 40-foot shaly bed in the sandstone member. The discordance is generally gradual, but in places the contact cuts sharply across the strata. Thin, fingering offshoot sills, some of which rejoin the main mass and envelop a slice of the adjacent sediments, are common where the sill lies near the thin-bedded base of the sandstone member.

The thickness of the middle sill seems to range from not less than 375 feet to 750 feet or more, though nowhere can it be measured directly. The minimum thickness has been estimated from geologic relations in the vicinity of the Dodecahedron claim. A churn-drill hole (Chino hole 810) on that claim near the highway passed through 417 feet of sill and into the shale member of the Colorado formation, as shown in figure 3. The drill hole is near a minor fault, on the downthrown side of which the top of the sill is exposed; the throw of this fault is insignificant, and the thickness of the sill in this vicinity may therefore be taken at about 425 feet. Nearby, however, the thickness may be as low as 375 feet, for the base of the sill where exposed to the northeast, in the footwall of the Copper Glance fault, is about 50 feet stratigraphically higher than it is at the drill hole.

The probable maximum thickness of 750 feet or more is indicated by a drill hole in the bottom of Gold Gulch on the Owl claim. The hole was started in the middle sill and remained in that rock, except for several dikes, until it cut through the Owl fault at a depth of 758 feet. Several probable faults were cut and these may have caused duplication, but adjustments for adjacent topographic relief, and an additional thickness of sill below the intersection of drill hole and fault, would probably more than compensate for this. Furthermore, it is not possible to tell how much sill has been removed by erosion, and, all things considered, 750 feet is probably the minimum thickness at that place. Structure sections show an

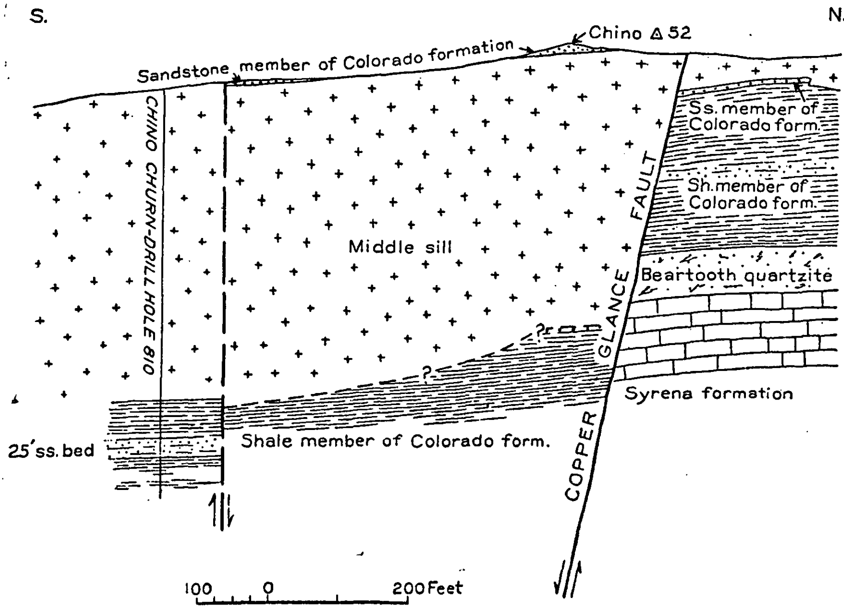


FIGURE 3.—Section across the Copper Glance fault and through Chino churn-drill hole 810 on the Dodecahedron claim, showing thickness of middle sill and probable throw of the Copper Glance fault.

equally great thickness elsewhere in the same fault block. (See pl. 2, sections *A–A′* and *B–B′*.) It is noteworthy that the sum of the minimum thickness of sill and the maximum determined stratigraphic discordance is approximately equal to the probable maximum thickness, which suggests that the concordant thickness may be 500 or 600 feet and that anything greater or less is due to discordant bulges or embayments on either or both contacts.

Petrography.—The rock of the middle sill is a mottled greenish-gray fine-grained, nearly equigranular rock that generally weathers to a dull pink. As in the earlier quartz diorite, primary alteration is widespread. The freshest rock was observed south of Central, in a small quarry adjacent to the highway. The rock there contains a few phenocrysts of medium-grained white feldspar and needles of shiny black hornblende in a finer-grained granitoid intergrowth of feldspar, hornblende, and a little granular magnetite. As a rule, no crystalline angles can be observed on the feldspar grains in the average rock, but in the basal part of the sill these grains show a decided tendency to be automorphic. Megascopically visible apatite crystals invariably occur in this basal zone, but careful scrutiny in the field and in the laboratory failed to find them in any part of the sill that has normal texture. Most of them have a ratio of length to breadth of 6 to 1. The maximum thickness of the apatite-bearing zone is about 25 feet.

As seen under the microscope, the rock is more porphyritic than appears in the hand specimen. The phenocrysts are generally fine-grained and include about 25 percent of feldspar, 5 percent of hornblende, and a few droplike grains of quartz. The groundmass is a granitoid intergrowth of quartz and subordinate feldspar. The feldspar phenocrysts consist of sodic labradorite (An_{52}) and a trace of orthoclase. All feldspar grains are partly albitized, and in the basal apatitic rock albite is the only plagioclase present. Here and there a labradorite grain shows a slight zoning or combined albite-carlsbad twinning. The pericline twinning that is fairly common in the plagioclase of the earlier quartz diorite was observed only in the albite of the basal apatitic rock. All feldspar grains are at least slightly sericitized or calcitized and many have been epidotized. The hornblende, where fairly fresh, is brownish green and generally corroded. It is almost invariably chloritized and is replaced also by epidote, calcite, and less commonly by quartz. Magnetite is fairly common as medium-grained clusters and scattered grains, and apatite also is present, though it is much less abundant than in the earlier quartz diorite. A few grains of zircon were seen.

In a general way, the later quartz diorite is somewhat less altered than the earlier quartz diorite, though the alteration minerals are the same. Alteration of the later quartz diorite is described in detail in the section entitled "Rock alteration."

The following analysis was furnished by the geologic department of the Chino mines:

Analysis of later quartz diorite from the northwest corner of the C. G. Bell claim

[Analyst, J. J. Jones, chief chemist, Nevada Consolidated Copper Co., Chino branch. Sample was dried before being analyzed. Contains epidote, sericite, chlorite, and secondary quartz]

SiO_2	62.67	CaO	6.93	P_2O_5	0.03
Al_2O_3	17.13	Na_2O	.65	MnO	.35
Fe_2O_3	4.14	K_2O	3.97		
FeO	2.00	TiO_2	.41		100.00
MgO	1.72				

COMPARISON BETWEEN EARLIER AND LATER QUARTZ DIORITES

The two varieties of quartz diorite strongly resemble each other, microscopically as well as megascopially, and the descriptions given in the foregoing pages have been made with more than ordinary attention to detail, in order to facilitate recognition. In furtherance of this idea a comparative summary of the principal petrographic features of the two rocks is given in the following table.

Comparative summary of principal features of earlier and later quartz diorites

Earlier quartz diorite	Later quartz diorite
Megascopic:	Megascopic:
Porphyritic, containing 30 to 50 percent of phenocrysts, ranging from 0.5 to 9 millimeters in length.	Nearly equigranular, containing only a few phenocrysts 2 to 4 millimeters in length.
Contains many strongly embayed, double-ended quartz crystals, as individuals and as clusters. May be absent locally but will be found in the rock close by. Average about 3 millimeters in diameter.	Quartz phenocrysts are rare and occur only as rounded grains generally less than 1 millimeter in diameter.
Contains biotite in shapeless to subhedral flakes and in pseudohexagonal books as much as 1½ millimeters thick and 6 millimeters in diameter.	No biotite observed.
Contains many perfect hornblende crystals, generally between 1 and 4 millimeters long.	Perfect hornblende crystals are rare and small.
Some of the feldspar phenocrysts are sharp-cornered crystals ranging from 0.5 to 7 millimeters in length.	Sharp-cornered feldspar crystals occur only in a thin zone at the base of the sill. Are invariably small and all are of nearly the same size, about 1 or 2 millimeters in length.
Scattered apatite crystals occur throughout	Apatite crystals occur only in basal zone in conjunction with the sharp-cornered feldspar.
Strongly altered	Generally less altered than earlier quartz diorite.
Microscopic:	Microscopic:
	Shows small range in grain size between groundmass and phenocrysts.
Combined albite-pericline twinning of feldspar is common.	Combined albite-pericline twinning of feldspar noted only in albite of the basal apatitic rock.
No combined albite-carlsbad twinning observed	Some feldspar grains show combined albite-carlsbad twinning.
Feldspar phenocrysts show strong tendency to automorphism.	Only an occasional feldspar phenocryst is automorphic except in basal zone.
Apatite abundant	Apatite less abundant than in earlier quartz diorite.

The megascopic criteria are clearly the best. Among them are some that are positive, such as the presence of large corroded crystals of quartz in the earlier quartz diorite. Most of the criteria for the recognition of the later quartz diorite are negative, but the conjunction of several of them is equivalent to positive identification. The microscopic criteria are based on an examination of 27 thin sections.

GRANODIORITE PORPHYRY DIKES

General features.—Granodiorite porphyry dikes, locally called "birdseye porphyry", are very prominent and abundant in the northeastern part of the Bayard area and are essentially confined to that part of the area showing strong fracturing. They cut through the sills and the pre-Tertiary sedimentary rocks, but they are clearly overlain by the Tertiary sediments. At Santa Rita and Hanover are stocks of granodiorite, associated with disseminated copper and contact-metamorphic deposits, that represent the parent rock from which the dikes were derived.

The granodiorite porphyry dikes are older than the commercially important ore deposits of the area, but they are younger than a group of noncommercial quartz-pyrite veins that represent an earlier period of weak mineralization. The Ground Hog and Lucky Bill ore bodies are later than the dikes and lie in a fault zone that tends to follow the dike contacts, but on the Burchard and Osceola claims a network of dikes cuts squarely across the Copper Glance vein and some of its spurs, and the Dutch Uncle-Tin Box vein is crossed by dikes at three places. Spencer and Paige[27] suggest and seem to prefer the idea that there are two ages of dikes rather than two ages of veins. That there are two ages of veins, however, cannot be questioned, for some dikes not only cut veins as described but are themselves cut by other veins, as clearly shown on the Bull Frog, Burchard, and Osceola claims.

The dikes deviate strikingly from simple tabular bodies. Many of them were injected into preexisting faults and associated fissures that were part of an intricate linked network trending northeastward, and they therefore tend to form a similar pattern, trending in the same direction as the faults and having forked, hooked, and spidery shapes in plan and section that reflect the details of the fracture pattern they occupy. The Ivanhoe dike system and the group of dikes west of it are excellent examples of this arrangement. The fracture pattern can be restored with fair accuracy by drawing center lines through the dikes and their arms, and figure 4 is a plan view of the Ivanhoe dike in which this has been done.

Some dikes cut across earlier fissures instead of following them, but the dike is likely to widen or jog at the fissure or to send a short tongue along it. The geologic map shows these features more clearly than they can be described. Where the dikes cut through sedimentary rocks they are likely to widen or narrow abruptly along a bedding plane, like a sill. The dike magma seems to have been a penetrative one, for some of the dikes that have been mapped are several hundred feet long, though only 2 to 10 feet thick.

The granodiorite porphyry dikes tend to weather readily, generally crumbling to a coarse sand in which the different rock minerals can be recognized, though very quartzose parts weather to large hard boulders. Jointing of the dikes parallel to the walls is common.

Petrography.—The granodiorite porphyry dikes show a noteworthy irregularity in color, texture, and proportion of the different minerals, even within a single mass. The end phases are recog-

[27] Spencer, A. C., and Paige, Sidney, Geology of the Santa Rita mining area, New Mexico; U. S. Geol. Survey Bull. 859, p. 39, 1935.

nizably different. One is a light-colored coarse-grained porphyry that locally is nearly granitoid in texture. The phenocrysts, which make up 50 percent or more of this variety, are embedded in a finely crystalline to aphanitic groundmass and include abundant orthoclase and plagioclase, less abundant hornblende and biotite in

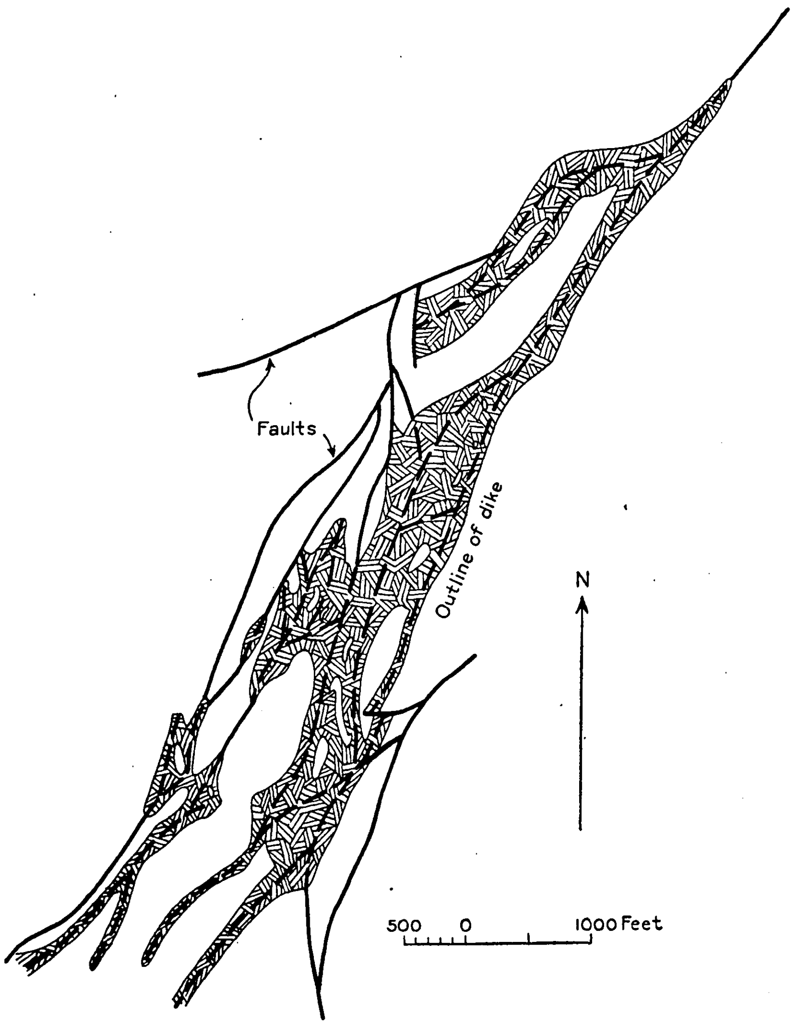


FIGURE 4.—Plan of the Ivanhoe dike showing how the grotesque shapes of the granodiorite porphyry dikes are the result of injection along a set of linked faults.

nearly equal proportions, considerable quartz, and a trace of apatite and titanite. Magnetite grains, some of them striated octahedra, can be seen in the groundmass. The phenocrysts are fine to very coarse grained; orthoclase phenocrysts nearly 4 centimeters long and hornblende and quartz phenocrysts over a centimeter long have been observed. The biotite consists of dull blackish-green pseudohexagonal books, whose thickness nearly equals or exceeds the diameter; the average diameter is 2 to 3 millimeters. The hornblende phenocrysts are of nearly the same color and size as the biotite books and range from irregular grains to automorphic prisms slightly mottled by chlorite. Prisms of apatite and honey-colored wedge-shape crystals of titanite, both 4 millimeters in maximum length, are common. Most of the apatite phenocrysts are stubby and have a ratio of length to breadth of 3½ to 1, but a few having a ratio of 6 to 1 were seen.

The granodiorite porphyry showing the strongest variation from that just described is a medium-colored rock generally containing much less than 50 percent of phenocrysts in a dark stony groundmass of nearly the same color as the biotite phenocrysts. (See pl. 6, *A*.) At some places phenocrysts constitute only about 20 percent of the rock. Most of them are white feldspar, generally medium grained. Hornblende and quartz are decidedly sparse. Biotite is more abundant than in the other rock; the books are slightly tapered at one end, and the thickness of some of them is nearly twice the diameter. Accessory minerals are apatite, titanite, and magnetite, though phenocrysts of apatite and titanite are less prominent than in the light-colored dikes.

The thick books of biotite constitute a characteristic feature of the granodiorite porphyry dikes and serve to distinguish these dikes positively from parts of the quartz diorite sills that resemble them; in the quartz diorite the thickness of the few biotite books is only a small fraction of the diameter. The presence of titanite phenocrysts is diagnostic.

As estimated from thin sections, about 60 percent of the feldspar in all the granodiorite porphyry dikes is andesine, about An_{40} as determined in the light-colored dikes. In the other dikes many of the plagioclase crystals are zoned about An_{30-40}, the zones being very thin and oscillatory. This trivial discrepancy is the only one observed among the microscopic characters of the different dikes, other than the expected difference in the proportions of the phenocrysts. Microscopic observation shows that the "biotite" crystals are now bright-green chlorite pseudomorphs that contain grains of octahedrite scattered along the cleavage planes. The hornblende, on the other hand, is only slightly chloritized, though in color it is nearly identical with the chloritized biotite.

Alteration, other than chloritization of the biotite, seems to be meager except in a few favored localities. Pyritized and sericitized rock is most prominent in the vicinity of veins, but albite, calcite, and epidote are fairly widespread. Alteration of the granodiorite porphyry dikes is described in greater detail in the section on rock alteration.

TERTIARY (MIOCENE?) ROCKS

In the southern part of the Bayard area the erode[illegible] the Cretaceous rocks is overlain by an accumulation of Tertiary (Miocene?) sedimentary material composed of slightly consolidated volcanic sand, volcanic tuff, and ill-sorted tuffaceous gravel. At San Jose Mountain and in the hills east of Bayard Canyon these deposits are covered by a thick series of quartz latite flows, thin remnants of which also cap some of the knolls to the west. Layers of tuffaceous material are interbedded with the lava flows, particularly beyond the limits of the mapped area. Quartz latite dikes related to the flows are prominent in part of the area.

The Tertiary sediments of the Bayard area are divided into two cartographic units—a gravel, sand, and tuff unit that makes up most of the section, and an overlying bed of brown sand. Several feet of tuff and sand intervenes locally between the brown sand and the overlying lava flows, but only in Lucky Bill Canyon can this be shown on the geologic map without resorting to extreme exaggeration. At several places this tuff grades into the overlying lava. Figure 5 is a diagrammatic columnar section of the Tertiary sedimentary rocks.

The total thickness of the Tertiary sediments ranges from 10 to about 420 feet. The average thickness is 200 feet. The following section was measured on the North Star claim, on the south bank of Whitewater Creek.

Section of Tertiary sedimentary rocks, North Star claim

	Feet
Volcanic flows.	
Quartz latite tuff, incoherent, in places pumiceous and rudely stratified; grades into massive tuffaceous-appearing flow rock	15
Brown sand; lower 3 feet consists of coarse, angular, roughly sorted conglomerate; locally coherent	19
Gravel, sand, and tuff; gray to white fine- to coarse-grained volcanic sand, including subordinate coarser beds and several layers of gravelly tuff in the upper part; basal gravel absent	133
Total	167
Upper sill in Colorado formation.	

GRAVEL, SAND, AND TUFF

The Tertiary gravel, sand, and tuff rest directly on the eroded surface of the underlying rocks. Owing to the nature of this surface the thickness of the gravel, sand, and tuff is highly irregular. The average thickness in the Bayard area is about 180 feet. At the Ground Hog and Lucky Bill mines the thickness as exposed in the mine workings is between 320 and 400 feet, probably nearer the lower figure.

The base of this unit consists of a variable thickness of coarse gravel that contains fragments of all the older rocks. The gravel is thickest in the depressions of the old erosin surface and is absent from the crests of some of the old hills. The thinner parts of the gravel generally contain a heterogeneous mixture of unconsolidated, in part rotted subangular to angular fragments of the underlying

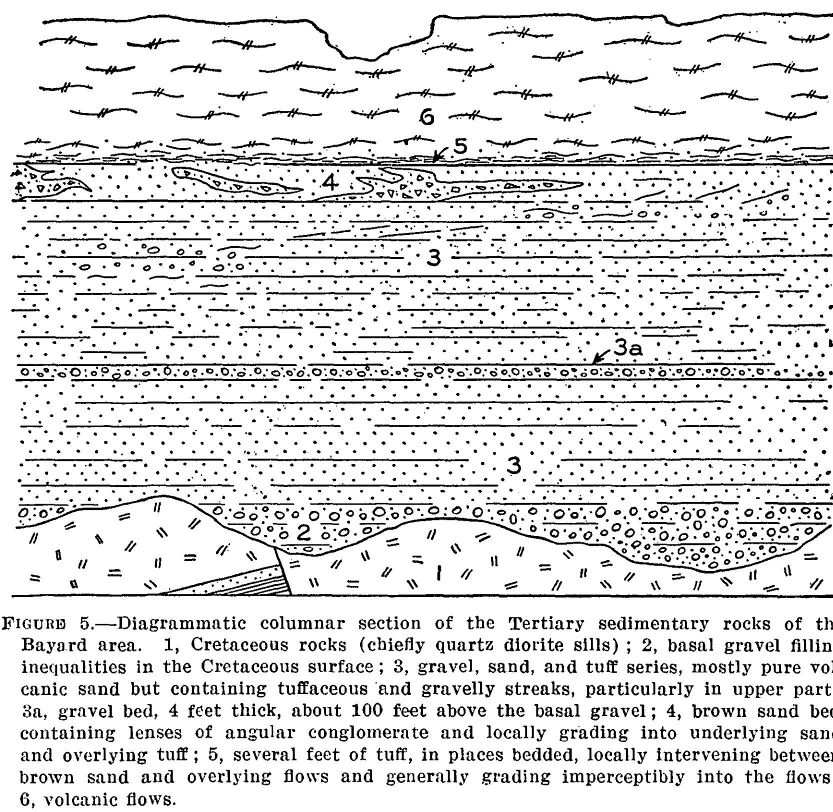


FIGURE 5.—Diagrammatic columnar section of the Tertiary sedimentary rocks of the Bayard area. 1, Cretaceous rocks (chiefly quartz diorite sills); 2, basal gravel filling inequalities in the Cretaceous surface; 3, gravel, sand, and tuff series, mostly pure volcanic sand but containing tuffaceous and gravelly streaks, particularly in upper part; 3a, gravel bed, 4 feet thick, about 100 feet above the basal gravel; 4, brown sand bed containing lenses of angular conglomerate and locally grading into underlying sand and overlying tuff; 5, several feet of tuff, in places bedded, locally intervening between brown sand and overlying flows and generally grading imperceptibly into the flows; 6, volcanic flows.

rock. The thicker parts are bedded, rudely sorted, and fairly well consolidated. (See pl. 7, *A*.) The fragments are subangular to well rounded, and the average assortment consists of pebbles half an inch to an inch in diameter in a finer-grained matrix. The fragments represent all the older rocks of the district and include in addition several varieties of foreign volcanic rocks that point to an earlier period of volcanism somewhere toward the north, probably the Cretaceous volcanism in the vicinity of Pinos Altos. In the extreme southwest corner of the area the gravel is highly tuffaceous and is over 200 feet thick, lying directly under the lava.

A series of thin-bedded, water-sorted white and gray sand and gravel, including several discontinuous layers of massive tuff, overlies the basal gravel and is interbedded with it in a narrow transition zone. The gravelly layers are subordinate and occur chiefly in the upper half. They are commonly only a few inches thick, but a layer 4 feet thick crops out at several places near the middle of the formation. The gravel pebbles are several millimeters to 1 or 2 centimeters in diameter; the smaller particles generally are rounded, but the larger ones are angular and are similar in composition to the angular fragments of the brown sand. The sandstone members are fine- to coarse-grained and have streaks and partings of fine gravel. They are well laminated and locally cross-bedded; many of the layers show a rude gradation in grain size from bottom to top. Most of the beds are incoherent, but some are well cemented with chalcedony. Only near the base and in the upper part of the series do the sands contain fragments of the underlying Cretaceous rocks; elsewhere they are made up entirely of volcanic material. The predominant constituent differs in the different beds. It may consist of grains of perlite (a variety of volcanic glass), fragments of volcanic rock, or shreds and fragments of pumice. Glass shards and grains of quartz, feldspar, biotite, augite, and minor hornblende are also present. (See pl. 7, *B*.) Most of the grains are subrounded. At the south end of the area the upper 30 feet of the formation consists of a light bluish-green sandstone, distinctly bedded and consolidated. The green color is due chiefly to chlorite and is the result of alteration subsequent to deposition. The green sand crops out as far south as Hurley, and drill holes still farther south cut several layers of it.

The layers of massive tuff range from compact, fine-grained vitric tuff to a light-weight rock consisting essentially of frothy, glassy ash. These rocks contain a few granules and pebbles of volcanic rock and fragments of biotite, feldspar, quartz, and hornblende. Devitrification of the glass is well advanced in some of the tuff.

The tuff and sandstone have been converted to bentonite adjacent to some of the strong faults of the district, where altering solutions have percolated readily. The altered rock is generally pink, particularly when wet, and is soft and soapy. When moistened it swells to about five times its normal volume, and the slurry absorbs coloring matter readily. Over nine-tenths of the rock disperses in water and may be decanted; the dispersed material is similar to the montmorillonite that characterizes the bentonite from Rideout, Utah.[28] The small amount of residue consists of biotite, magnetite,

[28] Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties: Am. Ceramic Soc. Jour., vol. 9, no. 2, pp. 76–96, 1926.

quartz, feldspar (sanidine, oligoclase, and andesine), apatite, and zircon.

BROWN SAND

The brown-sand layer overlies the gravel, sand, and tuff only in the area southeast of the San Jose Mountain and Ground Hog faults. Its average thickness is 20 feet; it is consistent in thickness over most of the area in which it occurs and is an excellent horizon marker.

In character and composition the brown sand is distinctly different from the pure, clean volcanic sands underlying it. Its color in shades of grayish brown is due primarily to limonitic pigment and cement. Lenses of roughly sorted angular conglomerate are prominent, particularly toward the west, and constitute about a third of the formation. (See fig. 6.) They are generally small

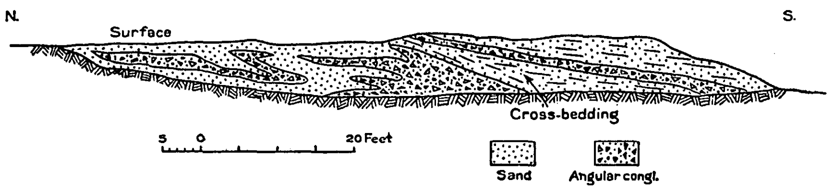


FIGURE 6.—Field sketch of brown sand showing interbedded angular conglomerate.

and thin, but at places they make up the full thickness of the bed. The angular fragments, all of which are thoroughly iron-stained, include Colorado sandstone, the different varieties of Cretaceous igneous rocks that are present in the area, and a foreign hornblendic rock that is prominent in the basal gravel. The sandy matrix of the bed is generally incoherent. It is made up almost entirely of volcanic material, but the grains are iron-stained, whereas in the earlier volcanic sands they are fresh and clean; in addition the sandy matrix contains grains of epidote that could have been derived only from the Cretaceous rocks. Streaks and particles of white ash are common. The brown sand gradually becomes less distinctive toward the east and eventually losses its identity beyond the mapped area, as it grades laterally into the gray volcanic sands.

GENESIS OF THE TERTIARY SEDIMENTS

Most of the Tertiary sediments are lake deposits of volcanic ash, and it is evident that the brown sand was deposited after the lake had been nearly filled, for obviously it is a shallow-water deposit. The original inequalities of the prevolcanic topography had been largely filled by gravel prior to the volcanic activity, much of the gravel having been transported for considerable distances. Near the shores of the lake and on the adjacent land the gravel brought into the area was mixed with volcanic ash, and deposits of tuffaceous gravel were formed, as in the southwest corner of the area. This tuffaceous gravel may have been reworked several times.

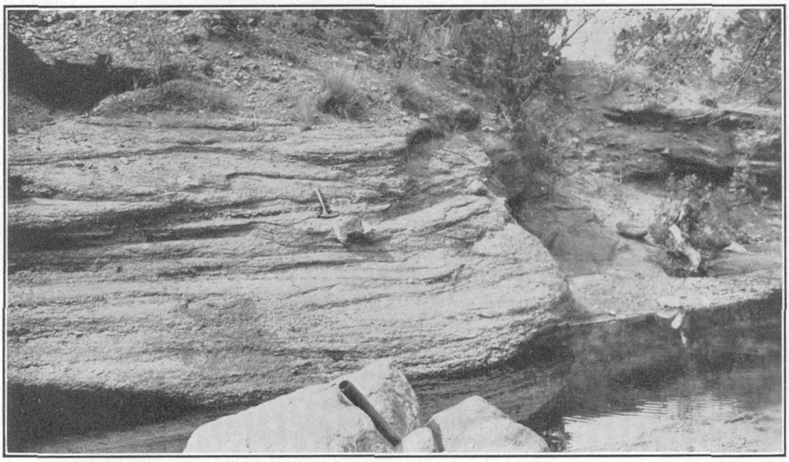
The oxidized nature of the volcanic sandy matrix of the brown sand suggests that the matrix was derived from adjacent land deposits of volcanic ash, but the large proportion of Cretaceous rock fragments implies that the ash was not abundant. Yet ash must have been falling upon the land at the same time as it was falling into the lake, and a moderate thickness of ash and of tuffaceous gravel probably covered the area adjacent to the lake during the early stages of volcanism; presumably the gravelly and less pure upper part of the lake beds represents this material stripped from the shore by later erosion. The 4-foot bed of gravel near the middle of the lake beds points to a change in drainage conditions and may indicate the beginning of the stripping action.

The predominance of conglomerate layers in the western part of the brown-sand bed and the fading out of the distinctive features of this bed toward the east indicate that the shore line of the lake lay near the western limit of the brown sand and consequently somewhere between San Jose Mountain and the Door Knob claim. Only 10 feet of Tertiary sediments lies between the Cretaceous rocks and overlying lava on the Door Knob claim, and just northwest, on the Jean and Geronimo claims, the topography shows that the flows must have rested directly upon Cretaceous rocks, indicating that the shore line was a little to the east. It is significant that water-sorted sand lies east of that place but that only tuffaceous gravel lies west of it.

QUARTZ LATITE DIKES

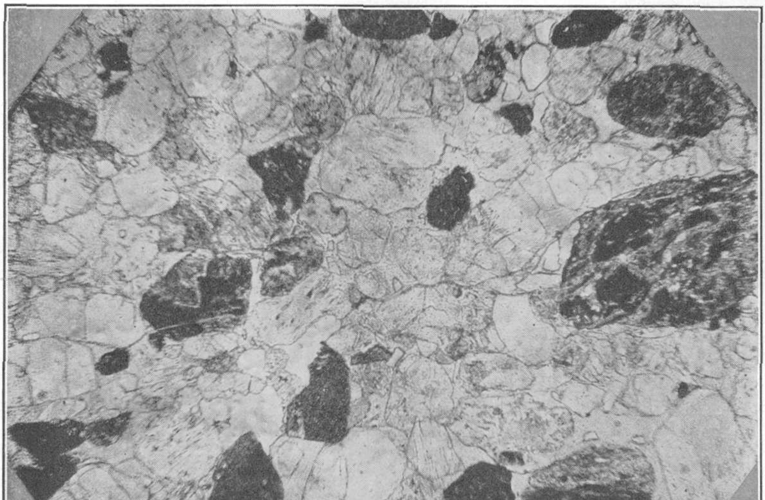
General features.—Quartz latite dikes crop out in the north half of the Bayard area and cut all other rocks except the volcanic flows and the Tertiary sedimentary rocks. Several of the dikes, however, cut bedded Tertiary gravel in the Hanover Basin, about a mile to the north. They were injected probably after a period of faulting that is thought to have occurred near the end of the explosive stage of volcanic activity (see pp. 50–51), and they are therefore nearly contemporaneous with the brown sand of the Tertiary sedimentary rocks.

The age relation of these dikes to mineralization is definite; the dikes are later than the period of ore formation, but were themselves bathed by weak, barren primary solutions. The dikes cut the contact-metamorphic zinc ores at Hanover, the contact-metamorphic iron ores in the open pit of the Republic mine at Fierro, and the disseminated copper ore at Santa Rita and split the Three Brothers, Johney, and Cashier veins in the Bayard area. But at several places



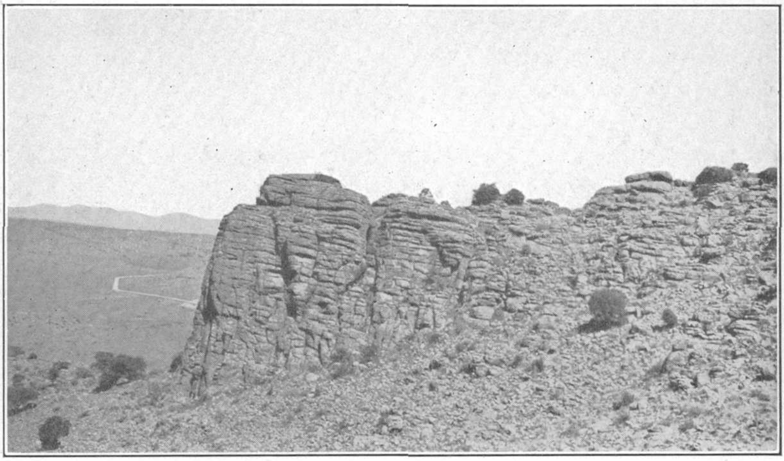
A. BEDDED CONSOLIDATED GRAVEL OF THE TERTIARY GRAVEL, SAND, AND TUFF. SOUTH END OF BAYARD CANYON.

The boulders, one of which is indicated by the hammer, are in place.

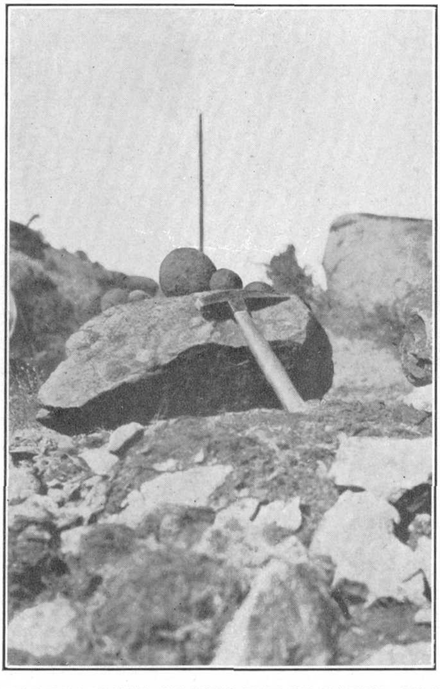


B. THIN SECTION OF VOLCANIC SANDSTONE FROM NEAR BASE OF THE GRAVEL. SAND, AND TUFF SHOWN IN PLATE 3, *A*.

Contains 50 percent of perlite and subordinate amounts of brown volcanic glass, shreds and fragments of pumice, pieces of volcanic rocks, and crystals of quartz, feldspar, and augite, set in a cement of chalcedony.



A. PSEUDOBEDDING IN THE QUARTZ LATITE FLOWS.



B. NODULAR SEGREGATIONS OF EPIDOTE IN LATER QUARTZ DIORITE.

in this area and elsewhere the dikes are sericitized, silicified, pyritized, one or all, and on the Johney claim the dike that splits the main vein is itself cut by oxidized stringers and is sprinkled with pyrite.

An aphanitic border and flow structure within this border parallel to the walls are common features of the quartz latite dikes. (See pl. 6, *B*.) They are pronged to some extent, but they lack the odd shapes characteristic of the granodiorite porphyry dikes, presumably because the preexisting fissures had been largely sealed by the earlier dikes and by vein matter and because the fracture pattern is less complex in the area in which the quartz latite dikes are prominent. Individual outcrops range in size from streaks hardly large enough to map to strong dikes as much as 80 feet wide and over a mile long. Most of the outcrops are small and narrow, but several of them may line up to form a string of considerable length. On the ridge between Hanover Creek and Lovers Lane several segments form a string about 3,500 feet long. At the south end of the string the top of the dike is exposed in a shallow arroyo on the Cashier claim. The dike fails to reach the surface by not more than 15 feet on the adjacent low ridge, but appears again in the next arroyo; evidently the segments are parts of the same dike, the irregular upper limit of which nearly coincides with the erosion surface. At the time of intrusion the pre-Tertiary erosion surface at this place was buried under less than 250 feet of volcanic sediments; that surface was not much different from the present one, so that the dike must have reached just about to the base of the volcanic sediments and therefore within about 250 feet of the surface.

Petrography.—The quartz latite dikes are gray in different shades and contain as a rule 10 to 25 percent of fine- to medium-grained phenocrysts in a gray aphanitic groundmass. The phenocrysts include white feldspar, thin pseudohexagonal spangles of shiny black biotite, a little quartz, scattered grains of magnetite, and a rare elongate crystal of apatite. Long books of biotite similar to those in the granodiorite porphyry were noted in some of the quartz latite dikes near Hanover.

Under the microscope the feldspar is seen to consist of orthoclase and oligoclase (about An_{20}) in variable but nearly equal proportions. The biotite, where fresh, is greenish brown and in places is extensively altered to magnetite. Intermingled with the magnetite and in places in biotite unassociated with magnetite are numerous minute grains of octahedrite. The quartz of the rock is largely confined to the groundmass, which is composed of a microgranitic, nearly cryptocrystalline intergrowth of quartz, orthoclase, and plagioclase. The accessory minerals consist of a little primary magnetite, a trace of zircon, and a prominent amount of apatite in minute grains, both needlelike and stubby. The needle variety ranges in length from 0.03 to about 1 millimeter and has a ratio of length to breadth of 9 to 1. It is perfectly automorphic. The stubby variety, which is generally corroded, is of somewhat greater average size and has a ratio of length to breadth of only about 3 to 1.

Secondary calcite is present in all the quartz latite dikes; evidence of partial replacement of nearly all the minerals is prominent, and calcite pseudomorphs are common. The alteration seems to have shown only slight preference for the calcium-bearing feldspar. In some grains of altered biotite the calcite is associated with a little chlorite, and some pseudomorphs consist of calcite-chlorite intergrowths.

QUARTZ LATITE FLOWS

Porphyritic quartz latite forms the rugged lava hills along the southeastern border of the mapped area, and thin remnants of this rock cap some of the low hills in the southwest part. The flows overlie the Tertiary sedimentary rocks and reach a maximum thickness of about 600 feet. Pseudobedding is prominent locally. (See pl. 8, *A*.) The rock weathers to a dull, badly pitted surface, but generally it has an appearance of sparkling freshness. It contains about 30 to 35 percent of fine- to medium-grained phenocrysts in a streaky groundmass of pinkish-brown glass in which spherulites are locally prominent. Some flows are coarse-grained and have abundant phenocrysts; others are fine-grained and consist mostly of glass. The phenocrysts consist, in order of abundance, of oligoclase (zoned An_{17-23}), glittering sanidine, quartz, thin books and flakes of shiny blackish-brown biotite, and grains of magnetite.

The biotite is dark red-brown to yellowish, the color depending on its orientation, and is extensively altered to magnetite, which commonly occurs as a rim of small grains. A few grains of hornblende identical in color with the biotite were seen in one thin section, and a trace of augite was noted in thin sections of the upper flows. Apatite and less abundant zircon and titanite are accessory minerals. The apatite is both stubby and needlelike, and both varieties are corroded, the stubby variety markedly so, the other only incipiently along the cleavage. The groundmass is generally grayish-brown glass, slightly devitrified and here and there containing fibrous or feathery feldspathic spherulites. A protoclastic structure of the rock is characteristic; although some of the phenocrysts show smooth, generally resorbed outlines, most of the crystalline part of the rock consists of minute, sharp, broken pieces of quartz and feldspar. Some of the larger phenocrysts are broken and cemented by glass, and large laths of biotite are bent, twisted, and shredded.

In the eastern part of the district, about coextensive with the brown sand, the lower 25 feet of the quartz latite differs in several respects from the overlying part, probably because of having come to rest in the shallow water in which the brown sand was deposited. (See fig. 8, 3.) It is massive and weathers to huge knobs and bouldery shapes, whereas the overlying rock is pseudobedded and weathers slabby; it is white rather than brownish, and the groundmass is lusterless as contrasted with the sparkle of the other rock. Large, sharply angular iron-stained fragments of Cretaceous rocks identical with the conglomerate fragments of the underlying brown sand are common.

GENETIC RELATIONSHIP OF QUARTZ LATITE DIKES AND FLOWS

The name "quartz latite" as applied to the dikes implies that the rock is of volcanic origin, but there is little in the mineralogic and textural nature of the rock to indicate that it should be called "quartz latite" rather than "granodiorite." The conclusion that the dikes are genetically related to the flows is based on the fact that the dikes cut the Tertiary gravel, on the fact that they approached within 250 feet of the surface at the time of injection, and on a mineralogic comparison with the quartz latite flows.

The mineralogic comparison of the dikes with the flows, particularly a comparison of the heavy mineral accessories and their characteristics, is especially suggestive of a close genetic relationship between the two rocks. The most obvious likeness is the similar composition of the plagioclase feldspar in both rocks. Both rocks contain a trace of zircon and relatively abundant apatite, and in both the apatite occurs as needlelike and stubby crystals in which the ratios of length to breadth are essentially identical—9 to 1 and 3 to 1—and on which the crystal terminations also seem identical so far as this feature can be determined on minute crystals in thin section. In both rocks the stubby apatite is markedly corroded. The needle apatite in the flow rock is slightly corroded, whereas that in the dikes is automorphic, but the rock of the flows was unquestionably in a fluid condition for a longer time than the rock of the dikes, and it appears only natural that, although the needle apatite is uncorroded in one rock, it should show slight corrosion in another rock in which it had remained longer in a fluid and therefore unstable environment. It is recognized that differences in degree of corrosion might be due as much to slight differences of composition either of the minerals or of the corroding medium as to differences in time.

The flows contain a trace of titanite, but diligent search failed to reveal this mineral in the dikes. On the other hand, the dikes contain the titanium mineral octahedrite, which is evidently a late magmatic alteration product of the biotite, and this mineral is absent from the flows. These differences, however, may not vitiate the apparent kinship between the two rocks but may indicate only a redistribution of titanium in the interval between injection of the dikes and extrusion of the flows.

Gilluly and Reed,[29] who have correlated igneous rocks by comparison of heavy mineral accessories, state that the characteristics of minerals, such as have been described for apatite, are more significant than the presence or absence of these minerals in an individual specimen or the relative amount as compared to other minerals or to the whole rock; of these characteristics they consider particularly significant the bounding surfaces of a mineral and the ratio of length to breadth. The comparisons described in the preceding paragraphs were made on thin sections; coupled with the structural evidence, these comparisons, particularly those that Gilluly and Reed indicate as important, point so strongly to a close genetic relationship between the dikes and flows that it was deemed unnecessary to study the accessory minerals by the more refined method of first separating them from the rest of the rock. Chemical analyses are generally valuable in correlation, but the strong carbonation and local pyritization of the dikes make this method hardly applicable to the present problem.

Stocks seemingly identical lithologically with the quartz latite dikes crop out at several places in the Silver City quadrangle, one of them within a mile of the Bayard area, and Paige[30] suggests that these stocks were the source of the lava flows. Some of the larger dikes, such as that which extends from the Joseph mill site to the Johney claim, also may have reached the surface and have been the feeders for a little effusion, but most of the dikes did not. The age of the dikes and their close relationship to the flows bear out the suggestion that the quartz latite stocks, and perhaps some of the dikes, were feeders to the flows.

QUATERNARY ROCKS

A short dike of basalt, about 200 feet long and 40 feet wide, crops out approximately at the contact between flows and tuff due west of Bayard station. It is not shown on the geologic map. It is later than the flows and probably represents the Pleistocene basalt of the Silver City quadrangle[31] and the desert region to the south. No

[29] Gilluly, James, and Reed, J. C., Heavy mineral assemblages of some of the plutonic rocks of eastern Oregon: Am. Mineralogist, vol. 17, pp. 201–220, 1932.
[30] Paige, Sidney, op. cit. (Folio 199), p. 10 and pl. 3.
[31] Idem, p. 10.

other evidence of Quaternary igneous activity in the Bayard area was noted.

The small amount of Quaternary gravel present in the area has been described in the pages on surface features. Unconsolidated sand, gravel, and clay fill the desert flat to the south and encroach upon the Bayard area.

STRUCTURE

REGIONAL FEATURES OF THE SILVER CITY QUADRANGLE

Paige[32] describes a broad, shallow syncline whose axis extends southeastward from Pinos Altos to a point southeast of Central, passing west of that town. Numerous sills of quartz diorite, the most prominent of which are in the Colorado formation, are interlayered with the sedimentary rocks on the east limb of the syncline, the trough of which roughly coincides with the edge of the sill area. Paige's section across the syncline shows a smoothly dipping east limb but a strongly buckled west limb. The sills were injected prior to folding, and perhaps the location of the trough and the paucity of subordinate warping on the east limb are the results of the competent layers of igneous rock in that limb. The east flank of the syncline is modified by an anticlinal arch, the Fort Bayard arch, whose axis pitches southwestward from a point east of Fierro to a point near Central.

Stocks of granodiorite penetrate and deform the rocks, bulging them upward into local domes and domal anticlines. Structural warps formed in this manner occur at Gomez Peak, at Copper Flat, and in the Santa Rita-Hanover region. Granodiorite porphyry dikes followed intrusion of the stocks and are prominent in the Central district. Stocks and smaller masses of granodiorite, all of essentially identical character, crop out here and there in an area of nearly 400 square miles, extending from Hanover to White Signal, and are presumably related to an underlying reservoir that may extend for many miles under the adjacent Tertiary lavas and Quaternary valley fill. The economic possibilities of the general area are not in the province of this report, but it is worth pointing out that ores have been mined from the vicinity of every outcropping stocklike mass, some of the deposits being of tremendous size, and that similar deposits may be associated with masses covered by Tertiary or Quaternary formations.

Tertiary lava flows and interlayered tuffs, now present only locally, probably covered the entire Silver City quadrangle at one time. Except where modified by local fault tilting, they are nearly hori-

[32] Paige, Sidney, op. cit., p. 10 and geologic maps.

zontal, dipping southeastward at the rate of about 120 feet in a mile.

The faults of the Silver City quadrangle fall into two groups—one trending northwestward, roughly parallel to the broad folding of the rocks, the other trending northeastward, roughly at right angles to the first group and parallel to the subordinate folding represented

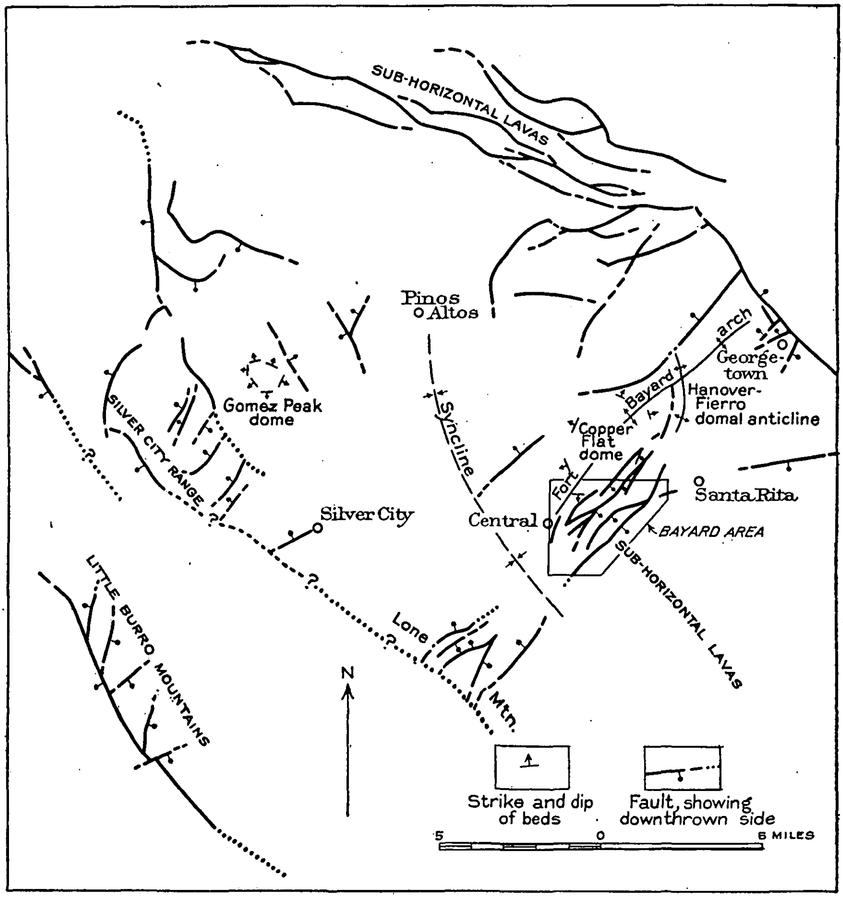


FIGURE 7.—Map of the principal faults and folds of the Silver City quadrangle, showing relation of structure in the Bayard area to the regional structure of the quadrangle. Small arrows show dip of beds; half dumbbells show downthrown side of faults. Faults are dotted where concealed.

by the Fort Bayard arch. Figure 7 shows the principal faults of the quadrangle. The northwesterly group contains a few widely spaced faults with throws measured in thousands of feet. The northeastward-trending faults are more closely spaced, are generally much shorter, and have throws usually only a fraction of those of the other group. Many of them, according to Paige's mapping, stop against members of the other group; a few cross and displace these slightly. In a broad way they appear to be complementary to the northwestward-trending faults and cognate with them. The northeastward-trending faults are prominent in the Silver City Range, in the Little Burro Mountains, at Lone Mountain, and in the Central district, particularly in the Bayard area.

The displacement of the faults of the quadrangle is the sum of many recurrent movements along the same fault zones; the displacements shown by the younger rocks, such as the lavas and tuffs, indicate only the movement since those rocks were deposited, which may be relatively small compared to the aggregate displacement along the same faults in the underlying older rocks. The earliest faulting occurred in the interval between injection of the quartz diorite sills and injection of the granodiorite stock and therefore accompanied the early folding. Faulting definitely recurred after injection of the granodiorite dikes, after effusion of the volcanic rocks, and after deposition of the Pleistocene gravel,[33] and the geology of the Bayard area suggests that there was also an intervolcanic period of faulting.

STRUCTURE OF THE BAYARD AREA

GENERAL FEATURES

The Bayard area is on the eastern limb and near the trough of the Pinos Altos-Central syncline. The nose of the Fort Bayard arch lies within the area, and the adjacent synclinal warping influences the dip and strike of the strata for a considerable distance. The average dip is northwestward, as compared to the regional southwestern dip of this flank of the syncline. The attitude of the beds ranges from horizontal to a dip of about 20°, but most of the local dips are the result of tilting of fault slices and blocks.

At a few places the sills in the Colorado formation have bulged up the overlying sediments, but such warps are subordinate and generally insignificant.

FAULTS

AGE

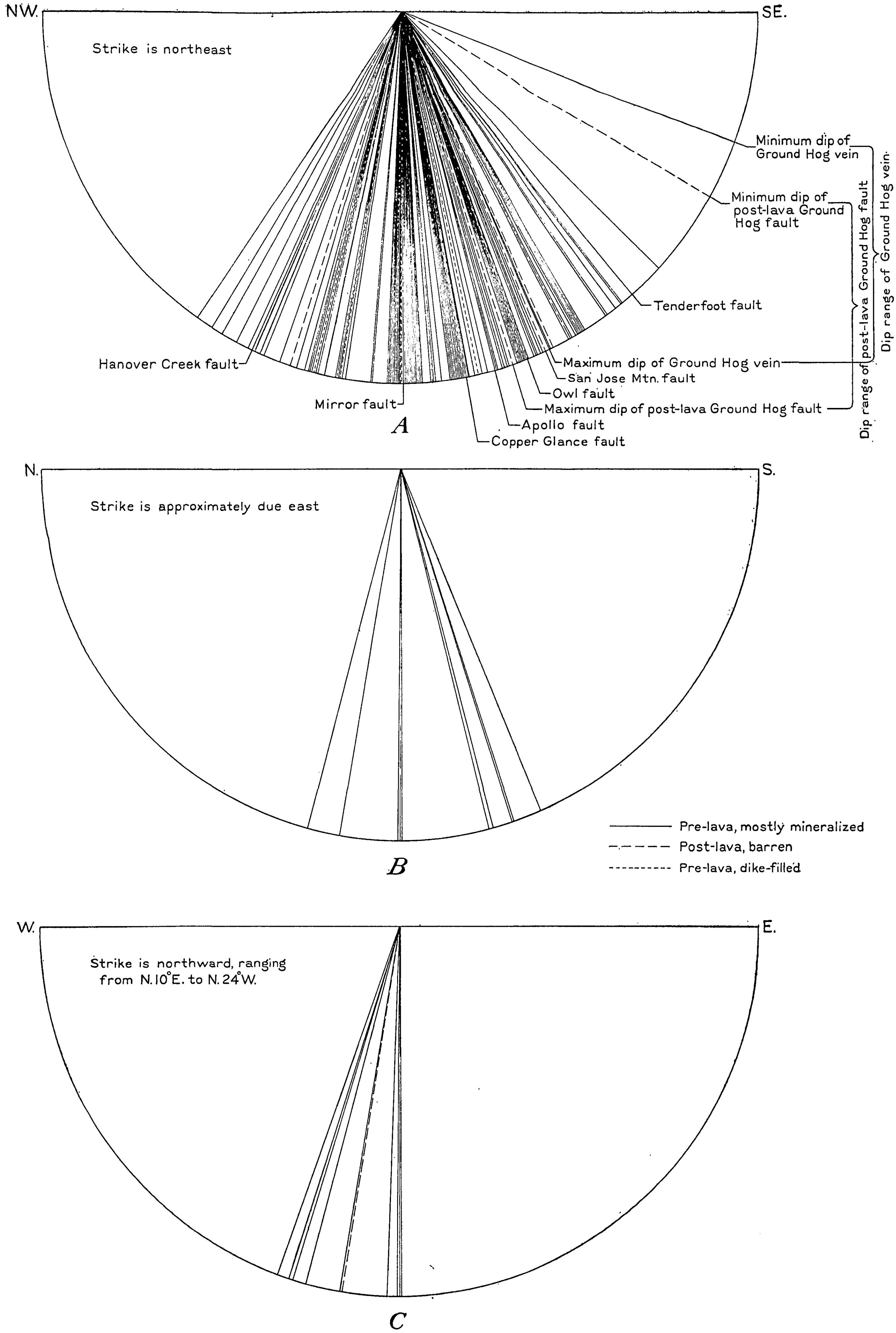
Three major periods of faulting can be recognized in the Bayard area—one which was subsequent to the intrusion of the sills and along members of which later granodiorite porphyry dikes were injected, a second period, after the injection of the dikes, and a third period after the expulsion of the volcanic rocks. The Ivanhoe-Lovers Lane zone, the earliest faults at the Ground Hog mine, the Copper Glance fault, the Owl fault, the Dutch Uncle-Tin Box vein, probably the Hanover Creek fault, and some smaller faults belong to the first period, all members of which were later mineralized,

[33] Paige, Sidney, op. cit. (Folio 199), pp. 11, 12.

though not to a commercial extent. The faults occupied by the Ground Hog vein, the veins on the Burchard, Osceola, and Goodyear claims, the Homestake vein, and the Paola vein are the most prominent members of the second group. The Ground Hog fault (as distinct from the Ground Hog vein) and the San Jose Mountain fault are the principal members of the post-volcanic group, all of which are barren. These manifestly followed earlier fault zones, at some places lying along the earlier fissures, elsewhere diverging from them and faulting them with spurs and branches. The Ground Hog zone is the only one that has been sufficiently exposed to permit study, and the details of this zone are given in the descriptions of the Ground Hog, San Jose, and Lucky Bill mines.

On plate 9, a map showing the outcrops of the veins and faults of the area, an attempt has been made to discriminate between prevolcanic and postvolcanic faults, though obviously it is not possible to determine the exact age of many of them. Doubtless along many of those indicated as prevolcanic later movement has occurred, but it is impossible to determine this solely from the outcrops. The distinction between prevolcanic and later faults is essentially a distinction between mineralized and unmineralized fissures, but this criterion must be used with caution, because faults of a probable intervolcanic period, discussed in the following paragraphs, may be slightly mineralized. It is noteworthy that the Tertiary faults that can be studied followed the major Cretaceous fault lines, as indicated by the Owl-Bayard, San Jose Mountain, and Ground Hog faults; many of the subordinate Cretaceous faults pass under and are covered by Teritary sediments that show no signs of later fracture.

A fourth period of faulting seems to have occurred near the end of the explosive stage of volcanic activity. No fault of the area can be labeled unequivocally as belonging to this period, though there are strong reasons for believing that the Bayard fault and the postlava Ground Hog fault originated at that time. The throw of the Tertiary gravel along the Bayard fault amounts to 100 feet or more, but the overlying lava has been displaced only a few feet, if at all, to judge from the altitude of the base of the lava on the Door Knob and neighboring claims and on San Jose Mountain; the inference is that displacement along the Bayard fault was largely, if not totally, completed prior to extrusion of the lavas. On the Ground Hog fault the throw as measured by projection of the brown sand from San Jose Mountain is less than the throw shown by the base of the gravel as indicated by underground workings. The two figures can be brought into accord by assuming a warp in the brown sand and overlying lava, but the necessary warping is unnatural, and the disagreement suggests that the Ground Hog fault originated



CHARTS SHOWING DIRECTION AND AMOUNT OF DIP OF VEINS AND FAULTS OF THE BAYARD AREA.

and attained a throw possibly as great as 60 feet before the brown sand or the lavas were deposited. It is recognized, however, that the disagreement might be due to the uneven surface at the base of the gravel.

The distribution and character of the Tertiary sediments support the idea of an intervolcanic period of faulting. It has been pointed out in the paragraphs on the genesis of these sediments that the brown sand was deposited after the lake in which the volcanic sands were sorted had been nearly filled, and that the material of the brown sand was derived from Cretaceous rocks from which a cover of volcanic ash deposited at an early stage had been stripped. There are two sets of conditions under which this could have happened. Either (1) an old Cretaceous ridge existed adjacent to the lake, and the volcanic ash deposited on this ridge was later swept into the lake as the result of an unexplained rejuvenation of drainage, nearly filling the lake and reexposing the Cretaceous rocks to erosion; or (2) the Cretaceous rocks were denuded of their cover of volcanic ash as a direct result of having been uplifted by a recurrence of faulting. The first hypothesis infers a Cretaceous topographic relief greater than seems to have existed. On the other hand, existing structural conditions are exactly what they should be if the second hypothesis is correct. Necessary corollaries to the fault hypothesis are that the shore line of the lake in which the brown sand was deposited should mark the approximate position of the fault along which the Cretaceous rocks were uplifted, and that the brown sand should lie on the downthrown side of the fault, in the nature of a fanglomerate. The Bayard fault is in the vicinity in which the shore line must have been (see p. 42), and the brown sand is on its downthrown side. The sketches in figure 8 illustrate the sequence of events involved. The first sketch shows the conditions just prior to the recurrence of the faulting. In the second sketch renewed movement has taken place along the Owl and Ground Hog faults, and the volcanic sediments from the rising area have been transferred to the lake, reexposing the Cretaceous rocks; the lake has been almost filled by the reworked sediments, and deposition of brown sand has begun. To the reworked material is due the impure character of the upper part of the gravel, sand, and tuff. The third sketch is self-explanatory. The fourth is a cross section drawn to scale along a line extending from a point west of the Jean claim eastward to the Denver claim. Parts of formations removed by erosion have been restored in order to show the improbability of postlava movement along the Bayard fault and the difference in throw of the Ground Hog fault as indicated by the brown sand and by the base of the gravel.

CHARACTER

The faults of the Bayard area cover a zone about 2 miles broad trending northeastward into the Hanover area. They cannot be traced to the southwest because of the valley fill, but the zone may well be a continuation of that at Lone Mountain. In detail, as shown on plate 9, the fault pattern is made up of several persistent members, some of them broadly curved, linked together by a multitude of subordinate faults and insignificant fissures. Spurs and local link-

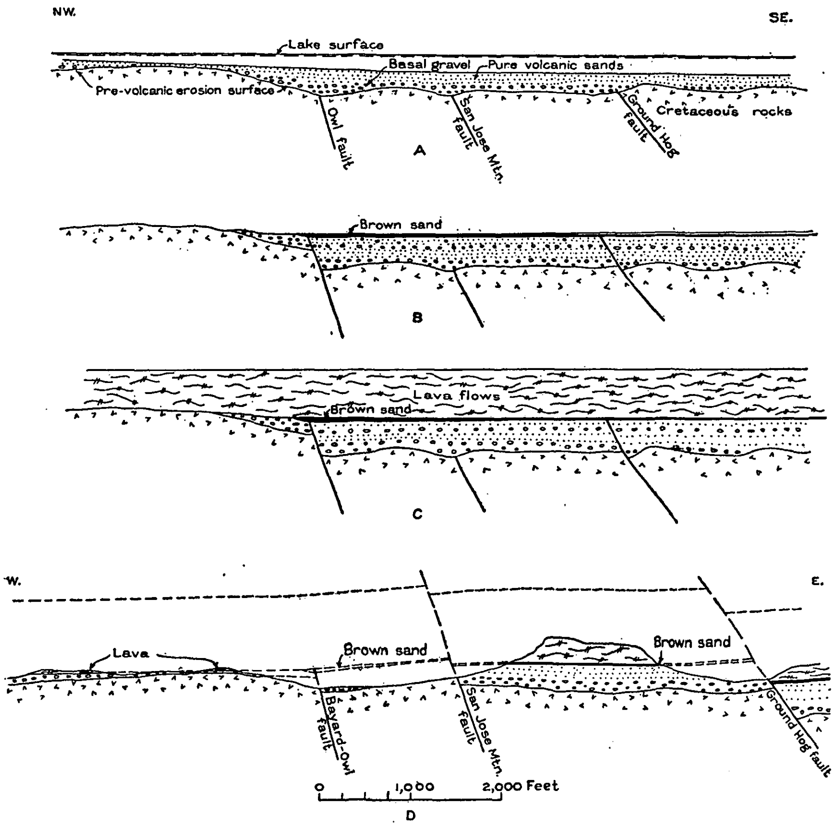


FIGURE 8.—Sketches showing successive steps during the intervolcanic period of faulting. See text.

ages are common features. Many faults seem to be fairly sharp breaks, but locally some of these diffuse into complex linked systems, as is well illustrated by the Ivanhoe-Lovers Lane fault. Nearly all the faults strike strongly northeastward; a few subordinate ones trend eastward and an equal number northward. Dips lie on either side of the strike, but most commonly they range between vertical and 60° SE., the only major fault that dips northwestward being the Hanover Creek fault. The flatter dips are more common with the stronger faults. Dips differ widely from place to place along some of these, the greatest range being from 21° to 65° along the Ground Hog vein. The diagrams in plate 10 show the predominant attitudes.

All the faults are normal, and the downthrow is therefore generally to the southeast, in conformity with the dip. The net result, as shown in the geologic sections, is a series of step faults with an occasional small horst or graben slice. The faults die out either by splitting into several members, the composite throw of which at first is equivalent to that of the original break, or by a simple decrease of throw. Some of the splitting members further split up and fray out. The simple rifts, those that die out by simply decreasing in throw, do so at an average rate of about 100 feet of throw per 1,000 feet of strike length. At variable distances from the end of a fault the throw becomes fairly constant until the fault joins with another or until it begins to die out in the other direction.

The Apollo is the only major fault both ends of which die out within the area. The throw can be determined with fair accuracy near the north end, where the shale member of the Colorado formation is dropped against the lower sill, and from that point to the northeast it decreases at the rate of about 95 feet per 1,000 feet of strike length. Near the middle of the fault outcrop the throw involves parts of the shale member, the overlying sandstone member, and the lower and middle sills in the Colorado formation, and amounts to about 475 feet, indicating an average change in throw for the whole fault of about 120 feet per 1,000 feet of strike length. On the Copper Glance fault, the throw of which can be determined closely at one place (see fig. 3), the decrease in throw to the southwest for each 1,000 feet along the strike is about 105 feet; to the northeast the Copper Glance fault joins with the Lovers Lane fault. The throw of the post-lava Ground Hog fault increases to the southwest at an average rate of 100 feet per 1,000 feet of strike length until it reaches about 300 feet, at which it seems to remain, at least as far southwestward as the throw can be determined. This fault is hard to trace north of the C. G. Bell mine, but it appears to pass through a shallow shaft that lies adjacent to the road on the north bank of Whitewater Creek; this must be near its northernmost extension, however, because only 400 feet away the unbroken outcrop of a quartz vein passes squarely across the trend of the fault. The pre-lava Ground Hog vein ends at essentially the same place as the post-lava fault, roughly paralleling the later fault a short distance in the footwall. Spurs and branches of the post-lava fault cross over to the vein and displace segments of it, and post-ore movement has occurred along the vein, but the formations in the walls of the vein have been sufficiently exposed at the Ground Hog mine to permit the tentative estimate that the pre-ore throw at that place was about 240 feet, indicating a change in throw of about 95 feet for each 1,000 feet along the strike. The Hanover Creek fault dies out within the Bayard area, but no horizon marker is exposed upon which determinations of throw can be based. The Mirror fault also dies out within this area but does so partly by splitting.

The Lovers Lane and Owl faults are the strongest ones in the area. The throw of the Lovers Lane fault is well over 1,300 feet north of its junction with the Copper Glance fault. The throw involves as much as 50 feet of the Syrena formation; the full thickness of the Beartooth quartzite, 65 feet; the full thickness of the shale member of the Colorado formation, 220 feet; the full thickness of the middle sill, which in this vicinity is 400 feet or more; an unknown thickness of the upper or sandstone member of the Colorado formation between the middle and upper sills; the full thickness of the upper sill, 450 feet or more; and about 100 feet of the sandstone member above the upper sill. South of the Copper Glance fault the throw is decreased by the throw of that fault, and in addition the Lovers Lane fault diffuses into the complex Ivanhoe zone, along members of which the dikes at the Ivanhoe and Ground Hog mines were injected.

The throw of the Owl fault is at least 900 feet on the Bull Frog claim (see fig. 16), and to the north it may equal or exceed that of the Lovers Lane fault. South of the Bull Frog (Owl) mine the Owl fault splits into three members—the Slate vein, which itself splits up before joining with the south end of the Apollo zone; the Lost Mine vein, which gradually dies out; and a third fault of much greater throw that passes into the Tertiary Bayard fault.

The following table summarizes data on the principal faults:

Principal faults of the Bayard area

Name	Maximum throw (feet)	Change in throw per 1,000 feet of strike length (feet)	Remarks
Apollo	475±	95–120	
Bayard			Insufficient data.
Copper Glance	575	105	Joins with Lovers Lane fault at one end.
Dutch Uncle-Tin Box			No data.
Ground Hog vein	Indeterminable	95±	Has post-ore movement and is faulted by spurs and branches of the post-lava Ground Hog fault.
Ground Hog fault (post-lava).	300	100	
Hanover Creek			Insufficient data.
Lovers Lane	At least 1,300		Diffuses into Ivanhoe zone.
Mirror			Dies out partly by splitting.
Owl	At least 900		Splits southward into several members.
San Jose Mountain	At least 150		Insufficient data.

CHRONOLOGIC SUMMARY

The earliest geologic occurence of particular significance in the study of the ore deposits of the Bayard area was the injection of the earlier quartz diorite sills, the most prominent of which are the upper and lower sills in the Colorado formation, but this was followed almost immediately by injection of the large middle sill. Regional folding took place subsequent to the emplacement of the sills, which acted as highly competent members and influenced the degree of warping; as a consequence the east limb of the regional syncline on which the Central district lies has a moderately uniform dip, whereas the western limb, containing no sills, is strongly buckled. The uniformity of the east limb is somewhat modified by several bulges caused by later intrusions of granodiorite stocks, and also by the Fort Bayard arch, a transverse fold that lies partly within the Bayard area. Numerous granodiorite porphyry dikes that are related to the Santa Rita stock crop out in this area. Many of them cross or occupy earlier faults whose exact age is uncertain. Many fissures doubtless resulted from stresses incident to the stock intrusion, and these lines of weakness probably controlled the location of some dikes; but other dikes, notably the Ivanhoe and Ground Hog, occupy faults of considerable throw that were probably formed before the intrusion of the stock. The early faults were lightly mineralized prior to the injection of the dikes, but the known commercial deposts of the area lie along later faults that tend to follow the dike contacts.

After the formation of the ore deposits, the area was eroded to a rolling surface from which essentially all topographic expression of earlier structure was removed, and the ore deposits were oxidized and truncated. This was followed by a period of explosive volcanic activity during which an extensive series of gravel, tuff, and volcanic sand was deposited. The end of the explosive stage seems to have been accompanied by a minor recurrence of faulting along some of the earlier flaws. The Bayard and post-ore Ground Hog faults originated at that time, and movement along the Bayard fault seems to have been confined to that period. The quartz latite dikes were probably injected shortly thereafter. These dikes are slightly mineralized, but no economically important minerals were deposited at that time. Some of the larger dikes may have served as feeders for the thick lava flows that subsequently covered the entire region, but the major feeders were probably the quartz latite stocks that crop out at several places in the Silver City quadrangle. Faulting recurred after extravasation of the lavas but seems to have been restricted to the major zones of earlier faulting. Subsequent erosion was guided by the post-lava faults until the underlying tuffaceous rocks were reached. Erosion then spread laterally by a rapid retreat of the cliffs caused by undercutting of the incoherent volcanic sediments and tuffs, and as these were exposed they were rapidly stripped away to uncover the Cretaceous rocks beneath. Continued erosion apparently found it easier to undercut the lavas and to remove the Tertiary rocks than to cut into the rehabilitated Cretaceous surface, and in the Bayard area this surface is much as it was before having been covered by the Tertiary sediments.

The following is a brief tabular summary of the sequence of events:

Injection of earlier quartz diorite sills.
Injection of later quartz diorite sills.
Faulting.
Mineralization.
Injection of granodiorite stocks and dikes.
Faulting.
Economic metallization of the area.
Erosion and oxidation of ores.
Explosive volcanic activity and deposition of Tertiary sediments.
Subordinate faulting along a few earlier breaks.
Injection of quartz latite dikes.
Faint mineralization.
Extrusion of lavas.
Faulting along the major Cretaceous fault zones.
Quaternary erosion cycle.

ROCK ALTERATION

All the intrusive rocks of the Bayard area have been widely altered by hydrothermal angencies whose activities may be divided into two stages—an early hydrothermal stage preceding ore formation, and a later hydrothermal stage of the ore-forming period. It is impossible to make a sharp distinction between minerals produced by ore-forming solutions and those produced by earlier hydrothermal agencies, as they are all the result of an essentially continuous process, and in this report the distinction is made arbitrarily between minerals that are widespread through the rocks and those that are confined to the veins and their immediate vicinities. Some minerals belong to both groups. The alteration suite consists of albite, chlorite, epidote, calcite, sericite, and quartz. In a general way, the degree of alteration varies with the age of the rocks, but in each rock the relative sequence of alteration seems identical.

EARLY HYDROTHERMAL STAGE OF ALTERATION

ALBITIZATION

Albite occurs in all igneous rocks of the Bayard area except the Tertiary lava flows. It is replaced by the other alteration minerals and clearly represents the earliest hydrothermal alteration imposed on the different rocks. In each rock it shows particular features of distribution and abundance, being most abundant in the oldest rock and progressively less so in each younger one. In the earlier quartz diorite, the oldest igneous rock of the area, all the original feldspar is partly albitized, and albite phenocrysts are scattered throughout the rock. Albite is the only feldspar present in the large sheeted mass of earlier quartz diorite on Whitewater Creek. All the original feldspar is partly albitized in the later quartz diorite also, but although replacement of some original phenocrysts is far advanced, no albite phenocrysts were seen except in the narrow apatitic zone at the base of the sill; in this zone, where the rock is more strongly sheeted than elsewhere, albite is the only feldspar present, as in the Whitewater Creek mass of earlier quartz diorite. Albitization is erratic in the next younger rock, the granodiorite porphyry dikes. It is present everywhere in the light-colored dikes but is sparse or absent, except in structurally favorable places, in the finer-grained and less porphyritic dark-colored dikes. The roots of some of the prongs of the Ivanhoe dike along Whitewater Creek are completely albitized where they penetrate the albitic mass of the earlier quartz diorite, but no sign of albite could be seen in a thin section of a narrow granodiorite porphyry dike along Tenderfoot Gulch, several hundred feet away but still in the albitic mass of quartz diorite. Albite was noted in only one specimen of the Tertiary quartz latite dikes.

The albite phenocrysts are essentially pure albite, An_0. Theoretically it is highly improbable that phenocrysts of pure albite should have crystallized from a magma so calcic as to have yielded labradorite; therefore the albite phenocrysts are believed to be the end product of the widespread albitization of the pyrogenic feldspars. The albite phenocrysts show polysynthetic twinning according to both the albite and pericline laws, and the development of this twinning can be studied in several phenocrysts in which albitization is incomplete. (See fig. 9.) The albite veinlets have different extinction angles in the different twinning bands of the host plagioclase, and it is almost obvious that continued replacement would lead to twinned albite crystals. Some veinlets differ in extinction in the same twinning band of the host, and some of the larger albite blebs show a faint twinning at a large angle to the twinning lamellae of the host, presumably leading to the development of pericline twinning in the albite metacryst.

The degree of albitization seems to be dependent, in part, on the permeability of the rocks. Such thoroughly albitized rocks as the large mass of the upper sill along Whitewater Creek, the roots of the granodiorite porphyry dikes in it, and the basal zone of the middle sill, indicate places where albitizing solutions were able to percolate readily, either because of fracturing or because of the texture of the rock, or both. In the upper sill on the Ruth claim is a long dikelike sheeted outcrop that is as completely albitized as the large mass to the west, the sheeting evidently having permitted maximum penetration by the albitizing solutions. The strong sheeting at the base of the upper sill and the equally strong local sheeting at the base of the middle sill probably facilitated albitization in a similar

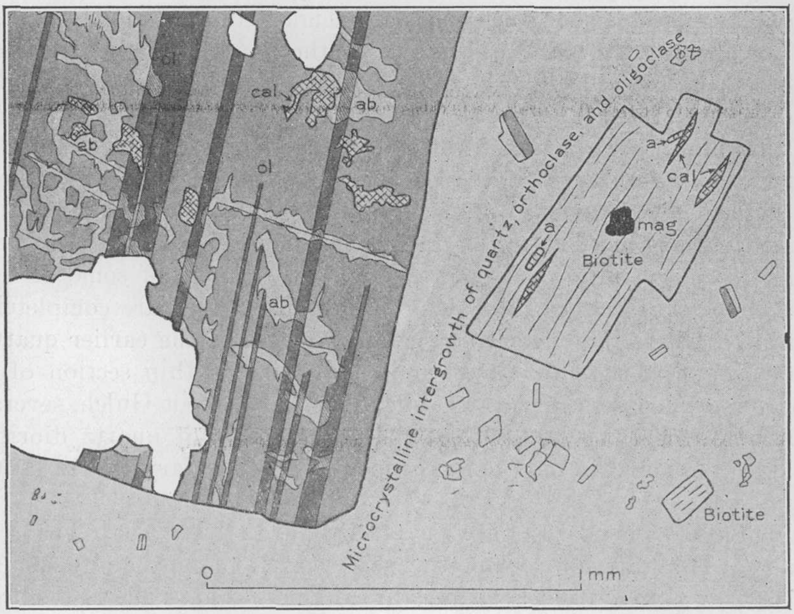


FIGURE 9.—Camera-lucida drawing of thin section of quartz latite dike showing replacement of oligoclase (ol) by albite (ab) and replacement of both feldspar and biotite by calcite (cal). Apatite prisms (a) and magnetite (mag) in the biotite. White spaces in the oligoclase are holes in the section; other areas not labeled are comparatively large grains in the groundmass.

fashion. The erratic distribution of albitization in the granodiorite porphyry dikes illustrates the effect of rock texture on the passage of altering solutions.

Although albite was the earliest alteration mineral in all the rocks, there must have been at least two periods of albitization. Partly and wholly albitized feldspar phenocrysts are replaced by epidote in the Cretaceous (?) plutonic rocks, yet albitized feldspar was noted in a quartz latite dike that is younger than the widespread epidotization of the other rocks.

CHLORITIZATION

Chlorite represents the second stage of alteration. Like albite, it is progressively more abundant in each older rock. It is insignificant in the quartz latite dikes, the youngest intrusive rock. In this rock a few of the biotite crystals, most of which are fresh, have a thin alteration rim of chlorite, and in some of the calcitized biotite a little chlorite is intergrown with the calcite. The granodiorite porphyry dikes are the next older rocks and show moderately greater chloritization. In these rocks all biotite has been converted to optically homogeneous bright-green chlorite pseudomorphs. Under crossed nicols a few of these show the "ultra-blue" color typical of some chlorite, but most have a yellowish-brown interference color. The birefringence is estimated at about 0.01. The mineral is biaxial (+) with a small optic angle and is presumably clinochlore. The clinochlore pseudomorphs characteristically contain grains of octahedrite and are partly replaced by epidote and locally also by calcite, sericite, or quartz. Where sericite is abundant the optically homogeneous clinochlore is recrystallized to an aggregate of sheaves and foils of dull-green chlorite of very low birefringence, presumably penninite, and the penninite in places seems contemporaneously intergrown with the sericite. The hornblende of this rock is rather fresh but in places is slightly replaced by penninite. Patches and flakes of penninite lie here and there in the groundmass, and rarely an isolated flake occurs in the feldspars.

Chloritization is still stronger in the later quartz diorite. This rock does not contain biotite, and the comparison is based on the state of the hornblende and on the amount of chlorite distributed in the groundmass and in the feldspars. The chlorite is of the dull-green variety. It tends to be optically homogeneous in the crystals, but the irregular patches in the groundmass are made up of aggregates of flakes or sheaves, many of which are partly sericitized. Other sheaves and flakes seem intergrown with sericite, particularly in altered feldspar. In the earlier quartz diorite, the oldest rock, chloritization is extreme. Residuals of hornblende and biotite are rare, and even pseudomorphic chlorite patches are uncommon. This is due in part to replacement by later alteration minerals but is largely the result of intense chloritization. Much of the chlorite cuts veinlike through the rock, being clearly foreign to the place it occupies, and in many places the chlorite forms a mesh enclosing the earlier minerals.

As with albitization, there must have been at least two stages of chlorite alteration—one confined to the Cretaceous (?) rocks and earlier than the epidotization of these rocks, and the other originating in the quartz latite dikes, which were injected after the other rocks were epidotized. The apparent break-down of clinochlore (?) to penninite (?) and the intergrowths of penninite (?) with sericite may indicate a further age subdivision.

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EPIDOTIZATION

CHARACTER AND DISTRIBUTION

The term "epidote" is used in these pages to include all minerals of the epidote group that occur in the Bayard area. Megascopically only two members of this group can be recognized—pink clinozoisite and green pistacite—but microscopic study indicates that there is probably a continuous series ranging from pink clinozoisite containing about 4 percent or less of Fe_2O_3 to green pistacite (common epidote) containing about 9 percent or more of Fe_2O_3. Manganese is present throughout the range, the amount of manganese being greatest where the amount of iron is least, to judge from the intensity of the soda-bead test. Estimates of the Fe_2O_3 content were read from curves[34] showing the relation of optical properties to iron content. Inasmuch as the optical properties vary with the manganese as well as with the iron content, the percentages given can be only approximate, but they serve to show the compositional variation.

Epidote is confined to the Cretaceous (?) intrusive rocks and to adjacent parts of the sedimentary rocks. Like the albite and chlorite, it is most abundant in the oldest intrusions. It occurs chiefly as grains, aggregates, and clusters of radiating needles in the phenocrysts and scattered in the groundmass, and less commonly as thin films along joints. The earlier quartz diorite sills and the granodiorite porphyry dikes contain both the pink and the green varieties, but only the green variety seems to be present in the later quartz diorite. The two varieties are intergrown here and there, but as a rule the iron-poor clinozoisite prefers the feldspar, whereas the iron-rich pistacite shows a similar but less strong preference for the ferromagnesian minerals.

A more striking occurrence of epidote is as nodular segregations, ranging from less than half an inch to 10 inches in diameter, that seem confined to parts of the thick sills in the Colorado formation. (See pl. 8, *B*.) Each nodule contains a core of epidote, locally porous but elsewhere cemented by a small quantity of contemporaneous quartz. This core grades into and is surrounded by a fine-grained zone of epidosite made up of about equal proportions of quartz and epidote, the epidote occurring chiefly as pseudomorphic aggregates that preserve closely the original texture of the rock. Some of the pseudomorphic aggregates contain a little intergrown quartz, and epidote is scattered in the quartz groundmass. The only original rock-making minerals that can be discerned are a little apatite and zircon, opaque dust, and quartz phenocrysts enlarged by secondary

[34] Winchell, N. H. and A. N., Elements of optical mineralogy, 2d ed., pt. 2, p. 355, 1927.

growth. The epidosite in turn grades into one or more shell-like crusts that are similar to the surrounding rock except that they contain somewhat more epidote and quartz. Many of the epidote pseudomorphs in the epidosite and outer zones are porous, but others are cemented with a little contemporaneous quartz. Some joints in the rock exhibit phenomena similar to those in the nodule—that is, epidote walls grading into a fine-grained siliceous epidosite band and ultimately into normal-appearing rock, but the nodules themselves are not traversed by joints. The nodules contain either pink or green epidote or both.

AGE, CHARACTER, AND ORIGIN OF THE EPIDOTIZING SOLUTIONS

Epidote is later than albite and chlorite, contemporaneous with some quartz, and earlier than calcite and sericite in each rock in which it is found. Broadly speaking, epidotization took place before the beginning of Miocene (?) volcanic activity, for epidote is widespread in all the Cretaceous (?) plutonic rocks but is absent from the Miocene (?) volcanic rocks that cut and overlie them.

Epidote widely distributed throughout the body of the rocks is much more common than epidote as thin films along joints, from which it may be inferred that the altering solutions were contained in large part in the intruding magmas and were driven off as these solidified. Pistacite seems to be the only epidote mineral in the later quartz diorite, whereas both pistacite and clinozoisite are present in the earlier quartz diorite and in the granodiorite porphyry dikes; presumably, therefore, the solutions accompanying the later quartz diorite were slightly richer in iron than those accompanying the other rocks, but even they must have been iron-poor, for a good part of the iron in the epidote could have been derived from the ferromagnesian minerals. The solutions seem to have been moderately rich in lime and lacking in silica and probably also in alumina. Pseudomorphic replacement of labradorite and of the less calcic feldspars by epidote liberates a part of the silica content of the feldspars but requires that lime and alumina be furnished from outside sources. Hornblende contains approximately the proper amount of silica but requires nearly equal amounts of outside lime and alumina, as computed from data given by Clarke.[35] That silica has been liberated in the course of epidotization is demonstrated by the epidosite parts of the rock and by the quartz-epidote intergrowths of some of the pseudomorphs. If only the lime indigenous to the rock is consumed, it is evident that the resulting epidote pseudomorphs would be porous and that not only still more

[35] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, p. 388, 1924.

silica but also alumina would be set free. The fact that many pseudomorphs are decidedly porous or are composed only in part of epidote indicates that alumina may have been liberated at some places; presumably this alumina was consumed at other centers of epidotization nearby, and therefore it is quite probable that no foreign alumina had to be supplied.

If the reasoning in the foregoing paragraphs is sound, the following conclusions seem justified:

1. Each rock was epidotized by altering agencies emanating from itself. The progressive increase in intensity of alteration from the youngest to the oldest rock adds support to this conclusion because each rock is likely to have been additionally altered in some degree by solutions from each subsequent intrusion.

2. In large part the juices were distributed homogeneously in the injected magma, and reaction with the solidified rock as they were liberated resulted in wide-spread epidotization.

3. In the earlier sills and in the granodiorite porphyry dikes the epidotizing juices were essentially identical; in the intervening later quartz diorite sills they carried a little more iron. All were moderately rich in lime, poor in iron, and lacking in silica and probably in alumina. Most of the iron in the epidote was derived from the ferromagnesian minerals, but even so the total amount available was small; epidote may contain as much as about 19 percent of Fe_2O_3, but in the rocks under consideration this mineral has a maximum of only about 9 percent. The secondary quartz that is associated with the epidote evidently was derived from the altered feldspars, and the alumina necessary for the epidote probably was derived from the same source. The juices may have carried a little manganese, though some of this element may have been derived from the hornblende.

SILICIFICATION

Hydrothermal quartz, aside from that produced in wall rock by ore-forming solutions, is contemporaneous with epidote and resulted from epidotization of feldspar and possibly also from hornblende, as described above. Correlative to this is the observation that quartz of the early hydrothermal stage does not occur in the quartz latite dikes.

CALCITIZATION

Calcite is a primary alteration mineral in all the intrusive rocks, including the quartz latite dikes. It is widespread, though in comparatively small quantities. Unlike the earlier alteration minerals, it is about equally prominent in all the rocks, though the paucity of other alteration minerals in the quartz latite of the dikes makes it appear slightly more abundant in that rock than it really is.

Calcite replaces all the primary minerals irrespective of composition. It is later than epidote in the epidotized rocks and later than chlorite in the quartz latite dikes, from which epidote is absent. It is earlier than sericite in all the rocks, though part of the calcite may be contemporaneous with the earliest sericite. Figure 10 illustrates the age relation of calcite and sericite.

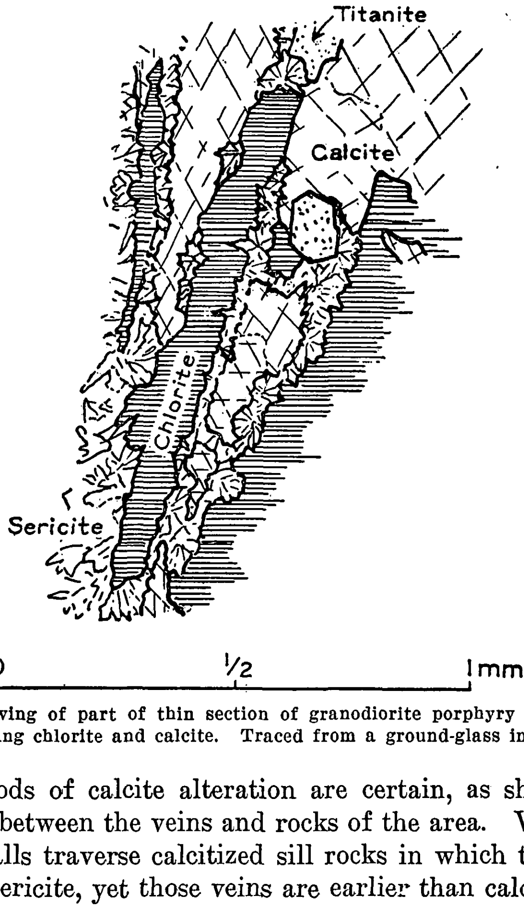


FIGURE 10.—Drawing of part of thin section of granodiorite porphyry showing sericite replacing chlorite and calcite. Traced from a ground-glass image.

Three periods of calcite alteration are certain, as shown by the age relations between the veins and rocks of the area. Veins having sericitized walls traverse calcitized sill rocks in which the calcite is earlier than sericite, yet those veins are earlier than calcitized granodiorite porphyry dikes, thus proving two ages of alteration. In addition, calcitized quartz latite dikes are later than calcite-bearing veins that in turn are later than the granodiorite porphyry dikes. As there were three periods of calcite alteration of the country rocks and an additional period in which calcite was deposited in the veins, it is remarkable that all the calcite should be of similar composition. Tests disclose the presence of both manganese and iron in all the carbonate, yet this is calcite and not ankerite. The calcitic nature of the alteration carbonate is shown, under the microscope, by the position of the twinning bands, which bisect the acute cleavage angle. This optical test definitely distinguishes calcite (and magnesite) from ankerite and dolomite.[36] The manganese content of the calcite in the country rock has produced most of the black weathering stain that is so prominent locally.

SERICITIZATION

Sericite is lightly distributed through the rocks as the last alteration mineral to be formed during this stage of alteration, and it therefore replaces all other minerals. As may be expected, sericite is particularly abundant in the wall rocks of the veins, as described in the following paragraphs, and undoubtedly most of the sericite was formed during the vein-forming periods.

VEIN-FORMING STAGE OF ALTERATION

The wall rocks of the veins of the Bayard area are at many places markedly different from the rock a short distance away. They are thoroughly bleached and strongly pyritized, and the feldspathic and ferromagnesian constituents are replaced by quartz and silky sericite. This alteration is most intense along the veins in the eastern part of the area, gradually lessening toward the west, where at some places it is indicated only by disseminated pyrite. Broad zones of bleached rock border the croppings of many of the veins, but the bleaching at those places is due partly to supergene kaolinization by the sulphuric acid liberated by oxidation of the pyrite.

The profound alteration that in the adjacent Santa Rita district has completely destroyed all distinction between different rocks, even between igneous and sedimentary rocks, is rare in the Bayard area. The rock texture is nearly everywhere sufficiently preserved to permit identification of the rocks and is totally destroyed only at a few places where silicification is complete. The altered shale of the Colorado formation is readily recognizable by its fine grain and blocky fracture, and the associated sandstone may be identified by the sand grains, which can be made out with the aid of a hand lens. The sills and dikes can be distinguished from the sedimentary rocks by the preserved igneous texture and from each other with equal facility by the remarkable difference in the degree of alteration of the two rocks. Alteration in granodiorite porphyry so advanced as to require close scrutiny for identification of the rock extends for a maximum of only about 2 feet from the vein walls, and at only one place has granodiorite porphyry been noted so greatly altered as to be identified only by observing its gradation into fresher rock. Generally this strong alteration forms a band

[36] Knopf, Adolph, The Mother Lode system of California: U. S. Geol. Survey Prof. Paper 157, p. 35, 1929.

less than an inch wide, even in breccia fragments completely surrounded by ore. Sericite pseudomorphs after the diagnostic biotite books can generally be distinguished in the most altered rock, and orthoclase crystals only slightly sericitized have been observed under the microscope within a few millimeters of the contact between altered granodiorite and massive sulphides several feet thick. The quartz diorite sills, on the contrary, are altered to an extreme degree for a much greater distance from the veins, and at such places they can be identified only by the absence of features characteristic of other rocks or by observing gradations into fresher rock. The quartz diorite as a rule is completely replaced by quartz at the vein walls and along subordinate stringers, and in places the veins consist almost solely of silicified rock. The adjacent rock is a bleached pyritic material in which sericite pseudomorphs partly preserve the original igneous texture but which retains no diagnostic features. Beyond this zone the rock is recognizable by virtue of its own characteristics and grades into the ordinary altered quartz diorite of the district.

Microscopic study shows that the bleached granodiorite porphyry and the bleached quartz diorite in which igneous texture still persists are now made up of fine-grained sericite pseudomorphs in a matrix of quartz and interstitial sericite. Many of the pseudomorphs have sharp outlines indicative of the original minerals, but others are variably replaced by later quartz. All gradations exist between rock showing this stage of alteration and rock showing essentially complete replacement by quartz and containing sericite only as a few residual tufts. Pyrite is distributed throughout the rock, seemingly without discrimination, occurring both in the groundmass and in the pseudomorphs. The only rock mineral that seems to have escaped replacement is zircon. Apatite appears to have been the next most stable mineral, but in some rocks even the apatite shows partial destruction. Epidote was fairly stable, and in places the quartz is colored green by included relicts of that mineral.

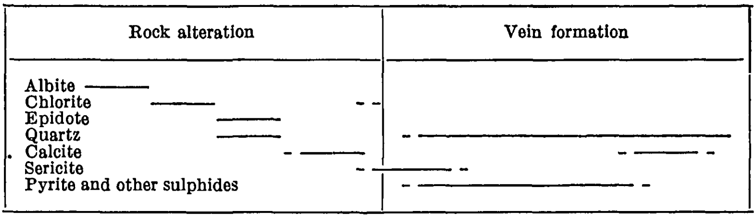
Vein solutions commonly attack different igneous rocks without great preference, and where alteration has progressed to the stage of intense sericitization and silicification the resulting altered rocks generally look alike, regardless of original character. Any differences in associated rocks in which alteration has progressed to that stage, particularly if the rocks are allied types, must therefore be due either to a difference in the permeability of the rocks or to attack by different solutions. In the Bayard area the quartz diorite adjacent to the veins and faults is almost invariably much more shattered than the granodiorite porphyry, suggesting that the differences in alteration of these two rocks are the result of differences in permeability. But the granodiorite must have been greatly shattered at those places where several feet of ore lies wholly within granodiorite walls, yet even there the alteration band is insignificant. It has been shown that the granodiorite porphyry dikes were injected along preexisting mineralized faults, and it is therefore obvious that the sill rocks along the pre-granodiorite veins and faults were attacked by vein-forming solutions during one period more than the dikes.

SUMMARY AND CONCLUSIONS

The hydrothermal alteration minerals in the igneous rocks of the Bayard area are albite, chlorite, epidote with quartz, calcite, and sericite, named in their genetic order. In each rock the suite of alteration minerals is identical, except for the lack of epidote and quartz in the quartz latite dikes. All minerals earlier than calcite are progressively more abundant in each older rock; widespread calcite and sericite are about equally abundant in all rocks. The presence of epidote of itself proves two periods of alteration, one with epidote prior to injection of the quartz latite dikes and one without epidote later than those dikes. The details of epidotization suggest further subdivision. The widespread dissemination of epidote, the prominence of the disseminated epidote as compared with the thin films of epidote along joints, and the character of the epidotizing solutions as inferred from the variety of epidote mutually support one another in suggesting that each rock was altered by the juices that accompanied the intrusion. The progressive decrease in intensity of alteration from the oldest to the youngest rock adds support to this suggestion. Thus there appear to have been three periods of epidotization and consequently four periods of albitization and chloritization, one after each of the four periods of intrusion. The suggestion that each period of intrusion was followed by one of alteration is further supported by the fact that each of the last three periods of intrusion was followed by calcite and sericite alteration.

Each period of calcite-sericite alteration was followed by a period of vein formation. Quartz-sulphide veins traverse the altered quartz diorite sills, but are themselves cut by altered granodiorite porphyry dikes; the dikes in turn are cut by veins of the main period of mineralization, and some of these veins are cut by mineralized quartz latite dikes. The logical inference from these relations is that each period of alteration culminated in vein formation, the wall-rock alteration that accompanied the passage of the vein-forming solutions having been a continuation of the processes that caused the widespread alteration of the rocks. The following diagram shows this continuity graphically:

Continuity of rock alteration and vein formation in the Bayard area



The final general conclusions that may be drawn from the relations and inferences summarized above are that the earliest alteration of each rock may have been deuteric; that each rock was further altered by its own solutions seeking an outlet through the solidified and cracked rock; that each rock was altered still more by solutions escaping from later intrusions; and that each period of alteration culminated in vein formation.

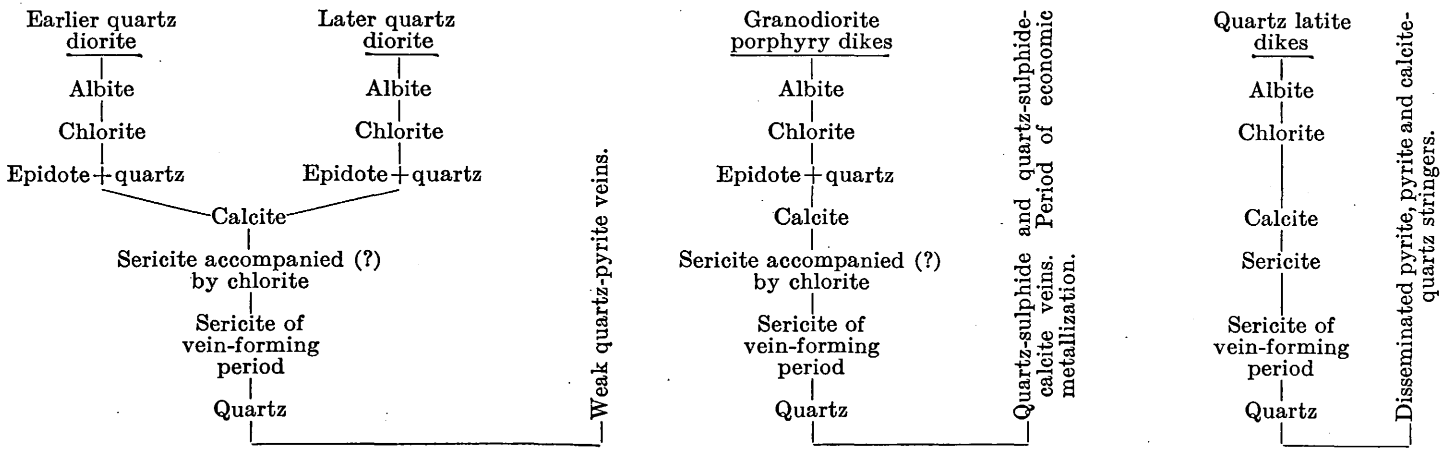
The table on page 68 summarizes the chronologic relations. It will be noted that only a single period of calcite-sericite alteration is attributed to the quartz diorites, whereas two periods are shown for the earlier minerals. It seems probable that deuteric and later hydrothermal alteration of the earlier quartz diorite by its own solutions ceased with epidotization and that the calcite and sericite in this rock were produced by solutions from the later quartz diorite. This probability is suggested by the absence of a period of mineralization intermediate in age between the earlier and later quartz diorites and fits in with the idea that these two rocks are parts of the same magmatic differentiate and very close in age.

ORE DEPOSITS

Three distinct periods of hypogene mineralization have been recognized in the Bayard area, as described briefly in the summary of the section on rock alteration—(1) a period older than the granodiorite porphyry dikes and seemingly genetically related to the quartz diorite sills; (2) a period later than and genetically related to the granodiorite porphyry dikes; and (3) a period related to the Tertiary quartz latite dikes, which were injected after the deposits of the earlier periods had been truncated by erosion and oxidized. The first two periods resulted in the formation of quartz-sulphide veins. The third period was insignificant and produced no veins, but minerals of that period appear to have been deposited in the oxidized zones of veins of the preceding periods.

Distinct from the veins is a bedded replacement deposit of magnetite in the Syrena formation on the Fifty-six and adjacent claims. It is related in age to the second period of mineralization mentioned above. Oxidation and erosion of the quartz-sulphide veins have

Chronologic relations between rock alteration and vein formation



given rise to two other classes of deposits, both of minor economic importance; these are vanadium deposits associated with lead carbonate ores along the Ground Hog vein, and gold placer deposits. A complete list of the deposits of the district is as follows:

1. Quartz-pyrite veins earlier than the granodiorite porphyry dikes, carrying small amounts of lead and zinc deposited at a later time.
2. Magnetite replacement deposits.
3. Argentiferous zinc-lead-copper veins later than the granodiorite porphyry dikes.
4. Veins showing meager quartz-pyrite mineralization associated with quartz latite dikes.
5. Vanadium deposits.
6. Gold placer deposits.

This list is arranged in order of age, though in it the deposits are also separated according to mineral content.

MINERALOGY

In considering the mineralogy of the deposits it is essential that the minerals of the original vein filling, formed by hot ascending waters (hypogene minerals), should be distinguished clearly from those that have been derived from the original minerals by weathering processes after the deposits had been exposed or brought close to the surface by erosion (supergene minerals). Some of the deposits owe their commercial importance to supergene processes; such are the gold placer deposits, the vanadium ores, the bonanza lead carbonate ore bodies in the upper parts of the veins, the rich chalcocite-native silver ores lower down, and a small quantity of copper ore that seems related to the magnetite ore on the Fifty-six claim. An example of supergene impoverishment, on the other hand, lies in the insignificant quantities of supergene zinc minerals that now occur in place of large quantities of sphalerite that were present originally.

Two lists of the vein minerals of the Bayard area are given below for ready reference, one listing the minerals alphabetically, the other by metals and origin. These lists include only those minerals that were formed during the processes of mineralizátion, both hypogene and supergene, and do not include primary rock-making minerals nor the alteration minerals of the early hydrothermal stage.

Vein minerals of the Bayard area, listed alphabetically

Anglesite	$PbSO_4$
Azurite	$2CuCO_3.Cu(OH)_2$
Barite	$BaSO_4$
Beidellite	$(Al,Fe)_2O_3.3SiO_2.nH_2O$
Bornite	Cu_5FeS_4
Calamine	$Zn_2SiO_4.H_2O$

Vein minerals of the Balard area, listed alphabetically—Continued

Calcite	$CaCO_3$
Cerusite	$PbCO_3$
Chalcanthite	$CuSO_4.5H_2O$
Chalcedony	SiO_2
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Chrysocolla	$CuSiO_3.2H_2O$
Copper (native)	Cu
Covellite	CuS
Cuprite	Cu_2O
Cuprodescloizite	$(Pb,Zn,Cu)_3(VO_4)_2.(Pb,Zn,Cu)(OH)_2$
Endlichite	$PbCl_2.3Pb_3(V,As)_2O_8$
Galena	PbS
Goethite	$Fe_2O_3.H_2O$
Gold (native)	Au
Goslarite	$ZnSO_4.7H_2O$
Gypsum	$CaSO_4.2H_2O$
Halloysite	$Al_2O_3.2SiO_2.nH_2O$
Jarosite	$K_2O.3Fe_2O_3.4SO_3.6H_2O$
Kaolinite	$Al_2O_3.2SiO_2.2H_2O$
Magnetite	Fe_3O_4
Malachite	$CuCO_3.Cu(OH)_2$
Mallardite	$(Mn,Cu,Zn)SO_4.7H_2O$
Plumbojarosite	$PbO.3Fe_2O_3.4SO_3.6H_2O$
Psilomelane	MnO_2 with absorbed impurities
Pyrite	FeS_2
Pyrolusite	MnO_2
Pyromorphite	$PbCl_2.3Pb_3P_2O_8$
Quartz	SiO_2
Sericite	$H_2KAl_3(SiO_4)_3$
Silver (native)	Ag
Smithsonite	$ZnCO_3$
Specularite	Fe_2O_3
Sphalerite	ZnS
Wad	Mixtures of oxides, chiefly of manganese, with water
Willemite	Zn_2SiO_4
Wulfenite	$PbMoO_4$

Vein minerals of the Bayard area, listed by metals and origin

ORE MINERALS

Gold:
- Hypogene: With auriferous sulphides, exact nature unknown.
- Supergene: Native gold.

Silver:
- Hypogene: With argentiferous sulphides, exact nature unknown.
- Supergene: Native silver.

Copper:
- Hypogene: Chalcopyrite.
- Supergene:
  - Azurite.
  - Bornite.
  - Chalcanthite.
  - Chalcocite.
  - Chrysocolla.
  - Copper (native).

Vein minerals of the Bayard area, listed by metals and origin—Continued

ORE MINERALS—continued

Copper—Continued.
- Supergene—Continued.
  - Covellite.
  - Cuprite.
  - Cuprodescloizite.
  - Malachite.

Lead:
- Hypogene: Galena.
- Supergene:
  - Anglesite.
  - Cerusite.
  - Cuprodescloizite.
  - Endlichite.
  - Plumbojarosite.
  - Pyromorphite.
  - Wulfenite.

Zinc:
- Hypogene: Sphalerite.
- Supergene:
  - Calamine.
  - Cuprodescloizite.
  - Goslarite.

Zinc—Continued.
- Supergene—Continued.
  - Smithsonite.
  - Willemite.

Iron:
- Hypogene:
  - Magnetite.
  - Pyrite.
  - Specularite.
- Supergene:
  - Goethite.
  - Jarosite.

Manganese:
- Hypogene: Manganiferous calcite.
- Supergene:
  - Psilomelane.
  - Pyrolusite.
  - Wad.

Vanadium:
- Supergene:
  - Cuprodescloizite.
  - Endlichite.

GANGUE MINERALS

Oxides:
- Hypogene: Quartz.
- Supergene:
  - Chalcedony.
  - Quartz.

Carbonates:
- Hypogene: Calcite.
- Supergene: Calcite.

Silicates:
- Hypogene:
  - Beidellite.

Silicates—Continued.
- Hypogene—Continued.
  - Sericite.
- Supergene:
  - Beidellite.
  - Halloysite.
  - Kaolinite.

Sulphates:
- Hypogene: Barite.
- Supergene: Gypsum.

GOLD

The gold content of the hypogene ores is insignificant. It ranges from a trace to about 0.05 ounce to the ton and is generally too low for smelter payment. The supergene ores carry somewhat more gold, though still, as a rule, in meager quantities. At some places in the western part of the district, where the veins carry a variable amount of manganiferous carbonate, the gold content in the oxidized ores is appreciable, shipments of lead carbonate ores from the Three Brothers and Silver King mines having contained as much as 0.42 ounce to the ton. On the St. Helena and Eighty-eight claims, near the town of Central, the veins carry very little besides quartz and pyrite and have been worked for their gold content. The ore from the St. Helena is said to have averaged about 0.75 ounce to the ton in gold and that from the Eighty-eight much more, but only a few tons of such a grade was mined. The gold recovered by amalgamation from the Eighty-eight vein ranged from 0.5965 to 0.6655 fine. It is reported that a shipment of ore from the Owl mine, in Gold Gulch, yielded $7,800, chiefly in gold; the assays shown on an assay map of the mine, however, do not bear out this report but indicate instead that the gold content was as meager there as elsewhere in the area.

Fine gold has been panned from otherwise nearly barren, gougy veins on the Gold Spot and Lost Mine claims; the gold there lies in clayey pockets and in stringers of altered black calcite and manganese oxides. The fineness of this gold averages about 0.760. On the Gulch vein along the highway to the west, adjacent to the St. Helena, gold was panned from large pockets of sooty manganese oxides associated with considerable black and brown calcite.

Placer gold derived from the veins is widely distributed. Most of it is fine and angular, but nuggets as large as a small lima bean have been found. The placer gold is about 0.705 fine.

SILVER MINERALS

HYPOGENE MINERALS

All the primary ores carry several ounces of silver to the ton, associated with the base-metal sulphides, though the silver content varies considerably from place to place in the district. No assays of pure mineral specimens are available to show the silver content of the different base-metal sulphides, but detailed assay records of ore and of concentrates from the Ground Hog mine make it possible to obtain this information mathematically. A description of the computations has been published elsewhere and need not be repeated here.[37] According to these computations and to the interpretations placed upon them, about half the silver content of the mixed-sulphide ore in the main shoot of the Ground Hog mine has been contributed by submicroscopic supergene silver minerals locked up in a chalcocitic tarnish on the chalcopyrite and sphalerite. In this tarnished ore, which contains an average of 10 ounces of silver to the ton, the galena yields 1 ounce of silver for each 50 pounds of lead (34.6 ounces of silver to the ton of galena) and contributes 35 percent of the silver in the ore; the tarnished chalcopyrite yields 1 ounce of silver for each 22 pounds of copper (31.4 ounces to the ton of chalcopyrite) and contributes 47 percent of the silver in the

[37] Lasky, S. G., Distribution of silver in base-metal ores: Am. Inst. Min. Met. Eng. Tech. Pub. 557, 1934.

ore; and the tarnished sphalerite yields 1 ounce of silver for each 154 pounds of zinc (8.7 ounces to the ton of sphalerite) and contributes 18 percent of the silver in the ore. It has been calculated that in the strictly unaltered ore the galena may contain 1 ounce of silver for each 50 pounds of lead (34.6 ounces of silver to the ton of galena), the chalcopyrite about 1 ounce of silver for each 100 pounds of copper (6.9 ounces to the ton of chalcopyrite), and the sphalerite about 1 ounce of silver for each 1,000 pounds of zinc (1.3 ounces to the ton of sphalerite); the mineralogic distribution of the silver in this unaltered ore is approximately 75 percent in the galena, 20 percent in the chalcopyrite, and 5 percent in the sphalerite. The silver content of the pyrite in the ore is negligible.

In the western part of the district, according to available data, the galena in the sulphide ores that have been mined contributes 60 to 80 percent of the silver content, which ranges from 1 to 5 ounces a ton; the sphalerite contributes 1 to 20 percent of the silver content, and the copper minerals contribute 20 to 25 percent. The silver-lead ratio ranges from 1 ounce for each 110 pounds of lead at the Betty-Jo mine to 1 ounce for each 250 pounds of lead at the Three Brothers mine. The copper content of the ores in this part of the district averages less than 1 percent, and it is probable that the disproportionate amount of silver associated with the copper minerals is largely supergene and that in the fresh primary ore the galena contributes 70 to 90 percent of the silver content.

SUPERGENE MINERALS

The average oxidized ores, which consist of fairly pure lead carbonate, are commonly lower in both silver content and silver-lead ratio than their hypogene counterparts. In the Ground Hog mine, where opportunity for study is available, the lead carbonate ores fall sharply into two groups—(1) those at and very close to the surface, carrying only about 15 to 35 percent as much silver to the ton as their hypogene counterparts, in the ratio of 1 ounce of silver to about 260 pounds of lead; and (2) those at lower depths, having approximately the same silver content and the same silver-lead ratio as the hypogene ore. These figures indicate a silver impoverishment ranging at least from 25 to 80 percent. The average ratio is about 1 ounce to 130 pounds of lead, and the average impoverishment is at least 60 percent; this average ratio is the same as the apparent average ratio at the Lucky Bill mine, where large quantities of both groups of cerusite ore have been mined but where complete records are not available. The Lucky Bill mine is adjacent to the Ground Hog mine and on the same vein.

At the Three Brothers mine, on a vein deposit in limestone, the lead carbonate ores carry nearly twice as much silver as the hypogene ores, indicating an enrichment in silver during oxidation, which contrasts with the strong impoverishment in the oxidized ores of the other veins. This can probably be explained by the fact that the limestone wall rock at the Three Brothers mine would inhibit leaching and transportation of the silver, causing it to be residually enriched.

The silver leached from the oxidized ores was precipitated in the sulphide zones below, and in the Ground Hog vein some of it now occurs in the native form associated with secondary chalcocite and with clay minerals. The silver forms thin flakes and leaves in cracks in the chalcocite and is said to be confined to the top of the chalcocite zone, which lies directly below the lead carbonate zone. Leaf silver was very prominent at places in a chalcocite stope at the south end of the 300-foot level of the Ground Hog mine; several thousand tons of chalcocite ore that averaged 1 ounce of silver to 40 pounds of copper was shipped from that part of the mine. In addition, as described in the preceding paragraphs on hypogene silver minerals, submicroscopic supergene silver minerals, probably native silver and argentite, are associated with chalcopyrite and sphalerite in the mixed-sulphide ores. The calculated ratios between silver and base metals indicate that about half the silver content of the mixed-sulphide ore currently mined at the Ground Hog mine is contributed by these supergene minerals, two-thirds of the supergene silver being associated with the chalcopyrite and one-third with the sphalerite. In the sulphide ores thus far mined in the western part of the Bayard area about a fourth of the silver content seems due to supergene silver minerals.

COPPER MINERALS

HYPOGENE MINERALS

Chalcopyrite.—Except in the Ground Hog zone, chalcopyrite ($CuFeS_2$) constitutes only a small percentage of the sulphides, and can rarely be seen by the unaided eye. It is prominent in the Ground Hog zone and is said to have been the chief ore mineral at the Ninety mine. In the Ground Hog vein it commonly forms small but readily visible grains and irregular fine-grained clusters intergrown with sphalerite and galena. Here and there a crystal occurs in the small drusy cavities that are common in the ore. Locally the chalcopyrite forms medium-grained patches as much as 2 or 3 inches across and streaks about an inch wide and a foot or two long. This coarser chalcopyrite is invariably associated with sphalerite, the galena being markedly subordinate at such places. Rarely is chalcopyrite megascopically intergrown or in any other way megascopically associated with the pyrite of the ore, though study of polished sections discloses minute droplets of chalcopyrite in the pyrite. Many specimens of sphalerite, gathered from all over the district, have been examined microscopically, and all have been found to contain minute inclusions of chalcopyrite. The inclusions are so small that it is not commercially feasible to free them by grinding; they go into the zinc concentrate, and their copper content is lost to the miner.

Considerable silver is associated with the chalcopyrite, though only a little is contained in the chalcopyrite itself. It is estimated that an average of 1 ounce of silver is associated with each 65 pounds of chalcopyrite, but that the chalcopyrite itself contains only 1 ounce to every 290 pounds, the rest being contained in the chalcocitic coatings on the chalcopyrite. (See pp. 72–73.)

SULPHOSUPERGENE MINERALS

Bornite.—Bornite (Cu_5FeS_4) represents an intermediate step in the replacement of chalcopyrite by chalcocite and occurs only in a microscopic transition zone between the chalcopyrite and the encroaching chalcocite, locally with an intermediate zone of covellite.

Chalcocite.—The familiar sooty chalcocite (Cu_2S) in cracks and pockets and the equally familiar black coating are associated with the primary sulphides to the lowest levels exposed. The chalcocite is massive and steely at many places where supergene alteration is far advanced, and large bodies of such material containing only residual traces of primary sulphides have been mined at the top of the chalcocite zone. Flakes of native silver and films of cerusite lie along cracks in the chalcocite, and considerable kaolinite and beidellite are locally associated with the chalcocite. In some specimens the chalcocite appears to be impregnating the clays, but elsewhere in the same specimens and in others stringers of kaolinite traverse the chalcocite. An associated hard black clay was found to be an intimate mixture of chalcocite and clay minerals.

Chalcocite pseudomorphs after galena are fairly common in the Ground Hog mine and in the adjacent Lucky Bill mine. The galena cleavage is perfectly preserved, and some of the associated leaf silver lies along these preserved cleavage planes. Etching of the pseudomorphic chalcocite proves that the inherited isometric cleavages has had no influence on the orthorhombic cleavage of the chalcocite, which shows the typical rhombic etch pattern.

The chalcocite shows an unusual preference for the hypogene sulphides. Lindgren[38] reports that galena and sphalerite are more easily replaced by secondary copper sulphides than is chalcopyrite, galena the most easily of all. In the Ground Hog ores, however, there are innumerable examples of chalcopyrite replaced by bornite

[38] Lindgren, Waldemar, Mineral deposits, 4th ed., p. 836, 1933.

and chalcocite along minute veinlets and cracks while adjacent sphalerite and galena show not the faintest sign of attack. The secondary sulphide replacement stops abruptly at the contacts, even though the guiding cracks continue. At many other places islands of chalcopyrite in galena and sphalerite are almost completely replaced without the least alteration of the enclosing lead or zinc sulphide. The sphalerite in these ores seems slightly more susceptible to copper enrichment than the galena, to judge from the wide-spread chalcocite-covellite tarnish on the sphalerite.

Covellite.—Bluish spots, indentifiable as covellite (CuS) by changing to purple when moistened, occur in some of the sooty chalcocite pockets, and covellite is partly responsible for the copper tarnish on sphalerite. Here and there it forms an intermediate phase in the replacement of galena and bornite by chalcocite. A little covellite is associated with anglesite in the oxidized zone, and it has also been noted on chalcocite as the first oxidation product of that mineral.

OXYSUPERGENE MINERALS

Azurite and malachite.—Stains and crusts of the basic copper carbonates, azurite ($2CuCO_3.Cu(OH)_2$) and malachite ($CuCO_3.Cu(OH)_2$), are fairly common in minor quantities in the oxidized zone. The San Jose mine is reported to have produced much copper-carbonate ore in the early days of the district, but no commercial quantities can be seen at the present time. Most of the lead carbonate ores carry a little copper, part of which is present as copper carbonate. Copper-carbonate stains are common in a magnetite-impregnated shaly layer of Syrena limestone on the Fifty-six and Door Key claims, and crystalline nodules of these minerals have been mined from an adjacent decomposed granodiorite porphyry dike.

Chalcanthite.—Chalcanthite ($CuSO_4.5H_2O$), the hydrous copper sulphate known as " blue vitriol ", occurs sparingly here and there along fractures and along the walls of workings in both the oxidized and sulphide zones, where it was formed by evaporation of copper-sulphate solutions.

Chrysocolla.—Chrysocolla ($CuSiO_3.2H_2O$) is conspicuous in some of the lead-carbonate ores of the Ground Hog vein and accounts for some of the small copper content of those ores. Much of the chrysocolla shows a rectangular grating, which a few specimens prove to be inherited from galena. Some of the residual bunches of galena in the carbonate ore show a band of chrysocolla lying between galena and cerusite, the chrysocolla penetrating here and there along the galena cleavage pattern. The surrounding cerusite penetrates the chrysocolla in irregular veinlets and along the inherited cleavage and is therefore unquestionably later. A thin film of anglesite lies between the galena and the chrysocolla, but it cannot be determined whether the chrysocolla replaced the galena directly, the residual galena later oxidizing to anglesite, or whether the replacement included an anglesite stage. Either process seems possible, and, regardless of which actually operated, it is clear that the earliest supergene solutions must have been charged with soluble silica.

Native copper.—Small, thin flakes of native copper have been observed in the Ground Hog mine as deep as the 600-foot level along channels of strong circulation, such as post-ore faults, which directed the supergene solutions. Native copper is said to have been found in all mines along the Ground Hog vein, and doubtless traces occur in some of the other veins. Generally the flakes of copper occur in the decomposed clayey rock or clayey gouge seams along the veins, but some is scattered in the lead-carbonate ore, though there also it seems to be associated with small clay pockets.

Cuprite.—The copper oxide cuprite (Cu_2O) was not observed by me in any of the ores, but according to F. W. Richard the capillary variety, chalcotrichite, occurs sparingly at the Ground Hog mine.

Other minerals.—Cuprodescloizite, a basic lead-zinc-copper vanadate, is described in the section devoted to vanadium minerals.

LEAD MINERALS

HYPOGENE MINERALS

Galena.—Galena (PbS) is one of the most abundant sulphides of the Bayard area. It occurs intimately mixed with considerable sphalerite and subordinate chalcopyrite, and less intimately with pyrite; it ranges from a fine-grained though not steely aggregate to coarse-grained material yielding cleavage fragments as much as an inch on edge. A few crystals have been seen in small vugs that are lined chiefly with crystalline sphalerite. Where the ore has been cut by post-ore faults the galena is likely to be smeared and to have "eyes" of typical galena in a matrix of crushed galena whose shear or "flow" lines lap around the "eyes." In the Ground Hog mine the ore contains streaks of galena parallel to the vein walls and from a fraction of an inch to several feet in width, some of which are sufficiently pure and large to permit selective mining of high-grade lead ore.

It is estimated that galena forms 20 to 50 percent of the total sulphides of the ores of the district. In the intimate mixtures that constitute the milling ore of the Ground Hog mine, galena forms 15 to 20 percent of the total sulphides and is a little less abundant than chalcopyrite. As shown on pages 72–73 the galena carries a valuable quantity of silver and yields 70 to 90 percent of the silver content of the ores. In the mixed-sulphide ores of the Ground Hog vein the galena carries 1 ounce of silver to about every 58 pounds, equivalent to 0.4 ounce of silver for each percent of lead in the ore, but in the veins to the west the silver content of the galena seems to average only about a fourth of this.

Residual nodules of galena occur throughout the lead carbonate ores, all partly altered to anglesite and some surrounded by a rim of chrysocolla that has replaced the galena. In the secondary sulphide zone galena has been pseudomorphically replaced by chalcocite, and at lower depths, where copper enrichment is only incipient, some galena has a purple covellitic tarnish.

SUPERGENE MINERALS

Anglesite.—Anglesite ($PbSO_4$) is as widespread as the galena from which it is derived, but it is insignificant in quantity. Its occurrence as a grayish tarnish and as thin-banded gray to white crusts surrounding nodules of galena in the lead carbonate ores is so characteristic of the usual occurrence of anglesite that no special description is necessary. It shows all stages of alteration to cerusite.

Cerusite.—Cerusite ($PbCO_3$) is by far more abundant than all other supergene ore minerals combined. Mining in the early days was confined to the extraction of lead carbonate ore near the surface, and such ores are still being mined. The entire production of the Silver King mine and most of that of the Lucky Bill and San Jose mines consisted of cerusite ore, some of which was almost pure lead carbonate. Considerable cerusite ore was mined also from the upper levels of the Ground Hog mine.

The cerusite occurs in all the forms common to the mineral. It makes up vitreous to resinous masses, here and there containing drusy cavities and locally passing into a porous though compact crystalline aggregate. Some of the friable material known as "sand carbonate" has been mined. The color ranges from white to grayish black in the seemingly pure mineral, and some is stained brown to black by manganese and iron oxides and yellow to greenish by wulfenite, endlichite, and pyromorphite, which locally are rather prominent.

Most of the cerusite was formed in place and was derived from anglesite as the second step in the destruction of galena, but a great deal of it must have been transported in solution, even though its solubility is very low. Veinlets of cerusite cut into and replace chalcedony, and cerusite fills late cracks in chalcocite-clay mixtures in the upper sulphide zone.

The cerusite ores carry a variable amount of silver, as described on page 73.

Plumbojarosite.—Plumbojarosite ($PbO.3Fe_2O_3.4SO_3.6H_2O$) has been found at several places in the district in soft, inconspicuous outcrops of some veins and underground at the San Jose and Three Brothers mines. It is generally mixed with jarosite and is most abundant and most conspicuous at places along the Copper Glance vein. A shallow shaft on this vein at the western edge of the Cashier claim discloses two streaks of earthy impure plumbojarosite, each about a foot wide, associated with a little residual galena and anglesite. Cuts along the vein at the east edge of the claim also show pockets and streaks of jarosite. A lead determination was obtained from a sample of jarosite collected from a pit on the western vein of the Three Brothers mine (on the Lucky Lead claim), probably representing a little admixed plumbojarosite, and microscopic pale-yellow hexagonal plates of plumbojarosite were observed while examining a sample of beidellite collected from one of the oxidized stopes of that mine.

The plumbojarosite is earthy and greenish yellow to ocherous yellow and brown. In the darker shades it may resemble light-colored limonite, but can be distinguished by its soft talcky feel as contrasted with the gritty feel of limonite. It is commonly associated with variable amounts of limonite and with other jarosites. Nowhere in the district except possibly on the Cashier claim does the plumbojarosite occur in commercial quantities, but its prominence in outcrops suggests the advisability of prospecting such places.

Wulfenite.—Typical orange to yellow square tabular crystals of wulfenite ($PbMoO_4$) are common in the oxidized zone of nearly all mines and have been found as deep as the fourth level of the Ground Hog mine. The wulfenite is usually associated with vanadium minerals in drusy cavities or embedded in cerusite and is one of the latest minerals formed. Crystals from the second level of the Ground Hog mine contain a thick coating of chalcedony, and locally the associated vanadium minerals appear to be growing upon the wulfenite.

Pyromorphite.—An apple-green to greenish-yellow cryptocrystalline material is conspicuous in the oxidized ores at the Ground Hog mine. Chemical tests show the presence of lead, chlorine, and the phosphate radicle, indicating that the mineral may be pyromorphite ($3Pb_3P_2O_8.PbCl_2$), "green lead ore." It forms hard, compact to somewhat earthy masses and stringers in cerusite and impregnates the adjacent rock, replacing the nonquartzose parts and forming smooth to nodular crusts in the cavities. According to F. W. Richard, this material is a fair indicator at the Ground Hog mine of the presence of lead carbonate ore.

Lead vanadates.—Endlichite and cuprodescloizite are described under the heading "Vanadium minerals."

ZINC MINERALS

HYPOGENE MINERALS

Sphalerite.—Sphalerite (ZnS) is the most abundant ore mineral of the Bayard area, constituting 35 to 45 percent of the average sulphide content. It is intimately mixed with galena and chalcopyrite and less intimately with pyrite.

Most of the sphalerite of the area is a dark-brown ferriferous variety closely akin to marmatite. It is pale yellow at a few places, but the different varieties show no constant geographic or geologic distribution. It is coarse-grained at the Ground Hog and adjacent mines, but much finer-grained in the outlying prospects; at the Three Brothers mine it is the dark finely granular variety known as "false galena." Modified tetrahedral crystals projecting into small vugs are common in the Ground Hog ores. They are locally crusted with colorless quartz needles, and a few are sprinkled with minute grains of chalcopyrite. Most sphalerite has a black copper sulphide tarnish, particularly in the Ground Hog vein.

All the sphalerite of the area contains microscopic inclusions of chalcopyrite, although in the pale-yellow variety they are sparse and occur only in some grains. Here and there a few inclusions of galena are mixed with the chalcopyrite. The sphalerite carries only a trace of silver, estimated at 1 ounce of silver for each 1,500 pounds or more of sphalerite, or a maximum of about 0.02 ounce for each percent of zinc, but a large amount of silver seems to be locked up in the chalcocitic tarnish on the sphalerite. (See pp. 72–73.) In the mixed-sulphide ores thus far mined in the Bayard area the tarnished sphalerite has contributed as much as 25 percent of the total silver content, but it is estimated that in strictly unaltered ores the sphalerite will contribute not more than about 5 percent of the silver.

SUPERGENE MINERALS

Calamine.—Calamine ($Zn_2SiO_4.H_2O$) is a rare mineral in the Bayard area, despite the large quantities of sphalerite in the sulphide ore and despite the abundance of soluble silica known to have been present in the oxidizing solutions that could have fixed the zinc as the silicate. At the Lion No. 2 shaft scattered pockets and stringers of white calamine, made up of intergrown clusters of radiating crystals, occur in oxidized wall rock and were noted in brown jaspery vein quartz in a small pile of reject. A little similar calamine interbanded with black supergene quartz was found with a small pile of smithsonite ore on one of the dumps on the Peerless No. 2 claim. Doubtless calamine occurs elsewhere also, but in such small quantities as are not to be seen readily.

Goslarite.—Efflorescences of goslarite ($ZnSO_4.7H_2O$) are very common in the workings of the Ground Hog and adjacent mines. It is most common in the sulphide zone and generally forms long silky fibers on the walls of the workings along cracks that cut the ore and country rock. It has been formed by evaporation of zinc sulphate solutions that have percolated along the cracks.

Smithsonite.—Smithsonite ($ZnCO_3$) is an uncommon mineral in the Bayard area. Its absence at the Three Brothers mine, the limestone environment of which is favorable for its formation, is particularly surprising. One lot of 60 tons is said to have been shipped from the Lion No. 2 workings, but none can be seen in place at the present time. Small piles of smithsonite lie on some of the dumps along the Peerless No. 2 veins, where it has been sorted from a quantity of worthless material. It forms bluish-white botryoidal crusts, brown cellular boxwork, and porous masses of cemented globules that look much like fish roe, all intergrown with one another and with iron and manganese oxides.

An interesting occurrence was noted at several places in the lower levels of the Ground Hog mine, where supergene carbonate solutions had penetrated into the heart of the sulphide zone. Small pockets of brittle smithsonite, a foot or less in diameter and connected with other pockets by thin stringers, occur in the sphaleritic ore, which is impregnated with limonite and with secondary clay minerals. The smithsonite encrusts the sulphides and the vein quartz and generally forms a cellular boxwork made up of thin brittle plates emplanted with tiny rhombs and hollow scalenohedrons. It is tan-colored and contains a great deal of iron. Minute quantities of similar material line some of the small vugs in the ore and cut the vein matter in microscopic stringers.

Some assays of lead carbonate ore show small quantities of zinc and sulphur. The zinc content in many of these assays is much higher than would be necessary to satisfy the sulphur as sphalerite, and doubtless some of the zinc is present as smithsonite.

Willemite.—Rosettes and clusters of minute, slender to stubby gray prisms of willemite (Zn_2SiO_4), the anhydrous silicate of zinc, were noted in a vug in the slightly oxidized outcrop of a vein on the Lion claim. It is associated with secondary crystalline quartz and chalcedony.

Textbooks on mineralogy describe willemite as a rare mineral, but it is probably wide-spread in minute amounts as an oxidation product of zinc ore in the southwestern United States, where its formation in place of calamine is probably analogous to the formation of hematite instead of limonite in the dry climate of that part of the country.

Other minerals.—Cuprodescloizite, a basic lead-zinc-copper vanadate, is described in the section on vanadium minerals.

IRON MINERALS

HYPOGENE MINERALS

Pyrite.—Pyrite (FeS_2) is a common mineral in all the veins and is extremely prominent in some. It is scattered in the country rock and gouge adjacent to the veins, and large volumes of rock are impregnated with it in those parts of the area where veins are abundant. Its characteristic occurrence in the veins is as segregated streaks and bunches surrounded and impregnated by the other sulphides, and at many places it is by far the predominant sulphide, the vein matter consisting essentially of quartz and pyrite. It is almost invariably crystalline and occurs as small individuals and clusters of cubes and pyritohedrons in drusy intergrowths with the quartz. Excellent crystals, as much as a centimeter on edge, line some of the druses. Small drusy clusters of pyrite are common in the sphalerite-galena-chalcopyrite mixtures; the other sulphides coat the pyrite and associated quartz at the edges of the druses. Many clusters of pyrite crystals are embedded in the other sulphides, but they can be cleanly separated and show very little evidence of replacement. This is true even on a microscopic scale, the pyrite occurring chiefly as crystalline clusters or individuals whose outlines are rarely corroded.

In a few specimens small veinlets of pyrite and of quartz and pyrite of a later age cut the other sulphides, and a few minute crystals of pyrite unassociated with other sulphides are embedded in the calcite of the calcite-bearing veins. Some pyrite is associated with the magnetite ore on the Fifty-six and Door Key claims, and at one place a trace is intergrown with specularite in epidotized sandstone. Good crystals of pyrite replace halloysite and beidellite at the Ground Hog mine.

Here, as in other ore deposits, the pyrite is the least susceptible of all the sulphides to replacement by chalcocite. It remains fresh and untarnished in mixtures in which all other sulphides show a variable degree of replacement, and residuals of it occur in secondary sulphide ores in which the other primary sulphides have been destroyed.

The silver content of the pyrite is negligible.

Magnetite.—Magnetite (Fe_3O_4) is not a constituent of the quartz-sulphide veins of the Central district but is plentiful on the Fifty-six and Door Key claims in a shaly bed of the Syrena formation. It is intimately intergrown with specularite and forms small knotty aggregates and larger, smoother streaks and masses. Stringers of quartz and pyrite cut the magnetite, and threads of pyrite form an intricate network in some specimens.

Specularite.—Specularite (Fe_2O_3) is intergrown with magnetite in limestone replacement deposits, as described above, and has been noted also in epidotized sandstone of the Colorado formation adjacent to a granodiorite porphyry dike on the Keystone and Star claims, where it is intergrown with a trace of pyrite. Specularite is unknown in the vein deposits of the Bayard area, but is mentioned by Graton [39] as occurring at the Wildcat mine, about a mile due east of the Ivanhoe mine.

SUPERGENE MINERALS

Jarosite.—Earthy jarosite ($K_2O.3Fe_2O_3.4SO_3.6H_2O$), the potassium analog of plumbojarosite, is associated with the plumbojarosite as already described. Doubtless the jarosite and plumbojarosite are accompanied and chemically contaminated by other members of the jarosite group, which is a common feature of the group.

Limonite.—The term "limonite" as here used includes all the amorphous hydrated iron oxides, which chemically are said to consist of $Fe_2O_3.H_2O$ (goethite) with differing amounts of adsorbed or capillary water.[40] Limonite is very abundant in the oxidized parts of the veins and occurs in the variety of forms characteristic of this material. Much of it is earthy and yellowish brown or reddish; in places it is considerably admixed with manganese oxides. Porous limonite and limonite-silica boxworks containing pseudomorphs after pyrite are common. The vein quartz in the oxidized zones is stained and coated with limonite, and the cherty brown quartz that makes up the barren parts of the veins in the oxidized zone owes its color to impregnation by iron hydrate.

In the lower part of the oxidized zone supergene cavities in the partly oxidized ore are lined with a yellowish-brown to blackish-brown velvety-looking crust made up of delicate radiate needles of goethite. The needles are commonly less than half a millimeter long and have grown upon an earlier dense brown limonite and upon surfaces of inert and comparatively inert primary minerals such as quartz and pyrite. Here and there the goethite has been altered to amorphous limonite.

MANGANESE MINERALS

HYPOGENE MINERALS

The primary minerals from which the manganese oxides of the veins were derived consisted largely, if not entirely, of the manganiferous calcite of the wall rock and the manganiferous calcite that is a prominent gangue mineral in some veins of the area. The cal-

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[39] Graton, L. C., op. cit. (Prof. Paper 68), p. 312.

[40] Posnjak, W., and Merwin, H. E., The hydrated ferric oxides: Am. Jour. Sci., 4th ser., vol. 47, pp. 311–348, 1919.

cite of the wall rock has been described in the section on rock alteration, and the vein calcite is described in the section on gangue minerals.

SUPERGENE MINERALS

Manganese oxides.—The manganese oxides are most abundant and best developed in the western part of the area, in those veins in which manganiferous calcite is a prominent gangue mineral. The varieties pyrolusite (MnO_2), psilomelane (chemically equivalent to MnO_2 with varying amounts of adsorbed impurities, chiefly water), and wad, an earthy impure mixture of oxides, chiefly $Mn_2O_3.nH_2O$ and $Fe_2O_3.nH_2O$ (limonite), can be recognized here and there, but generally they form intimate mixtures with one another and with limonite.

The igneous rocks throughout the district are strongly stained by manganese oxides along many fracture zones. The manganese oxides were derived from oxidation of the alteration calcite in the adjacent rocks and do not indicate the presence of veins.

VANADIUM MINERALS

Vanadates of lead, copper, and zinc are common in small quantities here and there at the outcrop and in the oxidized zone of the veins of the area, and at the Lucky Bill mine they occurred in commercial quantities. They are of supergene origin.

Cuprodescloizite.—Thin crusts and stains of green cuprodescloizite ($(Pb,Zn,Cu)_3(VO_4)_2.(Pb,Zn,Cu)(OH)_2$) are present somewhere along the oxidized outcrops of most veins of the area and have been seen underground in the Ground Hog mine.

Endlichite.—Endlichite ($PbCl_2.3Pb_3(V,As)_2O_8$), an arseniferous variety of vanadinite, has been mined for its vanadium content at the Lucky Bill mine and has been observed also at the Ground Hog and Lion No. 2 mines. It forms delicate capillary fibers that in places are intergrown into an asbestoslike felt. The color ranges from different shades of yellow to nearly white. The endlichite is commonly associated with wulfenite and subordinately with pyromorphite, and in specimens from the Ground Hog mine it has grown upon a crust of cuprodescloizite. Cavities in limonite boxwork are a common habitat, and the endlichite was, therefore, one of the very latest minerals formed.

The endlichite is called " vanadinite " in the district, but chemical tests show that considerable arsenic is present.

GANGUE MINERALS

OXIDES

Quartz.—Quartz (SiO_2) is the most abundant constituent of the veins of the area. Though it varies greatly in amount from place to place, being least abundant in the sulphide ore shoots, in which the quartz content may decrease almost to nothing, it forms a large part of the vein filling and locally has completely replaced large masses of adjacent wall rock.

There is little difficulty in distinguishing the vein quartz from the jasperoid formed by replacement of the country rock. The silicified country rock is a grayish fine-grained intergrowth of quartz that contains a variable quantity of small disseminated crystals of pyrite, identical in distribution and size with those of the pyritized but unsilicified rock. Here and there small flecks and patches of sericite and clay minerals give an indication of the original rock texture. The vein quartz can be recognized by its coarse grain and whiter color, even where it cuts through the jasperoid and shows no typical vein characteristics such as comb or drusy structure or the presence of vein sulphides.

Masses of white, coarsely crystalline, typical vein quartz, containing small druses and practically devoid of sulphides, occur in the massive sulphides, but most commonly the quartz in the sulphide ore shoots consists of water-clear slender prismatic crystals growing in small druses upon surfaces of the different sulphides. Thin stringers of quartz cut through the sulphides. In the pyritic parts of the veins the quartz forms a cement for the crystalline pyrite and at places forms crystalline combs between an earlier quartz-pyrite intergrowth and later sphalerite, chalcopyrite, and galena.

In the Ground Hog mine cloudy, unbroken, doubly terminated prismatic quartz crystals occur in some of the slickensided beidellite streaks. They must have grown in place and are probably hypogene, as metacrysts of pyrite occur in the same material. In the calcite-rich veins of the western part of the area stringers of white, somewhat milky quartz cut through the carbonate masses. Amethystine quartz occurs in small stringers in some of the quartz latite dikes.

Stubby prismatic crystals of glassy quartz of supergene origin occur in cavities in the oxidized and secondary ores. With the exception of some of the manganese and iron oxides, this quartz was the latest mineral to be formed, for it has grown upon limonite, upon supergene quartz walls of limonite boxworks, and upon chalcedony, which in turn has coated wulfenite. Brown and reddish-brown jaspery quartz, locally called "mahogany" quartz, forms prominent outcrops of some veins, and large masses of it occur throughout the oxidized zone. It is massive cherty-appearing material, breaking with a conchoidal fracture, in which only small sporadic grains of glassy quartz can be seen with the unaided eye or with the hand lens. Various stages of its formation can be seen at many places, and it clearly represents the silicified rock of the barren parts of the vein, impregnated and more thoroughly cemented by supergene quartz and limonite; glassy, uncolored quartz cuts the jaspery material and lines small drusy cavities in it. Some of the vein quartz is similarly changed and cut by stringers of supergene quartz, and at places the secondary silicification by "mahogany" quartz has cemented vein and adjacent rock so homogeneously that the original location of the vein fissure cannot be recognized.

Chalcedony.—Small quantities of chalcedony (SiO_2) occur throughout the oxidized ores. It crusts other minerals, such as wulfenite and hypogene drusy quartz, and lines small cracks. Some has been observed enveloping and filling cracks in residual cores of galena in partly oxidized ore, where seemingly it is earlier than the surrounding cerusite, like the chrysocolla bands already described.

CARBONATES

Calcite.—Hypogene calcite is rare in the veins of the Ground Hog zone, but a ferriferous, manganiferous variety is common in the western part of the area and locally constitutes most of the vein filling. It is white to cream-colored where fresh but is generally stained brown by iron oxides and black by manganese oxides. Both oxides have been derived in part from the calcite, which contains 0.2 percent of $FeCO_3$ and 0.4 percent of $MnCO_3$.[41]

The calcite is a late hypogene mineral, though not the latest. It is interstitial to the early quartz, traverses the quartz-sulphide intergrowths in thin stringers, and in places forms a band along the walls of the quartz-sulphide veins, but it is itself cut by stringers of later quartz. It generally carries minute sporadic crystals of pyrite but no other sulphides.

Small quantities of supergene calcite are found in the secondary ores, observable chiefly as small stringers and veinlets traversing massive chalcocite and "mahogany" quartz; it forms rhombic crystals where it lines open spaces along the stringers. The delicately banded variety of calcite known as Mexican onyx occupies nearly the full width of the Apollo vein at a shallow shaft at the north end of the Johney claim.

SILICATES

Halloysite.—Veinlets and bands of hard, porcelaneous halloysite, an amorphous hydrated silicate ($Al_2O_3.2SiO_2.nH_2O$), one of the clay minerals, have been seen in places along the vein in the lower part of the oxidized zone at the Ground Hog mine. The halloysite is partly altered to beidellite, which cuts it in a network of veinlets. Small crystals of unaltered pyrite are scattered through some of the halloysite, most of them in the beidellite stringers.

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[41] Partial analysis by T. C. Bunch, New Mexico School of Mines.

Halloysite is a supergene, submicroscopically crystalline mineral of the kaolinite group,[42] and the presence of pyrite is therefore significant. The pyrite is younger than the halloysite, probably also younger than the beidellite, and therefore indicates a period of sulphide precipitation subsequent to supergene alteration of the ores.

Beidellite.—Veins and stringers of massive beidellite ($(Al,Fe)_2O_3.3SiO_2.nH_2O$) occur along the walls of the veins to all depths open to observation. It is commonly slickensided and locally contains brecciated, crushed fragments of ore. Massive beidellite also fills drusy cavities in the primary ore and cuts the ore in stringers that extend into the walls. It is common in the chalcocite zone, where it has been largely altered to kaolinite.

The massive beidellite ranges from gray to olive green and when moist is very soapy. It dries out readily, becoming white, cream-colored, or brown, according to the iron content and its degree of oxidation. Specimens that had dried out on the laboratory shelf over a period of many months regained their original color and soapy feeling within an hour when immersed in water. Indices of refraction, β and γ, differ slightly in different specimens but average about 1.545, indicating a moderate iron content. The sign of the mineral is negative and the optic angle is small. Its birefringence seems a little less than that of sericite.

In addition to the massive beidellite, the sulphide ores are cut by thin stringers of powdery white beidellite, which occurs also in the small drusy cavities of the ore, particularly in the incoherent quartz-pyrite intergrowths; it is also interstitial to quartz in silicified rock where it has replaced residual nonsilicified material. Pockets of similar beidellite are scattered in the oxidized ores. The powdery beidellite cannot be distinguished megascopically from powdery white kaolinite that occurs in an identical manner and that may have formed in part by alteration of the beidellite.

A slickensided olive-green beidellite on the sixth level of the Ground Hog mine contains scattered doubly terminated quartz prisms and unbroken crystals of pyrite. The quartz crystals are clouded with beidellite, and both quartz and pyrite clearly must have grown in place. The same clay contains also broken crystals of quartz and pyrite and crushed pieces of ore that were torn from an earlier anchorage; evidently the beidellite was originally a post-ore fault gouge, the quartz and pyrite metacrysts having been formed after the gouge had been converted to beidellite.

Kaolinite.—White powdery kaolinite ($Al_2O_3.2SiO_2.2H_2O$), distinguishable from similar-appearing beidellite only by its indices of

[42] Ross, C. S., and Kerr, P. F., Halloysite and allophane: U. S. Geol. Survey Prof. Paper 185–G, pp. 135–144, 1934.

refraction and low birefringence, is very common in the sulphide ores, where it occurs as thin stringers, as ramifying veinlets, and as a light powder in cracks and other open spaces. Massive material is common in the chalcocite zone, where it has been formed largely from beidellite.

Sericite.—Sericite ($H_2KAl_3(SiO_4)_3$), as described in the section on rock alteration, is an alteration mineral that was formed prior to replacement of the rocks by quartz. It is rarely present in those parts of the veins that are open to observation, however, because most of it that escaped replacement by quartz has been altered to kaolinite and beidellite.

SULPHATES

Barite.—A few small crystals of barite ($BaSO_4$) were found in vein calcite on the dump of the Betty-Jo (Rapp No. 1) shaft, on the Johney claim.

Gypsum.—Minute needles of gypsum ($CaSO_4.2H_2O$) are found here and there in the veins from the surface down, generally along gouge or clay seams. A description by Graton [43] indicates that it is much more abundant at the Ivanhoe mine than has been observed elsewhere in the area.

PARAGENESIS

Three periods of mineralization in the Bayard area have been outlined in preceding sections—(1) prior to injection of the granodiorite porphyry dikes, (2) shortly after this injection, and (3) after injection of the Tertiary quartz latite dikes. In studying the paragenesis of the ores of the district it is necessary to consider, therefore, the effect of each period upon the preceding ones.

The vein fissures of the first two periods contain an identical suite of minerals—quartz, pyrite, sphalerite, chalcopyrite, galena, and calcite. Had such a suite of minerals been deposited during both periods, one would expect to find a repetition of sequence and a very complicated paragenesis in some of the earlier veins where later solutions had managed to penetrate. On the contrary, however, the paragenesis in the vein fissures of the two periods is identical and is comparatively simple. It seems probable, therefore, that the mineralization of the first period consisted simply of sericite-quartz-pyrite alteration of the wall rock and perhaps precipitation of a little quartz-pyrite vein matter, and that the economically valuable sulphides were deposited during the second period, which yielded the commercially important ore deposits of the area. Many of the granodiorite dikes cross earlier veins having sericitized, silicified,

[43] Graton, L. C., op. cit. (Prof. Paper 68), p. 314.

and pyritized walls, so that this degree of mineralization is known to have occurred in the first period.

The paragenesis of the ores is fairly evident to the unaided eye. Quartz and pyrite were the first vein minerals deposited, but they followed at least partial silicification and pyritization of the wall rocks. Local comb structures, cemented aggregates of pyrite and quartz in the valuable sulphides, and the minerals in the drusy openings of the ore all show that the economically valuable sulphides were deposited later than most of the quartz and pyrite. Stringers of chalcopyrite in sphalerite can be seen on careful examination, and in a few specimens stringers of chalcopyrite cut galena; all sulphides are cut by veinlets of quartz. Calcite was deposited after the valuable sulphides, but it carries a trace of disseminated pyrite that is probably contemporaneous with the calcite; the trace of associated barite also seems to belong to this stage. Veins of barren quartz in the calcite represents the final stage of mineralization.

Microscopic examination simply amplifies the megascopic observations. Most of the pyrite occurs as uncorroded crystalline aggregates that have been lightly fractured, microfaulted, and cemented by the other sulphides. One polished specimen from the Ground Hog mine shows veinlets of late pyrite in chalcopyrite, and a polished specimen from the Slate No. 1 shaft shows galena-pyrite stringers in other sulphides. The relative age of the sphalerite is clearly indicated by numerous veinlets of chalcopyrite and galena that cut it, but the age relation between the galena and chalcopyrite is less clear. Several features imply contemporaneity; most contacts are smooth, each mineral contains islands of the other, and many of the veinlets in sphalerite contain both galena and chalcopyrite. Here and there a veinlet of galena penetrates chalcopyrite, but locally the galena contains veinlike rods of chalcopyrite parallel to the galena cleavage. The veinlike shape of the chalcopyrite is not as convincing as the veinlets of galena in chalcopyrite, but inasmuch as very few metasomatic sulphides assume automorphic faces, the parallelism between the veinlike chalcopyrite masses and the galena cleavage suggests that the chalcopyrite at those places follows a cleavage plane and is the later mineral. Apparently the galena and chalcopyrite are essentially contemporaneous, with slight local overlaps of one or the other. No polished specimens show distinct veinlets of chalcopyrite in galena, such as can be seen in some hand specimens.

The few chalcopyrite inclusions in pyrite are doubtless roughly contemporaneous with their host, but the age of the chalcopyrite inclusions in sphalerite is less certain and depends upon the debatable origin of the inclusions—that is, whether they are the result of replacement or of unmixing from solid solution. Nothing critical has been observed, but several features suggest replacement. The inclusions show all gradations in size and shape from barely visible dots to rows of dots, threadlike veins, and fairly large irregular areas. Minute inclusions and threads of galena are associated locally with the chalcopyrite. Thin sections and chemical etching prove that many of the inclusions lie along grain boundaries as well as along cleavage planes. It may be significant that the chalcopyrite islands in galena, in the galena-chalcopyrite-sphalerite mixtures, almost invariably lie against a mass of sphalerite; this suggests that the sphalerite may have exerted some influence, presumably chemical, on the precipitation of chalcopyrite, which in turn suggests that the inclusions in the sphalerite may have derived their iron content from the ferriferous host and were formed at the same time as the rest of the chalcopyrite in the ore. The influence of sphalerite on chalcopyrite deposition is suggested on a large scale by the ore bodies themselves, in which chalcopyrite is much more abundant in the sphalerite-rich parts than in the galena-rich parts, even though galena and chalcopyrite were essentially contemporaneous. The suggestion that chalcopyrite inclusions in sphalerite may have derived their iron content from the sphalerite [44] seems a plausible idea for examples in which either a simpler process of replacement or an unmixing origin is not obvious.

Quartz-chalcopyrite, quartz-galena, quartz-pyrite, and simple quartz veinlets cut earlier minerals in a large range of specimens. Evidently quartz was precipitated during all stages of mineralization, beginning and ending the process, though only insignificant amounts were deposited during the metallization stage.

The earliest supergene solutions were highly charged with silica, and the jaspery cementation of the quartzose parts of the veins was produced by them. The alteration of the sulphides followed a normal pattern. Sphalerite was dissolved and the zinc dissipated in the ground-water circulation, only scanty amounts of oxidized zinc minerals being left behind. Galena was converted to anglesite and cerusite, which remained essentially in place as rather pure bodies of lead ore. A little copper from the chalcopyrite remained in the oxidized zone, but most of it was transported and redeposited at lower depths, largely as chalcocite and in slight amount as bornite and covellite; the chalcocite showed the following somewhat abnormal order of preference for the primary sulphides: Chalcopyrite, sphalerite, galena, pyrite. Silver was leached from the upper zones and was redeposited in the chalcocite zone.

[44] Loughlin, G. F., and others, Geology and ore deposits of the Magdalena mining district, N. Mex.: U. S. Geol. Survey Bull. (in preparation).

Supergene alteration of the ores was unusual in that there were two periods separated from each other by a period of hypogene mineralization. The general geology of the Central district proves that the quartz latite period of hypogene mineralization followed extensive oxidation of the ores. Mineralization during the quartz latite period was insignificant, however, and only sericite, quartz, and pyrite were produced. No veins were formed, but some solutions circulated along the existing veins and created the interesting anomaly of hypogene minerals later than supergene minerals in the same vein. Although the present oxidation cycle apparently has removed most traces of the last hypogene period from the veins, proof of its imposition on the supergene ores lies in the presence of pyrite and quartz metacrysts in the clay minerals halloysite and beidellite. Pyrite crystals occur in halloysite, chiefly in beidellite stringers, and cubes of pyrite and doubly terminated quartz crystals occur in massive slickensided beidellite. In the halloysite both pyrite and beidellite are unquestionably later than the halloysite and have replaced it. In the slickensided beidellite the unbroken and automorphic nature of the quartz and pyrite and the clay inclusions in the quartz constitute ample proof that these minerals were formed in place and have replaced the clay. The slickensided beidellite contains crushed and broken pieces of quartz, pyrite, and other sulphides in addition to the metacrysts and was originally a post-ore fault gouge. Manifestly the metacrysts cannot belong to the period of ore formation but must instead have been formed after the ores had been faulted and the fault gouge converted to beidellite. The only known faulting subsequent to ore formation and prior to the last period of hypogene mineralization was that of the intervolcanic period described in the section on structure. As this faulting took place after the oxidized and truncated ore deposits had been covered by a blanket of Tertiary sedimentary rocks, it is clear that the beidellite must have been formed much later than the first supergene period. The beidellite-forming solutions probably differed greatly from those that formed the halloysite of the first supergene period and the kaolinite of the present period; they were probably warmer than ordinary supergene solutions and may have contained a variety of unusual solutes derived from the volcanic environment. In this connection it should be recalled that the volcanic sands and tuffs are altered to montmorillonite adjacent to strong faults, particularly along the Ground Hog zone, where beidellite is common in the ores, and that montmorillonite and beidellite are closely related members of the same isomorphous group of clay minerals.

The current supergene period has modified all earlier features of the ores, although it is difficult to differentiate between the effects

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of this and of the earlier period. The late supergene quartz and chalcedony and most, if not all, of the supergene calcite have been formed during the present period, and the earlier chalcocite ores have been partly changed, but the chief feature of this period is the formation of lead vanadate ores, which have been of a little commercial importance.

Figure 11 is a graphic summary of the foregoing paragraphs.

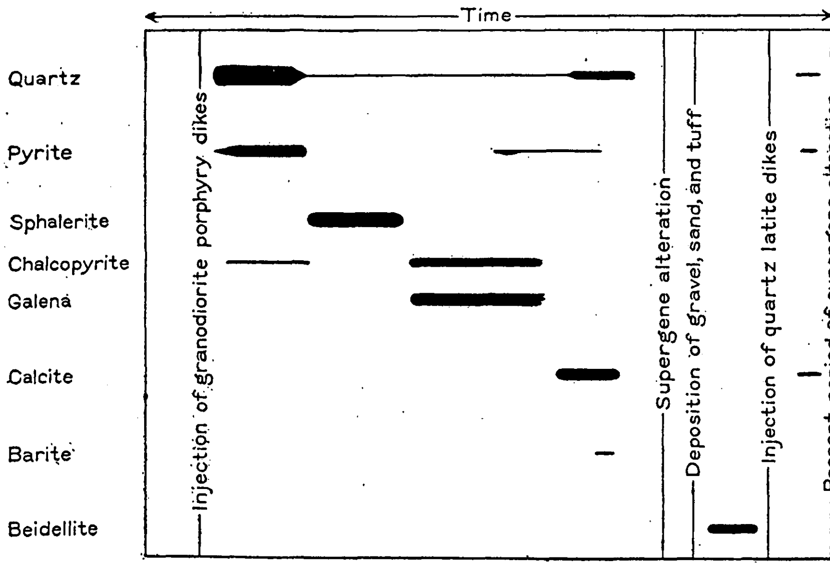


FIGURE 11.—Mineral succession in the Bayard area.

VEINS EARLIER THAN GRANODIORITE PORPHYRY DIKES

In considering the veins earlier than the granodiorite porphyry dikes it is imperative to differentiate between the vein filling and the fissures that the vein filling occupies. This is particularly necessary because of the probability that metallization of these veins occurred during a second period of mineralization, as pointed out in the section on paragenesis. The conclusion reached there is that pre-dike vein deposition consisted only of quartz and pyrite. The uniform association of placer gold with all veins suggests that gold accompanied those minerals, but the gold content of the early veins is not of commercial importance, and the possibility that they may contain valuable base-metal deposits is entirely dependent upon the readiness with which they may have allowed circulation of the ore-forming solutions of the post-granodiorite period.

The fissures that are known to have originated prior to the injection of the granodiorite porphyry dikes are those of the Ivanhoe-Lovers Lane-Ground Hog zone, the Copper Glance fault and most of its spurs, the San Jose Mountain fault, which is really an imbricating continuation of the Copper Glance fault, the May Bell vein, the Dutch Uncle-Tin Box vein, and the Owl vein and its links with the Dutch Uncle. Because of their structural relation to the Owl zone, the Lost Mine and Slate faults also probably belong to that period. The Hanover Creek fault probably originated at that time also, as certainly did the adjacent small veins on the Alloy claim. All these contain different amounts of base-metal sulphides. Along some of them post-granodiorite movement opened up channelways for the ore-bearing solutions that followed; these are discussed in the section on deposits later than the granodiorite. Along others there was just as certainly no such movement, and the amount of valuable vein matter that they contain consequently depends upon how tightly they had been filled by minerals of the pre-granodiorite period or by dikes that may have been injected along them. The Ground Hog and Ivanhoe dikes prove that some fissures were effectively sealed by dikes. At many places, however, the dikes cut directly across the vein fissures, at some places without change in the smooth intrusive contact but elsewhere sending short tongues along the vein, implying that the veins were already practically sealed at those places, as the dike pattern gives the impression that the magma was a penetrative one. It cannot be argued that a rock magma is as penetrative as an ore-bearing solution, but in this district the field relations indicate that where the fissures were too tight to permit penetration by a very insinuating granodiorite magma they were also too tight to permit formation of base-metal deposits of commercial size and importance. The ore-bearing solutions did penetrate along the veins, as is known from the occurrence of small quantities of ore minerals along them, but the veins were too tight to permit circulation of great volumes of these solutions and, what is more important, they must have lacked the large proportion of open space necessary for the deposition of base-metal ore bodies of exploitable size. If this reasoning is sound, then, with particular exceptions, those veins of pre-granodiorite origin along which there has been no post-granodiorite movement may be regarded as poor places to prospect. The exceptions are (1) the Copper Glance vein, (2) the Slate vein and those west of it, and (3) all veins at depths where they cut the underlying limestone formations.

The dikes that cross the Copper Glance vein are strongly sericitized in the vicinity of the vein; exposures of plumbojarosite are strong at three places along this vein; and a few tons of high-grade galena ore has been mined from it on the Cashier claim. These facts point to the passage of ore-bearing solutions in moderate quantities and imply that, although the Copper Glance vein may have been impenetrable where crossed by dikes on the Burchard and Cashier claims, it may have contained more open channelways nearby.

The Slate vein is beyond the area in which the granodiorite porphyry dikes occur and therefore escaped the danger of being sealed by them. Small quantities of ore have been mined from it at two places. The vein at the Lion No. 2 workings, where lead-carbonate ore associated with wulfenite and vanadium minerals has been mined, is very similar to oxidized parts of the Ground Hog vein. The veins west of the Slate vein that may belong to the early group are similar to the Slate vein in that they also are outside the granodiorite area and carry minerals of the ore-forming period. On the other hand, they lie at some distance from the probable source, near Santa Rita, of the mineralizing solutions, which may have dropped part of their metalliferous load before reaching this area.

The third exception is less specific than the other two but may have greater commercial significance. The pre-granodiorite veins crop out in relatively inert rock in which the formation of ore bodies depends largely upon the existence of open spaces, but many of them at variable distances below the surface cut great thicknesses of limestone, a rock that is commonly amenable to replacement by ores and that carries valuable deposits at many places in the surrounding area. Even tight veins through which only small quantities of solutions could circulate might be strongly mineralized in such rock. The cross sections in plate 2 show the depths at which limestone may be expected, and it must rest with the miner to decide whether this rock lies at depths too great to be prospected properly at reasonable expense.

MAGNETITE REPLACEMENT AND RELATED SUPERGENE COPPER DEPOSITS

On the Fifty-six claim the shaly beds near and at the top of the Syrena formation have been altered to a dense indurated rock that here and there carries blebs and streaks of magnetite and that includes layers of knotty shale in which the knots consist of growths of magnetite as much as an inch in diameter. The most intensely impregnated place is adjacent to the northward bulge of the hook of the Ivanhoe dike. Magnetite is exposed also just under the Beartooth quartzite at the western edge of the limestone area on the Ivanhoe claim. A compass needle is deflected about 45° at the tunnel on the Door Key claim between the two exposures, though no magnetite can be seen there. The magnetite ore is cut by pyrite and quartz-pyrite stringers, and the adjacent dike is strongly impregnated with pyrite. The magnetite-bearing layers have been more or less oxidized to a limonitic gossan as far north as the Bell of the Hill claim, and copper-carbonate stain is very common. Microscopic study shows that the magnetite is intergrown with specularite and that the pyrite contains microscopic inclusions of chalcopyrite. The deposit is doubtless a contact-metamorphic phase of the post-dike mineralization. Similar though less abundant iron-oxide impregnation has occurred on the Keystone and Star claims, where the epidotized sandstone member of the Colorado formation adjacent to a granodiorite porphyry dike contains disseminated bunches of specularite and subordinate pyrite.

Numerous workings lie along the magnetite bed and in the adjacent dike, as shown on plate 1, but none are now accessible. To judge from their character, size, and number, a fair amount of ore appears to have been extracted, and local residents state that copper-carbonate ores were mined from the granodiorite. The workings seem to have been erratic and tortuous, indicating that the ore was pockety. The carbonate occurred as nodules of malachite and azurite distributed through kaolinized granodiorite. The northern extension of the Ivanhoe vein borders the dike, and evidently the copper was derived from this vein and from the cupriferous pyrite in the adjacent magnetite deposits. The copper-sulphate solutions formed by oxidation would necessarily migrate downhill into the kaolinized granodiorite, where they would be neutralized and the copper precipitated.

VEIN DEPOSITS LATER THAN GRANODIORITE PORPHYRY DIKES

The period of mineralization that followed the injection of the granodiorite porphyry dikes was the period of economic metallization. Except for the small magnetite replacement deposits already described, which are a contact-metamorphic phase of this period, the deposits are fissure fillings and occur in all openings through which the ore-bearing solutions were able to circulate. Many of the openings were residual spaces along veins of the pre-dike period, and, as would be expected, the deposits in them are scanty and of doubtful commercial importance. The larger and commercially important deposits, those considered under the present heading, occur along those fissures that, though perhaps of pre-dike origin, had undergone post-dike movement and thereby had new channelways formed along them.

The veins that come under this category are the Ground Hog vein, on which are the Ground Hog, Lucky Bill, San Jose, Denver, and C. G. Bell mines; the Ivanhoe, Tenderfoot, Owl, Homestake, Paola, and San Jose Mountain veins; the veins on the Goodyear, Osceola, and Burchard claims; the Boston Bicket vein, a spur of the Lost Mine vein that may be included in this group; small veins on the Bull Frog, Owl, and Bell No. 1 claims; and the Quitter and Mountain View veins. Many of the veins in the western part of the area, where dikes are absent and proof of age is lacking, probably should be included here. Among them are the Apollo, Three Brothers, and Pioneer veins and perhaps also the Slate vein, which has already been described as belonging to the earlier period.

HYPOGENE ORES

The deposits lie along brecciated fracture zones in which the amount of ore is a direct function of the amount of fracturing. Replacement of wall rock is practically confined to silicification and pyritization, processes that formed rocks even less susceptible to replacement by ore minerals than the original rocks. Replacement was strongest in the quartz diorite and seemingly weakest in the granodiorite. Here and there the rocks seem to contain disseminated particles of vein sulphides, but close examination shows that most, if not all of these, lie along minute stringers.

The ore consists of massive varitextured argentiferous mixtures of galena, sphalerite, pyrite, and chalcopyrite accompanied by subordinate quartz and calcite. The mixtures range from fine-grained, sugary, intimate intergrowths to rather coarse-grained masses composed chiefly of one mineral. In the Ground Hog mine the ore has a suggestion of banding in galena, mixed sulphide, and thin pyritic streaks parallel to the plane of the vein, and some of the galena streaks are sufficiently pure and large to be mined cleanly and shipped directly to the smelter. The experience of the miners at that mine has been that the best galena ore tends to lie along the hanging wall. Another notable feature of the Ground Hog ore is that the chalcopyrite is much more prominently associated with sphalerite than with galena. Some of the Ground Hog ore contains many small druses lined with crystals of all the different vein minerals.

Gangue minerals make up but a scanty part of the ore shoots, but elsewhere in the veins they form the predominant or only vein matter. In parts of the veins the filling consists largely of quartz and pyrite; in other parts filling of any sort is scant, and the vein is made up of silicified, pyritized wall rock. Calcite is the only vein filling at many places in the western part of the area. Passage from one kind of vein filling to another is gradual at some places but is abrupt at others; ore has been seen to stop against barren quartz along a tight joint. Breccia and gouge selvages are common and range from thin streaks to bands several feet thick; at places, however, the vein lies against a slickensided wall without intervening gouge, or stops against a simple joint, or is in cemented contact with country rock along an irregular line, numerous stringers and tongues of ore penetrating the walls. Breccia fragments of rock having a great range in size are common in the veins and occur in all varieties of vein filling. (See pl. 11.)

The ore in the Ground Hog vein differs from that in the veins to the west in several mineralogic details. In the Ground Hog ore the sphalerite is all marmatitic, chalcopyrite is an economically important mineral, averaging about one-fifth of the sulphide content, and calcite is rare. In the other veins the sphalerite is sporadically the pale-yellow, iron-poor variety, calcite is common and in many places is predominant, and chalcopyrite is insignificant, yielding a copper content of less than 1 percent to the ores. Assay values of ore shipments also suggest that sphalerite is proportionally less abundant and galena more so in the western veins than in the Ground Hog, but not enough ore has been mined from the western veins to give an accurate idea of the average ore. The ores of the Bayard area are presumably related to the granodiorite stock that crops out at Santa Rita, three-fourths of a mile northeast of the mapped area, and these mineralogic differences may be the results of progressive modifications of the solutions as they traveled westward from their source. The decrease of chalcopyrite almost to the vanishing point in the outer zone is probably due chiefly to lessening concentration, perhaps partly induced by lessening temperature. Chalcopyrite generally forms before galena in the mesothermal type of deposits of which the ores of this area are characteristic, and the contemporaneity of galena and chalcopyrite in the ores may be the result of an excessive concentration of lead. Calcite is characteristically a late mineral, and its abundant deposition by solutions impoverished in ore minerals is to be expected; the upper parts of the Ground Hog vein that have been removed by erosion were probably similar to the calcite-rich veins to the west. An increase in the galena-sphalerite ratio, as indicated in the western veins, is also characteristic of outer mineralization zones, in which the minerals are deposited by solutions that have already dropped much of their sphalerite load in inner zones and consequently are impoverished in zinc and residually enriched in lead.

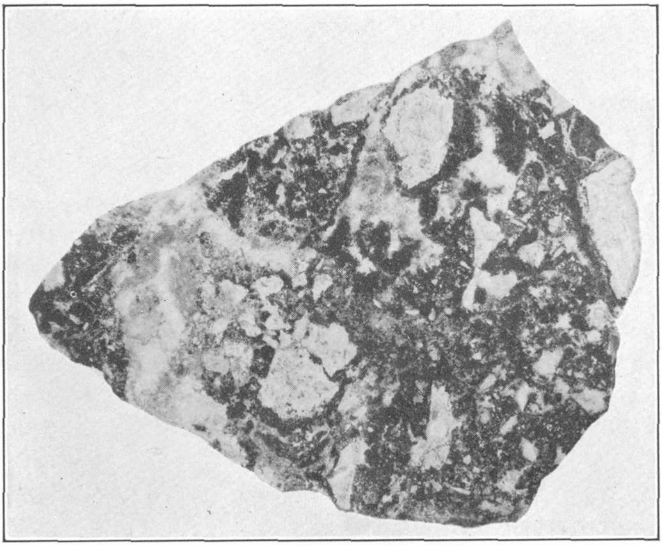
STRUCTURAL FEATURES

The economically important veins of the group under discussion are those members of the linked fault system of the area that became the sites of granodiorite porphyry dike injection and were later reopened. Reopening showed an extreme tendency to follow the walls of the dikes; the dikes are commonly pronged, and the crotches and wedge ends of the prongs appear to have been guides that picked up and directed the fissures. In places, therefore, the dikes form hanging wall, footwall, or both walls of the vein, or neither wall where the vein swerves from one dike to another. (See pls. 12 and 16.)

The ore shoots, to judge from development at the Ground Hog and Lucky Bill mines, are lenslike, 25 feet in maximum thickness and over 1,000 feet in maximum length. Those along the Ground Hog vein pitch flatly to the northeast, but the attitude in other veins has not been determined. At the Ground Hog mine the principal ore shoot lies in a sheeted zone along a dike in the hanging wall of the main break, which was choked by gouge and breccia against the passage of ore-bearing solutions. The character of the sheeted zone is indicated by thin pyritic streaks in the ore; at casual glance the pyrite seems to fill cracks in earlier-deposited sulphides, but more careful study indicates that the pyrite was the earliest sulphide and that it fills the original cracks of the sheeted zone, the pattern of these cracks having been preserved by failure of the later sulphides to replace the pyrite. The sheeted zone was faulted into several segments prior to ore deposition, but the ore has retained the general outline of the segments and thereby falsely appears to have been broken up by post-ore faults, which elsewhere in the mine have segmented the ore in a similar fashion. The details of these features are given in the description of the Ground Hog mine (pp. 110–116).

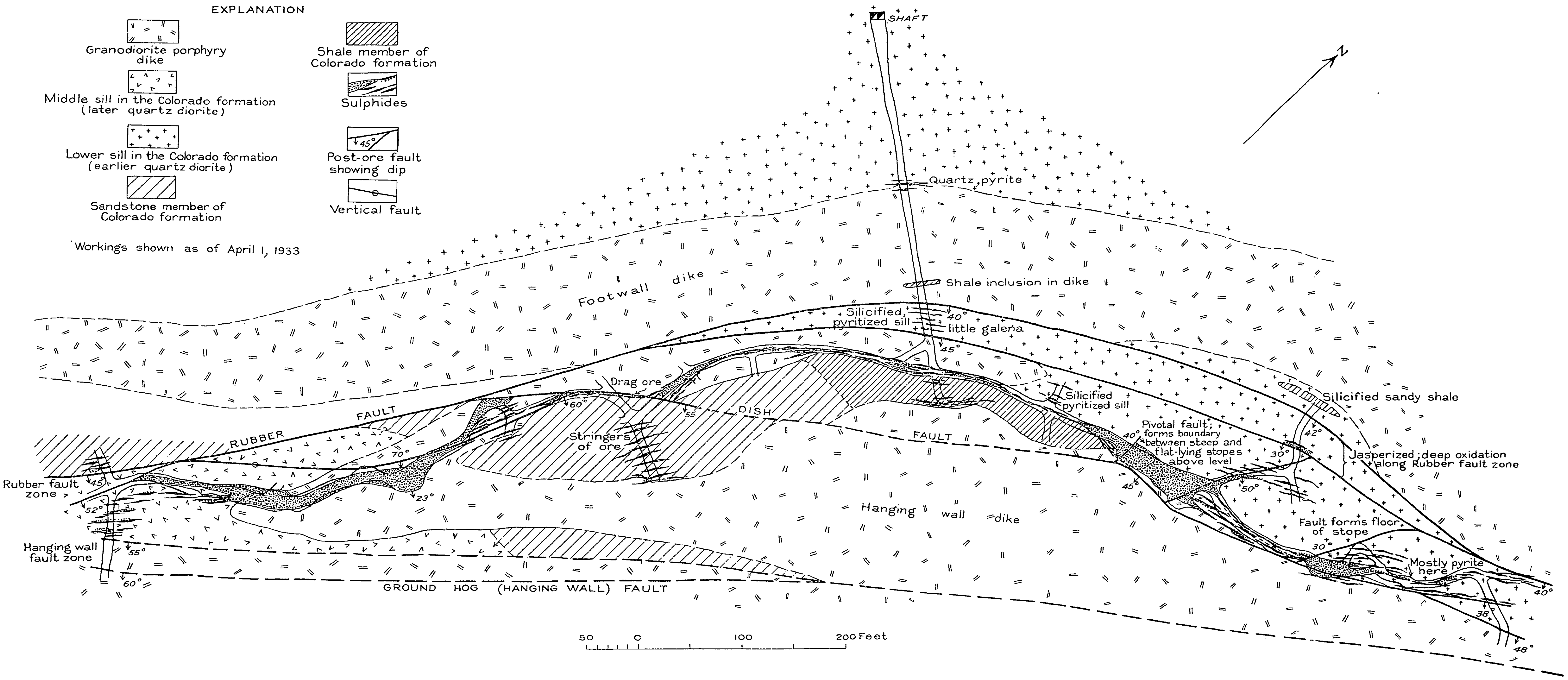
The ore bodies are the result of continual reopening and filling of fissures. The mineral distribution along the vein indicates that the mineral-bearing solutions were forced to take different paths at different times; and the drusy cavities in the Ground Hog ores, the banding, and the original sheeting and jointing of the vein zone preserved in massive ore by streaks of early quartz and pyrite all prove that the solutions were repeatedly diverted into more open channelways at several periods.

Post-ore faults are common in the area and occur along and parallel to the veins. They are chiefly associated with those veins that are major members of the fault system, as those were the lines of weakness that the Tertiary faulting favored. Such are the Ground Hog, San Jose Mountain, and Owl veins. There were two periods of Tertiary post-ore faulting, but the first, that preceding the third hypogene period of mineralization, apparently had little structural effect upon the veins other than to reopen some of them and permit injection of quartz latite dikes, as at the Johney (Rapp) and Three Brothers mines. At the San Jose Mountain and Owl veins the relation of post-ore faulting to the pre-ore fissures is obscure, because these veins are not open to study; but to judge from a few surface exposures the post-ore faulting largely coincided with the



A. POLISHED SPECIMEN OF BRECCIA ORE FROM THE GROUND HOG MINE.
Natural size.

B. BRECCIA ORE IN THE GROUND HOG MINE.
South end of stope 19 above level 350.



GEOLOGIC PLAN OF LEVEL 6, GROUND HOG MINE.

Though the geology on this level is a little more complex than on the other levels, it is fairly typical of the mine.

earlier fissures. In the Ground Hog zone the main post-ore fault lies a short distance in the hanging wall of the vein, but there was also pronounced faulting in the vein zone itself.

The veins in the Ground Hog-Ivanhoe zone exhibit a greater variety and complexity of structural features and more detailed evidence of intermineralization adjustment than those to the west; but this is only natural, for the Ground Hog-Ivanhoe zone has been the principal site of structural adjustment since faulting in the district began, and may be expected to show a fracture system more complex in both history and pattern than the weaker and in part sympathetic fissures beyond it.

SUPERGENE ORES

The supergene ores of the Bayard area consist chiefly of lead carbonate and chalcocite ores. A small amount of lead vanadate ore of supergene origin has been mined for its vanadium content. A little zinc carbonate ore is said to have been shipped from the Lion No. 2 mine, but only small quantities of any oxidized zinc minerals can be seen anywhere at the present time. Calamine seems to be most abundant, and enough sorted calamine ore has been accumulated on the dumps of the Manhattan claim to make a small shipment. Willemite was found in the outcrop of one vein, and goslarite is growing in mine workings at the present time. One of the vanadium minerals, cuprodescloizite, is zinc-bearing. Small lots of copper-carbonate ore are said to have been shipped from the Fifty-six claim, as described under "Magnetite replacement and related supergene copper deposits", and Graton[45] reports that the "San Jose mine, near the south end of the Hanover district, was an important producer of copper, gold, and some silver from ore said to be chiefly copper carbonates in porphyry." At the present time oxysupergene copper minerals are distributed throughout the oxidized zone, but nowhere in commercial quantities except possibly on the Fifty-six claim. They include azurite, malachite, chrysocolla, native copper, chalcanthite, cuprodescloizite, and a trace of cuprite.

Lead carbonate ores are the most valuable supergene ores of the area. Mining in the early days of the district was confined largely to extraction of cerusite ore from near the surface, and ore of this class is still being mined. A variable amount of anglesite and a little galena are associated with the cerusite, the amounts depending upon the stage of oxidation. Plumbojarosite occurs locally, and enough appears to be in sight on the Cashier claim for a small shipment. Oxidized copper minerals, vanadium minerals, wulfenite, pyromorphite, and pockets of manganese and iron oxides occur here

[45] Graton, L. C., op. cit. (Prof. Paper 68), p. 318.

and there in the cerusite ores, and assays indicate that these ores contain also a little zinc carbonate. The silver content of the cerusite ores commonly ranges from 1 ounce or less to the ton in ore near the surface to a content in deeper ores equivalent to that in the primary ore. (See p. 73.) As the lead carbonate ores are residual from mixed sulphides from which other metals have been leached, they are invariably much higher in grade than their primary counterparts, the lead content averaging about 20 to 25 percent.

The chalcocite ores consist of massive to sooty chalcocite containing other sulphides in variable amount, depending upon the depth at which they are found; clay minerals and native silver are commonly present in the upper parts of the chalcocite bodies. The chalcocite ores are much less valuable than the lead carbonate ores and have been mined only in the Ground Hog and Lucky Bill mines. As mined they average only 5 to 10 percent of copper and 2 to 4 ounces of silver to the ton. Most of the chalcocite ore is mixed with lead carbonate, and the two classes have been mined together.

DEPTH OF SUPERGENE ALTERATION

The depth of supergene alteration is exceedingly erratic, as might be expected from the numerous faults that have allowed supergene solutions to penetrate to great depths below a general level. Fresh sulphides crop out along the Owl vein in the bed of Gold Gulch and lie within a few feet of the surface at other places in the area. On the other hand, strong oxidation has been encountered to the lowest depths explored in the Ground Hog mine (altitude 5,500 feet) and mixed carbonate-chalcocite ores have been mined from the 500-foot level of that mine (altitude 5,660 feet). Water level coincides rather closely with the base of the carbonate zone throughout the district, and in the Ground Hog vein comes fairly near to forming the dividing plane between the chalcocite and carbonate ores. Nothing is definitely known concerning the depth of oxidation during the prevolcanic-erosion period; ore containing mixed chalcocite, carbonate, and hypogene sulphides was mined from the Gilchrist stope in the Ground Hog mine, about 125 feet above the present water level, and it may be that the top of the chalcocite zone in that stope roughly marks the position of the water table of that period.

MINERALIZATION RELATED TO QUARTZ LATITE DIKES

The mineralization of the quartz latite period was trivial and consisted chiefly of sericitization, pyritization, and silicification of the quartz latite dikes. The dike on the Johney claim is traversed by oxidized pyrite stringers, and the Three Brothers dike contains stringers of amethystine quartz. The quartz latite dikes were injected later than the intervolcanic period of faulting and therefore it is possible that the post-tuff faults are faintly mineralized. No independent veins of this period have been identified, but in some places the solutions circulated along earlier veins that were reopened during the intervolcanic period of faulting. This took place at the Ground Hog mine, and the Footwall vein of that mine may owe some of its confusing appearance to movement along the post-ore Rubber fault during this period and to cementation and impregnation of the sulphide and rock gouge by pyrite and quartz of the last period of mineralization.

VANADIUM DEPOSITS

Vanadium minerals have been observed at the outcrops and in the oxidized ores at several places, but only at the Lucky Bill mine did they occur in quantities sufficient to form a commercial deposit. The deposit was small and evidently was mined as a side issue. The only vanadium ore produced as such was a 15-ton lot shipped to Germany in 1911.

The vanadium minerals, which include endlichite and cuprodescloizite, were first recognized at the Lucky Bill mine by Paul F. Larsh, who later acquired an option on the property and mined the deposit. The following paragraphs are extracts from a description of the deposit written by him.[46]

> In May 1911 I crossed the property and was impressed by the presence of large amounts of lead vanadate in the dumps, which, up to that time, had been called "lead oxide" or "yellow carbonates." * * *
>
> The overlying rocks where not removed by erosion are rhyolite and tufa several hundred feet thick. The underlying rock that contains the vein is monzonite porphyry[47] forming both walls. * * * In the vicinity of the vein, as far as the quartz porphyry has been explored, it is traversed by numerous quartz seams or veinlets highly impregnated with lead vanadates as fine canary-yellow needlelike crystals. The overburden, tufa, in the vicinity of the vein, is also mixed with both vanadates and carbonates of lead. The smaller seams or cracks in the porphyry are filled with an asbestoslike lead vanadate, the whole, especially near the vein, comprising a stockwork probably of commercial value. * * *
>
> The ores consist of hard lead carbonate with some galena and hard lead vanadates, the carbonates and vanadates predominating. These minerals are thoroughly cemented with silica, making them hard and glassy, and do not slime much when crushed. * * * The carbonates and vanadates are almost completely segregated and can easily be mined separately or can be hand sorted if mined together. In drifting one is sometimes in all-carbonate ore and sometimes in all-vanadium ore. Frequently a small streak of either may exist with several feet of the other mineral.

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[46] Larsh, P. F., Lucky Bill lead-vanadium mine: Eng. and Min. Jour., vol. 96, pp. 1103–1105, 1913.

[47] Later quartz diorite.—S. G. L.

A 15-ton lot of sorted ore, which was shipped to Germany, consisted of two-thirds of the highest grade and one-third of the second-class vanadium ores and assayed 9.16-percent vanadium pentoxide. * * * The ore was evidently satisfactory, as requests for regular shipments were made.

The "needlelike" and "asbestoslike" lead vanadates mentioned by Larsh are the endlichite described in this report. The hard massive ore has been described by Hess [48] as follows:

Specimens of the ore sent to the United States Geological Survey are yellow with green blotches and are peculiarly massive. In microscopic section the rock is seen to be made up of vanadinite crystals in quartz, which apparently replaces a brecciated porphyritic rock. The green color is probably due to descloizite.

Hess' description suggests that the material is the same as that described in this report as pyromorphite, the lead chlorophosphate, which locally is intimately associated with the vanadium minerals. Chemical tests on samples collected by me show the presence of phosphate, chloride, and lead but no arsenic nor vanadium.

GOLD PLACER DEPOSITS

Every arroyo, no matter how small, in the prevolcanic rocks contains placer gold, and even the small rain channels on the slopes below the veins yield colors. A map of the placer ground would be essentially a map of the drainage pattern of the nonvolcanic area, but the most productive areas have been south of the Copper Glance vein, the down-slope side of the Owl-Dutch Uncle-Tin Box-Lost Mine vein linkage, and the vicinity of the veins along the highway into Central at the western edge of the area mapped. The gold was unquestionably derived from the veins and not from the country rock, as some residents of the area believe. In panning up an arroyo the miners find that the gold content gradually increases to the point where the arroyo crosses a vein, then abruptly drops, to increase again until another vein is crossed. Many veins too small to be shown on the map have yielded gold according to this test.

Each panful of gravel yields a few colors, and occasionally a nugget as large as a small lima bean is found. The particles are rough and irregular and could not have been transported far. The fineness of the gold is about 0.705.

HISTORY AND PRODUCTION

In the early days of mining in the Central district attention was directed chiefly to the copper deposits at Santa Rita, which, as then recognized, consisted of shallow vein deposits and veinlike lenses of comparatively high-grade ore. Everywhere copper seemed to be the

[48] Hess, F. L., Mineral Resources U. S., 1911, pt. 1, p. 950, 1912.

chief metal of interest, but deposits of silver-bearing lead carbonate ore were recognized and mined in the adjacent Bayard area. The earliest veins satisfactorily prospected in this area were evidently the San Jose and Ivanhoe. The San Jose mine was mentioned in 1870 by Raymond,[49] who describes it as having been profitably worked prior to that date. He also mentions the "Stuart ledge", a gold vein "in the immediate vicinity of Fort Bayard"; this may be the Texas vein, which was one of the best known of the early properties. Governor Otero [50] wrote in 1903:

> The oldest mines in the [Santa Rita] district, with the single exception of the Santa Rita Mining Co.'s properties, are the San Jose and Ivanhoe, both of which have been worked almost continuously since the early eighties, producing copper, lead, and silver ores in large quantities.

The Atchison, Topeka & Santa Fe Railway reached the Central district in 1891, and under that stimulus a few small smelters were built in the district to treat ore from individual mines. One of these was built at the Ivanhoe mine in 1899(?) and was operated until the argentiferous lead carbonate ore was mined out; it seems to have been shut down and dismantled early in 1903. A second smelter was built on the north bank of Whitewater Creek, on the North Star claim, and handled the ore from the San Jose mine. The Ivanhoe and adjacent claims were purchased late in 1904 by the General Electric Co., which, under the name "Hermosa Copper Co.", purchased these claims as the nucleus of proposed large-scale copper-mining and smelting operations. Their engineers believed that the ore of the Ivanhoe mine consisted chiefly of pyritic copper ore, which would be valuable in smelting. At that time the Ivanhoe was considered one of the most promising prospects of the entire Central district. John M. Sully was assistant superintendent of the Hermosa Copper Co. when in 1905 and 1906 he made his first examination of the Santa Rita deposits, with the view of including them in the proposed enterprise. The Hermosa Copper Co. continued exploration at the Ivanhoe mine and on the adjacent claims, but nothing was found that seemed sufficiently attractive, and work was finally discontinued in 1907.

The San Jose mine has been worked sporadically ever since its discovery, but strangely enough very little seemed to have been done in prospecting the vein beyond the claim boundaries. About 1900, however, a flood down Lucky Bill Canyon exposed the vein at the mouth of the canyon, 3,000 feet from the San Jose mine, and the Denver, Lucky Bill, and Ground Hog claims were located on

[49] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869, p. 404, 1870.

[50] Otero, M. A., Report of the Governor of New Mexico to the Secretary of the Interior for 1903, p. 68, 1903.

the trend of the vein, which in that vicinity is covered by volcanic rocks. Mining was started on the Lucky Bill claim, but the Ground Hog claim apparently received no attention until 1914, after Ross, Larsh & Co. had started shipping large quantities of lead carbonate ore from the Lucky Bill mine. The Ground Hog claim changed hands several times in the next 10 years, each owner shipping a little secondary ore, and was finally taken under option in the fall of 1924 by the Hayward-Richard Leasing Co. That company mined a little secondary ore and in the spring of 1928 discovered the extensive shoot of mixed-sulphide ore that is being mined at the present time (1933). The company was unable to market at a profit the complex ore from the new shoot, and in June 1928 it sold a 51-percent interest in the property to the Asarco Mining Co., a subsidiary of the American Smelting & Refining Co. The Ground Hog mine has been working on this ore body continously since its discovery and to January 1, 1933, had mined from it 182,000 tons of high-grade ore; at that time the ore body had been fairly well delimited by development work but had by no means been mined out.

Rich gold ore is said to have been discovered in 1903 at the Owl mine in Gold Gulch. Development and exploration were vigorously carried on throughout the vicinity, but the excitement lasted only a year or so.

An unsuccessful attempt was made in 1905 to recover placer gold from the gravel of Whitewater Creek, but "after boilers, two powerful steam turbine pumps, and a Hendy hydraulic elevator had been installed, it was found that both water and gold were lacking."[51] Nevertheless, small quantities of placer gold are widely distributed in the drainage system of the area, and the local residents manage to make a meager living in times of unemployment by mining the gravel by hand methods. The average daily yield per man seems to be about 0.05 ounce. The gravel is gathered in sacks or boxes and carried to the nearest available water, where it is painstakingly panned or treated in hand rockers. The gold is marketed locally by exchanging it with the merchants for necessary commodities. The price paid is arbitrary.

Mines in the Bayard area produced to the end of 1932 about 275,000 tons of ore, from which lead, zinc, copper, silver, and gold valued at about $7,000,000 were recovered. The following table shows the annual production from 1905 to 1932; this table was compiled from data furnished by the United States Bureau of Mines and by mine owners and is as accurate as the information at hand permits. About 99 percent of the production shown in the table has

[51] Graton, L. C., op. cit. (Prof. Paper 68), p. 318.

come from the Ground Hog and Lucky Bill mines, on the Ground Hog vein.

Metals recovered in the Bayard area of the Central mining district, New Mexico, 1906–32

Year	Ore (short tons)	Gold (ounces)	Silver (ounces)	Lead (pounds)	Copper (pounds)	Zinc (pounds)	Total value
1906	178		942	148,105			$9,083
1907	223		1,115	173,943			9,955
1908	36		142	29,000			1,293
1909	22		94	16,943			777
1911	723		2,565	399,296	1,066		19,460
1912	3,676		12,744	2,000,299	3,791		98,476
1913	509	10	1,844	66,800	315		4,309
1914	346	61	777	121,400	8,088		7,502
1915	2,788	4	13,981	1,382,656	47,617		80,488
1916	3,280	22	14,832	1,733,132	13,610		133,151
1917	5,804	8	27,772	1,786,721	360,396		275,102
1918	6,729		43,491	2,668,214	483,958		354,472
1919	2,746		13,793	1,232,024	40,339		81,574
1920	3,065		9,000	919,438	47,392	22,506	93,918
1922	873		2,801	348,333	1,870		22,211
1923	2,992	60	13,533	1,246,858	19,514		101,330
1924	3,685	3	17,370	1,041,023	141,349		113,499
1925	11,036	9	45,682	1,850,680	1,014,600		337,071
1926	18,987	6	54,427	1,889,070	1,073,873		335,554
1927	12,045	28	64,331	1,802,592	1,020,956		284,364
1928	13,921	21	84,414	2,619,248	713,357	2,134,000	386,110
1929	40,344	105	228,742	5,100,707	1,911,730	6,265,000	1,181,357
1930	48,053	103	314,226	6,107,120	2,464,170	9,539,000	1,204,760
1931	46,238	127	388,781	6,790,000	3,097,600	7,921,000	949,445
1932	43,594	73	445,101	6,687,000	3,238,000	7,617,000	760,116
Total	271,893	640	1,802,500	48,160,602	15,703,591	33,498,506	6,845,377

NOTE.—No production in 1905, 1910, or 1921.

MINES AND PROSPECTS

The Bayard area contains only one operating mine, the Ground Hog mine of the Asarco Mining Co., which is the largest mine in the area. The old San Jose mine, on the adjacent San Jose claim, is now part of the Ground Hog workings; the Ground Hog ore shoot extends under the San Jose claim, and a large part of the ore produced by the Asarco Mining Co. comes from that claim. The second largest mine, in point of both production and extent of mine workings, is the Lucky Bill. The Ground Hog, San Jose, and Lucky Bill workings are on the same vein and continuous and are described as a unit in the following pages. The Ivanhoe mine, long idle, is the third largest property in the area. It lies along a continuation of the Ground Hog vein zone but is not on the Ground Hog vein itself.

Many of the other properties of the area have a moderate production to their credit, but all are small and none have been sufficiently prospected or developed to prove their value. None of them extend much below water level, and their production has consisted chiefly of lead carbonate ore. Many of them are inaccessible; with a few exceptions maps of their workings are nonexistent, and some of the descriptions given herein are therefore chiefly judicious reproductions of hearsay information, amplified by whatever field observations could be made.

LUCKY BILL, GROUND HOG, AND SAN JOSE MINES

LOCATION

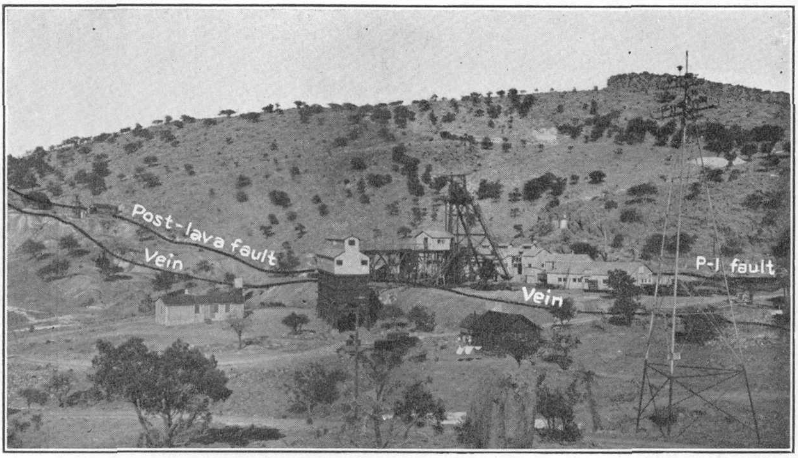
The Ground Hog vein lies near the eastern edge of the mapped area and southeast of Vanadium station. It crops out for about half a mile and extends southwestward for an additional 3,000 feet or more along the east side of Bayard Canyon, where it is covered by Tertiary sedimentary rocks. The Ground Hog mine lies at the head of Bayard Canyon; the San Jose shaft is several hundred feet along the vein to the northeast, and the Lucky Bill shaft is about 2,000 feet southwest.

HISTORY AND PRODUCTION

The San Jose claim is one of the oldest locations in the district. The mine was profitably worked prior to 1869,[52] producing copper, gold, and silver in ore said to have been chiefly copper carbonates. It was worked sporadically, producing chiefly argentiferous lead carbonate ores and a little high-grade galena ore, until taken over by the Ground Hog mine in 1928, since when most work on the San Jose claim has been part of the Ground Hog operations, though a little leasing has been carried on through the old San Jose workings. At the San Jose shaft the vein outcrop forms a prominent wall of jaspery quartz 7 feet high and 15 feet thick that unquestionably attracted early attention. The glory hole from which most of the San Jose ore was mined is continuous with this prominent cropping, but between the glory hole and the point where the vein passes under the Tertiary gravel, about midway between the two Ground Hog shafts, the outcrop was inconspicuous and in addition was covered by rock debris from the adjacent lava cliffs, and no attempt appears to have been made to investigate the continuation of the vein in that direction. The Ground Hog and Lucky Bill claims were located in 1900, after a freshet had exposed the vein at the mouth of Lucky Bill Canyon, but subsequent attention was largely confined to the Lucky Bill mine. Very little ore was mined, however, until the Lucky Bill mine was taken over by Ross, Larsh & Co. in 1911, after Paul Larsh, one of the principals, had noted a large amount of lead vanadate on the dumps.

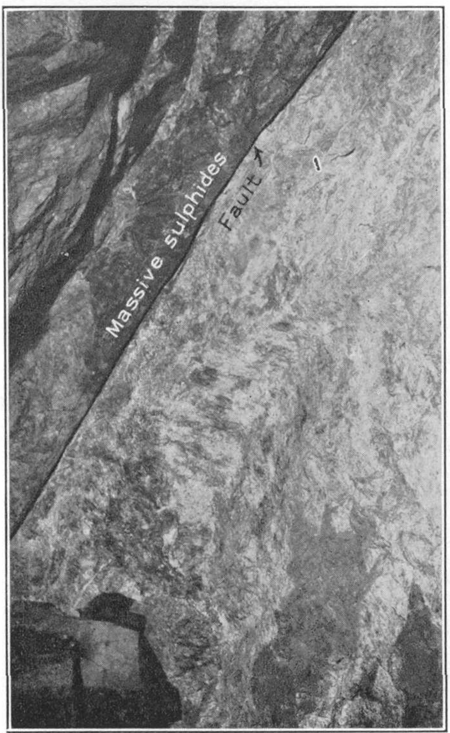
Production prior to 1911 amounted to less than 500 tons, having a value of about $21,000. Ross, Larsh & Co., during their first year

[52] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869, p. 404, 1870.



A. GROUND HOG MINE, LOOKING EAST.

San Jose shaft and glory hole at the right.



B. VEIN ON THE 600-FOOT LEVEL OF THE GROUND HOG MINE SLICED OFF BY A MEMBER OF THE RUBBER FAULT.

Looking upward.

and a half of operations, produced over 4,000 tons of lead carbonate ore having an average lead content of 27.72 percent and yielding net smelter returns of $50,000.[53] They also shipped one 15-ton lot of vanadium ore to Germany that was valued at $847 f. o. b. Bayard, N. Mex. The mine was taken over in 1919 by the Black Hawk Consolidated Mines Co., which holds the property at the present time. The following table, compiled from data furnished by the United States Bureau of Mines, shows the annual production of the Lucky Bill mine to the end of 1932. The material mined was chiefly lead carbonate ore, but included some chalcocite ore and a few tons of mixed sulphide ore.

Metals recovered from the Lucky Bill mine, 1906–32

Year	Ore (short tons)	Gold (ounces)	Silver (ounces)	Lead (pounds)	Copper (pounds)	Zinc (pounds)	Total value
1906	178		942	148,105			$9,083
1907	223		1,115	173,943			9,955
1908	36		142	29,000			1,293
1909	22		94	16,943			777
1911	723		2,565	399,296	1,066		19,460
1912	3,676		12,744	2,000,299	3,791		98,476
1913	441		1,498	10,800	315		1,429
1915	2,468	2	12,412	1,365,680	17,300		73,548
1916	2,888	1	13,599	1,617,074	3,480		121,406
1917	3,331		12,291	1,412,862	114		131,664
1918	3,468		16,231	1,910,412	3,068		152,628
1919	2,247		7,171	976,694	20,359		63,584
1920	2,980		7,911	899,475	34,821	22,506	88,821
1922	860		2,756	342,923	1,870		21,869
1923	2,759		12,568	1,192,478	18,954		96,566
1924	3,604		16,837	1,022,773	138,832		111,290
1925	3,735		12,312	857,600	188,800		93,955
1926	6,952	3	16,242	847,000	247,000		112,537
1927	5,093		22,281	553,514	473,753		108,566
1928	1,646		6,198	226,782	112,435		32,970
1929	327		647	3,557	30,730		5,957
1930	453		798	120,500	1,200		6,488
1931	460	1	681	156,000	600		6,045
1932	102	1	301	47,000			1,516
Total	48,672	8	180,366	16,330,710	1,298,488	22,506	1,369,883

NOTE.—No production in 1905, 1910, 1914, or 1921.

The earliest production officially recorded from the Ground Hog mine was in 1914, when 54 tons of ore was shipped. During the next 3 years the net smelter returns on shipments from this mine amounted to $50,000, representing about 3,000 tons of cupriferous cerusite ore mined from the Hotchkiss stope, about 100 feet below the surface at the south end of the claim. The mine was taken over by Gilchrist & Dawson, Inc., in 1917, and from that time until February 1920, when ore shipments ceased because of temporary closing of the smelters, it produced 6,318 tons of oxidized and sulphide lead-copper ores, chiefly from the Gilchrist stope, above the

[53] Larsh, P. A., Lucky Bill lead-vanadium mine: Eng. and Min. Jour., vol. 96, p. 1105, 1913.

300-foot level in the southern part of the mine. During that period, under the stimulus of war-time metal prices, shaft 1 was sunk below the 300-foot level, and the property was equipped for air drilling. The mine remained idle until the fall of 1924, when it was taken under option by the Hayward-Richard Leasing Co., which deepened the shaft and explored the vein on the 400-foot level. Attention was directed chiefly to exploring the vein south of the shaft under the country from which earlier production had come, and real success was not encountered until the country to the north was investigated. The work was under the supervision of F. W. Richard, whose description of that period in the mine's history is quoted below.[54]

The leasing company deepened the shaft to the 400-foot level, crosscut to the vein, and explored it to the south of that level. Some small and irregular ore bodies were found and stoped as soon as exposed; as much as 500 tons of ore was seldom in sight. This condition required that a large amount of development work be done to keep in ore. Stoping was by means of open stulled stopes, without filling. The production of the leasing company from the fall of 1924 to June 1928 was 30,012 tons of lead and copper ore. This ore was of three classes—lead carbonate ore with a little copper and silver, lead and copper sulphide ores carrying some silver, and secondary copper ore.

In the spring of 1928, after drifting north on the 400-foot level through a long barren zone, a 3-inch stringer of sulphide was encountered which, after 65 feet of further drifting, was intersected by a cross fracture and opened into a good-sized ore body. This ore body was distinctly different from those previously found and consisted of primary sulphides of lead, zinc, and copper. As development progressed it proved larger and more continuous than any other ore body along the vein. However, owing to the complex nature of the ore, the leasing company was unable to market it, and in June 1928 a 51-percent interest in the property was sold to the American Smelting & Refining Co.

The Ground Hog mine has been working continuously on the ore body discovered by the Hayward-Richard Leasing Co. A new shaft, now known as the " north shaft ", was put down near the center of this ore body and upon its completion in 1929 the old shaft was abandoned. Plate 13, *A*, is a photograph of the surface plant at the north shaft, showing the San Jose shaft and glory hole at the right.

An unfortunate feature of the history of the Ground Hog mine is that a large part of its productive life, up to the time of writing (1933), has coincided with a period of economic depression during which metal prices were abnormally low. As a result, the net value of production in terms of dollars is materially less than it would otherwise have been. The following table, compiled from data furnished by the Asarco Mining Co. and by the United States Bureau of Mines, shows the production of the mine to January 1, 1933. About 80 percent of the tonnage mined has been primary ore.

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[54] Richard, F. W., Mining methods and costs at the Ground Hog unit, Asarco Mining Co., Vanadium, N. Mex.: U. S. Bur. Mines Inf. Circ. 6377, p. 2, 1930.

Metals recovered from the Ground Hog mine, 1914–32

Year	Ore (short tons)	Gold (ounces)	Silver (ounces)	Lead (pounds)	Copper (pounds)	Zinc (pounds)	Total value
1914	54		185	10,665	8,088		$1,594
1915	316	2	1,569	16,976	30,317		6,940
1916	211	1	1,122	81,158	10,130		8,917
1917	2,473	8	15,481	373,859	360,282		143,438
1918	3,261		27,260	757,802	480,890		201,844
1919	499		6,622	255,330	19,980		17,990
1920	85		1,089	19,963	12,571		5,097
1924	75	3	529	16,880	2,517		2,096
1925	7,273	9	33,353	990,300	825,800		226,653
1926	11,940	1	38,059	1,022,300	826,873		221,316
1927	6,658	1	41,456	1,184,488	547,059		159,815
1928	12,275	21	78,216	2,382,466	590,922	2,134,000	353,140
1929	39,880	72	227,800	5,047,000	1,881,000	6,265,000	1,175,400
1930	47,287	86	312,600	5,912,000	2,462,000	9,539,000	1,195,700
1931	45,778	126	388,100	6,634,000	3,097,000	7,921,000	943,400
1932	43,492	72	444,800	6,640,000	3,238,000	7,617,000	758,600
Total	221,557	402	1,618,241	31,345,187	14,393,429	33,476,000	5,421,940

NOTE.—No production in 1921–23.

MINE WORKINGS

To April 1, 1933, the Ground Hog vein in the Ground Hog, Lucky Bill, and San Jose mines had been explored for a strike length of about 4,000 feet and for a vertical depth of 620 feet below the highest point on the outcrop; this is equivalent to a dip depth of about 850 feet. Plates 14 and 15 are a plan and projection of the mine workings, which total about 7½ miles in length. Of this total, about 26,000 feet consists of drifts and crosscuts, and 13,000 feet of shafts, raises, and winzes. This footage is distributed among the mines approximately as follows:

	Feet
Lucky Bill mine	6,650
Ground Hog mine	28,850
San Jose mine (old workings)	3,500

A horizontal diamond-drill hole 400 feet long has been driven into the hanging wall of the vein on the 500-foot level of the Ground Hog mine, and a steep down hole, the first under a new drilling campaign, was being put down from the 650-foot level at the time of writing. Five holes, totaling about 1,100 feet, have been fanned in a vertical plane from a point near the south end of the 300-foot level of the Lucky Bill mine.

The workings of the three mines are continuous. A raise from the Ground Hog 400-foot level connects with the east end of the 300-foot level crosscut of the San Jose mine, and the 300-foot level of the Ground Hog mine connects through stopes with the 200-foot level of the Lucky Bill mine.

It is estimated that an average of 13 tons of ore has been mined or blocked out for each foot of exploration and development.

GEOLOGY AND ORE DEPOSITS

Plate 16, a series of geologic sections across the Ground Hog vein, and plate 12, a geologic map of the Ground Hog 600-foot level, which is typical of the rest of the mine, show the relations of the vein to the different country rocks. A large portion of the productive part of the vein lies in a narrow strip between two roughly parallel granodiorite porphyry dikes; the longitudinal relations between these dikes and the ore shoots are shown on plate 15. The southern limit of the eastern (hanging wall) dike lies a little north of shaft 1; in the lower levels this dike has a small footwall prong that gives it somewhat of a fishhook shape. The western (footwall) dike overlaps the other and extends well past the Lucky Bill shaft. The small prong of granodiorite porphyry that crops out in the footwall of the vein at the north end of the San Jose claim is evidently the western dike, which fails to crop out at the Ground Hog mine because of a deep trough along its upper edge. It is probable that the western dike is the southern continuation of the Burchard-Osceola dike, the outcrop of which ends only 200 feet away, and that the discontinuity of the outcrop is due to a second trough in the upper edge of the dike. The Ground Hog dikes were injected along the southwestern continuation of the Ivanhoe-Lovers Lane fault zone, the eastern dike occupying the principal member of that zone in the northern part of the mines; the dike lies between the sandstone member of the Colorado formation and the middle sill and occupies a fault whose throw must be at least 500 feet. The south tip of this dike swings away from the fault, its place being taken by another member of the dike complex that occupies this zone.

Post-dike faulting, in the fissures of which ore was later deposited, tended to follow the inner walls of the two parallel dikes described. In the south end of the Ground Hog mine and in the Lucky Bill mine, where only the western dike is present, the vein lies along or parallel to the hanging wall of this dike. The south end of the Lucky Bill mine is inaccessible, and the details of the course taken by the vein beyond the end of the dike therefore cannot be determined, but evidently the vein finally swings over to the footwall of a third dike, as granodiorite porphyry forms the hanging wall of the vein at the Denver shaft, 200 feet south of the Lucky Bill end line. At the Ground Hog mine, where both dikes are present, the fracturing was largely confined to the narrow strip of rock between them, the planes of fracture tending to follow the dike walls, swinging from the hanging wall of one to the footwall of the other, as shown in the accompanying sections (pl. 16). The main break, which is known as the "Footwall vein", follows the hanging wall of the western dike and the footwall of the "fishhook" of the eastern dike.

The throw along this break amounts to about 240 feet, due allowance being made for the throw of post-ore faulting along the same zone, but presumably the break at this place was tight or fairly well sealed with gouge and breccia, because mineralization along it is inconsequential. The little pods of ore that lie along it here and there are tantalizing, but only a very small amount of ore has been mined from it, the main ore shoot (the Crescent ore body) having been deposited in a sheeted zone along the footwall of the eastern dike. The banding of the ore preserves the original sheeting and cross jointing of this zone. The ore contains streaks of quartz and pyrite, both parallel and transverse to the dip of the vein, that outline a typical joint grid. Microscopic study shows that the quartz and pyrite in these streaks were deposited before the surrounding ore sulphides, which failed to replace the pyrite, so that the original fracture system in which the pyrite was deposited has been preserved by the pyritic streaks in the final ore body. (See fig. 12.) An interesting feature of the pre-ore, post-dike fracturing is shown between the 400- and 500-foot levels in section B–B′, plate 16. The massive ore body seems to be broken into several displaced segments by small vertical faults that bend into the underlying main break. The faults themselves, however, contain ore, and microscopic study shows that the minerals of this ore and their paragenesis are identical with the minerals and paragenesis of the massive ore body. Evidently the fracture zone was faulted prior to ore deposition, the final ore body retaining the general outline of the faulted fracture zone and thereby falsely appearing to have been broken by post-ore faults.

Reference to plate 15 will show that, with very minor exceptions, all the ore bodies thus far discovered along the Ground Hog vein lie within a single zone or band that pitches 11° NE. The principal body of ore in this band is the Crescent ore body of the Ground Hog mine, a crescent-shaped lens whose pitch is identical with that of the ore zone. Plate 14 illustrates the shape of this ore body and the variations in width along it on the different levels; the crescent shape is due partly to a swing of the vein from the hanging-wall dike to the "fishhook" prong of this dike (see pl. 12), and partly to the shape of the strip between the two dikes. This ore body has a maximum stope length of about 1,200 feet and a maximum thickness of 25 feet. The average dip is 45° to 50°, but near the horns of the crescent, particularly on the 600-foot level, the dip flattens in places to less than 20°, and the ore will not run in the chutes. A similar flattening occurs at places along some of the small ore bodies that lie between the Crescent ore body and the big body of oxidized ore at the south end of the Lucky Bill mine.

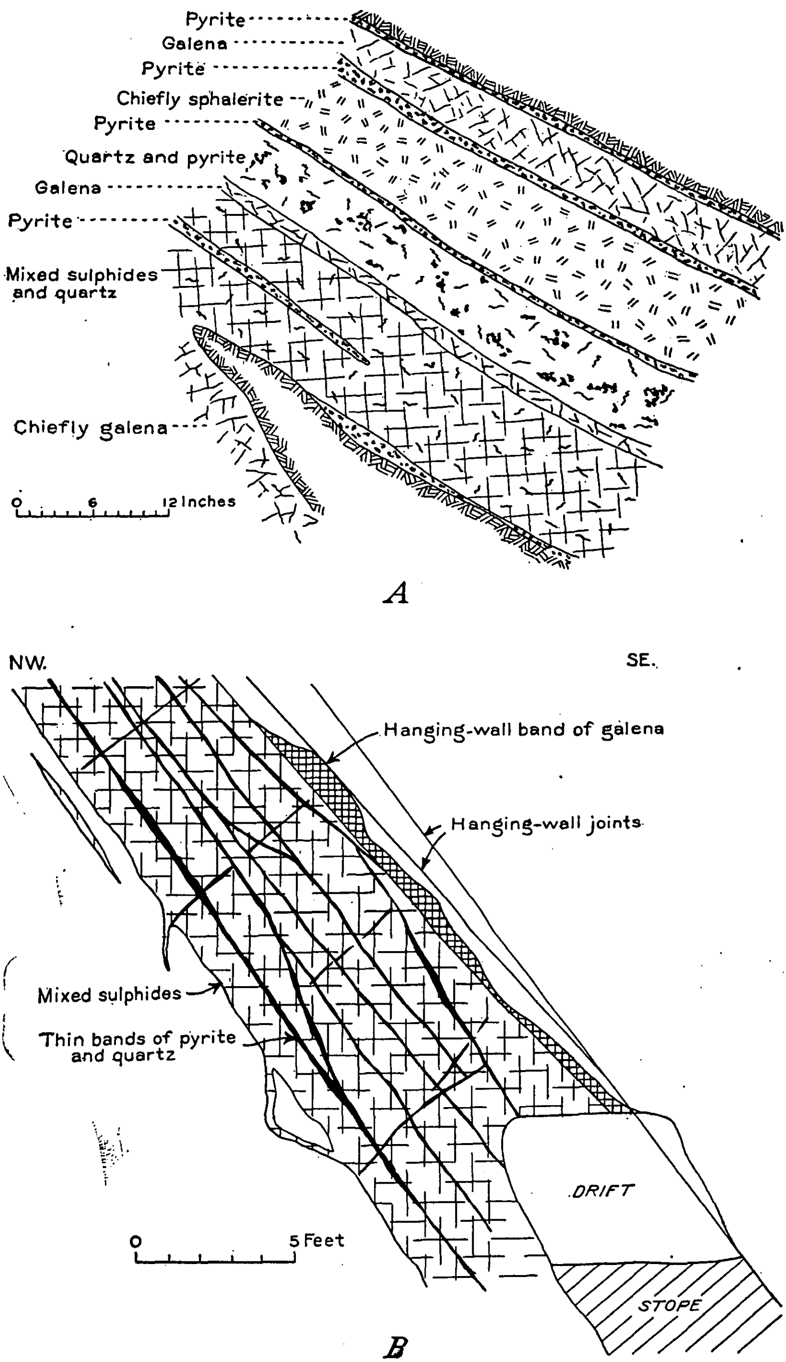


FIGURE 12.—Sketches of stope faces in the Ground Hog mine, showing typical banding of the ore and preservation of the original joint system by streaks of early quartz and pyrite. *A*, Stope 14 above the 500-foot level; *B*, stope 10 above the 400-foot level.

According to information furnished by the company and as shown on plate 15, the big Lucky Bill ore body was stoped from the 100-foot level to the overlying Tertiary gravel and had a stope length of 1,000 feet. The average ore width seems to have been 8 or 10 feet. The upper part of the shoot was removed by erosion before the gravel was deposited, and it is possible that the original primary shoot was fully as large as the Crescent ore body.

Post-ore faulting has been extensive in the Ground Hog zone but has affected mine exploration and development very little. The principal break of this age is the Ground Hog fault (known at the Ground Hog mine as the "Hanging Wall fault"), which brings the Tertiary sediments and lavas down against the Cretaceous rocks. This fault lies 50 to 225 feet in the hanging wall of the vein, to which it is roughly parallel. Minor spurs from the fault and links from it to other post-ore breaks in the same zone have crossed and faulted the vein, but the Ground Hog fault itself had no structural effect upon the vein so far as the vein was explored up to April 1, 1933. Fragments of sulphide ore are said to have been found in the fault breccia on the 200-foot level of the Lucky Bill mine, but these did not come from the main vein.

From the standpoint of the miner the most important post-ore fault at the Ground Hog mine is the Rubber fault, a linked fault that coincides with the footwall vein and therefore commonly lies well in the footwall of the Crescent ore body, though tending to follow the main vein elsewhere. (See pls. 12 and 16.) On the 400- and 500-foot levels, at the south end of the Crescent ore body, the Rubber fault flattens abruptly and cuts through the main vein into the hanging wall, though seemingly without displacing the ore. It there splits up into several steep members, which cut back through and displace the vein several feet and which then reunite in the footwall, so that on the 600-foot level the Rubber fault is again totally in the footwall of the vein. (See section *D–D'*; pl. 16 and fig. 13.) To this eccentricity of the Rubber fault is due its name, because, in the words of the foreman at the Ground Hog mine, "it has to be stretched to get where it is." Plate 13, *B*, is a flashlight photograph showing the vein sliced off by a member of the Rubber fault. At many places subordinate links of the Rubber fault cut over to the Crescent ore body and follow along one or the other of the walls or in the ore itself, as shown in section *C–C'*, plate 16, and cause disastrous cave-ins unless carefully watched. This is particularly true where the vein is slightly removed from the hanging-wall dike, because the thin shell of rock between the dike and the ore is badly shattered and is difficult to support. The links of the Rubber fault generally carry a layer of gouge and breccia, in places 10 feet thick, and where one of these links lies along the footwall of the ore the gouge-breccia layer sloughs away, undermining the heavy, flat-lying sulphides. This was common in the stopes at the south end of the 400-foot level of the Ground Hog mine. These difficulties have been controlled by using a filled square-set system of mining, but the cost per ton of ore mined is appreciably greater than it would be under a simpler system.

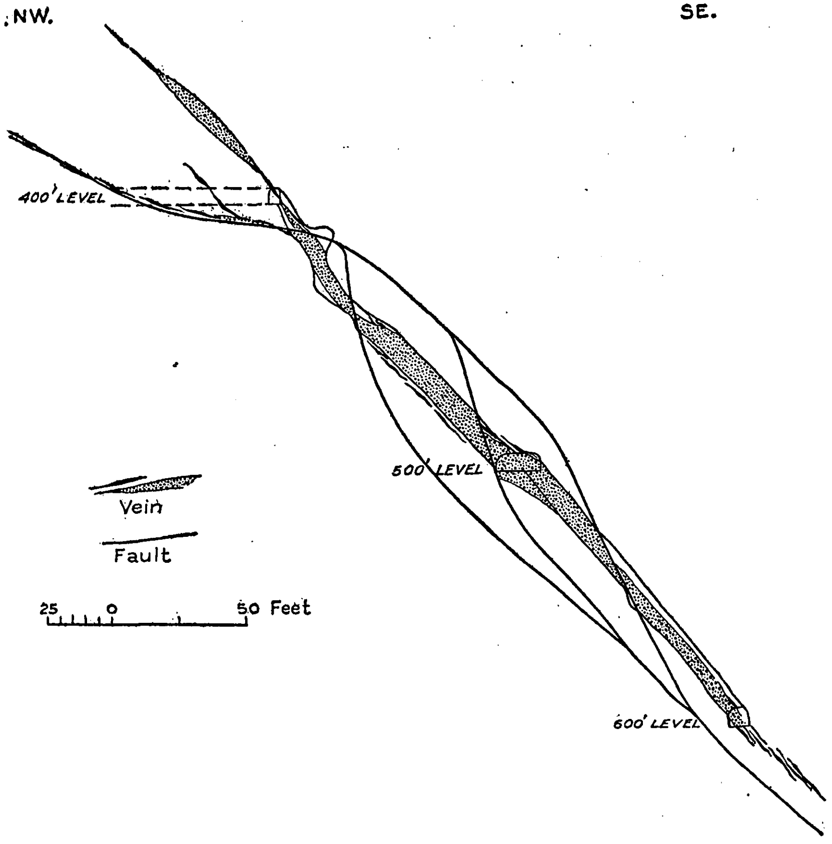


FIGURE 13.—Section through raise 7, Ground Hog mine, showing nature of the Rubber fault.

The greatest post-ore displacement of the vein is along a link, called the "Dish fault", between the Rubber fault and the Hanging Wall fault zone. This fault offsets the vein about 80 feet on the 600-foot level, but it contained considerable drag ore, and no difficulty was experienced by the miners in picking up the continuation of the vein. (See pl. 12.) What seems to be the continuation of this fault follows the hanging wall of the vein at the north end of the 600-foot level, and several links between it and the Rubber fault cut and jog the ore.

LONGITUDINAL PROJECTION OF THE LUCKY BILL, GROUND HOG, AND SAN JOSE MINES.

Strike N. 40°30′ E., dip 55° SE. Workings shown as of April 1, 1933.

The primary ore at the Ground Hog and Lucky Bill mines consists of massive coarse-grained argentiferous mixtures of sphalerite, chalcopyrite, galena, and pyrite, named in the order of abundance, accompanied by subordinate quartz and a trace of calcite. The ore has a suggestion of banding in galena, pyrite, sphaleritic and mixed-sulphide streaks parallel to the plane of the vein, as shown in figure 12, some of the galena streaks being sufficiently pure and large to be mined cleanly and shipped directly to the smelter. Broad bands of high-grade galena ore lie along the hanging wall at several places, and it has been the experience of the miners that the best galena ore is commonly found in that position. Coarse galena in the mixed-sulphide ore is sorted out and thrown in with the galena ore, the total direct galena shipments constituting about one-thirtieth of the tonnage mined. A notable feature of the ore is that chalcopyrite is much more prominently associated with sphalerite than with the other sulphides.

Breccia fragments of wall rock are common in the ore, and all gradations may be noted from ore containing small fragments of rock in a cement of sulphide and quartz to badly shattered rock traversed by ramifying stringers of ore. (See pl. 11.) The massive ore bodies commonly end by breaking up into a multitude of stringers cutting through the rock, and mining is stopped when the stringers become too small and the rock too predominant. This change extends over tens of feet at some places but is very sharp elsewhere. At many places where the wall rock has been converted to a pyritic jasperoid the ore passes into a jasperoidal mass without walls.

The average grade of ore mined at the Ground Hog mine has been approximately as follows: Zinc, 14.0 percent; lead, 9.5 percent; copper, 5.0 percent; and silver, 10.0 ounces to the ton. Computations (see pp. 72–73) show that 35 percent of the silver content of this ore is associated with galena, 47 percent with chalcopyrite, and 18 percent with sphalerite. The ore is slightly altered, however, and further calculations show that about half the silver content of the average ore is contributed by supergene silver minerals locked up in the chalcocitic tarnish and coatings on chalcopyrite and sphalerite, two-thirds of the supergene silver being associated with the chalcopyrite and one-third with the sphalerite. It has been calculated that the strictly unaltered ore may contain only about 5 ounces of silver to the ton and that galena will contribute about 75 percent of the silver content, chalcopyrite about 20 percent, and sphalerite only 5 percent.

According to mine records, the ore extracted from the San Jose claim averages 2 percent of copper and 4.5 ounces of silver to the ton more and 3 percent of zinc and 0.5 percent of lead less than that from the Ground Hog claim. These differences are evidently in large part due to the somewhat greater degree of supergene alteration in that part of the ore shoot that lies under the San Jose claim. (See pl. 15.) A little sorted primary ore shipped from the Lucky Bill mine is said to have contained 23 percent of lead, 20 percent of zinc, 4 percent of copper, and 15 ounces of silver to the ton.

Supergene ores consist chiefly of fairly pure cerusite ore and subordinate chalcocite ore. A few tons of vanadium ore, associated with lead carbonate ore, has been mined at the Lucky Bill mine, and

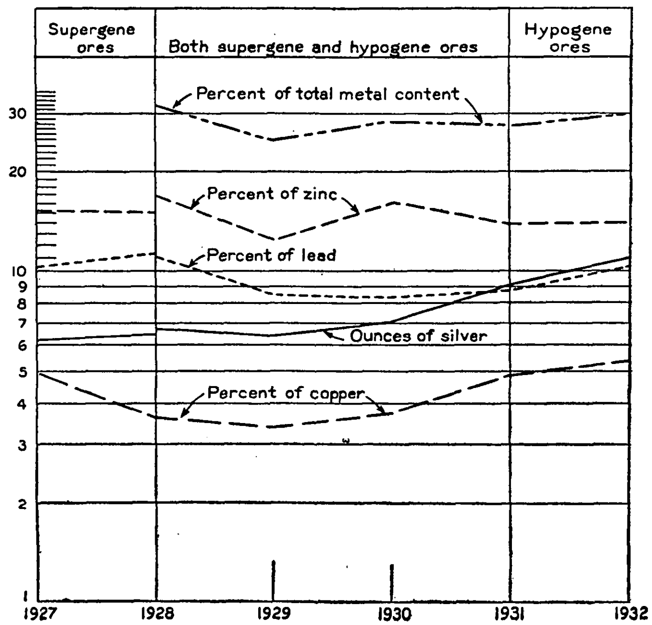


FIGURE 14.—Fluctuations in grade of ore mined at the Ground Hog mine.

copper carbonate is said to have been mined from the San Jose mine. Plate 15 shows the areas from which the chief varieties of ore have been mined, the depth to which prominent supergene alteration has penetrated, and the relation of the supergene ores to the present water level. Water level seems to form the boundary between cerusite and chalcocite ores, except in the Gilchrist stope and the old stopes in the San Jose mine. Possibly these perched chalcocite stopes indicate the position of the water table during the prevolcanic period of oxidation.

Figure 14 shows the fluctuations in the grade of the ore mined at the Ground Hog mine. Assays have been plotted on semilogarithmic paper in order to show the degree of fluctuation for each metal with respect to the others as well as to show the actual changes in metal content.

RECOMMENDATIONS FOR FUTURE EXPLORATION

The fact that the known ore bodies lie within a single band in the vein suggests that the continuation of this band in depth should be explored. The suggestion is strengthened by the trend of the band toward Santa Rita and the probable source of the metalliferous solutions and by the gradual approach of the band in depth toward the underlying Syrena formation, the replaceable limestone beds of which should be better host rocks than any in which the known ore shoots occur. The axis of the band should encounter the top of the Syrena formation at an altitude approximating that of the 850-foot level and about 1,200 feet beyond the north end of the Crescent ore body.

That this interval should be 1,200 feet, rather than much shorter or much longer is extremely interesting. The big ore shoot in the Lucky Bill mine is about 1,100 feet long; the space, in which a number of small shoots were found, between the Lucky Bill shoot and the Crescent ore body is 1,200 feet long; and the Crescent ore body is also 1,200 feet long. This regular spacing may be entirely accidental, but conceivably it may be the result of the nature and distribution of the stresses that produced the openings in which the ore lies; at any rate it seems worthy of the miner's serious consideration that a particularly favorable host rock should be at the place where the spacing independently implies the likelihood of another major ore shoot.

The stopes in the old San Jose workings and the two small surface stopes at the Ground Hog mine may represent the roots of an overlying parallel zone of ore shoots that has been removed by erosion, and on this premise the ground 400 feet or so below the present workings is worthy of being prospected as the possible position of a similar underlying zone.

C. G. BELL CLAIM

The C. G. Bell claim adjoins the San Jose claim on the northeast and was staked out to cover the continuation of the Ground Hog vein. The main workings are on this vein on the south bank of Santa Rita Creek. The shaft, which is vertical, is at the edge of a short slice of Colorado sediments along the vein; it is 250 feet deep, but the workings are inaccessible, and nothing is known of the underground geology except that shale was cut in the footwall of the vein on the 200-foot level, probably representing the section of sedimentary rocks between the middle and lower sills. The post-lava Ground Hog fault lies about 100 feet east of the shaft.

On the north bank of Santa Rita Creek west of the Ground Hog vein are some workings that prospect two short parallel veins along the walls of a granodiorite porphyry dike. (See pl. 1.) The main working seems to be a shaft on the east edge of the dike at a point where vein and dike diverge. The shaft is said to be 175 feet deep and to have 290 feet of drifts on the 100-foot level. The dump consists of silicified and pyritized rock and quartz-pyrite vein matter, some of which contains traces of chalcocite, covellite, and galena; 10 to 15 tons of chalcocite ore is said to have been shipped.

DENVER MINE

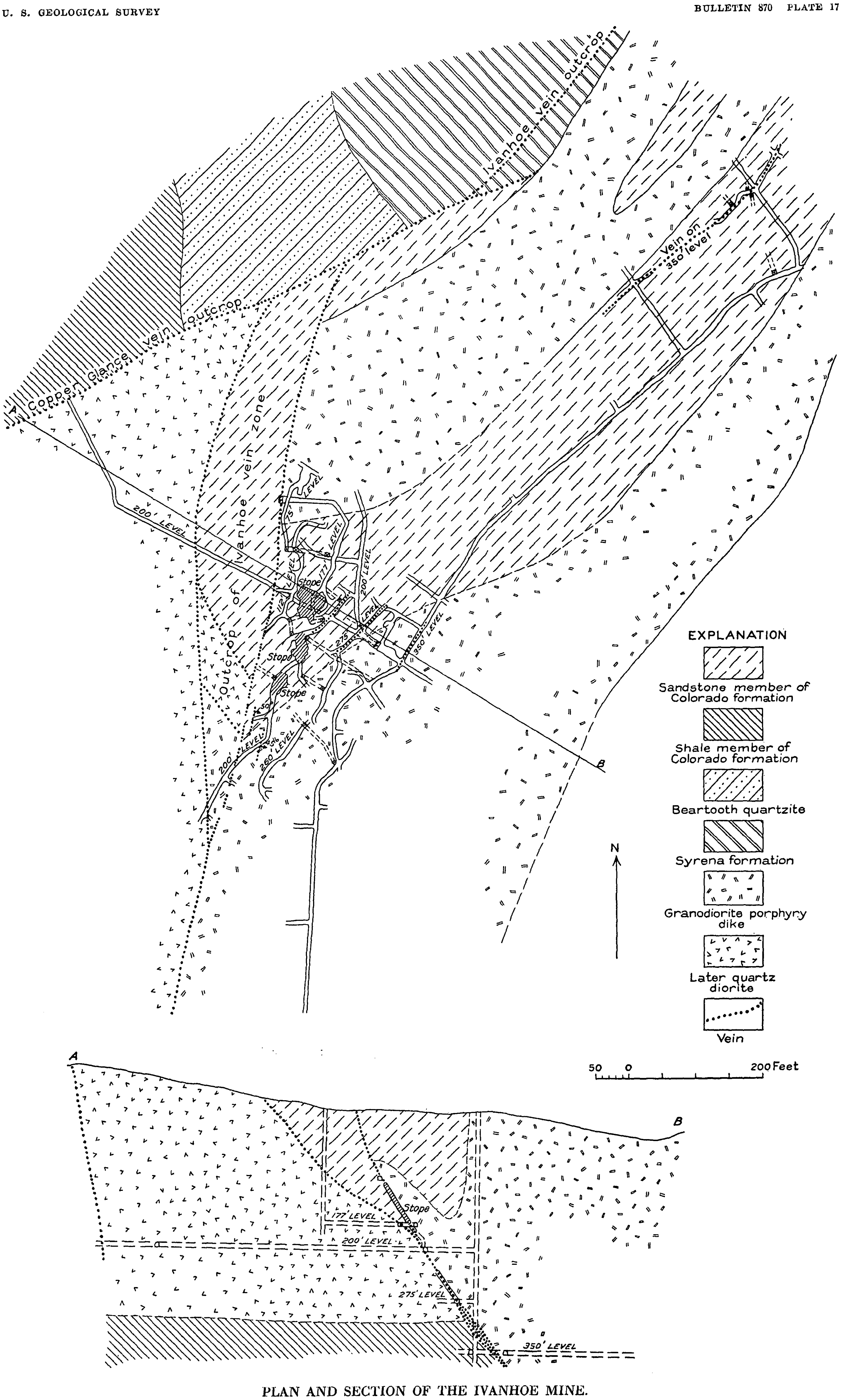
The Denver mine prospects the Ground Hog vein south of the Lucky Bill mine. The workings consist of an inclined shaft, which collars in Tertiary sediments about 200 feet from the Lucky Bill end line, and about 150 feet of additional workings on the 100- and 200-foot levels. The second level was under water and the shaft was in extremely poor condition at the time of my visit, and only a hasty examination of the first level could be made. The vein on this level lies along the footwall of a "birdseye" porphyry dike and is typical of the barren, partly jasperized, oxidized parts of the Ground Hog vein. Local reports state that 2 cars of ore has been shipped from the Denver mine.

IVANHOE AND NINETY MINES

The Ivanhoe and Ninety mines, which are a mile northeast of the Ground Hog mine, have been idle since early in 1907, and the workings have been inaccessible for many years. Information concerning underground conditions has been derived from private reports by W. L. Austin, E. C. Spilsbury, and F. H. Probert, written in 1904 and 1905; from Graton's description,[55] also written in 1905; and from an old map of the Ivanhoe mine furnished by the Santa Rita (Chino) office of the Nevada Consolidated Copper Co., the present owner, which acquired the Ivanhoe-Ninety property from the Hermosa Copper Co. in 1918.

The Ivanhoe mine was first operated on argentiferous lead carbonate ore, which was smelted at the mine, the Ivanhoe and adjacent claims at that time being owned by the Rio Grande Mining & Reduction Co. In 1904 the entire property of the Rio Grande company was acquired by the Hermosa Copper Co. as the nucleus of a proposed large-scale copper-mining project. The rich carbonate ores of the Ivanhoe mine had been depleted by that time, and the ore as then exposed in the workings, which consisted of a 200-foot vertical shaft and a few hundred feet of lateral development on the 85- and 177-foot levels, was largely pyritic chalcocite

[55] Graton, L. C., op. cit. (Prof. Paper 68), p. 314.



PLAN AND SECTION OF THE IVANHOE MINE.

Plan drawn from an old map; section shows probable geologic relations.

ore containing a little galena, similar to some of the chalcocite ore at the Ground Hog and Lucky Bill mines. According to a statement made by the management and quoted in Austin's report, this ore averaged 3.2 ounces of silver and 0.1 ounce of gold to the ton, 6.2 percent of copper, 16 percent of iron, and 49.2 percent of silica.

Graton's description of the Ivanhoe and Ninety mines is as follows:

> The mines are thought to be on the same lode, which strikes about N. 50° E. and dips 45° to 50° SE. The lode is a combination of fissure filling and replacement along a contact between quartz monzonite porphyry[56] and shaly limestone. * * * The porphyry lies on the southeastern or hanging-wall side and the limestone on the footwall side. The Ivanhoe mine was worked years ago, and a smelter was erected for recovering lead and silver. A 200-foot vertical shaft gave access to the deposit, but the principal work was done in the upper workings, where oxidized material was found. It is said that one stope in the cerusite zone was 400 feet long. A new shaft, 360 feet deep in September 1905, was being put down by the Hermosa Copper Co. It was farther from the outcrop than the old shaft and passed through the lode at a depth of 275 feet. A crosscut to the lode from the 200-foot level of the new shaft shows a soft streak with little ore, but in the bottom workings from the old shaft, a short distance above, the lode is 15 feet wide. Pyrite probably predominates, but chalcopyrite is irregularly distributed throughout; narrow bands of fine-grained galena parallel to the plane of the lode are commonly associated with dark zinc blende. Some zincky streaks are as much as 6 inches wide. Quartz is not plentiful and generally where it does occur it is as drusy, radiating crystals. The porphyry seems to be the most replaced, but bunches of limestone, unreplaced by ore but somewhat affected by contact metamorphism, are found in the ore, and in places the sulphides extend into the altered limestone of the footwall. Ore was also encountered where the shaft crossed the lode. The crosscut from the second or 350-foot level had not reached the lode at the time of visit. Much of the ore is soft, and oxidation is going on rapidly. The acid water coming down through the old workings reacts with the calcite of the limestone, producing gypsum, which forms in incrustations on the walls. This action is going on so rapidly that the air smells sour, and good ventilation is required owing to the quantity of carbon dioxide set free. The ore is said to average 8 to 11 ounces of silver and about $1 in gold to the ton, with some copper and lead. * * *
>
> At the Ninety mine, a third of a mile to the northeast, a shaft being sunk by the Hermosa Co. had struck the lode at a depth of about 360 feet. The bottom of the shaft, at 370 feet, was just getting into material that resembled the crushed altered limestone seen in the Ivanhoe mine. The ore consisted chiefly of chalcopyrite and quartz. Little lead or zinc was present, and pyrite was scarce. Good copper values appeared to extend over a width of several feet.

Plate 17 shows the relation of the surface rocks in the vicinity of the Ivanhoe mine to the mine workings; the section shows the probable geology. The shaly limestone footwall mentioned by Graton consists of the limy beds of the upper or sandstone member of the

[56] Granodiorite porphyry dike.—S. G. L.

Colorado formation. It is quite possible that Graton, not having studied the detailed surface geology of the area, regarded the Colorado sediments in the vicinity of the shafts as belonging to the same formation as the shale and limestone of the Syrena formation that crop out only 450 feet away, on the north side of the Copper Glance fault, where the Syrena forms the footwall of the dike with which the ores are associated. At the north end of the 350-foot level, driven subsequent to Graton's visit, the vein is cut in such a position as to indicate that it is the same as that which lies adjacent to and along the dike in the limestone area. In that part of the mine, therefore, the foot wall of the vein probably consists of limestone or shale beds of the Syrena formation. The vein cut in the Ninety shaft, which is about 750 feet northeast of this point, is evidently the same vein.

One of Probert's reports contains the following description of conditions at the new shaft:

During my stay at Hanover, ore came into the shaft at a depth of 295 feet. * * *

On the surface the rock forming the hanging wall is a decomposed coarsely crystalline greenish porphyry. Kaolinization of the feldspars is advanced. The shaft was started in this material, and there was but very little change in the ground until at a depth of about 275 feet, when slip planes and small clayey seams containing pyrite were encountered. At 290 feet the bottom of the shaft was in soft black clay, which was heavily pyritized but of low copper tenor. At 295 feet on the west side of the shaft, the "hard ore" was struck, dipping 45° E. At first the ore contained more galena than chalcopyrite, but on going through it the lead gave place to copper. Analysis of the ore when first met showed:

Lead	30 percent	Silver	11 oz.
Copper	4.2 percent	Gold	$0.62 per ton

After going through 10 feet of the ore an average sample showed:

Lead	8.85 percent	Silver	5.95 oz. plus
Copper	7.81 percent	Gold	$0.60 per ton

The shaft continued for 22 feet in this rich ore; then came a mass of low-grade clayey material followed by another rich streak 6 inches wide which assayed 16.3 percent copper. The day I left Hanover the permanent footwall was reported as found, the shaft being 320 feet deep. This proves the vein to be at least 16 feet thick at right angles to its dip. Unfortunately further development in depth is handicapped owing to the amount of water coming into the shaft. There were indications of a local straightening up of the vein in the bottom of the shaft, the slip planes dipping 53° SE.

At a depth of 200 feet below the collar, a level has been driven west for 105 feet toward the ore body. * * * The characteristic "hanging wall" porphyry persisted from the shaft a distance of 100 feet, when a soft mass similar in all respects to that found at 300 feet in the shaft was struck. Lean pyrite ore occupies the face of the drift. A raise was put up 17 feet perpendicularly, then an incline at 45° W. for 31 feet ran into the pyrite ore body. Drifting east from this point 16 feet made connections with the workings from the old shaft

200-foot level. The ore body is as strong here as in the shaft. An absolutely representative sample across a face of 10 feet of ore assayed 7.02 percent copper, while the richest portion, 2 feet wide, gave 17.14 percent. In this rich streak, near the hanging-wall side, galena was associated with the enriched copper sulphides. There was practically no gangue mixed with this 10 feet of ore. The breast of the drift had not penetrated the ore body, so that its thickness could not be determined.

The banding of the ore in galena and sphaleritic streaks, the bands of rich galena ore adjacent to the hanging wall, the local abundance of pyrite, and the nature of the quartz indicate that the ores are similar to those at the Ground Hog mine. The "soft black clay" along the hanging wall also brings to mind several places along the Footwall vein of the Ground Hog mine; beyond doubt some of the clayey streaks indicate post-ore faulting.

COPPER GLANCE MINE

The Copper Glance shaft is about 750 feet due west of the Ivanhoe No. 1 shaft. At that place the Copper Glance vein forms the contact between the shale member of the Colorado formation in the footwall and later quartz diorite in the hanging wall; it strikes N. 70° E. and dips, at the outcrop, 80° SE.

The mine is inaccessible, and the only available information concerning it is contained on the accompanying map (fig. 15), which is copied from an old blueprint. The altitudes of the levels indicate that most of the workings are probably in the Syrena formation, though no rock clearly of that formation was seen on the dump, which consists largely of heavily pyritized sill rock. Perhaps most of the rock broken was used as stope filling, though the stope shown on the map seems hardly large enough for that.

The workings show little relation to the vein outcrop. Perhaps the best mineral showings occurred along bedding contacts; the position of the stope suggests ore at the intersection of a favorable bed with the auxiliary fault in the footwall of the vein. The workings are said to connect with those of the Ivanhoe mine.

OWL MINE AND VICINITY

The Owl (Bull Frog) mine, idle since about 1905, is the principal prospect on the Owl vein, one of the faults along which locally there had been strong quartz-pyrite mineralization prior to injection of the granodiorite porphyry dikes. It is on the Bull Frog claim, where Gold Gulch crosses the vein outcrop. According to report, several cars of high-grade ore were shipped from the mine in 1903, one car of which netted $7,800. The mine changed hands shortly thereafter, and only 3 or 4 tons of ore additional was found. Graton evidently had reference to this situation when he

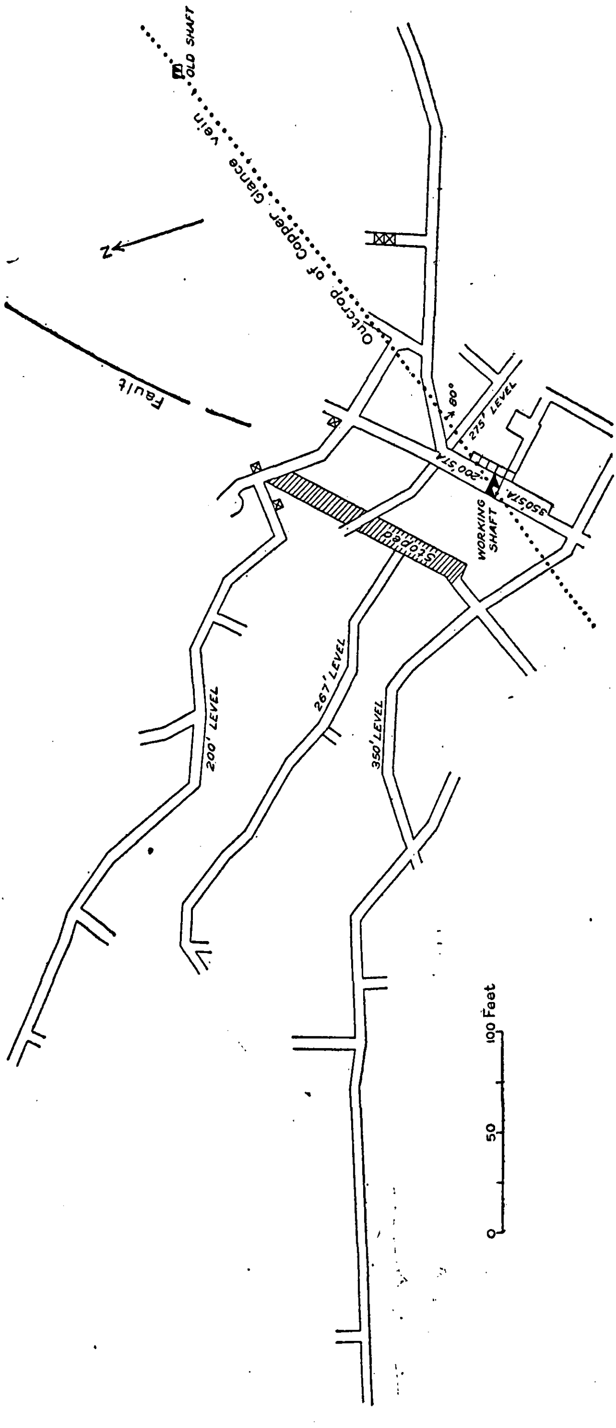


FIGURE 15.—Plan of mine workings, Copper Glance mine.

wrote:[57] "In 1903 rich gold ore was discovered [in Gold Gulch], and a new period of activity began. A mill was erected and development vigorously carried on, but this excitement was of short duration; in October 1905 the mill machinery had been taken away." The Asarco Mining Co. held an option on the property in 1929 but relinquished it after sampling the mine and putting down two deep diamond-drill holes. (See fig. 16.)

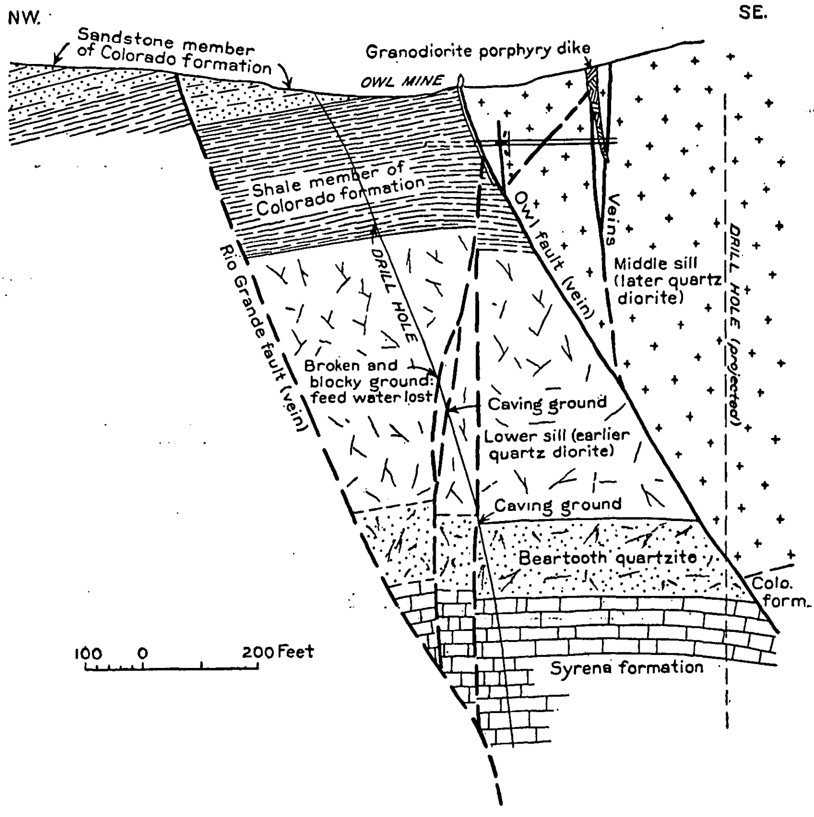


FIGURE 16.—Section showing probable structure in the vicinity of the Owl mine.

At the Owl mine the footwall of the vein is the shale member of the Colorado formation, and the hanging wall is the middle sill (later quartz diorite). Figure 16 shows the probable structural relations. The outcrop of the vein can be followed readily, though it is not particularly prominent. On the east side of the creek, where both walls are quartz diorite, the several members of the vein zone are marked by strong quartz ridges. Quartz-sulphide stringers containing sphalerite and subordinate pyrite and galena are exposed along the vein in the bed of the creek, occurring chiefly in the

[57] Graton, L. C., op. cit. (Prof. Paper 68), p. 318.

silicified footwall. At the portal of an adit into the west bank of the gulch the footwall of the vein is marked by several inches of gouge containing breccia fragments of quartz and pyrite.

The Owl mine was under water at the time of my visits, and the following information has been derived from mine maps. Figures 16 and 17 give a fair idea of the workings. The main shaft is an incline along the vein, which dips 79° at the surface and gradually flattens to 66° at the bottom of the shaft. On the 100-foot level a crosscut 120 feet long prospects the barren shale footwall; another, 230 feet long, prospects the quartz diorite hanging wall and cuts

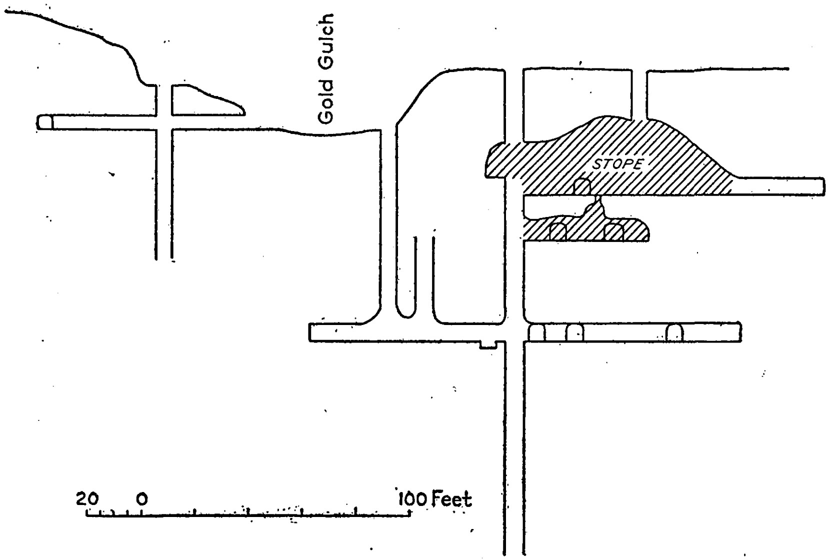


FIGURE 17.—Longitudinal projection, Owl (Bull Frog) mine.

several stringers of ore, the largest and best of which is at the edge of a small dike about 30 feet from the main vein. The main vein in the present headings carries a trace of gold, a trace to 0.6 ounce of silver to the ton, 0.5 to 6 percent of lead, and 1.2 to 5.2 percent of zinc.

About 200 feet northeast of the main shaft is an inclined shaft on a footwall spur of the Owl vein that dips 60° SE. The black shale that constitutes most of the dump is highly pyritized but contains only a trace of other sulphides. About an equal distance southwest of the main shaft and on the main vein is another shaft, perhaps about 100 feet deep, with a similar dump. On the adjoining Lucky Bill claim (not to be confused with the Lucky Bill claim on the Ground Hog vein), 650 feet northeast of the Main Owl shaft, an inclined shaft was sunk in the quartz diorite on a cross member of the vein linkage. Some ore is said to have been mined from that place. On the Rio Grande claim, 600 feet northwest of the Owl mine, a fault vein dipping 70° SE. in the sandstone member of the Colorado formation has been prospected by an adit and an inclined shaft. The workings are inaccessible, but a stope can be seen about 30 feet down the shaft. The material on the dump contains galena, pyrite, and copper carbonates. A thin quartz latite dike lies along the vein.

THREE BROTHERS MINE

The Three Brothers mine is on the Lucky Lead claim of the Three Brothers Mining Co., adjacent to the east boundary of the Fort Bayard Reservation. It is on a mineralized fault that drops the Beartooth quartzite against the upper part of the Syrena formation on the nose of the Fort Bayard arch. The fault at that place has a throw of about 150 feet, but the throw dies out to the southwest and has completely disappeared by the time the fault crosses the upper contact of the shale member of the Colorado formation. At the mine the fault is made up of two members, 40 to 100 feet apart at the surface, both of which are marked by showings of plumbojarosite and by limonite-boxwork gossans. A quartz latite dike lies between the veins, splitting them apart at their junction and occupying the fault plane from that point southward. The dike extends down the middle of the eastern vein for a short distance north of the shaft and there crosses into the hanging wall. (See pl. 1.)

The outcrops have been investigated by pits, cuts, and shallow shafts, some of which yielded a little ore. The principal workings prospect the eastern vein, which dips 70°–85° SE., and consist of an irregularly inclined shaft on the vein and about 350 feet of drifting on the 125-foot level. (See fig. 18.) Deeper underground work has been delayed until facilities have been provided to handle ground water, which stands about 4 feet below the level. The drift walls consist entirely of limestone and shale of the Syrena formation, the beds in the hanging wall lying about 30 or 40 feet below the Beartooth quartzite. Much of the vein as exposed on the level is completely oxidized and leached and consists of limonitic boxwork mixed with much gouge and manganiferous clay. South of the shaft, ore is continuous from a point about 20 feet from the shaft to the face of the drift, the ore ranging from 1 to 6 feet in width; several cars of sulphide ore was derived from the development work, and about 175 tons of lead carbonate ore was shipped from a long low stope 20 feet above the level. The vein splits at the stope chute into two tight members, the south end of the stope being on the footwall split. A 30-foot winze has been sunk on the hanging-wall split and shows the vein widening several feet below the drift level to over 4 feet of massive mixed sulphides. A foot of ore comes in at the face of the drift and along the floor, as if this ore and that in the winze were at the top of a pod pitching flatly northeast. Northward from the shaft the drift follows the leached vein for

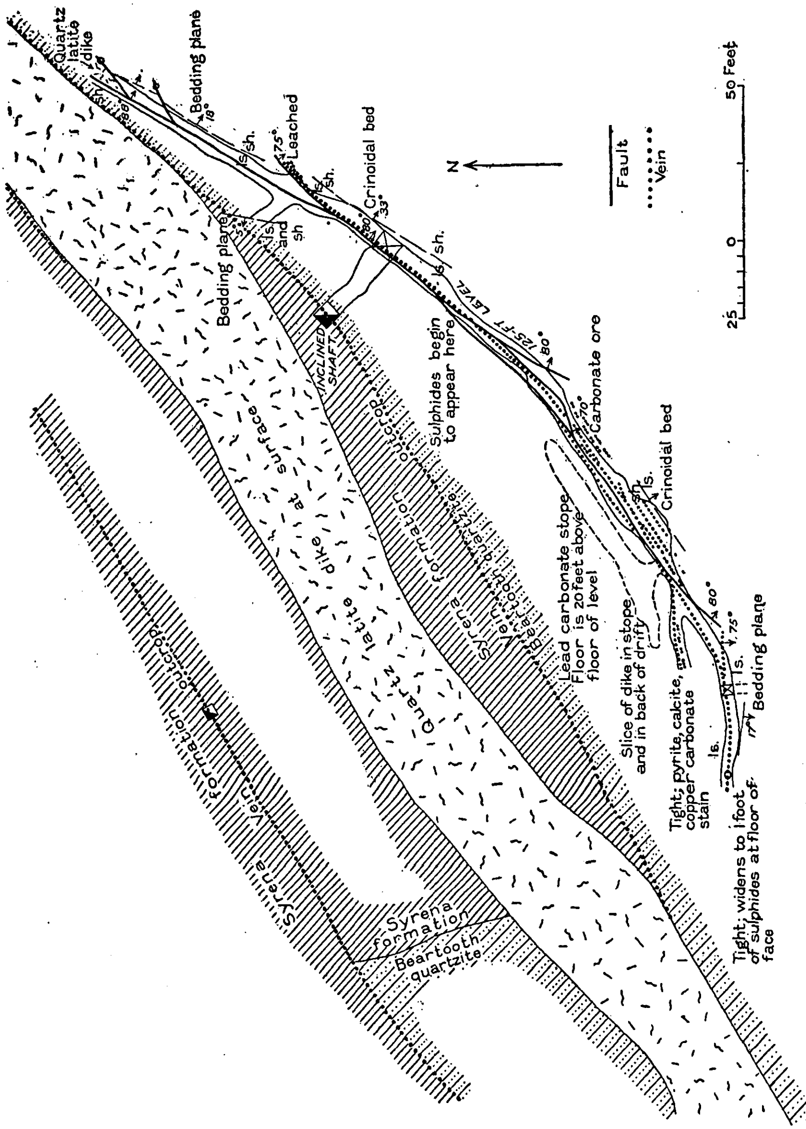


FIGURE 18.—Geologic map of the Three Brothers mine.

about 50 feet and then swerves to follow a barren gouge-filled fissure that is evidently post-ore; the last few feet of the drift penetrates the quartz latite dike. Strong gouge- and breccia-filled fissures, apparently post-ore, are common all along the drift, weakening the vein walls and requiring that a part of the workings be timbered.

The mixed sulphides consist of fine-grained sphalerite intimately mixed with subordinate fine-grained galena and pyrite. Coarsely crystalline calcite, cream-colored and sprinkled with minute grains of pyrite where fresh but generally stained light brown to black, is common at several places. The ore appears to have replaced the wall rock to a large extent. The walls are silicified to a maximum distance of 12 inches, but on the whole, silicification as shown by exposures on the level seems to have been surprisingly slight. The mine dump contains a great deal of cherty jasperoid, said to have come from the stope.

The property is said to have produced eight or nine cars of lead carbonate ore prior to its acquisition by the Three Brothers Mining Co. in 1926. This company shipped 3 cars each of sulphide and lead carbonate ore and then sold the property in 1929 to A. P. Mracek, who up to the spring of 1931 had shipped 3 cars of sulphide and 1 car of lead carbonate ore. The average grade of the sulphide shipments, which doubtless had been hand-sorted, is as follows: Zinc, 24 percent; lead, 13.5 percent; copper, 0.3 percent; gold, 0.02 ounce to the ton; silver, 2.0 ounces to the ton. Smelter returns for the cerusite ore are available only for the car shipped by Mracek in 1929 and for one of those shipped by the Three Brothers Mining Co. The average assay for these two shipments, which probably were made up of selected material, is about 13.6 percent of lead, 0.2 percent of copper, and 0.32 ounce of gold and 4.4 ounces of silver to the ton.

LOST MINE AND GOLD SPOT CLAIMS

All the arroyo gravel in the vicinity of the Lost Mine and Gold Spot claims yields excellent showings of gold on being panned, and as a result the veins on those claims have received considerable, though sporadic, attention since the very early days of the district. According to local report, baskets used by early Spanish and Mexican miners have been found in some of the workings. The veins have been extensively prospected, as shown in figure 19, by numerous shallow shafts, adits, cuts, and trenches in search for the gold ore suggested by the gravel, but with very little success. According to G. J. Ballmer, chief geologist at the Chino mines, the total production from the claims must have been less than $15,000. Nevertheless, pannings of vein matter from essentially every one of the workings show colors with remarkable persistency, and periodically someone cleans out the old caved workings and digs a few feet farther or deeper. All workings are shallow, the deepest shaft being 100 feet and the longest adit 170 feet.

The veins crop out chiefly in the Colorado shale and sandstone beds that lie between the lower and middle sills north of Bayard station. Although the outcrops are inconspicuous for the most part, they can be traced readily because of the different kinds of rock on the two sides, and the veins show up well in the workings. The Lost

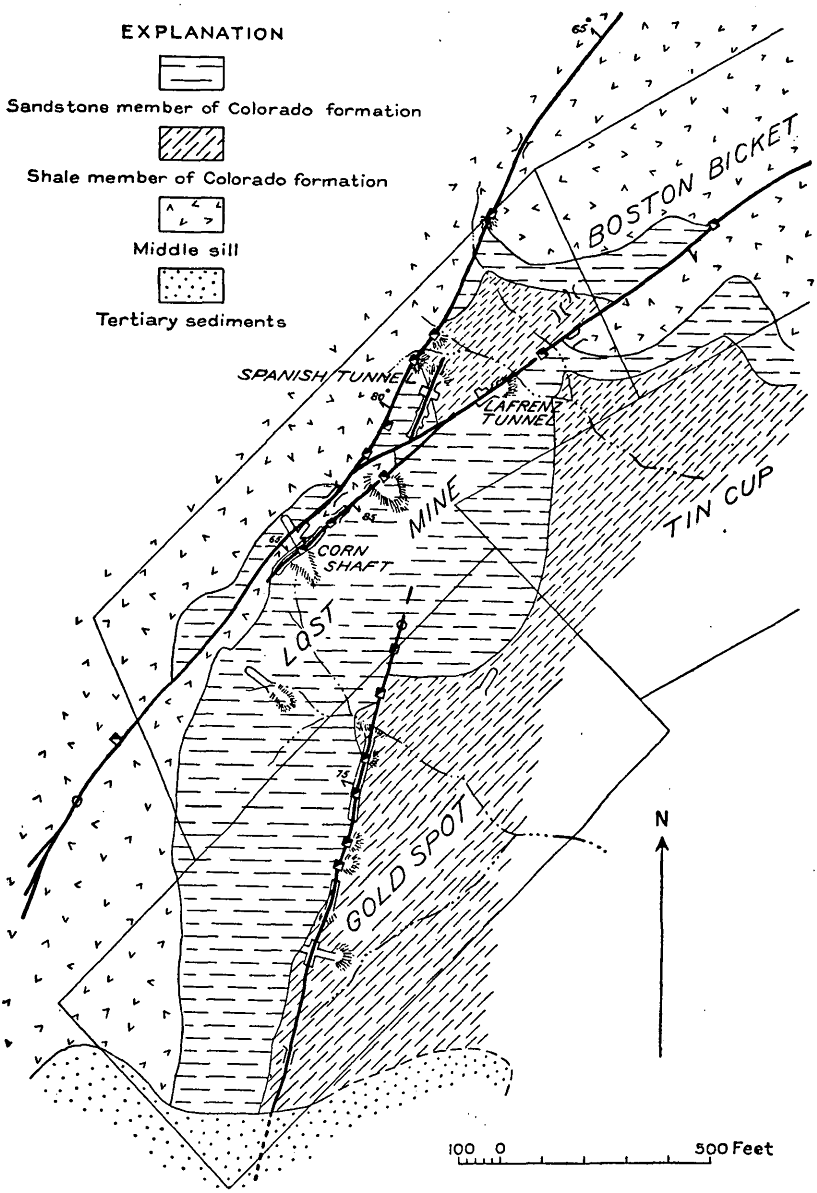


FIGURE 19.—Map of the Lost Mine and Gold Spot area, showing relation between mine workings and geology.

Mine vein is a mineralized spur of the Owl fault that leaves the main break at the top of the hill, near the west edge of the State No. 1 claim, and extends from that point longitudinally through the

El Tigre, Boston Bicket, and Lost Mine claims to fray out in the quartz diorite a few hundred feet beyond the Lost Mine end line. A quartz latite dike lies in the vein at the Lafrenz tunnel. The Spanish tunnel, supposed to be one of the old Spanish workings, is on a small footwall spur; and about midway between this tunnel and the Corn shaft, which is on a hanging-wall fissure of the Lost Mine vein, a link branches northward to the Slate vein.

The Gold Spot vein is a mineralized fault of small, almost insignificant throw. It may continue northward to connect with the Lost Mine vein but cannot be traced beyond the point shown on the map; to the south it passes under the Tertiary gravel and lava, to reappear in the elbow of Cretaceous rocks on the other side of the hill.

The vein filling in the principal fissures consists of gouge and breccia containing small pods and stringers of pyritic quartz and manganiferous calcite; auxiliary fissures in the walls are filled with thin stringers of quartz and subordinate oxidized pyrite that in places form a linked network as much as 10 feet in width. The stope at the Corn workings is on one of these auxiliary breaks in the hanging wall. A little manganiferous calcite occurs here and there, and Ballmer, who examined the claims for the Chino mines, found flakes of wulfenite and small cubes of galena in his pannings of vein matter. The gold is very pockety and occurs most abundantly as free gold in limonitic, manganiferous clay streaks, locally associated with partly decomposed black calcite. Any of these clay streaks, which are common, will yield colors in the pan. A set of representative samples taken by Ballmer in the course of his examination averaged less than 0.08 ounce of gold to the ton. The highest assay was 1.68 ounces on a sample from a ¾-inch stringer of brown and black clay along the hanging wall of the vein in the Corn workings. Exclusive of this figure, which is more than 1.5 ounces higher than any other assay, the average assay is only 0.025 ounce to the ton. All the dumps contain free gold, and nearly every panful of dump material will yield colors if care is taken to " rub down " the sample well.

The principal workings are at the Corn shaft on the Lost Mine claim. (See fig. 20.) Most of the gold produced came from these workings, and Ballmer's assays show these workings to be richer than any of the others. The assays ranged from 0.008 to 1.680 ounces to the ton and, excluding the abnormal high, averaged 0.034 ounce. A little ore also was mined from the Spanish tunnel. The link vein extending northward to the Slate vein has been prospected on the Lost mine claim by several shafts and shallow pits, but no ore has been found. The workings on the Gold Spot vein are fairly extensive, but no ore has been mined from them, although gold can be panned from the vein matter.

There is little likelihood that any commercial gold deposits can be developed on any of these veins. The gold is representative of that which occurs in small amounts in all veins of the district, big or little, and the rich pockets are doubtless the result of local supergene enrichment. Yet even these pockets are "rich" only in comparison with the meager gold content of the vein in general. The gold in fully a third of Ballmer's samples would have been reported as a "trace" by a custom assayer. By comparing the size of the stopes against reported production, it becomes clear that the average value of the ore extracted was not more than several dollars a ton—evidently the sort of occurrence that can be mined at a profit only by individuals or partnership groups that have no overhead expenses

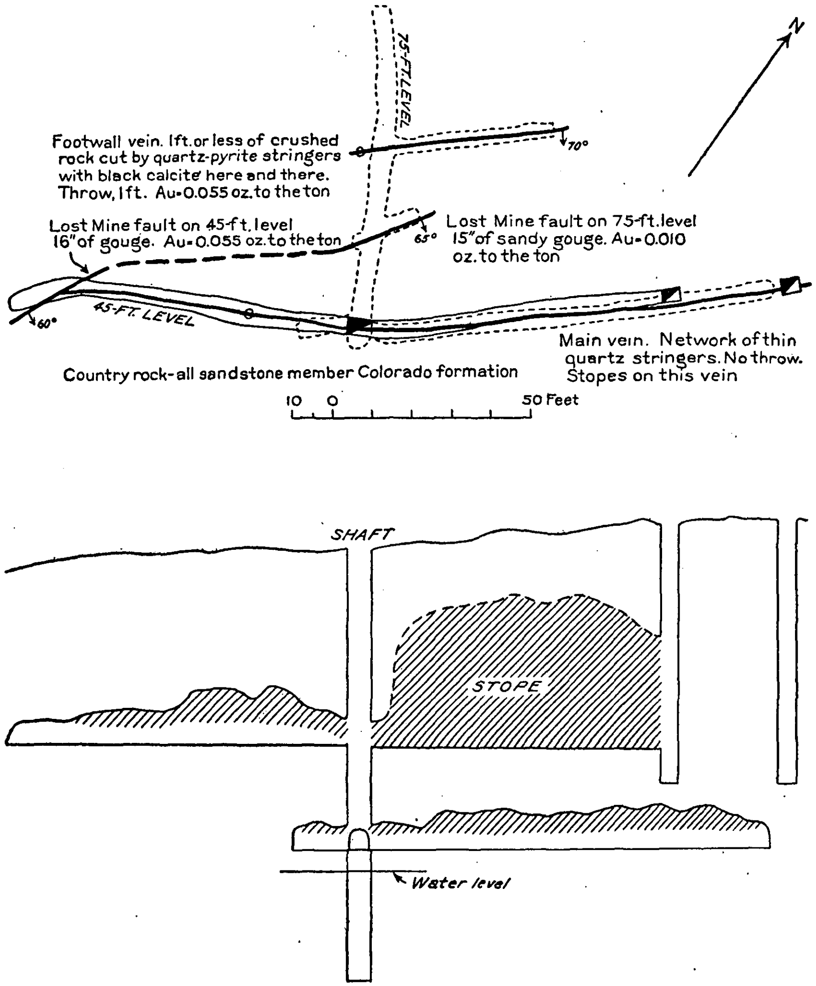


FIGURE 20.—Plan and projection of the Corn workings, on the Lost Mine claim.

and that are expert at cleanly gouging out rich streaks and at hand sorting. The solutions that deposited the base-metal ores of the area managed to penetrate into these veins, as shown by the traces of galena and wulfenite, and there is a remote possibility that base-metal ore bodies of commercial size might lie in the underlying quartz diorite, which is probably more strongly fractured than the sandstone and therefore would have offered freer passage to the solutions.

SILVER KING MINE

In point of production the Silver King mine ranks next to the Ivanhoe mine in the Bayard area. The workings were under water during my visits to the district.

The Silver King mine is on the Ajax claim, near the head of Rapp Canyon and near the south end of the Apollo vein, just south of its junction with the fraying members of the Slate vein. The Apollo vein at that place consists of two members 150 to 200 feet apart and approximately parallel in both dip and strike, connected by a northward-trending cross vein. (See pl. 1.) The parallel veins dip 55° SE. and the cross vein 65° E. The outcrops consist of the jaspery quartz typical of the area, though less thoroughly stained by limonite than usual. The workings comprise a shaft 160 feet deep on the eastern vein and several hundred feet of exploration on the 100- and 150-foot levels. All three veins, which are in the middle sill (later quartz diorite), have been explored.

Below is a list of the ore shipments as furnished by B. Cosgrove, Inc., of Silver City, the present (1933) owners of the mine.

Ore shipments from the Silver King mine

Shipper	Year	Tons	Assays				Remarks
			Gold (ounce per ton)	Silver (ounces per ton)	Lead (percent)	Zinc (percent)	
Foster Bros.	1913	15.5	0.058	2.6	31.7	--------	From cross vein.
		17.1	.068	2.2	20.8	--------	
		37.2	.078	2.1	20.5	--------	
		43.0	--------	2.0	15.6	--------	
		27.1	.141	1.8	15.4	--------	
		27.6	.052	2.0	15.0	--------	
		22.6	.29	2.3	33.0	--------	From east vein.
Skinner & Foy	1914	10 cars of ore and jig concentrates					Tonnage and assays not known.
Cinco Grande Mining Co.	1916	22.5	.18	.7	7.3	--------	Jig tailings of ore from east vein.
		30.3	.19	.7	9.0	--------	
		23.9	.212	.9	11.0	--------	
		28.2	.19	.9	10.8	--------	
		22.5	--------	--------	12.5	--------	Source not known.
		25.3	--------	--------	11.4	--------	
		28.0	--------	1.0	12.9	--------	
T. C. McSherry	1923	32.9	--------	2.6	13.1	6.6	Contains 5.8 percent of sulphur. Source not known.
Silver King Mining Co.	1929	48.4	.115	1.92	12.7	--------	Source not known.
		39.4	.14	1.68	17.1	--------	
		49.6	.42	2.74	30.0	--------	Sorted ore from 150-foot level southwest of shaft. Vein 1 to 3 feet wide.

Most of the ore is said to have come from the cross vein and to have been mined from a northward-pitching shoot that was stoped within 25 feet of the surface. With the exception of the one car shipped in 1923, all the shipments consisted of lead-carbonate ore containing gold and silver. The shipment in 1923 evidently was fairly fresh galena-sphalerite ore, to judge from the sulphur content reported by the smelter. The sulphides are said to have come in at depths of 80 to 100 feet. Small piles of ore on the dumps consist of mixed lead and zinc sulphides associated with quartz and coarsely crystalline pyrite, similar to chalcopyrite-free Ground Hog ore. Wulfenite is said to be prominent in the oxidized ores, and several specimens of this mineral were seen in the hoist house. From the fact that the jig tailings were rich enough to be shipped it may be inferred that much of the lead carbonate was the earthy variety, which cannot be concentrated efficiently by gravity methods.

According to R. L. Lafrenz, of Central, who at one time was foreman of the mine, the ore above the 100-foot level has been mined out, but very little has been mined from the 150-foot level. A raise between the two levels is said to be on good ore.

SLATE VEIN

The Slate vein is a footwall spur of the Owl vein, branching off on the low hill southwest of the Owl mine. The Slate vein itself has numerous minor spurs in both hanging wall and footwall, and at the Lion workings it splits abruptly into several members, one of which joins with the Silver King vein.

The Slate vein has been prospected by numerous shallow workings, and ore has been found at three places. These are the Slate, the Lion No. 2, and the Lion mines.

SLATE MINE

The Slate mine is on the eastern slope of Slate Hill, where the outcrop is a low, broad wall of silicified sandstone and quartz diorite stained here and there by a little cuprodescloizite. The mine workings consist of an inclined shaft on the vein, which dips 70° SE., and a drift on the 100-foot level extending southwestward for about 150 feet. Two small, low stopes have been excavated into the walls of the shaft, one at a depth of 50 feet and extending 70 feet southwestward, the other at a depth of 75 feet and extending for about 30 feet under the other stope. Water level lies at a depth of 105 feet. About 300 tons of lead carbonate ore is said to have been shipped from the upper stope, judged to be equivalent to the full tonnage excavated; no shipments were made from the lower stope.

The vein is on a fault between the shale member of the Colorado formation in the footwall and the sandstone member in the hanging wall. As exposed at the surface, another mineralized fault lies about 10 feet in the hanging wall, separating the sandstone from the quartz diorite that forms the hanging wall of the vein zone at that place. The second fault has not been explored. The vein on the 100-foot level contains considerable crystalline pyrite and minor amounts of black sphalerite, galena, and quartz cementing the partly silicified fault breccia. Sphalerite is somewhat more abundant than galena, and the vein walls are stained by copper carbonates derived from chalcopyrite inclusions in the sphalerite.

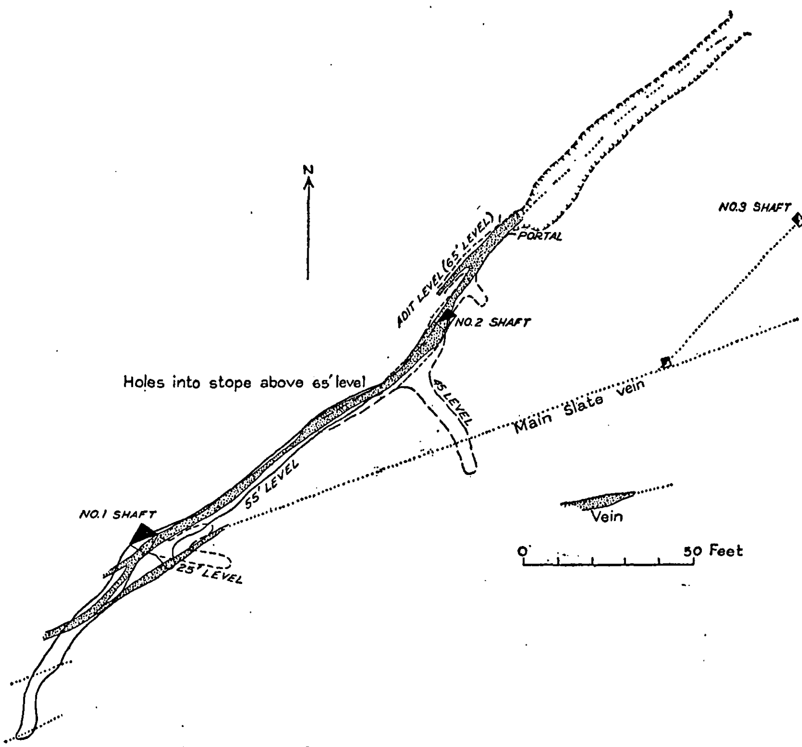


FIGURE 21.—Sketch map of the Lion No. 2 mine.

LION NO. 2 MINE

The Lion No. 2 mine is in later quartz diorite one-third of a mile southwest of the Slate mine, at a point where a faint footwall spur is linked to the main vein by two short cross veins. The ore has been found on the western cross vein.

Figure 21 is a sketch map of the Lion No. 2 workings. Shaft 1 is said to be 118 feet deep; it was completely filled in at one time but has been cleaned out and retimbered to the 50-foot level. On that level a drift to the southwest follows the vein, which there consists of leached quartz as much as 3 feet wide spotted with wulfenite and capillary endlichite, for about 30 feet and then swerves into the hanging wall, where it cuts two slightly mineralized parallel stringers. Northeast from the shaft the vein contains 1 to 3 feet of cerusite, and 65 tons of cerusite ore was mined from two small stopes above the drift. This ore averaged 17.5 percent of lead and 0.8 ounce of silver to the ton, presumably after being sorted and screened. The drift extends 80 feet from the shaft, breaking into a small stope above the adit level. The adit, which corresponds to the 65-foot level of shaft 1, opens into a stope at the bottom of shaft 2. About 33 tons of cerusite ore was shipped from this stope, and an additional 84 tons was derived from two other small stopes on this level and from development work. At the portal of the adit the vein consists of 2½ feet of soft red to black earthy limonite and wad. At the edge of the stope, 20 feet in, it consists of leached quartz and cerusite spotted with wulfenite and endlichite, similar to the material at several places along the Ground Hog vein. The dumps contain a little black calcite and considerable leached vein quartz having limonite boxwork derived largely from coarsely crystalline pyrite. A little cuprodescloizite stains the leached, drusy quartz outcrop of the main fissure.

The following table lists the shipments of lead carbonate ore from the Lion No. 2 workings. In addition, 60 tons of smithsonite ore is said to have been mined from shaft 3, which is a 40-foot shaft on the eastern cross vein, and to have been shipped to the old zinc oxide plant of the Grubnau Chemical Co. at Waldo, N. Mex. A little calamine (zinc silicate) was seen in some of the small piles of reject near the shaft.

Shipments of lead carbonate ore from the Lion No. 2 mine

Shipper	Date	Dry tons	Assays					Source
			Gold (ounce per ton)	Silver (ounces per ton)	Lead (percent)	Copper (percent)	Zinc (percent)	
J. H. Rapp	Nov. 1926	23.0	0.09	1.3	19.3	--------	--------	Stope, 65-foot level.
	Jan. 1927	28.5	--------	.7	12.0	--------	--------	Accumulated screenings from development rock, shaft 2.
	Feb. 1927	32.8	--------	.8	12.8	0.6	--------	Development ore, 65-foot level.
	Mar. 1927	32.5	.03	.9	19.1	--------	--------	Stope, 65-foot level.
C. R. Altman	July 1930	19.3	--------	.9	19.7	--------	0.3	Stope, 55-foot level.
	Aug. 1930	21.3	--------	.7	15.3	--------	--------	Do.
	Sept. 1930	24.0	--------	.8	17.0	--------	--------	Do.
Total	------------	181.4	.02	.9	16.2	Tr.	Tr.	

LION (RAPP NO. 2) MINE

The Lion mine is near the southwest end line of the Lion claim, just east of the point where the Slate vein splits up before joining the Silver King vein. The vein dips 78° SE. and at the surface consists of unpromising ribs of quartz in the later quartz diorite. An inclined shaft follows the vein to a depth of 100 feet and connects with a short footwall adit, the Cramer tunnel, at a depth of 40 feet. A drift extends for 20 feet on this level. At the north end of the drift the vein consists of several feet of brown jaspery ("mahogany") quartz spotted with specks and crusts of wulfenite; at the other end it consists of altered, crushed quartz diorite, also containing a little wulfenite. The workings below this level are filled, but the owner, C. R. Altman, of Silver City, says that a short cross-cut into the hanging wall, 40 feet below, exposes 16 feet of vein matter. The footwall is marked by a soft streak 4 feet wide corresponding to that on the drift above; a high-grade streak of carbonate ore lies along the hanging wall, and the intervening strip consists largely of "mahogany" quartz.

It is reported that 13 tons of ore containing 20.8 percent of lead, 13 percent of zinc, and 3.5 ounces of silver to the ton was mined from the hanging-wall streak. An additional 48 tons, which consisted of fine screenings from the development rock and which contained 5.4 percent of lead and 0.7 ounce of silver to the ton, was also shipped.

JOHNEY (BETTY-JO) CLAIM

The Johney claim covers the Apollo vein and its spurs between the Silver King mine and the Fort Bayard reservation. A set of caved openings, said to be caved open stopes extending 75 to 85 feet down to water level, lie along the vein in the north half of the claim. Just south of these openings, at about the center of the claim, is a shaft, variously called the "Johney", "Betty-Jo", and "Rapp No. 1" shaft, that is about 200 feet deep but without auxiliary workings. Pieces of pyritized quartz diorite on the dump are cut by vein stringers 2 inches or less thick, and considerable calcite, partly discolored brown and black, is scattered about. The vein stringers contain pyrite, sphalerite, galena, calcite, quartz, and a trace of barite; some of the calcite pieces are cut by thin stringers of barren quartz. Part of the dump is made up of black fissile Colorado shale, reported to have come in along the hanging wall at a depth of about 170 feet.

A second shaft 400 feet to the south follows the footwall of a quartz latite dike that splits a strong hanging-wall spur-vein. Both main vein and spur in this vicinity have at the outcrop considerable black calcite that is cut by interlacing stringers of quartz.

The vein extends southward into the Silver King property and is the west vein of that mine. At the south end of the Johney claim a shaft on the Silver King east vein is said to have penetrated sulphides at a depth of 80 feet, as represented by a small pile of quartz-sulphide ore on the dump. A little cerusite is exposed in the vein in a surface cut opposite the shaft.

Ore shipments from the several workings on the Johney claim include 80 tons of carbonate ore that averaged 1.4 ounces of silver to the ton and 8.4 percent of lead and 129 tons of sulphide ore that averaged 4.3 ounces of silver and 0.02 ounce of gold to the ton, 16.2 percent of lead, 7.9 percent of zinc, and 0.6 percent of copper.

ST. HELENA VEIN

The St. Helena and Eighty-eight mines, adjacent to the highway south of Central, have been prospected and worked as gold deposits since their location in 1887 and 1888. A 5-stamp amalgamation mill was erected in 1926 to treat the ore from the St. Helena workings, but its operations were never successful. The Eighty-eight shaft was sunk a few years later, and ore from it was being treated in the mill in 1932.

Water lies at a depth of 40 feet in this vicinity, and all the St. Helena workings are flooded or otherwise inaccessible. The Eighty-eight workings, which are on the east side of the highway, are on a nearly vertical spur to the St. Helena vein and consisted, in July 1932 of a shaft 70 feet deep from which a drift extended southward for 50 feet on the 40-foot level. The vein on this level is 3 to 18 inches wide and is composed chiefly of silicified sheeted quartz diorite marked on the footwall by a thin streak of gouge. A stringer of hard quartz and pyrite 1 to 4 inches wide and containing also a trace of galena lies along the hanging wall, and here and there the vein carries streaks of black calcite. According to the owner, Caetano Woods, of Hurley, the vein matter in the lower 40 feet of the shaft carries an average of 3 ounces of gold to the ton, the range being from 1 ounce to over 8 ounces. The average would therefore be about 1 ounce to the ton over a minimum mining width; if the vein contains this average it is hard to understand why more mining has not been done, and it must be inferred that some of the samples came from the richest parts of the vein. Mr. Woods reports that a 6-ton shipment, presumably of selected ore, yielded a net return of $31.60, or $5.22 a ton. This is equivalent to an estimated gross value of about $10 a ton, or only half an ounce to the ton of sorted ore. These figures refer to ore lying in the zone just below water level, and presumably the rich pockets indicated are the result of enrichment. Most of the small amount of ore mined from the Eighty-eight workings has been treated in the St. Helena stamp mill, and the recovered gold, which ranged in fineness from 0.5965 to 0.6655, was sold to the Denver Mint.

The main workings at the St. Helena mine are across the highway from the Eighty-eight shaft and consist of a shaft 180 feet deep and a drift on the 80-foot level that follows the vein 90 feet to the north and 40 feet to the south. About 200 feet south is another shaft 105 feet deep without lateral development, and near the south end of the claim is a caved tunnel extending northward along the vein for 225 feet. In addition there are numerous pits, cuts, and trenches along the vein. Gold is said to have been found in all the workings. The vein is similar to the Eighty-eight spur but is a little wider and locally carries a fair amount of black calcite.

The St. Helena vein zone extends northward into the Fort Bayard reservation, and most of its members in that vicinity carry considerable black calcite and subordinate quartz. The vein on the Peerless claim contains more quartz than the others, and a little quartz-sulphide ore was found on the dump of a caved shaft 300 feet north of the reservation fence, just south of the place where the vein begins to fray out. Pyrite and sphalerite are abundant, and the ore consists of a fine-grained sugary mixture of these minerals with subordinate galena and drusy quartz. South of the fence is a shaft 120 feet deep in which the vein is said to be 3 feet wide. East of the Peerless vein, on the Peerless No. 2 claim, the different members of the vein zone have been prospected by several shafts and pits, and nearly all the dumps of these workings have small piles of sorted smithsonite ore.

DUTCH UNCLE-TIN BOX AND MAY BELL VEINS

The Dutch Uncle-Tin Box and May Bell veins are of interest because they are veins of pre-granodiorite age along which post-granodiorite solutions managed to penetrate, although the veins had not been reopened. The Dutch Uncle-Tin Box vein, which has a strong quartz outcrop, is crossed at three places by granodiorite porphyry dikes (see pl. 1); it is prospected in the vicinity of the dike at the east end of the Tin Box claim and unquestionably does not extend into the dike, yet 400 feet to the southwest a large dump at an old shaft contains fragments of galena, chalcopyrite, and yellow sphalerite that represent the post-dike type of mineralization. On the Slate No. 1 claim, which adjoins the Dutch Uncle claim to the south, a little ore has been found in what may be considered a continuation of the Dutch Uncle-Tin Box vein. Lead carbonate was found within a few feet of the surface, and mixed sphalerite, pyrite, and galena a little deeper. The ore is very pockety, and occurs chiefly in stringers 1 inch or less in thickness cutting the pyritized and silicified wall rock.

The May Bell is a short vein in the narrow piece of ground between the Tin Cup and Copper Glance veins. The east end of the vein, on the Summit claim, is crossed and penetrated by a "birdseye" porphyry dike. Faint evidence of post-dike mineralization, such as malachite and chrysocolla, appears at some of the numerous workings along the vein; and near the west end of the outcrop, on the May Bell claim, specimens of yellow sphalerite, galena, chalcocite, covellite, pyrite, and white quartz with enclosed sulphides are scattered about the dump of two old shafts.

The occurrence of post-dike mineralization along these veins suggests that they may have been reopened after injection of the dikes, but if this is true the reopening process must have been weak, because the dikes are not noticeably fractured. It is just as probable that the lead and zinc sulphides were deposited in minor unsealed openings of the pre-dike vein, but under either condition the ore is likely to be pockety and in quantities too small to be of much importance.

TEXAS MINE

The Texas mine is west of Central and three-fourths of a mile beyond the mapped area, on a quartz vein that crops out inconspicuously near the west edge of the surface exposure of the middle sill in the Colorado formation. The vein strikes N. 60° E. and is nearly vertical. The mine has been idle since 1900 but is one of the best known of the older mines. The following quotation is from a report written in 1903 by the Governor of New Mexico.[58]

> While there are many partially developed properties in this immediate district, the largest operation is the Texas mine, owned by the Fort Bayard Smelting & Refining Co. The mill on this mine has a capacity of 75 tons per day. The ore is a concentrating proposition, carrying much gold, and the values have invariably increased with depth.

The mine was completely dismantled when I visited it. The following paragraph, written by Graton [59] in 1905, adequately describes what is known of the property:

> The Texas mine, situated about 1 mile west of Central, is said to have produced a considerable amount of silver and a little gold. * * * The shaft, which has three compartments and is capped by a large headframe, is said to be 600 feet deep. The dump is small, so that either the underground workings cannot be extensive or else much of the ground broken must have been ore.[60] * * * From specimens seen on the dump the ore seems to be principally pyrite, with some galena and probably finely divided grains of black zinc blende in a dull horny quartz gangue. Druses are common, and in these the quartz is crystalline. The ore was treated in a mill, yielding a heavy pyrite concentrate.

[58] Otero, M. A., Report of the Governor of New Mexico to the Secretary of the Interior for 1903, p. 66, 1903.

[59] Graton, L. C., op. cit. (Prof. Paper 68), p. 318.

[60] Some of the waste may have been used for stope filling.—S. G. L.

SUMMARY OF ECONOMIC CONCLUSIONS AND RECOMMENDATIONS

The purpose involved in studying the Bayard area was to investigate the possibilities of finding other deposits similar to that at the Ground Hog mine, which, though not a large-scale operation, is what is known in mining slang as a "good little mine." Several specific conclusions and recommendations have been set forth in detail in the preceding pages; these are summarized and collated in the following paragraphs.

The possibilities of the area are fundamentally connected with the conclusion, as described in the section on mineral paragenesis, that economic metallization occurred after injection of the granodiorite ("birdseye") porphyry dikes. The ore bodies in the igneous rocks are chiefly fissure fillings, and consequently the amount of ore in any vein is a function of the permeability of the vein fissure at the time of ore deposition. The fissures that originated prior to the injection of the dikes were largely sealed by a noneconomic quartz-pyrite mineralization and by injection of dikes along them, and deposits of commercial size are not to be expected in these fissures unless they had been strongly reopened. Exploration of many of the pre-granodiorite veins should therefore be deferred until more favorable places have received attention; the Dutch Uncle-Tin Box, May Bell and Lost mine veins and probably also the Hanover Creek vein belong in this deferred group, but all the veins in this group cannot be pointed out, as it is not possible to tell the age of each vein in the area. The Copper Glance vein is an exception that deserves consideration. It was not strongly reopened after the injection of the dikes, but the marked alteration of the dikes that cross it and the mineralization on the Burchard claim point to the passage of mineralizing solutions in moderate amounts. The Slate vein also deserves consideration. It is beyond the area in which the dikes occur and therefore escaped being sealed by them, and the occurrence of ore at the Slate, Lion, and Lion No. 2 workings proves that it was not well sealed during the first period of mineralization. The character of the vein at the Lion No. 2 workings and the amount of ore extracted at that place are heartening and suggest the advisability of further exploration.

The Ground Hog and Ivanhoe veins lie in zones that were reopened after having been previously sealed by dikes. In fact, they are parts of the same strong fault zone, and every post-dike fissure in the Ground Hog-Ivanhoe zone is worthy of attention, including those now covered by lava in the hanging wall of the Ground Hog fault. It is highly probable that the Ivanhoe mine was prematurely abandoned. The Ground Hog mine appears to have bottomed the main ore shoot, but there is reason to believe that undiscovered shoots exist. The known ore shoots of the Ground Hog vein, in the Ground Hog and Lucky Bill mines, tend to form a single gently pitching zone, and a particularly attractive place to prospect would seem to be the continuation of this zone to the northeast. Parallel zones may lie at deeper levels.

The veins in the western part of the district seem to be the products of solutions that had traveled a moderate distance from their source and had dropped part of their metalliferous load on the way. Calcite makes up a large part of the vein filling in the observable parts of these veins, but this mineral was deposited later than the sulphides, and its presence at the outcrop does not preclude the presence of sulphide shoots below, for it was probably deposited in a zone higher on the average than the sulphides. The erratic distribution of the calcite- and quartz-rich parts of the western veins suggests that the present surface is near the bottom of the calcite zone, a suggestion that is supported by the occurrence of ore at the Silver King, Betty Jo (Johney), Three Brothers, Peerless, and Peerless No. 2 workings, all of which ought to be prospected to greater depths.

The Three Brothers vein differs from the other veins in the area in that the ore is in limestone, a rock much more amenable to replacement by ore than the igneous rocks and therefore as a host rock not so strongly dependent upon open spaces. Each vein fissure in the district strong enough to reach down to the limestone, whether of pre-granodiorite or post-granodiorite age, is a potential ore bearer in that rock. The limestone is deeply buried at many places, however, and the cost of prospecting the limestone horizon properly must be balanced by the miner against the probable size of the anticipated ore bodies. The Syrena formation crops out at the surface near the Ivanhoe mine and may form the footwall of the vein on the lower levels of the mine, and that would seem to be a proper place to begin investigations. Inasmuch as the ore-bearing solutions became weaker as they traveled westward, the size and grade of the hypothetical ore shoots in the limestone should also decrease in that direction, and it would seem advisable, before deciding upon a program to prospect the limestone horizon, first to complete development of the Three Brothers ore shoot in order to find out whether the solutions at that distance from their source had still been able to form worth-while ore deposits. The Ground Hog mine will probably have prospected at least the upper part of the Syrena formation by the time this report appears in print, and experience at that mine should be taken into consideration.

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