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GEOLOGY AND ORE DEPOSITS

OF THE

MONTEZUMA QUADRANGLE, COLORADO

BY

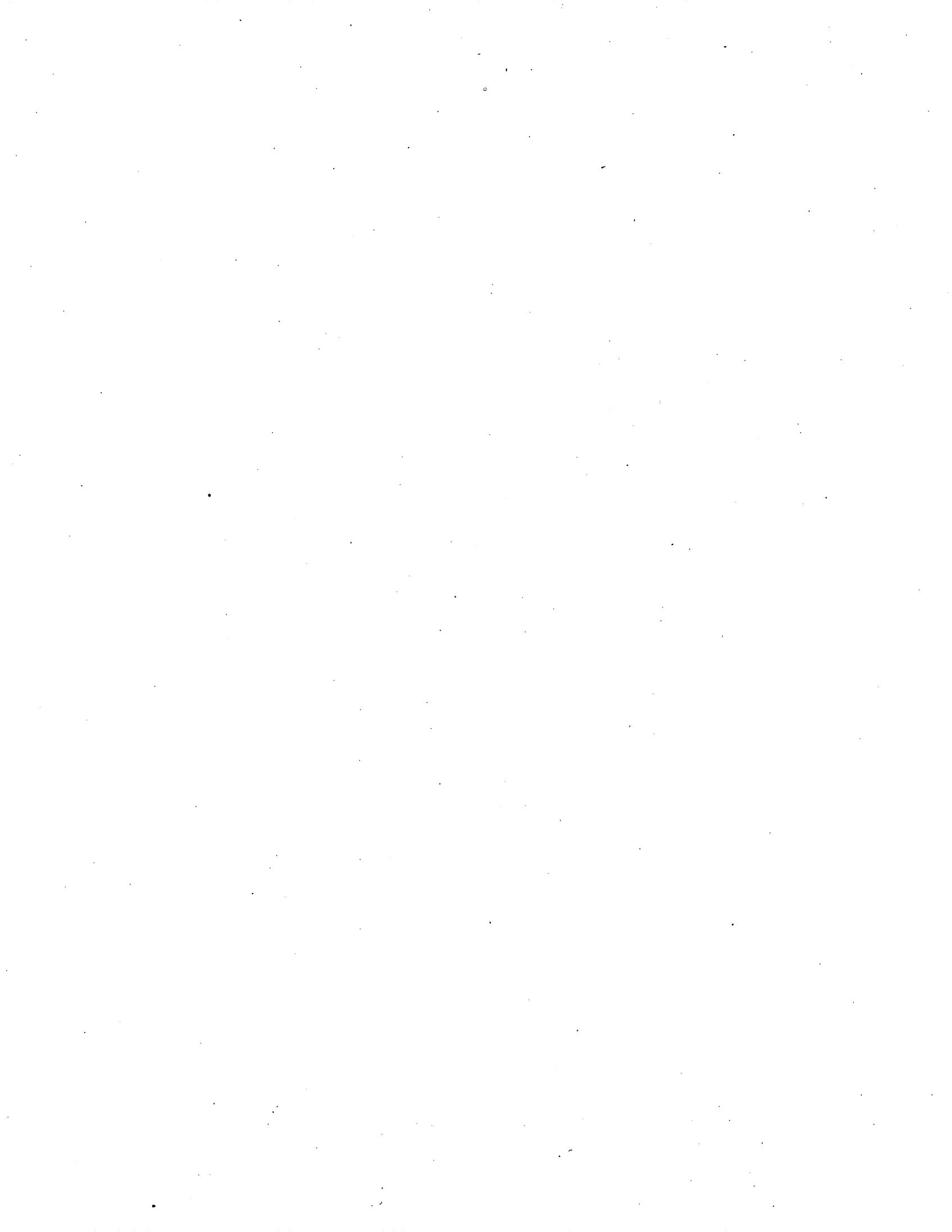
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ABSTRACT

Pre-Cambrian rocks cover most of the Montezuma quadrangle, but Mesozoic sediments are present in the southwestern part, and Tertiary intrusive rocks occur in a belt running from the southwest corner to the northeast corner. The Idaho Springs formation, the oldest in the quadrangle, covers most of the eastern half and is present along the western border. Quartz-biotite schist and gneiss containing sillimanite are the most abundant rocks in the formation, but quartz gneiss or quartz schist, lime silicate rocks, and garnetiferous schist are locally abundant. At some places ellipsoidal masses of quartz and sillimanite a few inches in diameter are distributed with remarkable regularity in the planes of schistosity. They are interpreted as the knots developed during the metamorphism of the schist rather than the mashing of an original conglomerate. In places granitic intrusions have converted the schist into an injection gneiss. The rocks were originally shaly sediments containing small sandy and calcareous lenses, and the planes of schistosity are nearly everywhere parallel to the original bedding planes. Isoclinal folds are common. The regional structure, though modified by the nearby granitic masses, shows a north to northeast trend.

The gneisses and schists in the west half of the quadrangle have been termed the Swandyke hornblende gneiss. They are probably metamorphosed quartz diorite sills or lavas of similar composition intercalated in or overlying the upper part of the Idaho Springs formation. The Swandyke gneiss, like the Idaho Springs formation, is changed to injection gneiss wherever pegmatitic or aplitic seams are abundant.

Although a large mass of quartz monzonite gneiss occurs to the east, there are only a few small masses of it in the Montezuma quadrangle. It is intrusive into the Idaho Springs formation and is believed to be somewhat later than the Swandyke gneiss. Like the earlier formations it shows the effect of granulation and recrystallization. Its contacts with the Idaho Springs formation are commonly parallel to the schistosity. Assimilation was locally important in determining its composition. It is probable that much of the early injection along the foliation planes of the schist was accomplished by this quartz monzonite magma.

Granite gneiss occurs in only a few isolated masses in the Montezuma quadrangle. The small bodies are lenticular, but the contact of large bodies with schists and gneisses is irregular. In places the granite gneiss forms sills directly related to zones of injection gneiss in the earlier schists and gneisses. Its predominant facies is a gneissic aplite or fine-grained gneissic silicic granite. Granulation of the quartz and feldspars in the granite gneiss is much less prominent than in the earlier rocks.

Dikes and small irregular masses of Algonkian age ranging in composition from hornblendite through diorite and quartz diorite to a nearly pure anorthosite occur in a few places. The central parts of the larger irregular masses of diorite and quartz diorite are usually massive and have a faint orthogneissic character, but the edges generally show a banded structure and some evidence of mashing. The quartz diorite is closely related to the early dioritic facies of the Pikes Peak granite.

The Pikes Peak granite is found only in the southeastern part of the Montezuma quadrangle but extends at least 80 miles southward. Quartz monzonite border facies are found in irregular masses at the edge of the main batholith. The two

grade into each other at many places and were not mapped separately.

The Silver Plume granite crops out extensively in the north half of the quadrangle, and many isolated masses are found in the south half. At many places it probably followed fault lines and fracture zones.

Pegmatite and aplite intrude all the above-mentioned pre-Cambrian rocks. Their structural relations indicate that their intrusion extended over a long period. They were probably intruded at intervals from a time shortly after the formation of the Swandyke gneiss to the end of the consolidation of the Silver Plume granite.

The Maroon formation (Pennsylvanian (?) and Permian), consisting of micaceous grit, shale, sandstone, and conglomerate, probably about 500 feet thick, crops out a short distance outside of the quadrangle. The Morrison formation (Upper Jurassic) comprises about 350 feet of sandstone and variegated shale. The Dakota quartzite (Upper Cretaceous) ranges in thickness from 20 to 227 feet. It generally comprises a thick basal gray quartzite, a middle member of thin-bedded quartzite and black to gray shale, and an upper bed of quartzite from 20 to 50 feet thick. It is unconformably overlain by about 350 feet of black Benton shale, above which lies a dark-colored petrolierous limestone that may belong wholly or in part to the Benton. This limestone is succeeded by the limy shales of the Niobrara, which is about 370 feet thick and is overlain by somber-colored Pierre shale, which is about 4,000 feet thick near Keystone.

The Flattop peneplain of the Rocky Mountain National Park, which developed and was much dissected before the formation of the pre-Oligocene Medicine Bow peneplain, has been traced south through the Fraser quadrangle into the Montezuma quadrangle. It is a smooth, irregular surface and forms the tops of the mountains in the southern part of the quadrangle at an altitude of about 12,000 feet. The Rocky Mountain peneplain of the east side of the Front Range is imperfectly developed in the southwestern part of the quadrangle. This surface lies between 10,000 and 11,000 feet above sea level.

Early Pleistocene glaciation was widespread. Remnants of valleys cut at this time are found as much as 1,500 feet above the floors of the present valleys in the high country near the Continental Divide. The deposits comprise early morainic material and high terrace gravel. Much of the material of these deposits is more deeply weathered than that of the later moraine and outwash gravel.

The present topography was largely carved in the Wisconsin glacial stage of late Pleistocene time, and the most conspicuous features are due to ice work. Since Wisconsin time erosion has changed the topography but little.

All the post-Cambrian igneous rocks of the Montezuma quadrangle probably belong to one period of intrusion. They occur in a zone called the "porphyry belt," which is coextensive with a belt of mineralization and extends southwestward across the Front Range from Boulder to Breckenridge. These rocks are younger than the folding and faulting, which probably occurred during the Laramide revolution, but are older than the Flattop peneplain and were therefore intruded about the beginning of basal Eocene time. They are mostly porphyries and range from calcic to silicic in composition but the bulk of them are intermediate between diorite and quartz monzonite. In

general the calcic types are early and the silicic types late. A study of the Front Range and other parts of Colorado suggests that the igneous and related structural history of the Front Range during the early Eocene is essentially as follows:

1. Intrusion in early Denver time (basal Eocene) of sills and dikes of felsite.
2. Uplift of the Front Range accompanied by intrusion and extrusion throughout middle Denver time of calcic andesite and potassic basalt.
3. Culmination of Laramide revolution, characterized by strong folding, thrust faulting, and tear faulting at the end of Denver time, accompanied by the intrusion of granite-diorite magma.
4. Minor faulting followed by intrusion of dikes and sills of medium-grained porphyritic quartz monzonite.
5. Faulting accompanying and preceding the batholithic invasion of coarse-grained porphyritic quartz monzonite.
6. Minor faulting and intrusion of dikes of porphyritic sodic quartz monzonite.
7. Intrusion of dikes of sodic rhyolite and sodic granite porphyry.
8. Intrusion of granite and rhyolite porphyry.
9. Intrusion of alkali syenite, trachyte, and bostonite.
10. Minor faulting and the formation of gold, silver, lead, zinc, and copper ores.
11. Intrusion of felsite dikes and pipes of rhyolite agglomerate.
12. Development of Flattop peneplain.

The quartz monzonite porphyries of group 5, which are represented by the large stocks at Montezuma and in the southwestern part of the quadrangle and by small stocks and dikes elsewhere, have many times the volume of all other early Tertiary intrusive rocks of the Front Range. The Montezuma stock cuts the Williams Range thrust fault, which was formed during the Laramide revolution (the third stage listed above). Most of the porphyritic quartz monzonite dikes are slightly altered, and the uniformity of the alteration suggests that it was endomorphic. This type of alteration becomes more and more noticeable in the later silicic rocks.

A comparison of published analyses and age relations of the Tertiary intrusive rocks of the Front Range suggests an orderly succession of differentiates from a deep-seated magma. Three types of magmatic differentiation are indicated. The earliest type started with an initially dioritic magma and resulted in calcic and ultracalcic rock. The second type also started with a dioritic magma but gave rise successively to monzonite, quartz monzonite, granite, and alaskite. The third type, splitting from the quartz monzonite differentiate, resulted in alkalic rocks such as bostonite, alkalic syenite, and alkalic trachyte. The second type of magma became progressively more hydrous, and the third type became progressively drier.

The regional structure of the pre-Cambrian rocks is much obscured by complex local folds. Most of the schist southeast of the mineral belt dips north or northeast, but close to the Pikes Peak granite it is folded into irregular anticlines and synclines. Northeast of the mineral belt a northward-trending anticline extends from Georgetown into Estes Park, and a syncline runs north-northeastward from a point near Breckenridge to Fraser.

The northward-trending Front Range is made up in large part of northwesterly folds having an echelon arrangement. These folds are commonly overturned toward the west and at many places are broken by reverse faults. Thrust faults occur on both borders of the range; the largest, known as the Williams Range thrust fault, crosses the southwest quarter of the Montezuma quadrangle. At its southeast end it passes into an overturned fold.

A narrow belt of fractures follows a sinuous northeasterly course from Breckenridge to Boulder and passes through the western border of the range where the Williams Range thrust

fault breaks from the overturned fold. In this belt nearly all the Tertiary igneous activity and mineralization of the central part of the range has been localized. The veins in this belt commonly occupy faults and fissures that strike from northeast to east, but a few northwesterly veins have been found. So far as known, in all the eastward-trending mineralized faults in the west half of the range the north wall has moved east almost horizontally. More vertical than horizontal movement is commonly shown in the northeasterly faults, and both reverse and normal faults are common. Most of the northwesterly faults dip northeast and are reverse faults.

The horizontal movement of the easterly faults suggests shearing related to the breaking of the overturned fold where it passes into the thrust fault. The eastward movement of the north walls of the shear faults in the block overlying the thrust fault suggests drag of an inactive block by an actively moving footwall block. It seems probable, therefore, that the Williams Range thrust fault is an underthrust.

The minerals of economic importance in the Montezuma quadrangle include gold, silver, sulphides of lead, zinc, silver, arsenic, antimony, copper, and bismuth, and their supergene alteration products. The earliest minerals deposited by the ore solutions were sericite, quartz, and pyrite, and the wall rocks near the principal veins are largely altered to these minerals. Sericite is confined to the wall rock, but quartz and pyrite are abundant both as fissure fillings and as disseminations in the walls. Locally calcite and manganese siderite were deposited shortly afterward. Chalcopyrite, locally associated with gold, was deposited in the next stage of mineralization and is in places contemporaneous with early sphalerite. In most places galena and sphalerite are essentially contemporaneous and are later than chalcopyrite. Tennantite and tetrahedrite are in part contemporaneous with sphalerite and galena. After the deposition of gray copper, ankeritic gangue minerals containing some iron and manganese were formed in many of the veins. The ankerite stage ended the mineralization of many veins, but some were reopened and invaded by silver-bearing solutions which deposited quartz, argentite, native silver, silver sulphantimonides and sulpharsenides, and some galena. Bismuth minerals in a quartz gangue were probably formed at about this time.

The ore deposits are classed as contact-metamorphic deposits, stockworks, and mesothermal veins. Contact-metamorphic deposits, not economically important, occur near the west end of the Montezuma stock and in the Cretaceous sediments in the southwest corner of the quadrangle. The host rock is Cretaceous shale, and the invading rock a coarse-grained monzonite porphyry.

Stockworks are found only in the southwestern part of the quadrangle. They are shattered masses of quartz monzonite porphyry, some of which are crowded with fragments of the Cretaceous sediments. The complexly fractured rocks are strongly sericitized and contain sporadic seams and masses of ore. Sphalerite, pyrite, galena, gold, silver, and bismuth are irregularly distributed in the primary ores. Enrichment was an important factor in making the early work on these deposits profitable. They are much richer in gold near the surface than below the zone of oxidation.

The veins were formed at moderate depth, pressure, and temperature. Most of them strike northeast or east-northeast and dip northwest, but a few dip steeply southeast. The most productive veins strike between N. 15° E. and N. 35° E. Lead-zinc-silver veins consisting chiefly of galena, sphalerite, pyrite, and quartz are common in the northeast quarter of the quadrangle. On Mount McClellan veins of this general type carry barite and fluorite. In the south half of the quadrangle tetrahedrite is much more common than farther north, but galena, sphalerite, and pyrite are the most abundant ore minerals. Barite is abundant in a southeastward-trending branch

of the mineral belt, running from Glacier Mountain to Hall Valley. In the southeast quarter of the quadrangle veins carrying bismuth and silver minerals are common, and these minerals are associated with chalcopyrite in a quartz gangue. A few veins occur in the hanging-wall block of the Williams Range thrust fault north of the North Fork of the Swan River, though this area is underlain by underthrust Cretaceous shales. The veins in the southern part of the Montezuma stock consist chiefly of sphalerite and pyrite and contain moderate amounts of galena in a quartz-ankerite gangue. Farther north in the stock small veins containing rich silver ores occur.

The distribution of the less common ore minerals suggests that certain mineral associations are characteristic of distinct types of ore. In many of the ores gold and silver are associated with chalcopyrite, and silver is commonly associated with tetrahedrite and tennantite. The lighter-colored gray copper ores contain more silver than the dark-colored gray copper. Ores containing chalcopyrite and no gray copper commonly have a quartz or ankerite gangue, but the gangue of veins containing gray copper generally contains barite. The most abundant silver minerals, miargyrite, pyrargyrite, proustite, and stromeyerite, are commonly associated with manganiferous ankerite or rhodochrosite gangue. The bismuth-silver minerals, emplectite and schapbachite, are associated with quartz, pyrite, and chalcopyrite. Veins of massive pyrite or pyrite and quartz contain very little gold in the primary ores, but close to the surface they may have a high gold content due to enrichment.

Galena is commonly most abundant in the upper part of a vein. The copper content generally increases slightly with depth, and chalcopyrite usually becomes relatively more abundant than gray copper in the lower levels. The silver content of the ores shows little relation to the depth from the surface in the veins in the pre-Cambrian area. In Glacier Mountain, however, the ores are generally richer in silver in the lower part of the ore shoots than in the upper part. Most of the silver is believed to be primary, but enrichment has affected many veins. Rich secondary gold and silver ores bottom at much shallower depth in the pre-Cambrian rocks than in the later sedimentary rocks in the western part of the quadrangle. In the veins that

crop out on the Flattop peneplain rich gold ore was found only to a depth of 25 feet, where it changed abruptly into low-grade pyrite. In the ores that crop out on the Rocky Mountain peneplain rich secondary gold and silver continue to much greater depth.

The largest ore shoots range from 600 to 1,100 feet in length and have a vertical extent of 400 to 850 feet. The vertical range of ore deposition was at least 2,000 feet and probably more than 3,000 feet. However, it seems probable that the bottoms of the larger ore shoots indicate the bottoms of the local zones in which commercial bodies of ore were deposited nearby.

Hard, strong rocks such as pegmatite, granite, porphyry, and gneiss are the common walls of persistent ore shoots. Softer, more plastic rocks such as mica and hornblende schists rarely form the walls of extensive ore shoots. Ore shoots commonly occur at the intersections of veins, near the junction of branching veins, and where marked changes in the dip or strike occur. These changes can usually be correlated with open spaces caused by the movement of the irregular walls of the fault. In a fissure whose walls move horizontally a change in course will either allow the walls to pull apart or cause them to rub tightly together. Ore occurs where they pull apart. Similarly ore tends to occur in the steeper parts of premineral normal faults and in the flatter parts of premineral reverse faults. In areas of schist or gneiss ore shoots are more common where the vein breaks across the schistosity than where it is parallel. Veins having pyritized and silicified wall rock, recording many periods of brecciation, are more likely to have been open while metalliferous minerals were being deposited than veins that do not have these characteristics.

Reserves of high-grade ore are small, but there are many veins that might yield small but profitable amounts of ore if mined by lessees. Some of the baritic lead-zinc ores might be profitably concentrated in a flotation mill. Moderately large bodies of low-grade auriferous disseminated zinc-lead ores, unprofitable to the present time, occur in the stockworks near Tiger. The ore occurrences in the Ida Belle and Rainbow mines indicate the possibility of finding ore bodies in the brecciated zone of the Williams Range thrust fault where it is crossed by mineralized fissures.

GEOLOGY AND ORE DEPOSITS OF THE MONTEZUMA QUADRANGLE, COLORADO

By T. S. LOVERING

INTRODUCTION

FIELD WORK AND ACKNOWLEDGMENTS

The surface geology of the Montezuma quadrangle was mapped during the summers of 1926, 1927, and 1928, and the underground work was done chiefly in the fall of 1926 and the summer of 1929. The writer was assisted by L. B. Graff in most of the work, but for short periods in 1927 and 1928 Mart Barclay and H. W. Putnam acted as assistants.

Many of the mines in the quadrangle have been idle for years, and several of them were inaccessible, but the writer was allowed access to all mines open at the times of his visits except the Royal Tiger, and he wishes to express his appreciation of the courtesy of the many mine operators who facilitated this work.

Mr. C. W. Henderson, of the United States Bureau of Mines, contributed much helpful information on the mines; the production figures since 1904 are taken directly from his records, and most of the earlier production figures come from sources suggested by him. Mr. Percy Barbour, of Georgetown, kindly gave the writer access to his collection of mine maps, and many of those used as base maps for the geology of the mines are copied from his tracings. Dr. M. N. Short contributed much to the study of the ore minerals.

LOCATION AND POPULATION

As shown in figure 1, the Montezuma quadrangle is in the heart of the Colorado Front Range, about 40 miles west of Denver. It lies between parallels $39^{\circ}30'$ and $39^{\circ}45'$ and meridians $105^{\circ}45'$ and 106° and includes an area of about 230 square miles. The Continental Divide follows a sinuous northerly course through the quadrangle and is a natural boundary between counties of the eastern and western slopes. East of the Continental Divide the central and northern parts of the quadrangle are in Clear Creek County and the southern part is in Park County. West of the divide the northern part is in Grand County and the central and southern parts are in Summit County. The southwestern part of the quadrangle includes some of the Breckenridge district, which was studied by

Ransome in 1909¹ and by the writer in 1928;² the central portion was mapped by Patton and students of the Colorado School of Mines in 1908.³ Adjoining the quadrangle to the east is the Georgetown quadrangle, whose geology and ore deposits were mapped and studied in 1904.⁴ Part of the Central City quadrangle lying immediately northeast of the Montezuma quadrangle has been mapped and studied by Bastin and Hill.⁵

The Colorado & Southern Railway's narrow-gage line, which serves the country between Denver and Leadville, has a short spur from Dillon east to Keystone. This hamlet is on the Snake River about a mile east of the western boundary of the quadrangle and is dependent on a small lumber mill for its existence. In 1929 no post office or station was maintained there, although it was the only shipping point for the lumber and ore found in the Snake River drainage basin.

Montezuma, an incorporated town, is on the Snake River about 8 miles east of Keystone and very near the center of the quadrangle, to which it has given its name. Montezuma has a post office and general store, and daily stage service to Dillon is maintained throughout the year. According to the 1920 census Montezuma had a population of 69; in 1930 the population was 38. Mining is the chief industry of the region near the town.

Tiger, about the size of Montezuma, is on the Swan River $2\frac{1}{2}$ miles northeast of the southwest corner of the quadrangle. It is supported almost wholly by the activities of the Royal Tiger Mining Co. Its nearest shipping point is Braddock's Switch, about 4 miles west of the town.

Montezuma, Tiger, and Keystone are the only inhabited towns or hamlets in the Montezuma quadrangle. Swandyke, on the Middle Fork of the Swan River, is a small "ghost town", and only two or three empty buildings remain at Graymont, on Clear Creek. Silver Plume at the end of the Clear Creek branch of the Colorado & Southern Railway is only a mile east of the quadrangle and is the shipping point for the ores from the Clear Creek drainage basin.

¹ Patton, H. B., The Montezuma mining district, Colo.: Colorado Geol. Survey First Rept., pp. 112-144, 1909.

² Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle, Colo.: U.S. Geol. Survey Prof. Paper 63, 1908.

³ Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U.S. Geol. Survey Prof. Paper 94, 1917.

¹ Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U.S. Geol. Survey Prof. Paper 75, 1911.

² Lovering, T. S., Geology and ore deposits of the Breckenridge mining district, Colo.: U.S. Geol. Survey Prof. Paper 176, 1934.

TOPOGRAPHY AND DRAINAGE

The Montezuma quadrangle (see pls. 1, 2) lies on and near the Continental Divide, and as shown on plate 3, it contains much high, rugged country. The altitude ranges from 9,100 feet a short distance west of Keystone to 14,274 feet at the summit of Grays Peak, 5 miles northeast of Montezuma. Most of the valleys have been severely glaciated in recent geologic time

narrow and at many places rise to impassable knifelike divides.

The Continental Divide includes the highest and most rugged peaks in the region. In this quadrangle it is in general above 12,000 feet in altitude and passes through many peaks higher than 13,000 feet, including Grays Peak (altitude 14,274 feet), the highest peak in the Front Range and one of the highest in Colorado.

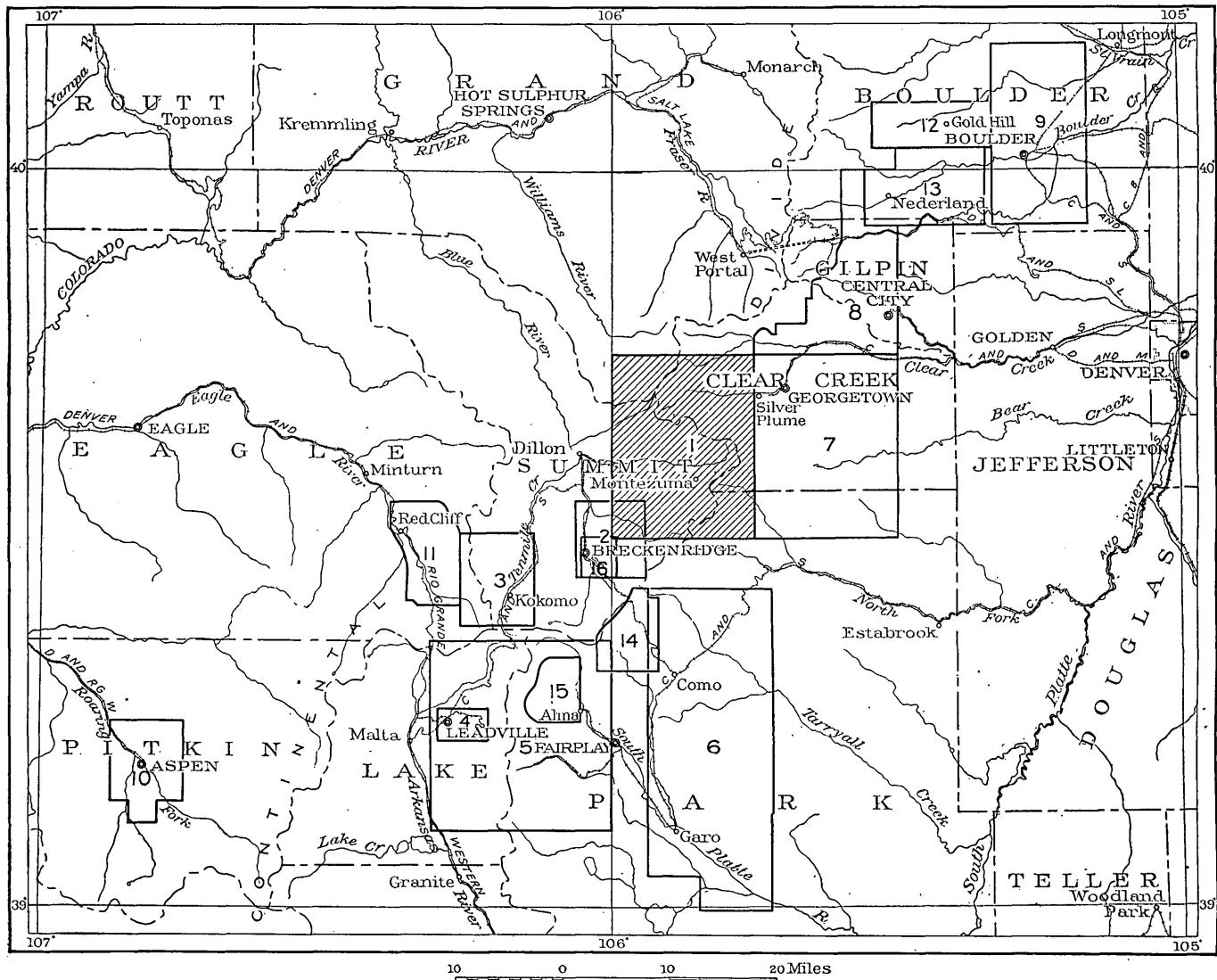


FIGURE 1.—Index map showing location of the Montezuma and neighboring quadrangles. 1, Montezuma quadrangle; 2, Breckenridge district (Prof. Paper 75); 3, Tenmile district (Folio 48); 4, Leadville district (Prof. Paper 148); 5, Mosquito Range (Mon. 12); 6, South Park coal field (Bull. 381-C); 7, Georgetown quadrangle (Prof. Paper 63); 8, Gilpin County and vicinity (Prof. Paper 94); 9, Boulder district (Bull. 265); 10, Aspen district (Mon. 31); 11, Red Cliff district (Colorado Geol. Survey Bull. 30); 12, Ward region (Colorado Geol. Survey Bull. 21); 13, Boulder tungsten area (Colorado Geol. Survey, 1st Rept.); 14, Tarryall district (Colorado Geol. Survey Bull. 31); 15, Alma district (Colorado Geol. Survey Bull. 3); 16, part of Breckenridge district (Prof. Paper 176).

and are broad and U-shaped. Steep-walled cirques are common at altitudes above 11,500 feet, and where the preglacial surface has been preserved they contrast strongly with the smooth topography of the old upland in which they were carved. (See fig. 2.) Remnants of the elevated tilted plateau are present only in the southwestern and eastern parts of the quadrangle; throughout the central part the ridges are

High spurs from the Continental Divide separate the major streams. As shown on plate 3, the valleys of the largest streams, such as the Snake River on the western slope and Clear Creek on the eastern slope, trend nearly east and west. North and south tributaries to these major streams have cut deep valleys into the high spurs from the Continental Divide and given the country its rugged, broken character.

Most of the northeast quarter of the quadrangle is drained by Clear Creek and its tributaries, and the southeastern part is drained by Geneva Creek, which discharges into the North Fork of the Platte River about 5 miles southeast of the quadrangle. The drainage basin of the Snake River occupies about a third of the region mapped and includes most of the central-western part of the quadrangle. The extreme southwestern part is drained by the Swan River, and the northwestern part is drained by Straight Creek and the South Fork of the Williams River. Large parts of these streams lie between 9,200 and 11,000 feet above sea level, and the interstream divides commonly rise from 1,200 to 2,000 feet above them.

Many beautiful glacial lakes spangle the high country, marking places where the glaciers of the ice age dug deeply and unevenly into the bedrock near the heads of the streams. At lower altitudes, usually less than 11,000 feet, many large ponds have been formed in the valleys through the activity of beavers, which are especially numerous on the western slope.

CLIMATE AND VEGETATION

No recent record of temperature and precipitation is available for any point in the Montezuma quadrangle, but at Dillon, 4 miles west of Keystone, at an altitude of about 8,800 feet, the mean annual temperature is 33.4° F. and the mean annual precipitation is 18.31 inches. In the high country east of Dillon, however, the average temperature is less and the precipitation is more. A clipping from a paper published in 1873 states that the snowfall at Sts. John that winter was an even 100 feet, that the ground was covered to an average depth of 9 feet, and that 4 feet of snow had to be cut through in June in order to open the road from Sts. John to Montezuma. Snow remains on the higher peaks throughout the year, and even in the lowest valleys deep drifts linger on northward-facing slopes until the later part of June. Most of the quadrangle is bare during July, August, September, and part of October. Heavy snows usually mantle the range late in October or early in November, and frequent storms during December, January, February, and the early part of March bury the region beneath several feet of snow. Storms are common in summer but generally occur more frequently in May, early June, late July, and August than in the other months of summer and fall.

About half of the quadrangle is above timber line, which ranges from 10,500 to 12,000 feet but is generally close to 11,700 feet. Below timber line forests of pine and spruce cover most of the mountain slopes, but thick groves of aspen are common in some places

and usually mark the sites of old forest fires. The most abundant conifers are the lodgepole pine (*Pinus murrayana*) and the Engelmann spruce (*Picea engelmanni*), but in dry localities in the lower parts of the region some yellow pine (*Pinus ponderosa*) and Douglas spruce (*Pseudotsuga mucronata*) are found. The balsam or alpine fir (*Abies lasiocarpa*) is a common associate of the lodgepole pine and is most abundant below an altitude of 11,000 feet. The limber pine (*Pinus flexilis*), on the other hand, is seldom found much below timber line. In wet marshy places and along streams dense growths of alders and willows occur, made up chiefly of the mountain alder (*Alnus*

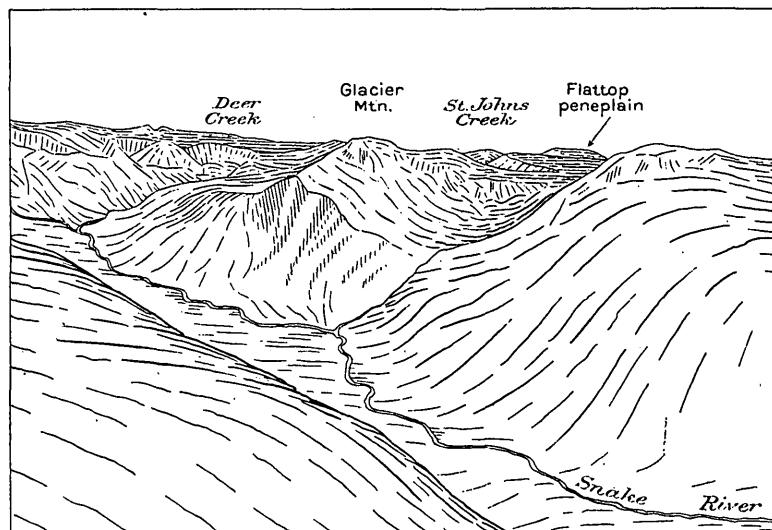


FIGURE 2.—Sketch showing glacial trenching of Flattop peneplain. From southern spur of Lenawee Mountain, looking south-southwest.

tenuifolia) and the subalpine willow (*Salix glauca*). Grasses and sedges are common in parklike open spaces near streams and in moist zones above timber line.

Temperature, in degrees Fahrenheit, at Montezuma, Colo., 1884
[As reported by the Montezuma Mill Run]

Week ending—	Highest	Lowest	Average maximum	Average minimum
Jan. 5	28	-15	13	-3
Jan. 12	24	-17	20	2
Jan. 19	37	-17	26	-7
Jan. 26	41	-14	25	-6
Feb. 2	46	-2	28	5
Feb. 9	38	3	30	8
Feb. 16	38	-24	25	-9
Feb. 23	40	-6	25	9
Mar. 1	44	-6	27	7
Mar. 8	42	3	27	17
Mar. 15	42	-9	30	6
Mar. 22	57	6	43	10
Mar. 29	62	-3	41	10
Apr. 5	65	4	44	13
Apr. 12	71	8	45	13
Apr. 19	55	11	46	16
Apr. 26	60	6	51	18
May 3	60	6	51	18
May 10	69	14	58	19
May 17	69	14	58	19
May 24	63	15	57	27
May 31	85	22	59	25

Temperature, in degrees Fahrenheit, at Montezuma, Colo., 1884—Continued

Week ending—	Highest	Lowest	Average maximum	Average minimum
June 7	64	28	69	35
June 14	92	30	69	35
June 21	72	30	67	35
June 28	72	30	67	35
July 5	72	30	67	35
July 12	72	30	67	35
July 19	72	30	67	35
Aug. 2	72	30	63	35
Aug. 9	76	30	60	35
Aug. 16	63	30	56	32
Aug. 23	63	30	56	32
Aug. 30	76	31	58	32
Sept. 6	76	31	58	32
Sept. 13	74	14	53	28
Sept. 20	68	18	57	30
Sept. 27	63	18	54	30
Oct. 4	62	18	54	30
Oct. 11	62	18	54	30
Oct. 18	62	18	54	30
Oct. 25	59	11	44	23
Nov. 1	59	3	34	13
Nov. 8	45	8	34	13
Nov. 15	45	8	34	13
Nov. 22	33	—9	22	11
Nov. 29	31	—2	21	9
Dec. 6	31	—2	21	9
Dec. 13	26	—8	21	5
Dec. 20	35	5	26	9
Dec. 27	35	5	26	9

Mean annual temperature, 31.5°.

INDUSTRIES, POWER, AND TRANSPORTATION

Most of the population is supported by the mining industry. There are a few ranches in the western part of the quadrangle on Soda Creek and the Snake River, and small sawmills were operating on the North Fork of the Swan River, on Clear Creek, at Tiger, and at Keystone in 1926–29. Many large bands of sheep graze above timber line in July, August, and September.

No attempt has been made to develop the water power of the region. The volume of the streams within the quadrangle is too small to warrant the construction of large hydroelectric plants, and as electric power is easily obtainable from the 100,000-volt transmission line passing through the quadrangle by way of the Snake River, Argentine Pass, and Leavenworth Creek, it is doubtful whether small power units would be economically justified.

The narrow-gage line of the Colorado & Southern Railway from Denver to Leadville by way of Grant, Breckenridge, and Dillon carries all products shipped from the western and southern parts of the region. The northeast quarter of the quadrangle is served by the Colorado & Southern narrow-gage line that extends from Denver to Silver Plume and by an autobus line that maintains year-round service. The comparatively light snowfall a few miles east of the Continental Divide permits automobile service in winter as well as summer, but on the western slope the roads are usually closed to cars from November to April, and during these months all freight is moved to and from

the railroad by horses, burros, or men. The Denver & Salt Lake Railroad (Moffat road), a standard-gage line, passes through Kremmling, 35 miles northwest of Dillon, and if the Colorado & Southern Railway Co. is permitted to abandon its Denver-Leadville narrow-gage line, Kremmling would be the nearest shipping point available throughout the year to the western part of the region.

The main roads in the region are kept in good condition, and most of the secondary roads can be traversed by automobiles, though with difficulty. The secondary roads crossing the Continental Divide have not been repaired in many years and are so badly washed out that it is doubtful if wagons could be hauled over them in their present condition. Many of the mines high above the valley floors are accessible only by trails, and supplies and ore are moved by pack trains.

A State highway over Loveland Pass was completed in 1933 and places Montezuma within 60 miles of Denver by road, less than half the former distance, making the whole quadrangle much more accessible than it was when this survey was made. Most of the road passes in the adjoining regions are closed from late in November to late May or early June, and Loveland Pass remains closed a somewhat longer time. It is probable that the western slope will always remain comparatively isolated during the winter.

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— See also Van Tuyl, F. M., and Lovering, T. S.

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DESCRIPTIVE GEOLOGY

Pre-Cambrian granites, gneisses, and schists cover most of the Montezuma quadrangle. Mesozoic sediments are present in the southwestern part, and Tertiary intrusive rocks occur in a belt running from the southwest corner to the northeast corner. The pre-Cambrian rocks are similar to those studied by Ball in the Georgetown quadrangle and can be easily correlated with them; additional work south of the Georgetown quadrangle has enabled the writer to trace the †Rosalie granite⁶ of Ball into the Pikes Peak granite of Cross, and as the formation names of Cross in the Cripple Creek region have priority over those of Ball,

⁶ A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U.S. Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

the term "Pikes Peak granite" is used in this report instead of "†Rosalie granite." The †Archean quartz monzonite mapped as a separate unit by Ball is almost indistinguishable from the Pikes Peak granite in most of its occurrences in the Montezuma quadrangle and has not been separated as a distinct formation by the writer. The Mesozoic sediments bordering the pre-Cambrian mass on the west have been studied in detail for the first time in this region, and the stratigraphy of the Upper Jurassic and Upper Cretaceous given on pages 16-22 is characteristic of these sediments from Como to Kremmling.

ALGONKIAN (?) FORMATIONS
IDAHO SPRINGS FORMATION
DISTRIBUTION

The Idaho Springs formation covers most of the east half of the quadrangle south of Clear Creek and is present along the western border north of the Snake River. The details of its occurrence and structure are shown in plates 3 and 4. It is the predominant schistose rock of the Front Range and is widely distributed in the region east and north of the Montezuma quadrangle, as shown in plate 5.

The schist in most of the quadrangle is closely folded and trends north. In the central part of the region the folds are moderately open and the strikes of the schistosity are less easily correlated because of the many subsidiary wrinkles imposed upon the folds. In the west-central part the axes of the folds strike northwest, but in the east-central part an east-west anticline is present. (See fig. 5.) In the southeast corner of the quadrangle the schistosity veers from southwest to south and finally to southeast as it is followed southward. This curving reflects the influence of the great east-west syncline whose axis is parallel to the valley of the North Fork of the Platte River a few miles southeast of the quadrangle.

AGE

The Idaho Springs formation is older than the Pikes Peak granite, which is older than the Cambrian quartzites of the Pikes Peak region and is believed to have been intruded in early middle Algonkian time. These pre-Cambrian rocks, as well as most of the other metamorphic and granitic rocks of the Front Range, have been referred to the Archean by some previous writers. Although the possibility that the Idaho Springs formation may be Archean must be admitted, a comparison of the geologic history of the region with that of the Lake Superior country strongly suggests that it belongs to the early Algonkian.⁷ It is here tentatively classified as Algonkian (?).

⁷ Lovering, T. S., Geologic history of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, pp. 73-74, 1929.

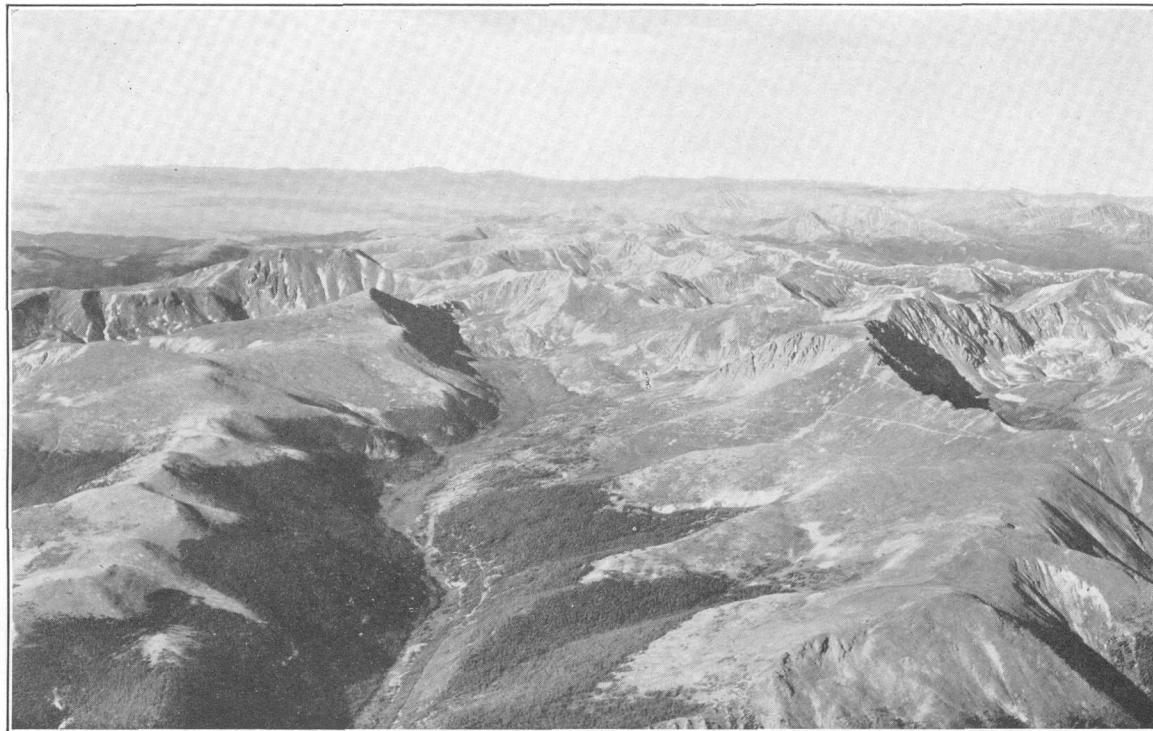
LITHOLOGY

Megascopic features.—The metamorphism of the Idaho Springs formation has developed many lithologic varieties, ranging from almost monomineralic schists to highly complex gneisses. The abundance of intrusive pegmatite varies greatly, but lit-par-lit injections and crosscutting seams and dikes of aplite and pegmatite are nearly everywhere present.

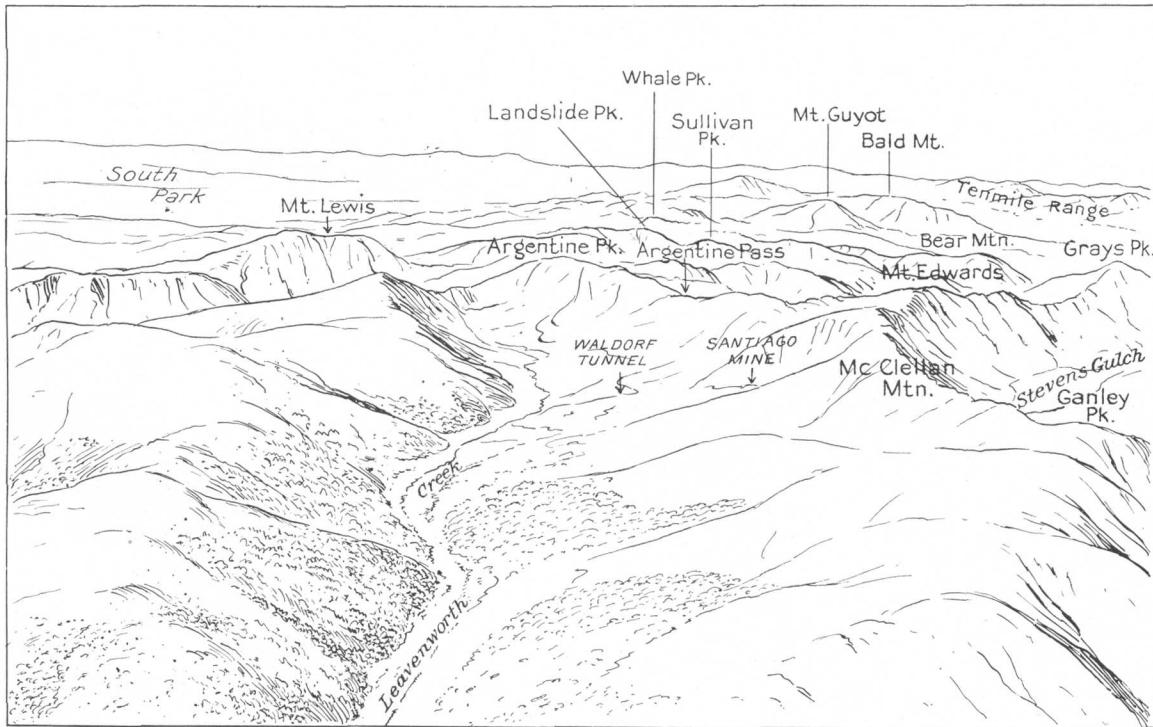
Quartz-biotite schist and gneiss are most common and grade into each other. The quartz-biotite schist is a moderately dense, gray rock, which presents a "pepper and salt" appearance on fresh fracture. It is made up of fine-grained quartz and biotite in nearly equal proportions with some accessory magnetite. The quartz-biotite gneiss is commonly a greenish-gray rock banded with black seams 1 to 3 centimeters wide, spaced from 2 to 15 centimeters apart. It is made up chiefly of quartz, microcline, plagioclase (oligoclase), and biotite, with some magnetite and sillimanite and rarely some hornblende. The black seams in the gneiss are largely biotite. All possible gradations between quartz-biotite schist and quartz-biotite gneiss can be found. These rocks are well shown in the region near Grays Peak and Argentine Pass. (See pl. 6, A.) Facies of the quartz-biotite gneiss and schist rich in sillimanite or muscovite or both are common throughout the formation.

Quartz "gneiss" and quartz schist make up only a small part of the Idaho Springs formation but are common in certain localities. The quartz "gneiss" is a gray to brown rock in which over 90 percent is quartz. It ranges from a dense fine-grained rock to a medium-grained granular gneiss resembling very siliceous granite gneiss. Hornblende and biotite are the chief accessory minerals. Very little feldspar is present, and the propriety of calling the rock a gneiss is questionable; its gneissic appearance and the fact that similar rocks have been described as quartz gneisses in nearby regions⁸ have led the writer to use this term. Quartz gneiss is found on the top of the high eastern spur of Argentine Peak directly north of Silver Dollar Lake and can be traced east and northeast from this point to Sugar Loaf Mountain, in the Georgetown quadrangle, where it was noted by Ball. The largest bed of quartz schist is in the southern part of the Montezuma quadrangle a short distance east of the contact of the Idaho Springs formation and the Swandyke hornblende gneiss. The quartz schist probably has a maximum thickness of about 1,500 feet and is lenticular. However, this belt of siliceous schist can be traced north from Red Cone for several miles. The quartz schist ranges from a quartz-sericite schist to a schistose quartzite containing a small amount of mica and a little feldspar. It consists chiefly of

⁸ Ball, S. H., op. cit. (Prof. Paper 63), p. 41. Bastin, E. S., op. cit. (Prof. Paper 94), pp. 27-28.



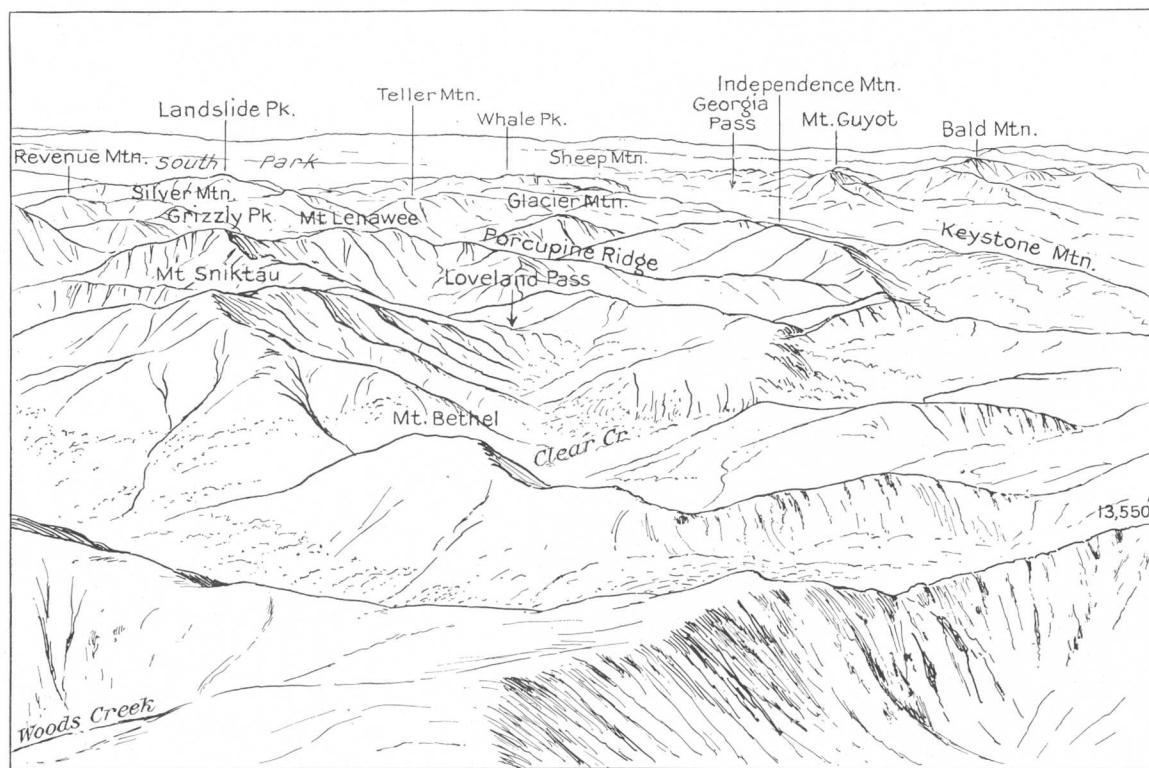
AIRPLANE VIEW LOOKING SOUTHWESTWARD UP LEAVENWORTH CREEK.
Courtesy of Geological Society of America.

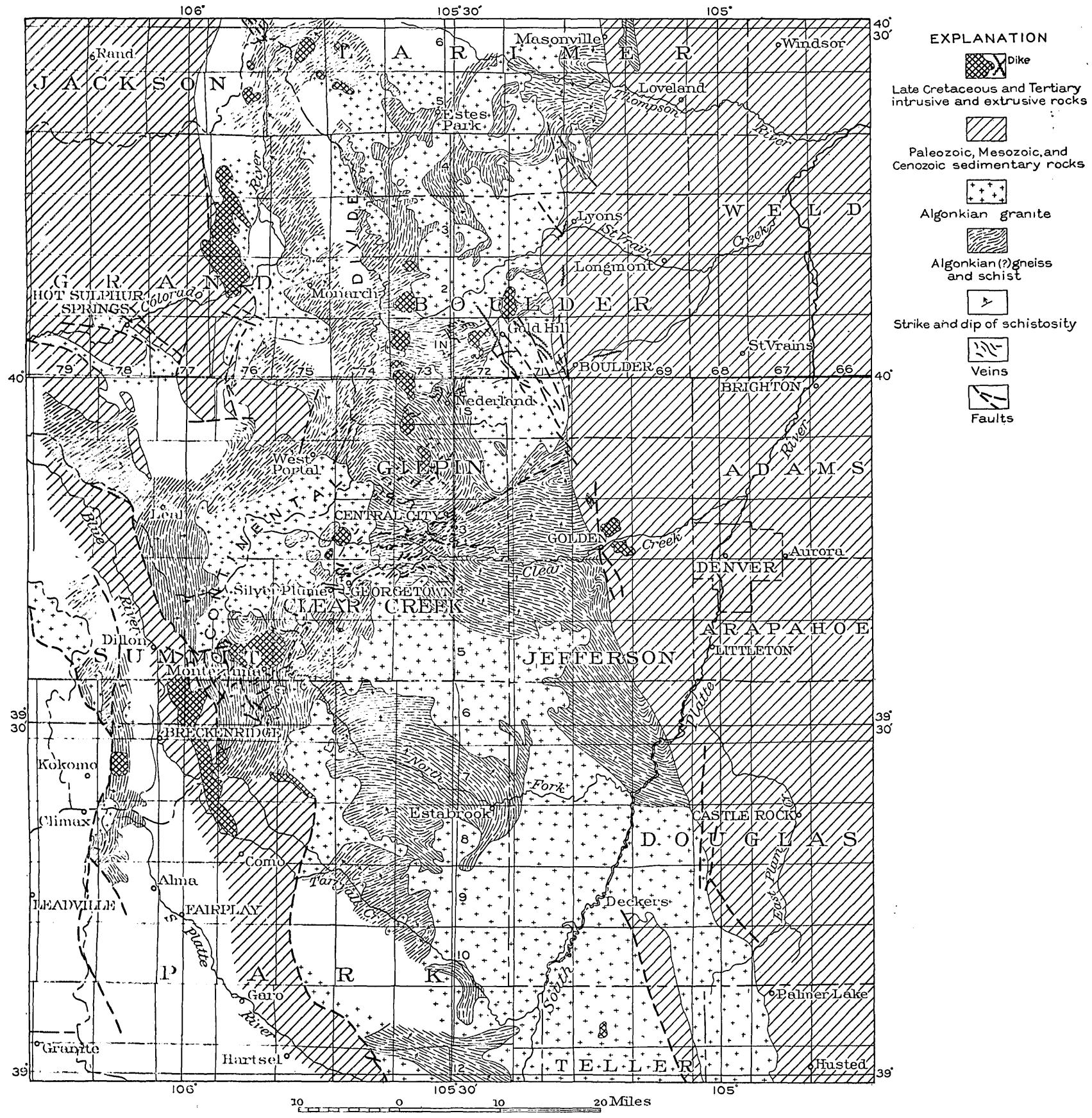




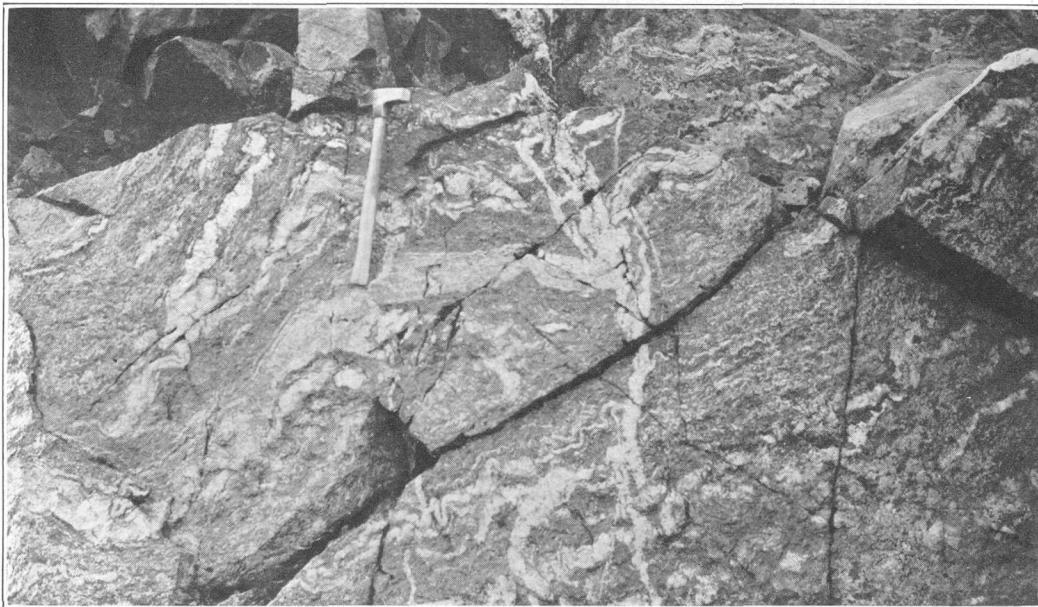
AIRPLANE VIEW LOOKING SOUTHWARD TOWARD LOVELAND PASS.

Courtesy of Geological Survey of America.

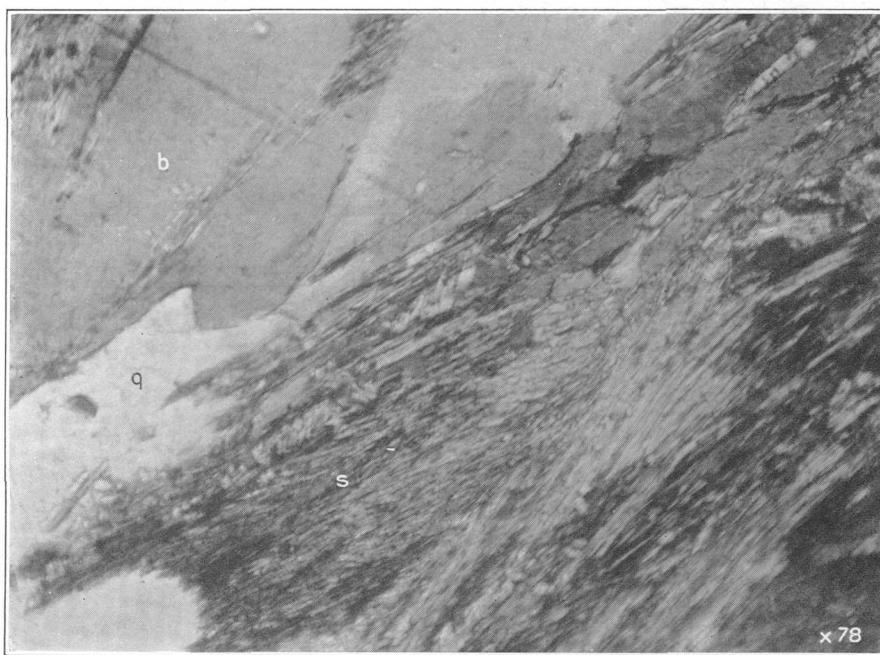




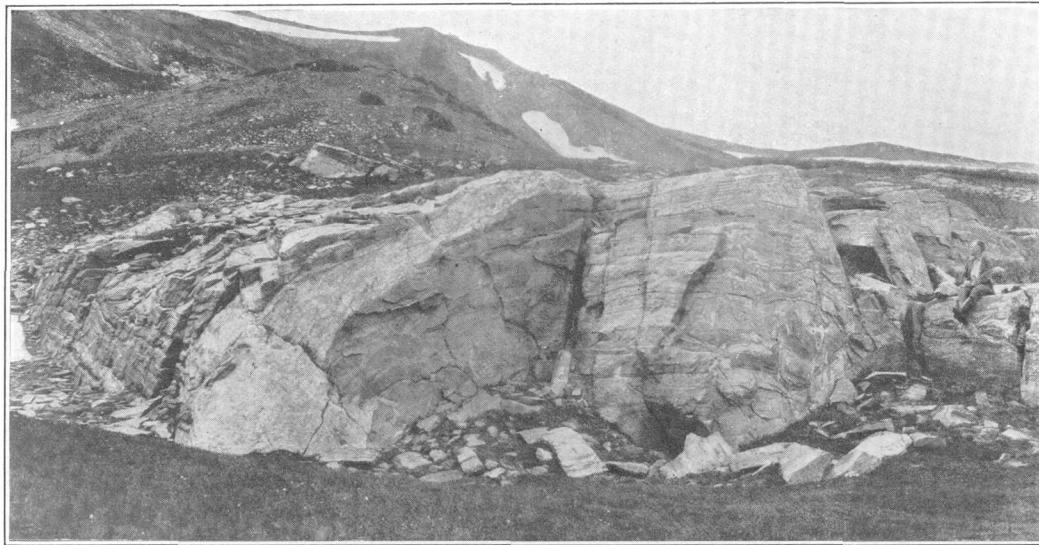
GEOLOGIC MAP OF THE FRONT RANGE,



A. IDAHO SPRINGS FORMATION ON EAST SIDE OF GRAYS PEAK.
Shows sill-like seams of aplite and pegmatite parallel to the nearly horizontal schistosity and cross-breaking branch seams.

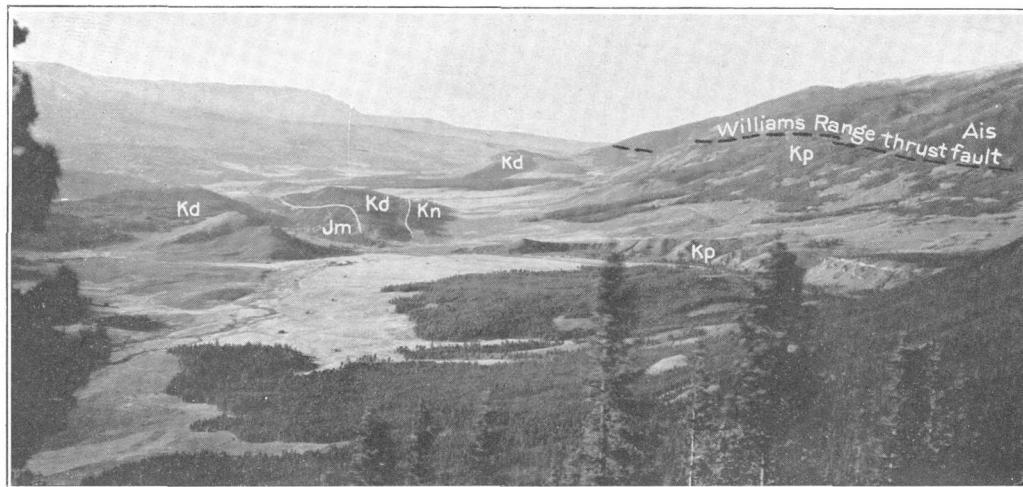


B. PHOTOMICROGRAPH OF QUARTZ-BIOTITE-SILLIMANITE SCHIST FROM NORTHEAST SLOPE OF GRAYS PEAK.
Showing pronounced schistose texture. Crossed nicols. s, Sillimanite; q, quartz; b, biotite.



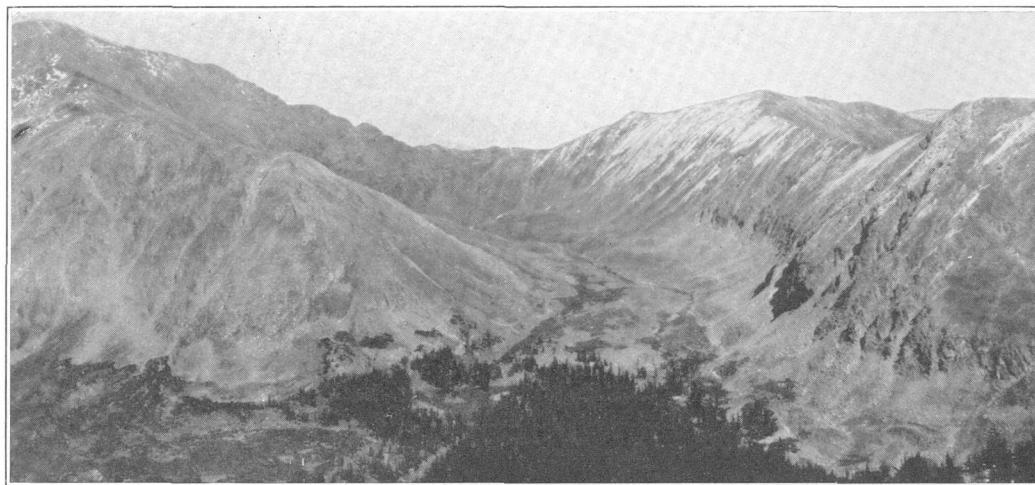
A. TYPICAL EXPOSURE OF SWANDYKE HORNBLENDE GNEISS NEAR HEAD OF ST. JOHNS GULCH.

The gneissic structure of the dark-gray hornblende gneiss is accentuated by the parallel and crosscutting light-gray seams of pegmatite and aplite. The dip of the formation is nearly horizontal at this outcrop, which is near the crest of an anticline.



B. ANTICLINAL DOME OF DAKOTA QUARTZITE (Kd) CUT THROUGH BY THE SNAKE RIVER.

Kp, Pierre shale; Kn, Niobrara limestone; Jm, Morrison formation; Ais, Idaho Springs formation.



C. VIEW LOOKING EAST AT RUBY GULCH FROM LENAWEET MOUNTAIN.

The steepness of the right-hand side of the gulch was caused by glacial scour where the course of the former glacier swung from southwest to west.

strongly sheared white quartz, in which most of the grains are between 0.2 and 1.3 centimeters in length. The weathered surfaces of some facies rich in sericite and feldspar simulate the blotched chalky appearance of altered porphyry, for which the quartz schist is sometimes mistaken.

Lime-silicate rocks, including hornblende-diopside gneiss, quartz-magnetite gneiss, and massive rocks composed of epidote, garnet, calcite, lime silicates, and quartz, are common in the Georgetown quadrangle but almost lacking in the Montezuma quadrangle. The lime-silicate rocks probably resulted from the regional and igneous metamorphism of limy sediments and are invariably close to granite stocks. A small mass of the epidote rock was observed on the northwest side of the valley of the North Fork of the Snake River about half a mile from its junction with the Snake.

Quartz-biotite-garnet schist is very common in the southwestern part of the quadrangle in the narrow strip of the Idaho Springs formation between the west edge of the Swandyke gneiss and the Cretaceous sediments. It is a strongly foliated rock composed chiefly of moderately coarse grained biotite, medium-grained garnet, quartz, and microcline, with some muscovite and magnetite. It weathers readily to crumbling reddish-brown fragments and tends to form smooth slopes. It is well exposed on the precipitous banks of the Middle Fork of the Swan River, however, and forms much of Tenderfoot Hill, northwest of Keystone.

Injection gneiss is abundant at many places. Pre-Cambrian aplites, pegmatites, and granites are so intimately injected into the schists everywhere that it is almost impossible to find any mass of schist 25 feet thick that is not seamed by one or more of the granitic rocks. In many places the seams of aplite and pegmatite lying parallel to the schistosity make up most of the rock, and the thin partings of schist that separate the intrusive seams give the rock the appearance of a granite gneiss. Although its composition is actually that of granite gneiss, it is more properly called injection gneiss, as it was formed by the injection of granitic magma into the schists. In extreme cases the schist has been so thoroughly permeated by the intrusive that only the shadowy outlines of its structure are preserved as biotite-rich layers. Gradations are common from simple schist through injection gneiss to granitic intrusives containing almost completely assimilated masses of schist. Injection gneiss is most frequently found bordering large masses of pegmatite, aplite, or granite, and the genetic relation of the gneiss is apparent.

The relations of the schists near a small stock of Pikes Peak granite in Bruno Gulch are unusually clear. The quartz-biotite-sillimanite schist of the region is greatly changed for a distance of several hundred feet from

the border of the granite stock. As the granite is approached, the normal quartz-biotite-sillimanite schist gradually gives way to a finely layered injection gneiss made up of alternating layers of biotite and quartz-microcline aplites. The next change observed is the segregation of some of the quartz and microcline into knots about 1.5 centimeters long scattered sparingly through the rock. Toward the granite mass these knots become more and more conspicuous; most of them are sharply angular, after the habit of orthoclase or microcline, and many of them consist of well-defined individual crystals containing small amounts of included quartz. Close to the granite contact these metacrysts are so abundant that the rock strongly resembles a coarse-grained granite gneiss, and indeed it is shown on the map of the Georgetown quadrangle as a granite gneiss. The aplites instrumental in forming the injection gneiss are very quartzose and contain only small amounts of feldspar. The seams parallel to the schistosity are cut by cross-breaking dikes and seams of white siliceous aplite and pegmatite of similar appearance. These intrusives are distinctly earlier than the metacrysts, many of which are associated with thin seams of pink aplite and pegmatite. Pink coarse-grained pegmatite consisting of orthoclase, microcline, quartz, biotite, and some muscovite is the latest rock in this locality. The areal relations indicate that the various pegmatites and aplites were derived from a common source and were given off at various stages in the consolidation of the Pikes Peak granite.

"Ellipsoidal masses" and "pebble-bearing gneiss" are the terms under which Ball and Spurr⁹ respectively describe facies of the Idaho Springs formation that somewhat resemble a metamorphosed conglomerate. In the Montezuma quadrangle grayish-white ellipsoidal or discoidal masses occur in the schists at several places. The masses are commonly from 1 to 3 centimeters long and about 0.5 centimeter thick. They consist largely of medium-grained quartz and always carry a small amount of sillimanite or fibrolite, but feldspar is rare. The masses usually occur in bands from 1 to 10 feet thick, and both the bands and the discoidal masses are parallel to the schistosity. These masses are distributed with remarkable regularity in the plane of schistosity, and the evenness of their spacing, usually from 1 to 3 inches apart, suggests the development of a knotted schist through severe metamorphism rather than the mashing of an original conglomerate. The quartz-fibrolite knots are much more closely spaced across the schistosity than parallel to it and may be separated from overlying or underlying masses by a mere film of schist. In some places the masses are drawn out to long, narrow elliptical bodies that swell and pinch; in other places the smooth elliptical shape

⁹ Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit. (Prof. Paper 63), pp. 41, 177.

of river pebbles is simulated. Here and there the ellipsoidal or discoidal masses are connected by thin veinlike seams of quartz, and the masses appear to be genetically related to such veins. The schistosity curves around the masses, and in some places they are crossed by fractures standing at a high angle to the schistosity. The knotted schists are widely distributed in the Montezuma and Georgetown quadrangles but were not noted by Bastin¹⁰ in the Central City quadrangle. They are most abundant near the large intrusive masses of pre-Cambrian granite and are rare in the region a few miles away from the mass of †Rosalie granite and quartz monzonite (see Pikes Peak granite, pp. 12-13) in the Georgetown quadrangle. The knotted schists in the Montezuma quadrangle occur chiefly near its eastern border and can be seen at many places near the heads of West Geneva and Leavenworth Creeks. It is worthy of note that the region in which the knotted schists or "metamorphosed conglomerates" occur abundantly coincides with that in which the most highly aluminous pegmatites were found. Tourmaline-bearing pegmatites are commonly associated with the knotted schists, and many of them carry garnet, sillimanite, or corundum. The writer believes that most of the ellipsoidal and discoidal masses in the schists are the result of extreme metamorphism attended by the migration of siliceous and aluminous material, in part magmatic and in part derived from the schist itself. No facies of the Idaho Springs formation that can be safely interpreted as a metamorphosed conglomerate has been observed in the Montezuma quadrangle.

Microscopic features.—A microscopic study of the Idaho Springs formation shows that the schistosity is developed chiefly through the parallelism of sillimanite and biotite crystals. The general elongation of quartz and feldspar in the direction of the schistosity is also an important factor, but the schistose structure becomes more and more clearly defined as the proportion of sillimanite or biotite becomes greater.

The most common minerals in the schists, named in the order of their abundance, are quartz, biotite, orthoclase, oligoclase, and sillimanite. Locally hornblende, magnetite, garnet, muscovite, sericite, tourmaline, and epidote (much of it near clinozoisite in composition) become prominent, and some of them, such as magnetite and sericite, are nearly everywhere present, though usually in small amounts. Zircon, titanite, apatite, and rutile are common accessory minerals.

Quartz occurs in granulated, sheared, and interlocking crystals showing wavy extinction. The size of the grains usually ranges from 0.1 to 2.0 millimeter, but in exceptional occurrences quartz crystals may reach a length of 1.0 centimeter. The quartz found in the schists near the western border of the quad-

rangle contains few fluid inclusions, but the quartz in the schists near the eastern border are crowded with hairlike lines of liquid and gas inclusions. In some of the liquid inclusions minute cubes of salt that exhibit Brownian movement can be seen.

Biotite occurs in bladelike crystals, many of which are much frayed at the ends. Some green biotite has been found, but most of that present is the brown variety. In a few places the biotite contains radioactive inclusions surrounded by pleochroic halos. Most of the biotite is fresh, but some crystals are partly altered to chlorite, magnetite, and sericite. (See pl. 6, B.)

Sillimanite occurs chiefly in laminae made up of rods parallel to the direction of schistosity but is common also in confused masses intergrown with other minerals. It is in places sparsely disseminated throughout layers consisting largely of quartz, feldspar, or mica and has apparently developed by replacement. As sillimanite was formed both through regional metamorphism and through contact metamorphism, it is not surprising to find some sillimanite that has replaced other minerals. Although needles of sillimanite penetrate all the other essential minerals of the schist, it has more commonly replaced biotite and muscovite than quartz or feldspar. Medium-grained muscovite is common in the sericitic quartz schists, and large crystals occur in many of the sillimanite schists. Sagenitic rutile and skeletal ilmenite crystals were observed in some of the muscovite, but most of it is free from inclusions. In many of the slides biotite and muscovite are contemporaneous, but a little muscovite is apparently secondary to the biotite. Orthoclase is the predominant feldspar and is in places micropegmatitically intergrown with quartz. The chief plagioclase found in the schists is an albite-oligoclase. Microcline and andesine occur rarely. Locally the feldspars show wavy extinction, and this is most pronounced in the strong gneissic rocks. Sericite is common as a fine-grained matrix in the quartz schists and as an alteration product of the feldspars in the feldspathic schists and gneisses.

STRUCTURE AND ORIGIN

During the study of the Idaho Springs formation in the Montezuma quadrangle the writer reached the conclusion that the schistosity is nearly everywhere parallel to the bedding planes of the original sediments. J. T. Stark and F. F. Barnes, working in the schists of the Sawatch Range, to the west, and M. F. Boos, studying the pre-Cambrian of the Rocky Mountain National Park, to the north, informed the writer that they had reached a similar conclusion. It is well known, however, that planes of schistosity may not be parallel to bedding planes, and for this reason little attention was given to the structure of the schist in earlier studies of the region.

¹⁰ Bastin, E. S., op. cit. (Prof. Paper 94), p. 29.

Some observers have recently found that lit-par-lit injection of sediments usually converts them into schists and gneisses whose schistosity is parallel to the bedding planes of the original sediments.¹¹ As there is reason to believe that most of the schistosity of the Idaho Springs formation was developed during a period of batholithic invasion and that lit-par-lit injection occurred on a large scale, the writer has given special attention to the detailed structure of the schist and has found that schistosity coincides with bedding throughout the quadrangle. The cause of this coincidence is discussed in the following paragraphs.

The main processes active in the formation of schist, according to Leith,¹² are granulation, recrystallization, rotation of grains through differential movement of adjacent layers, gliding on crystallographic planes, slicing, and coarse fracturing. These processes result in a mineral aggregation whose dimensional arrangement is nearly parallel, and schistose or flow cleavage is a cleavage parallel to the long and short or the long and intermediate dimensions of the mineral grains.

Recrystallization is commonly the result of solution and deposition almost in place, and it becomes more and more active and rapid as moisture and heat increase. The other processes all result from some form of shearing and can be ascribed to differential pressure. Although differential pressure is commonly the chief factor in the formation of schists, the texture and coarseness of grain are largely dependent on the conditions of temperature and moisture. The physical and chemical properties of the rock, the original arrangement of minerals, and the length of time involved are also important factors.

In the absence of heat and moisture, differential pressure does not readily cause the formation of large bodies of schist. Sediments may be intensely crumpled with no appreciable rotation of the mineral grains and without recrystallization, and, as a consequence, flow cleavage is lacking in many strongly folded beds. If a long-continued differential pressure should act on sediments after they were closely folded, tending to elongate them in one direction and to shorten them in another, flow cleavage would slowly develop parallel to the direction of elongation, even in the absence of heat and moisture as important contributing factors. The cleavage of roofing slate has evidently been developed in this way. The direction of elongation is essentially that of the flow lines in a viscous body deformed by differential pressure. Recrystallization takes place, and the new crystals grow in the direction of relief of pressure. The crystals are minute in slates, but if heat and moisture increase, recrystallization becomes more active, larger crystals grow, and a phyllite or even a schist develops. Many forms of flow cleavage, including slaty cleavage, are clearly inde-

pendent of bedding, and if the final result is a schist, schistosity is also independent of bedding, although in most places there will be a general parallelism between bedding and foliation in the limbs of folds. This parallelism reflects the tendency of limbs of folds to be perpendicular to regional compression in closely folded sediments. Where slaty cleavage has been imposed on closely folded sediments, the cleavage is generally the same over wide areas and is rarely contorted and closely folded itself. The slate belt of Pennsylvania affords a good example of metamorphism of this type.

During strong folding there is a varied differential movement between competent and incompetent beds. If deformation takes place at moderately high temperatures and pressures in the presence of moisture, schist may develop without any intermediate stage of slaty cleavage. Recrystallization takes place in the direction of greatest relief, which coincides with the flow lines of the material. During simple folding the beds have differential movement on the limbs but show no movement relative to one another on the crests of folds. As the folds become isoclinal with vertical axes, the flow of material from the thinning limbs to the swelling crests may be considerable, and the flow lines in the crests will on the whole be nearly parallel to the axes of the folds. If, however, the crests, instead of rising vertically, move sideways, forming overturns and fan-shaped folds, they will pass into material formerly on the limbs of the folds. The flow lines of the deformed material would then be complex but should be roughly parallel to the bedding of the contorted sediments. The countless minor folds and contortions in the Montezuma quadrangle indicate much flowage, and the fact that the elongate minerals follow the minor crumplings without being granulated suggests their development during the period of flowage. The development of schistosity under such conditions is essentially a dynamic process, in contrast to slaty cleavage and schistosity, which develop under much more static conditions.

Bedding planes themselves are original cleavage surfaces or partings, and the original minerals of a sediment tend to have a marked dimensional arrangement parallel to them. This arrangement would be increased by shearing along the bedding planes, and under favorable conditions of heat and moisture, recrystallization and crystal growth would take place quickly and would rapidly accentuate the original rock cleavage. Differential movement would be at a maximum in interlayered plastic and brittle beds. The injection of countless thin seams of water-rich magma along the bedding planes (lit-par-lit injection), would raise the temperature, increase the moisture content, and produce layers differing greatly in plasticity from the original sediments. Such conditions would be ideal for the rapid development of schistosity parallel to the bedding of a crumpling mass of sediments.

¹¹ Ross, C. P., and Butler, B. S., personal communication.

¹² Leith, C. K., Rock cleavage: U.S. Geol. Survey Bull. 239, pp. 65-76, 1905.

The contorted appearance of the Idaho Springs formation (pl. 6, *A*) and the abundance of lit-par-lit injections suggest that such conditions were present during its development. In this formation there is a concordance between the occurrence of certain recognizable sedimentary zones and the planes of schistosity, and the structure of the schist as interpreted from the dips and strikes of the schistosity is inferred to represent approximately the structure of the ancient sediments.

SWANDYKE HORNBLENDE GNEISS

Distribution and name.—The Swandyke hornblende gneiss, which overlies the Idaho Springs formation, is the chief metamorphic rock in the west half of the quadrangle. It was called the "hornblende gneiss" by Patton,¹³ who studied the Montezuma district in 1908. The studies of the writer in the Montezuma quadrangle and the regions to the north and south have shown that the formation is very extensive on the west side of the Front Range and should be recognized by a distinctive formation name. It is typically developed in the southern part of the Montezuma quadrangle, near the "ghost town" of Swandyke, on the Middle Fork of the Swan River, and it is proposed to recognize this region as the type locality of the formation. Accordingly the "hornblende gneiss" of Patton is here named the "Swandyke hornblende gneiss."

Structure.—The general strike of the Swandyke gneiss and of its schistosity is north to northwest, and its general structure is isoclinal, as shown in plate 4, section *D-D'*. In the southern part of the quadrangle its prevailing dip is to the east or northeast through most of the large syncline that the gneiss occupies, but its eastern contact with the Idaho Springs formation dips west at an average of about 70°. In the central part of the quadrangle, a few miles south of the Snake River, the gneiss has been thrown into a series of anticlines and synclines that trend from north to northeast. Owing to its position in a southward-plunging syncline the gneiss thins rapidly north of the Snake River and disappears a short distance north of the South Fork of the Williams River. It reappears a short distance to the northwest, and about 3 miles north of the Montezuma quadrangle it enters the west side of the Fraser quadrangle, where it crops out in a wide belt running northeast nearly to Fraser.

Lithology.—The Swandyke gneiss consists of hornblende gneisses and schists with some interlayered quartz schists, all intimately injected by pegmatite, aplite, granite, and granite gneiss. These granitic rocks make up almost 50 percent of the main area in which the formation is exposed. Where the intrusions are abundant the schists and gneisses are commonly so contorted that it is impossible to observe any relation to a regional structure. Where the intrusions are

less abundant, however, the direction of schistosity is remarkably uniform over large areas.

The most common variety of the Swandyke gneiss, well exposed in the type locality, is a medium-grained greenish-gray hornblende gneiss. It is banded parallel to the schistosity, owing to a slight segregation of feldspar and hornblende in alternate bands, but both minerals are abundant throughout the rock. On fresh fracture the gneiss has a conspicuous pepper and salt appearance, caused by the dark-colored hornblende crystals lying in a groundmass of gray plagioclase. On Glacier Mountain and in Keystone Gulch the hornblende gneiss grades into a diorite gneiss containing biotite as the chief ferromagnesian mineral. In a few places the hornblende gneiss passes into a dense chloritized greenstone.

The schists are of secondary abundance and are usually interlayered with the hornblende gneiss in lenticular masses from 5 to 100 feet thick and rarely more than a few hundred yards in length. Quartz schists and feldspathic quartz-biotite schist are more common than hornblende schist, but in some places layers of nearly pure hornblende schist occur. Garnet is rather common in both the hornblende and the biotite schist. No muscovite, sillimanite, or chlorite schists have been observed in the Swandyke gneiss.

On joint surfaces the gneiss weathers a dark green, but where the formation is exposed on cliffs the color is commonly a dull earthy brown or a dull grayish green. Against this background the intrusive pegmatites, aplites, and granites stand out as light-buff or pinkish seams and masses, which cut the darker-colored schists and gneisses into irregular blocks of greatly varying size.

Injection gneiss is developed in the schist facies of the Swandyke gneiss wherever pegmatitic or aplitic intrusives are abundant. The massive hornblende gneiss is a less favorable host rock for the thin lit-par-lit intrusions that produce injection gneiss, but in many places thin sills are so abundant that the rock must be classed as injection gneiss. In plate 7, *A*, typical exposures of the Swandyke gneiss are shown.

Hornblende and andesine are the chief minerals of the Swandyke gneiss and together make up over 90 percent of most of the dark bands in the formation. The schistosity is parallel to alternating bands of hornblende-rich and feldspar-rich seams; the long axis of the hornblende crystals and the cleavage are generally parallel to the plane of schistosity, but most of the feldspars have random orientations. The plagioclase and hornblende crystals commonly range from 0.2 to 0.4 centimeter in length. Some quartz is usually present in the dark bands, and it may make up a third of the rock in the light-colored bands. As hornblende and andesine decrease biotite and microcline usually increase. Where microcline is abundant the plagioclase is generally albite-oligoclase. A pa-

¹³ Patton, H. B., The Montezuma district in Summit County, Colo.: Colorado Geol. Survey 1st Rept., for 1908, pp. 123-124, 1909.

ite, magnetite or ilmenite, titanite, zircon, and some pyrite are common accessory minerals.

Origin.—The petrology of the formation indicates that it is a metamorphosed igneous rock intermediate between gabbro and diorite in composition. The Swandyke gneiss is essentially conformable with the enclosing Idaho Springs formation. In most places the contact between the two formations is gradational, but just south of the Montezuma quadrangle the base of the Swandyke hornblende gneiss is marked by a persistent bed of banded magnetite jasper. At most places a very coarse-textured garnet-epidote rock lies between the jasper and the hornblende gneiss. Schistose quartzite or "quartz gneiss" is interbedded with the hornblende gneiss a few miles southwest of Hall Valley, and some of the hornblende gneiss nearby weathers with a patterned surface suggesting the fragmental structure of a schistose volcanic breccia. The jasper and quartz gneiss are clearly of sedimentary origin, and it is believed that the intervening layers of hornblende gneiss were originally surface flows of andesitic composition. The areal relations shown on plate 3 suggest a thick series of lavas whose lower members were contemporaneous with the upper beds of the Idaho Springs formation.

Distinct intrusive relations were not found in the Montezuma quadrangle, but half a mile southeast of Whale Peak, just south of the mapped area, a dike of biotite-hornblende schist cuts quartz gneiss that is interbedded with hornblende gneiss. The dike cuts the quartz gneiss at a marked angle to the gneissic structure, but the schistosity of the dike is parallel to its own walls. The dike was probably formed in the same general period of volcanic activity as the andesitic lavas that make up the bulk of the Swandyke hornblende gneiss. According to Ball¹⁴ hornblende gneiss cuts the Idaho Springs formation at some places in the Georgetown quadrangle, but the dikes of hornblende gneiss observed in the Montezuma quadrangle are gneissic facies of the quartz diorite, which was nearly contemporaneous with the Pikes Peak granite. Intrusive hornblende gneiss was also found in the schists of the Central City quadrangle by Bastin,¹⁵ who mapped them as Archean quartz diorite; he found no hornblende gneiss that was earlier than granite gneiss. Granite gneiss is clearly later than the Swandyke gneiss in the Montezuma quadrangle, and it seems probable that some of the intrusive relations of the hornblende gneiss noted by Ball belong to dikes originating long after the Swandyke gneiss.

ALGONKIAN SYSTEM

QUARTZ MONZONITE GNEISS

Distribution and structure.—The quartz monzonite gneiss is not abundant in the Montezuma quadrangle,

although some large bodies occur in the Georgetown quadrangle and one of them extends a short distance into the Montezuma quadrangle south of Leavenworth Creek. A poorly exposed mass of quartz monzonite gneiss intrudes the Swandyke gneiss on Keystone Mountain. A small mass of the quartz monzonite gneiss is exposed on the Loveland Pass road about 1½ miles north-northwest of the pass. It is intrusive into the Idaho Springs formation and probably also into the Swandyke gneiss. It grades into the Swandyke imperceptibly in most places, however, and can be distinguished only by the appearance of biotite and disappearance of hornblende, although it is commonly more massive than the hornblende gneiss. Where it intrudes the Idaho Springs formation remote from the Swandyke gneiss, its contacts are parallel to the schistosity of the schists, and it shows intense penetration of the schist through lit-par-lit injection. It is probable that much of the early lit-par-lit injection of the schists, so instrumental in their metamorphism, was accomplished by this quartz monzonite magma.

Lithology.—The quartz monzonite gneiss is a moderately dark gray medium to coarse grained gneiss which is locally porphyritic. The most abundant minerals are smoky quartz, andesine or calcic oligoclase, biotite, microcline, orthoclase, and hornblende. Megascopic crystals of magnetite, pyrite, and titanite are visible in many places, and most thin sections show zircon and apatite as additional microscopic accessory minerals. Much of the feldspar and quartz shows marked granulation and some recrystallization. The minerals are aligned parallel to the gneissic structure, which is marked by alternating layers rich and poor in biotite. In many places schist inclusions are abundant. Their schistosity is always parallel to that of the gneiss, and streamers of biotite extend out from many of the inclusions into the enclosing rock, where they gradually fade out and are indistinguishable from the biotite-rich layers not obviously related to schist inclusions. Most of the inclusions have been intensely injected by the quartz monzonite magma, and in some places only a shadow of the former inclusion is left. It is apparent that assimilation was locally an important factor in determining the composition of the quartz monzonite gneiss.

GRANITE GNEISS

Distribution and structure.—Granite gneiss is abundant in the Georgetown quadrangle, but only a few masses have been found in the Montezuma quadrangle. It occurs in the region between the North and Middle Forks of the Swan River, on the ridge between Keystone Gulch and Soda Creek, and on Bear Mountain. The granite gneiss nearly everywhere follows the schistosity of the enclosing schists or gneisses, but in some places it cuts across the schistose structure. Small masses are lenticular or sill-like in form, but the contact of large bodies that have broken through schists

¹⁴ Ball, S. H., op. cit. (Prof. Paper 63), p. 45.

¹⁵ Bastin, E. S., op. cit. (Prof. Paper 94), pp. 32-33.

is very serrate and irregular, and innumerable apophyses feather out along the schistosity of the country rock. In some places it forms sills that are directly related to the formation of injection gneiss. The contact between the granite gneiss and the Swan-dyke hornblende gneiss is usually gradational, the granite gneiss passing into injection gneiss and this in turn into hornblende gneiss.

Lithology.—The granite gneiss comprises metamorphosed granite, aplite, and pegmatite, but gneissic aplite or fine-grained gneissic granite is the predominant rock. Most of it is a light-gray even-grained rock consisting largely of quartz and feldspar. Mica is rarely prominent, but biotite is usually present in small amounts, although in some of the formation the chief dark-colored mineral is magnetite. Locally muscovite occurs in large crystals, and facies containing garnet are common. The granite gneiss is more siliceous than the later granites and pegmatites and on fresh fracture has a sugary appearance. When examined with a hand lens the quartz grains are seen to be slightly granulated, a condition not found in the orthogneissic facies of the later granitic rocks.

The microscope shows that the quartz has been subjected to strain but has not been so extremely crushed and recrystallized as the quartz in the older formations. There is little tendency for the quartz or feldspar to occur in bands, and the texture is essentially granitoid. The biotite and muscovite, however, are parallel to the gneissic structure and occur in short strings of frayed and shredded crystals. Orthoclase and microcline are both common but rarely exceed quartz. Oligoclase is present in most of the formation and locally it is the only feldspar. Sodic granite gneiss of this type occurs on the northeast spur of Bear Mountain. Apatite, magnetite, and zircon are always present in small amounts, and here and there clear crystals of garnet can be seen.

The gneissic structure is due to the parallelism of the mica, the slight granulation of the quartz and feldspars, and the original parallel orientation of feldspars and quartz which occurs in some places. The structure is most prominent on the outer borders of granite gneiss bodies, and complete recrystallization is found only here.

QUARTZ DIORITE AND HORNBLENDITE

Distribution and structure.—The Algonkian quartz diorites and associated hornblendites are very sparsely distributed in the Montezuma quadrangle, although moderately abundant in the Central City and Georgetown quadrangles, where they were mapped as "Archean quartz diorite." It is now believed that the quartz diorites are of Algonkian age (see p. 11), and they are so classified in this report. Dikes and small irregular masses cut the Idaho Springs formation northwest of Silver Plume, near Argentine Pass and Mount

Edwards, and in the southern part of the quadrangle near the head of Sawmill Gulch.

Lithology.—Most of the Algonkian quartz diorite is a dark-colored medium or coarse-grained rock having a mottled black and white appearance. As it ranges in composition from a hornblendite through diorite and quartz diorite to a nearly pure anorthosite, its color ranges from greenish black to light gray. The darker facies of the formation commonly occur in dikes or near the borders of small stocks and usually have a well-developed gneissic structure. In some places, as in the dikes northwest of Silver Plume, they have been converted into hornblende schist. The central parts of the irregular masses of diorite and quartz diorite are usually massive or have a faint orthogneissic character, but the edges generally show a banded structure and some evidence of mashing. Although great variations in composition occur, most of the formation is a calcic quartz diorite resembling a coarse-grained gabbro, and as some augite is almost invariably present, many parts of the formation poor in quartz might properly be called gabbro.

Plagioclase (generally labradorite), hornblende, biotite, and quartz are the essential minerals, and in some places orthoclase or augite becomes an abundant constituent of the rock. Ilmenite, apatite, magnetite, titanite, and pyrite are common accessory minerals, and rutile and zircon are locally present. In the gneissic facies the biotite is aligned parallel to the schistose structure, the hornblende, plagioclase, and quartz are slightly segregated in bands, and the quartz and some of the feldspars show a pronounced wavy extinction.

According to Ball¹⁶ the quartz diorite grades into the so-called †"Archean quartz monzonite" (Pikes Peak granite) near St. Marys Lake but cuts it in other places. He accordingly favors the hypothesis that both rocks are differentiation products from the same magma but that the quartz diorite separated after most of the magma had solidified as quartz monzonite. Bastin,¹⁷ on the other hand, states that the relations of the granite gneiss and the quartz diorite suggest that the two rocks are of nearly the same age and may have come from a common source. As indicated on pages 13 and 49, the writer believes that the granite gneiss, quartz diorite, quartz monzonite, and Pikes Peak or †Rosalie granite belong to the same general period of magmatic invasion and that there is comparatively little difference in the age of the different rocks, although the granite gneiss is probably slightly older than the others.

PIKES PEAK GRANITE

Distribution and structure.—The Pikes Peak granite is found only in the southeastern part of the Montezuma

¹⁶ Ball, S. H., op. cit., p. 56.

¹⁷ Bastin, E. S., op. cit., p. 33.

zuma quadrangle but occupies a little more than half of the Georgetown quadrangle, where it has been mapped as †Rosalie granite and †Archean quartz monzonite. It extends southward at least 80 miles to the southern border of the Pikes Peak quadrangle, forming a belt of granite from 10 to 30 miles wide. The contact of this batholith with the enclosing schists and gneisses is moderately smooth and regular, and few stocklike protrusions are found in the region bordering the large mass. Near the north end of the batholith, however, some isolated masses of Pikes Peak granite occur a short distance away from the main body. Dikes of typical Pikes Peak granite are very rare, although at many places the granite grades into pegmatites that pass into dikes. When the border is examined in detail, however, many pegmatitic tongues can be found extending into the surrounding schists, and partly assimilated inclusions of the older rocks are very abundant in the monzonitic border facies.

Lithology.—The typical Pikes Peak granite is a coarse-grained granular pink rock, consisting largely of microcline and quartz. Porphyritic masses have been found in a few places and pegmatitic facies are common. Near the borders of the large masses an orthogneissic facies usually occurs, differing slightly in composition from the central granite. As the border of the granite is nearly everywhere parallel to the schistosity of the enclosing formations, the movement of the magma developed flow structure, which for long distances almost coincides in strike and dip with the nearby schists. This border facies is a gray, moderately coarse grained, slightly porphyritic rock, usually containing abundant biotite.

The typical pink Pikes Peak granite contrasts strongly with much of the gray, slightly gneissic quartz monzonite border facies, and Ball mapped them as separate formations; but complete gradations from one rock into the other can be found at many places between Summit Lake, in the Georgetown quadrangle, and Bruno Gulch, in the southeastern part of the Montezuma quadrangle. The orthogneissic structure of the quartz monzonite border facies is caused by the flow structure of the feldspars and biotite and to a less extent by the parallelism of the numerous imperfectly assimilated schist inclusions. The chief difference in composition between the two rocks lies in the relative abundance of biotite and oligoclase. With a decrease in these minerals and an increase in microcline, the quartz monzonite assumes the pink color of the typical Pikes Peak granite, and where the flow structure is not evident the two rocks are indistinguishable. The perfect gradation from one type of rock to the other shows that they are genetically related and that part of the Pikes Peak granite and part of the quartz monzonite are contemporaneous. The regional relations indicate that the quartz mon-

zonite is a border facies of the Pikes Peak batholith and is slightly earlier than the bulk of the granite. Although both rocks are coarsely granular, the quartz monzonite is finer grained than the granite. The feldspars in the quartz monzonite commonly range from 0.5 to 2 centimeters in length and those in the typical Pikes Peak granite usually range from 1 to 5 centimeters in length.

Under the microscope the Pikes Peak granite is found to be an uneven-grained, coarsely granitoid rock consisting chiefly of microcline, quartz, orthoclase, oligoclase, and biotite. Much of the microcline is microperthitic, and microcline, orthoclase, and oligoclase contain abundant inclusions of blood-red hematite. Quartz rarely shows any evidence of granulation and occurs both as xenomorphic crystals and as micropegmatitic intergrowths with feldspar and biotite. Hematite inclusions are much less abundant in the quartz than in the feldspars. Biotite commonly occurs in interstitial subhedral blades, and the bent, ragged crystals common in the older rocks are absent. Where hornblende is present, it occurs as individual columns or as intergrowths with biotite. It is most abundant in the monzonitic border facies of the granite. Magnetite, apatite, and zircon are the most plentiful accessory minerals, but locally titanite, allanite, and pyrite were also found. Muscovite is rare.

Age.—Samarskite from Devils Head, 37 miles east-southeast of the Montezuma quadrangle, probably occurring in miarolitic cavities in the Pikes Peak granite, has been analyzed and the lead, uranium, and thorium determined with considerable precision. The lead-uranium ratio indicates that the age of the mineral is approximately 1,025,000,000 years. This age corresponds to early middle Algonkian time.¹⁸ The Pikes Peak granite is definitely older than the Silver Plume granite, which cuts it at many places. It is believed to have formed near the middle of a batholithic cycle that commenced with the intrusion of the quartz monzonite gneiss and ended with the intrusion of the finer-grained facies of the Silver Plume granite.

SILVER PLUME GRANITE

Distribution and structure.—The Silver Plume granite crops out extensively in the north half of the quadrangle, covering a rudely triangular area whose apex is at Keystone and whose base extends along the northern boundary from a point 2 miles east of the northwest corner to a point 1½ miles west of the northeast corner. This mass is part of a small batholith that extends several miles north into the Fraser quadrangle. In the eastern part of the Montezuma quadrangle a narrow southwestward-trending body of granite stretches from Silver Plume to Mount Edwards, and isolated masses occur at several places, chiefly in the southeast quarter of the quadrangle.

¹⁸ Holmes, Arthur, The age of the earth: Nat. Research Council Bull. 80, pp. 338, 438-441, 1931.

The Silver Plume granite has sharp straight contacts with the older rocks at many places and probably followed fault lines and fracture zones more commonly than the older intrusive rocks. Inclusions of schist are common in the batholithic mass, and where they are abundant the schistosity is usually concordant in the different masses. It is probable that both roof pendants and xenoliths are present and that overhead stoping was an important factor in the invasion of the granite, although probably less important than in the development of the Pikes Peak batholith.¹⁹ Dikes of Silver Plume granite are rare, as the narrower masses are usually the pegmatitic facies discussed on page 15. In general, the granite occurs as a batholithic mass, small stocklike masses or irregular tongues from the batholith.

The type locality of the Silver Plume granite is only a mile east of the Montezuma quadrangle, and large masses of the rock extend across the border. Thus the correlation of the granite in the Montezuma quadrangle with the Silver Plume granite can be made with certainty. The Santa Fe and Bear Mountain granites of Patton²⁰ are both correlated with the Silver Plume granite by the writer.

Lithology.—Most of the Silver Plume granite is a pinkish-gray medium-grained, slightly porphyritic biotite granite. A conspicuous feature of the granite is the general parallelism of the subhedral to euhedral feldspar crystals. As there is no granulation except in shear zones, the alinement of the feldspars is a primary structure due to movement in the magma after the formation of crystals. This flow structure is very pronounced near the borders of moderately large stocks, where the granite is commonly porphyritic; here lathlike phenocrysts from 1 to 3 centimeters in length give this facies a striking appearance—the “corn rock” of the miners. The size of the crystals in the large masses of the granite, however, generally ranges from 0.25 to 1 centimeter. The parallel arrangement is confined almost entirely to the feldspars, and biotite and muscovite rarely show any parallelism. In Geneva Gulch, and a few other localities, however, small masses of Silver Plume granite have a pronounced orthogneissic structure developed through the alinement of both biotite and feldspars.

Differences in color caused by changing proportions of the minerals make some facies appear to be different formations, but gradations can be found between the normal Silver Plume granite and these variants. Some of the granite contains no mica except muscovite, and in the northern part of the quadrangle, near Hassell Lake, widespread chloritization has given a large mass of this muscovite granite a strong greenish cast. In some places hornblende is abundant, and with an increase in the amount of oligoclase present the granite becomes dark colored and has a dioritic

appearance, but this facies is rare. The Bear Mountain granite of Patton differs from his Santa Fe granite in being coarser-grained and containing biotite but no muscovite, whereas his Santa Fe granite carries both muscovite and biotite. (See pl. 11, A.) A calcic porphyritic differentiate grades into the granite in some places and cuts it at others. This rock was found only in a few places in the northern part of the quadrangle.

Orthoclase and microcline together usually make up more than half of the Silver Plume granite, quartz from 15 to 30 percent, and oligoclase about 15 percent. The amount of biotite and muscovite varies greatly. Only a few specimens were found in which mica made up as much as 20 percent of the rock. Blood-red inclusions of hematite such as those observed in the Pikes Peak granite are very rare in the Silver Plume granite, but a few orange-red laths were found in the early, coarse-grained border phases of the large stocks. Orthoclase and microcline usually occur in subhedral crystals from 2 to 5 millimeters in length and contain inclusions of quartz and oligoclase. Both oligoclase and quartz generally show much smaller grain size than the potash feldspars, although at some places large crystals of oligoclase are abundant. Micrographic intergrowths of quartz and the feldspars occur at the borders of some of the large feldspar crystals. Biotite is generally a late mineral and occurs in small interstitial flakes between the feldspar. Muscovite is usually present in larger crystals than biotite where both minerals are found in the same rock. The usual chloritic and sericitic alteration products of the essential minerals are present in most of the slides studied. Apatite, zircon, magnetite, and rarely rutile and titanite are accessory minerals.

PEGMATITES

Distribution and structure.—Pegmatite is abundant in the Idaho Springs formation, in the Swandyke gneiss, and near the borders of stocks and batholiths of Pikes Peak granite and Silver Plume granite. Small irregular masses and short dikes of pegmatite are common in the interior of the batholith in the northern part of the quadrangle, but much more pegmatite occurs near its edge than near the center. The general distribution of the larger pegmatite masses is shown on plate 3, but because of the irregularity of outline of many of them and the occurrence of much pegmatite as a labyrinthine network of innumerable closely spaced seams and dikes surrounding irregular fragments of schist and gneiss, an accurate picture of the pegmatites cannot be given on a map, and much generalization is necessary.

The bulk of the pegmatite and aplite is interlayered with the schists and gneisses of the Idaho Springs formation and the Swandyke gneiss and occurs in seams whose width ranges from less than an inch to several feet. These seams have many branches which

¹⁹ Ball, S. H., op. cit., p. 52.

²⁰ Patton, H. B., op. cit., pp. 126-128.

cut irregularly across the schistosity of the enclosing rock, and both the seams and their branches are cut by many dikes and irregular masses of later pegmatite. (See pl. 7.) The contact of the sill-like masses of pegmatite with the schists and gneisses is sharp at some places but is indefinite at others, where the walls have been partly assimilated or replaced by the pegmatite magma. Most of the pegmatite dikes are less than 10 feet wide and persist for less than a thousand feet, but a few are as long as half a mile. The pegmatites that occur in granite areas have sharp contacts with the enclosing rock at most places, but gradational contacts are not uncommon. Individual masses of pegmatite cut cleanly across the granite in some places and merge with it in others.

The structural relations of the pegmatites to themselves and to other rocks indicate that their intrusion took place through a long period. Ball²¹ recognized four different periods of pegmatite formation—an early period contemporaneous in a general way with the intrusion of the Swandyke hornblende gneiss, when pegmatites formed in greatest abundance; a second period broadly contemporaneous with the intrusion of the pre-Cambrian quartz diorite; a third period contemporaneous with the final solidification of the Silver Plume granite; and a fourth period of intrusion later than any of the others. The structural relations observed by the writer indicate that aplites and pegmatites were intruded after the formation of the Swandyke gneiss but before the intrusion of any other rock, that much of the granite gneiss is pegmatitic, that the pegmatites associated with the border facies of the Pikes Peak granite (the so-called "Archean quartz monzonite" of Ball), with the main mass of the Pikes Peak granite, and with the Silver Plume granite are in part contemporaneous and in part later than these granites.

Lithology.—Microcline is the predominant mineral of the pegmatites, but sodic plagioclase and quartz are also abundant. Biotite, muscovite, and magnetite are common but generally form only a small part of the total mass. The mineralogy of the pegmatites of different ages is not distinctive enough to permit mapping them separately, and all have been shown by one symbol on the geologic map. Certain characteristics are worthy of note, however.

The early aplite and pegmatite seams that inject the Idaho Springs formation and the Swandyke gneiss consist chiefly of quartz and oligoclase, or quartz and microcline. Many lenticular masses of pegmatitic quartz several feet wide and a few rods long occur in the Idaho Springs formation. They are probably contemporaneous with the early lit-par-lit pegmatite and aplite injections and are believed to be related to the magma that formed the Algonkian quartz monzonite gneiss. The pegmatites associated with the Pikes

Peak granite and its monzonitic border facies contain a variety of minerals. Oligoclase, microcline, quartz, biotite, muscovite, and magnetite are abundant, and orthoclase, tourmaline, garnet, allanite, epidote, corundum, sillimanite, scapolite, and hornblende occur locally. Not all the minerals of this second group have been found in the Montezuma quadrangle, but the few that were not observed have been reported by Ball²² from localities nearby in the Georgetown quadrangle. Oligoclase is more common than potash feldspar in the pegmatites related to the monzonitic border facies of the Pikes Peak granite batholith, and the reverse is true of the later pegmatites, which were approximately contemporaneous with the Pikes Peak granite itself. In the southeastern part of the quadrangle, near Kirby and Smelter Gulches, pegmatites that are probably related to the nearby stocks of Pikes Peak granite but may be related to small masses of Silver Plume granite contain tourmaline, garnet, sillimanite, and muscovite in addition to the ubiquitous quartz and microcline. Black tourmaline crystals as much as 2 inches in diameter and 4½ inches long are locally abundant in the pegmatites, and finer-grained tourmaline is common in the surrounding schists. Tourmaline is one of the earliest minerals of the pegmatites and the latest mineral of the schists. Microcline, which is later than the tourmaline, is earlier than quartz but much less abundant. Muscovite, in separate crystals and intergrown with sillimanite, is probably in part contemporaneous with quartz and in part later. Garnet is definitely later than quartz in many places but may be earlier than quartz at others. Sillimanite occurs in rosettes and fibrous mats between crystals of quartz, tourmaline, and orthoclase. Many crystals of tourmaline and orthoclase are partly replaced by sillimanite, which is evidently one of the latest minerals of the pegmatite. Some of the bladed sillimanite crystals are as much as half an inch long. Magnetite is locally abundant in the pegmatites of this part of the quadrangle, and on the ridge north of Kirby Gulch some dikes contain about 20 percent of it. Both quartz and orthoclase are earlier than the magnetite.

The pegmatites associated with the Silver Plume granite are generally simpler in their mineralogy than those associated with the rocks of the Pikes Peak granite batholith. Microcline is more abundant than quartz in these later pegmatites and is generally early. Biotite is present in nearly all the pegmatites that cut the Silver Plume granite, and magnetite is common. Many of these late pegmatites are banded, having a central seam of quartz and biotite bordered by massive pink feldspar.

Although there are many exceptions to the rule, the broad generalization that the mineralogy of the pegmatites is directly related to the character of the

²¹ Ball, S. H., op. cit., pp. 60, 61.

²² Ball, S. H., op. cit., p. 62.

country rock, first made by Ball,²³ has been substantiated by the writer's work in the Montezuma quadrangle.

Most of the pegmatites have biotite but little or no muscovite where they cut granite masses and contain muscovite but no biotite where their walls are schist. The tourmaline-sillimanite pegmatites occur in quartz-sillimanite-tourmaline schists. In the Georgetown quadrangle²⁴ pegmatites containing allanite are restricted to the monzonitic border facies of the Pikes Peak granite, which contains allanite as an original constituent. The pegmatites found in the hornblende gneisses and schists of the Swandyke gneiss contain much biotite and some hornblende but rarely contain primary muscovite. Where a persistent dike of pegmatite crosses the contact of such dissimilar rocks as granite and quartz-sillimanite schist, the mineralogic relations noted above are generally well shown, and the dike that contains biotite within the granite mass contains both biotite and muscovite near the schist contact and has muscovite but no biotite a few hundred feet away from the granite.

SEDIMENTARY FORMATIONS

The unmetamorphosed sedimentary rocks of the Montezuma quadrangle are all post-Cambrian and occur in the southwest quarter. Rocks of Paleozoic and Mesozoic age probably have a maximum thickness of 5,300 feet near Keystone. The Paleozoic rocks do not crop out within the quadrangle but underlie the later rocks not far below the surface where the Snake River crosses the western boundary. The sediments have been described in another report,²⁵ where some of the details of the stratigraphy near Breckenridge are more fully discussed than in the present paper. Most of the sediments lie in the northeastern part of the Breckenridge district, which was mapped by Ransome and Bastin in 1908,²⁶ and the writer has used their map with but few changes. In the Breckenridge district the sediments are so intricately cut by intrusive rocks that the stratigraphy is obscure, but along the Snake River west of Keystone the rocks are less disturbed, and a satisfactory section is exposed.

CARBONIFEROUS SYSTEM (PENNSYLVANIAN (?) AND PERMIAN SERIES)

MAROON FORMATION

Although the Maroon formation does not crop out within the Montezuma quadrangle it is exposed less than a mile to the west along the Snake River and from 1 to 2 miles beyond the southwest corner on

²³ Ball, S. H., op. cit., p. 64.

²⁴ Idem, p. 62.

²⁵ Lovering, T. S., Geology and ore deposits of the Breckenridge mining district, Colo.: U.S. Geol. Survey Prof. Paper 176, pp. 4-14, 1934.

²⁶ Ransome, F. L., The geology and ore deposits of the Breckenridge district, Colo.: U.S. Geol. Survey Prof. Paper 75, pl. 1, 1911.

Gibson Hill and along the Blue River. Its easterly dip implies that it extends beneath the western part of the quadrangle. South of the quadrangle, however, it thins rapidly eastward and is overlapped by the Morrison, and probably this structural condition continues beneath the quadrangle, as suggested in sections *B-B'* and *C-C'*, plate 4.

The exposures along the Snake River comprise about 100 feet of red and green micaceous shales overlain by the nonmicaceous beds of the Morrison formation. The base is not exposed. On Gibson Hill the formation is about 700 feet thick and includes a great variety of beds that change in character within short distances. At the Owl tunnel, on Gibson Hill, where the contact with the pre-Cambrian is shown, thick beds of bouldery conglomerate alternate with black shale in the basal part; near the Sultana mine, a mile northwest of the Owl tunnel, the basal bed is a gray grit 2 feet thick and is overlain by a thick bed of bright-red micaceous sandy shale. The Maroon formation has received considerable study by the writer during his 6 years of work in the Front Range and other parts of Colorado and the regional relations of the formation are discussed elsewhere.²⁷

JURASSIC SYSTEM (UPPER JURASSIC SERIES)

MORRISON FORMATION

The Morrison formation, like the Maroon, is exposed west and south of the Montezuma quadrangle. It also thins out eastward and is overlapped by the Dakota quartzite, but it is believed to underlie the western part of the quadrangle, as shown in sections *B-B'* and *C-C'*, plate 4. It consists of nonmicaceous variegated shales and light-colored sandstones that have a maximum thickness of 350 feet west of the quadrangle. These beds overlap the Maroon and are separated from it by an erosional unconformity whose irregularities are of small size. Their contact with the Dakota quartzite is abrupt in some places, but in others it is marked by a gradational zone of alternating quartzites and shales as much as 20 feet in aggregate thickness. For a detailed description the reader is referred to the writer's paper on the Breckenridge district.²⁸

CRETACEOUS SYSTEM (UPPER CRETACEOUS SERIES)

DAKOTA QUARTZITE

Distribution and stratigraphic relations.—The Dakota is a persistent formation in Colorado. In the Montezuma quadrangle it consists chiefly of quartzite, being composed of a massive basal quartzite, a thin-bedded shaly quartzite, and a medium-bedded quartzite. The formation ranges from 20 to 225 feet in thickness. It is essentially parallel to the underlying Morrison forma-

²⁷ Lovering, T. S., and Johnson, J. H., Meaning of unconformities in stratigraphy of central Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 353-374, 1933.

²⁸ Lovering, T. S., op. cit. (Prof. Paper 176).

tion and the overlying Benton shale, but it overlaps the Morrison and rests upon pre-Cambrian rocks in the southwestern part of the Montezuma quadrangle near the Swan River. The formation is 200 feet thick at Boreas Pass, 6 miles south of the southwest corner of the quadrangle, but thins rapidly as it is followed northeast. In Georgia Pass, $2\frac{1}{2}$ miles south of the quadrangle and 4 miles north-northeast of Boreas Pass, the Dakota quartzite if present is only 20 feet thick and is represented by a bed of quartzite and conglomerate that has its sedimentary contact with the Swandyke hornblende gneiss well exposed.

The thinning and successive overlap of the Maroon, Morrison, and Dakota formations eastward in the Breckenridge region has been interpreted by Ransome²⁹ and by the writer³⁰ as reflecting the gradual submergence of a highland that occupied much the same area as the present Front Range. It seems probable that the Dakota quartzite was not deposited in the region a short distance northeast of Georgia Pass, and it is possible that the thin quartzite found in the pass is stratigraphically higher than the upper Dakota beds farther west and should properly be classed as the basal member of the Benton shale. Detailed studies have not been made in this region, however.

Lithology.—The Dakota quartzite exposed on the east slope of the Swan River Valley (see pl. 3) is estimated to be between 20 and 50 feet thick and probably consists of only a single massive bed. Farther west, near the southwestern boundary of the quadrangle, the formation has three distinct members and is from 100 to 160 feet thick. There is no place in the quadrangle where a section of the formation can be measured, however, and the thickness must be inferred from information gathered outside. The Dakota is about 225 feet thick in the Snake River section $1\frac{1}{2}$ miles west of the quadrangle; about 100 feet thick on Prospect Hill, a mile southwest of the quadrangle; 175 feet thick at Rocky Point, 3 miles south of the quadrangle; and, as stated above, not more than 20 feet thick at Georgia Pass.

In the region southwest of the quadrangle the Dakota commonly comprises an upper and lower quartzite separated by a carbonaceous shale. The shale member disappears farther east, however, and only a single massive layer of quartzite is present. The three members are well exposed and easily distinguishable at Rocky Point, south of Breckenridge. They are well exposed in the Snake River section, but only one member can be recognized on Prospect Hill and in the region farther east.

Where three members are present the lowest is predominantly massive light-gray quartzite and ranges

in thickness from 75 to 120 feet. Gritty or conglomeratic beds are commonly found near the base, and a few thin beds of gray or rarely black shale are nearly everywhere present in the basal part of the formation. These shale beds are not persistent, however, and individual beds may thin and disappear in short distances. The middle member is the most variable in lithology. It contains more shale than any other part of the formation, but the individual shale beds are lenticular, and the thickness of the member ranges from 5 to 96 feet but in most places is less than 60 feet. Both black and gray shales are common, and the thin-bedded quartzite layers of this member are more commonly dark-colored or black than those in other parts of the formation. The upper member comprises massive and thin-bedded light-colored quartzite, separated by shale partings, and ranges in thickness from 10 to 30 feet. For more details of lithology the reader is referred to the writer's report on the Breckenridge district.³¹ The lithology of the Snake River section given below is characteristic of the region, but the thickness of the middle member is much greater than that found to the east and south.

Section of the Dakota quartzite $1\frac{1}{2}$ miles west of Keystone
Feet

Benton shale: Black shale with a thin basal conglomerate containing pebbles half an inch to 2 inches in diameter of chert, quartzite, micaceous red sandstone, schist, and granite-----	1
Dakota quartzite:	
Upper member:	
Medium-bedded gray quartzite-----	10
Thin-bedded gray quartzite-----	5
Massive light-gray quartzite-----	32
Middle member:	
Black shale-----	13
Massive gray quartzite-----	1
Thin-bedded shale and quartzite-----	3
Massive quartzite-----	25
Interbedded black shale and thin- to medium-bedded light- and dark-gray quartzite-----	50
Lower member:	
Massive gray sandy quartzite-----	16
Hard massive gray quartzite, conglomeratic at base-----	69
	224

Morrison formation: Fissile gray-green shales----- 10

Topographic expression.—The Dakota quartzite is the only prominent cliff-forming sedimentary rock in or near the Montezuma quadrangle. Nearly everywhere that the formation has a thickness of more than 50 feet it crops out in steep, cliffy slopes. As the hard, resistant quartzite is overlain by soft shales, erosion tends to remove the overlying formations from the Dakota, leaving it as a bare hill whose surface is essentially a dip slope. The anticlinal structure of the

²⁹ Ransom, F. L., op. cit. (Prof. Paper 75), p. 182.

³⁰ Lovering, T. S., op. cit. (Prof. Paper 176), p. 8.

³¹ Lovering, T. S., op. cit. (Prof. Paper 176).

Dakota between Keystone and Dillon is clearly expressed in the topography, as shown in plate 7, *B*. Where the formation is thin, it rarely crops out in a cliff, as the thick black shales that overlie it readily disintegrate and bury its outcrop with slope wash. In such places the presence of the formation is betrayed by numerous scattered blocks of quartzite a short distance below.

Correlation.—No fossils that could be identified have been found in the Dakota near the Montezuma quadrangle, although fragmentary plant remains are abundant near the base and in the carbonaceous shales of the middle member at many places.

The distinctive lithology of the formation, however, and its presence immediately below beds of definite Benton age show that it must be correlated with the

quartzite at the base of the Benton shale suggest a transition.

The Benton shale persists beneath the Niobrara formation throughout the southwestern part of the Montezuma quadrangle, as shown in the structure sections of plate 4. Some sliced masses of Benton shale occur near the Williams Range thrust fault a short distance north of Tiger but have not been separated from the Niobrara limestone on the geologic map.

Lithology.—In the Montezuma quadrangle the Benton shale is about 350 feet thick, but good sections are rare. Although poorly exposed, it can be measured with fair accuracy on the north side of the Snake River a mile west of the western boundary of the quadrangle. The basal conglomerate, containing pebbles of all the older formations, is easily found at the top of the

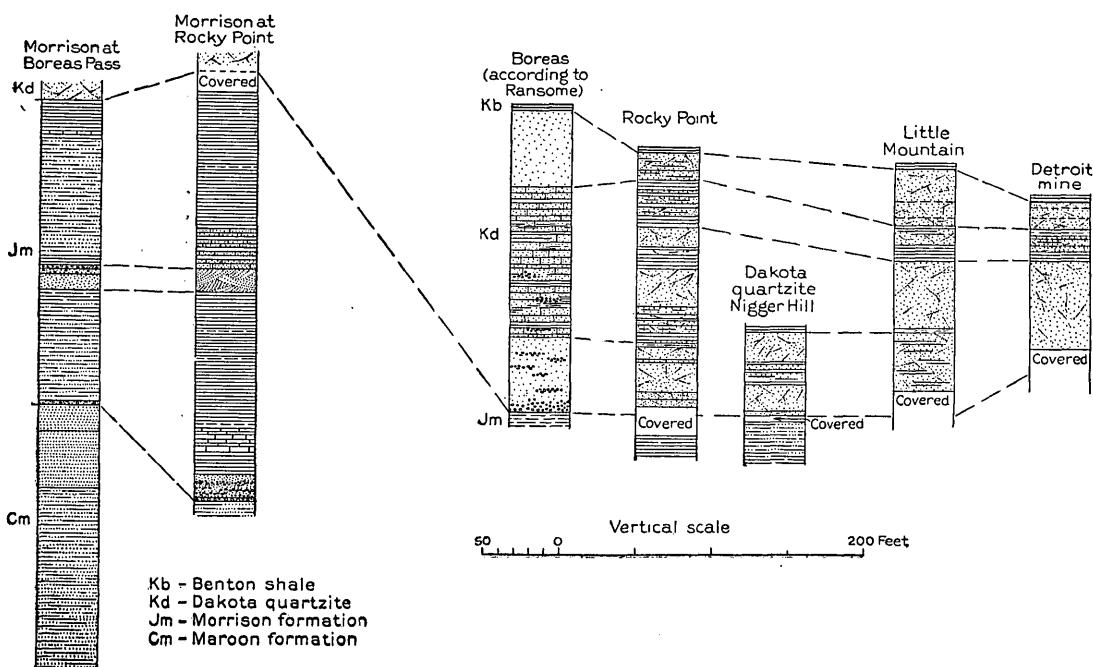


FIGURE 3.—Correlation of sections measured from Boreas Pass to Keystone.

Dakota formation of central and eastern Colorado. It is the most persistent and easily recognized formation in the State, and its regional correlation is shown in figure 3.

BENTON SHALE

Distribution and stratigraphic relations.—The black Benton shale is commonly from 300 to 400 feet thick, and in central Colorado it overlies the Dakota quartzite everywhere that it has not been removed by erosion. It crops out in a northward-trending belt a short distance west of the Montezuma quadrangle. Its contact with the underlying Dakota quartzite is marked locally by a bed of conglomerate from 6 to 18 inches thick, but it is conformable with the overlying Niobrara limestone. The contact with the Dakota is generally sharp, but in some places in the extreme southwestern part of the quadrangle a few thin beds of

Dakota quartzite, and the limestone that marks the upper limit of the formation crops out in a low ridge a short distance northeast, but the beds between these exposures are concealed. The lithology of the Benton is best studied in the railroad cut just northeast of Rocky Point, about $3\frac{1}{2}$ miles south of the southwest corner of the quadrangle. At this locality the lower 300 feet of the Benton shale is exposed, by far the thickest visible outcrop in the region, and though disturbed by intrusions of quartz monzonite porphyry and locally overturned, its general character can be determined. The upper part of the Benton can be seen in the railroad cut on Nigger Hill at the north end of the railroad trestle crossing Illinois Gulch, about 0.8 mile north of Rocky Point.

In this region the lower part of the Benton is commonly black fissile shale from 30 to 50 feet thick, but

in some places a layer of gray shale from 5 to 15 feet thick intervenes between the Dakota quartzite and the black shale. Locally a few thin beds of quartzite are present near the base of the formation. Between the lower black shale and a horizon about 250 feet above the base the shale, though dark, has a marked grayish cast, ranging from dark gray to grayish black, and is moderately fissile. Thin-bedded black shales and limestone alternate for about 35 feet above the grayish-black shales and are overlain by about 50 feet of black fissile shale. Capping the fissile black shale is a bed of shaly limestone about 25 feet thick. It is a fetid black limestone, probably in part the equivalent of the †Niobenton sand of the oil-well drillers of North Park. It seems to include the top of the Benton shale and the base of the Niobrara formation, for Niobrara fossils have been obtained near Breckenridge from the shales at the top of the limestone, which itself yields typical Benton forms. In the Snake River section Niobrara fossils were found in the top of a limestone whose base is black, fetid, and unfossiliferous and is 370 feet above the Dakota quartzite. The lower part of this limestone is believed to belong to the Benton shale. The general character of the Benton and its relation to the other formations are shown in figure 4.

Topographic expression.—The Benton shale is generally marked by a smooth depression between an escarpment of Dakota quartzite and the low ridge of dark-colored limestone that marks the base of the Niobrara formation.

Correlation.—Benton fossils have not been collected in the Snake River section. In the top of the formation at the railroad trestle in Illinois Gulch, near Breckenridge, *Inoceramus fragilis* Hall and Meek and *Prionocyclus wyomingensis* Meek were found by the writer and identified by J. B. Reeside, Jr. According to Reeside, these forms are typical of the upper Benton (Carlile fauna). Ransome³² collected *Ostrea lugubris* Conrad, *Inoceramus fragilis* Hall and Meek, and *Scaphites warreni* Meek and Hayden in a thin dark fetid limestone 500 feet north of Rocky Point. They were regarded as upper Benton forms by T. W. Stanton, who identified them. In the Tarryall district, 10 miles south of the Montezuma quadrangle, Muilenberg³³ found the forms listed above and in addition obtained specimens of *Inoceramus labiatus* Schlotheim, *Inoceramus dimidiatus* White, and *Trigonalonga depressa* White.

The Benton shale was first mapped as a separate unit in the region near the Montezuma quadrangle during the restudy of the Breckenridge district in 1928, although its presence was recognized earlier by Ransome and by Muilenberg. Benton fossils have been found at many localities west of the Front Range,

and it is now evident that the Benton shale is persistent for long distances to the north, west, and south of Breckenridge, but it has been comparatively little

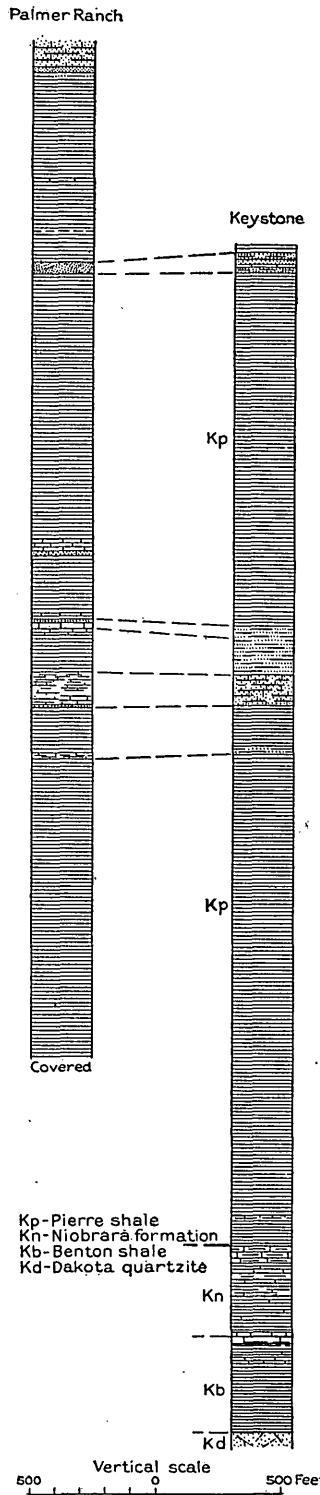


FIGURE 4.—Correlation of sections measured at Palmer ranch and Keystone.

studied in this region. Spurr³⁴ found 350 feet of black calcareous shale of Benton age underlying the Ni-

³² Ransome, F. L., op. cit., p. 41.

³³ Muilenberg, G. A., Geology of the Tarryall district, Park County, Colo.: Colorado Geol. Survey Bull. 31, p. 27, 1925.

³⁴ Spurr, J. E., Geology of the Aspen mining district, Colo.: U.S. Geol. Survey Mon. 31, p. 41, 1898.

brara limestone at Aspen, 50 miles west of Breckenridge. Eldridge³⁵ found 150 to 300 feet of black shale and interbedded fetid limestone of Benton age in the Crested Butte quadrangle, 60 miles southwest of the Breckenridge district. The Benton fauna found in the Tarryall district by Muilenberg was in black bituminous shale and fetid limestone overlying the Dakota quartzite.

Henderson³⁶ assigns a thickness of 300 to 400 feet to the Benton in the Rabbit Ears district and in the vicinity of Kremmling. According to drill records the Benton is 550 feet thick in North Park, near Walden, but Beekly gives the thickness as ranging from 100 to 200 feet and probably averaging about 165 feet.³⁷ In North Park the Benton shale consists of three distinct members—a lower black shale, an intermediate gray limy shale, and an upper sandy shale.

The correlation of the Benton shale in several districts in central Colorado is shown in plate 3 of Professional Paper 176.

NIOBRARA LIMESTONE

Distribution and stratigraphic relations.—The Niobrara limestone is about 350 feet thick and comprises the dark-colored shaly limestones and limy shales that overlie the Benton shale. It is present beneath the Pierre shale throughout the southwestern part of the quadrangle and crops out a short distance west of the western boundary on the north side of the Snake River. Broken masses of the formation occur at several places along the west side of the Williams Range thrust fault and at the mouth of Summit Gulch. Other outcrops of the Niobrara formation may be present in the part of the quadrangle that is covered by the northwest quarter of the Breckenridge geologic map, as most of this area was not remapped by the present writer, and Ransome did not separate the Niobrara from the Pierre and Benton formations. The Niobrara is conformable with the overlying Pierre shale and the underlying Benton shale, and its upper and lower limits are not sharply marked.

Lithology.—The Niobrara formation, so far as the writer knows, is not well exposed in any accessible locality near the Montezuma quadrangle, but information gathered in the Breckenridge district indicates its general character. Its base is commonly a gray limestone from 10 to 30 feet thick that rests upon the thin brown fetid uppermost limestone of the Benton shale, but locally the lowermost beds are calcareous shales. The formation is rather uniform for 250 feet above the base and is chiefly greenish-gray limy shale but contains some interbedded clay shale and sandy

shale. The upper 50 feet of the formation is made up of thin-bedded black limy shale and thin-bedded limestone containing abundant lenses and veinlets of secondary white calcite. Near the Snake River a persistent *Ostrea*-bearing limestone about 1 foot thick occurs 285 feet above the base. The general character of the formation is shown in the columnar section in figure 4.

Topographic expression.—The basal limestone commonly forms a low ridge that rises 15 to 25 feet above the floor of somber-colored shales adjoining it. The calcareous member at the top of the formation seldom weathers in relief, but its presence is usually indicated by abundant fragments of secondary calcite at the surface.

Correlation.—The Niobrara formation was known to occur in central Colorado, in the region near the Montezuma quadrangle, but prior to the restudy of the Breckenridge district it had not been separated from the Pierre and Benton shales. It is conspicuous near Kremmling, 40 miles northwest of Dillon, and was reported from that locality by Henderson³⁸ in 1913. A Niobrara fauna was found in the Tarryall district by Muilenberg,³⁹ but he did not separate the formation from the other Upper Cretaceous shales.

Ransome found imperfectly preserved specimens of *Inoceramus deformis* in the basal limy beds of the Niobrara 1,500 feet southeast of the summit of Little Mountain, close to a railroad cut. The following fauna was collected by the writer from the basal limestone of the Niobrara formation on the north side of the Snake River 1½ miles west of Keystone and was identified by J. B. Reeside, Jr.:

Inoceramus aff. *I. subquadratus* Schluter.
Ostrea aff. *O. congesta* Conrad.
Baculites sp.
Globigerina sp.

Inoceramus deformis Meek was found by the writer in a dark limestone near the Williams Range thrust fault in the southern part of sec. 13, T. 6 S., R. 77 W.

In the Snake River section, three-quarters of a mile west of the western boundary of the Montezuma quadrangle, the calcareous beds definitely belonging to the Niobrara formation are 350 feet thick. The somber-colored clay shales overlying these beds contain very few limy layers and are poor in fossils. Fragments of *Hypsylon*, *Ostrea*, and *Baculites* were found in a thin limy layer 125 feet above the calcareous beds of undoubted Niobrara age, but as the species could not be determined it is impossible to state the age of this layer definitely. The lithology is more characteristic of the Pierre than the Niobrara, and the writer believes that the top of the calcareous beds 350 feet above the Benton shale coincides with the top of the Niobrara formation.

³⁵ Eldridge, G. H., U.S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.

³⁶ Henderson, Junius, Reconnaissance of the geology of the Rabbit Ears region, Routt, Grand, and Jackson Counties, Colo.: Colorado Geol. Survey Bull. 5, p. 31, 1913.

³⁷ Beekly, A. L., Geology and coal resources of North Park, Colo.: U.S. Geol. Survey Bull. 596, p. 35, 1915.

³⁸ Henderson, Junius, op. cit., pp. 31-32.

³⁹ Muilenberg, G. A., op. cit., p. 28.

In the Anthracite-Crested Butte area the rocks called "Niobrara limestone" consist of a limestone bed about 30 feet thick overlain by about 150 feet of calcareous gray shale. At Aspen these rocks are said to be about 100 feet thick and to grade upward into shales of Montana age without any perceptible break. In North Park, according to Beekly,⁴⁰ the average thickness of the Niobrara formation is about 800 feet. Well records later confirmed this estimate. The formation in this region, as well as in the country to the south, is made up of a basal thin-bedded limestone overlain by interbedded calcareous and clay shales, locally capped by a thin limy sandstone.

The correlation of the Niobrara formation in several districts in central Colorado is shown in plate 3 of Professional Paper 176.

PIERRE SHALE

Distribution and stratigraphic relations.—The thick somber-colored shales of Montana age that lie above the Niobrara formation in the Montezuma quadrangle and the nearby region are identified with the Pierre shale of eastern Colorado. They border the pre-Cambrian rocks in the southwestern part of the quadrangle. At the junction of the North Fork of the Snake River with the main stream, a considerable area of silicified Pierre shale is exposed in a "window" in the warped surface of the Williams Range thrust fault. A short distance to the south a similar "window" occurs in Jones Gulch. The structural relations at these places are shown in plate 4, sections *B-B'* and *C-C'*.

The contact of the Pierre and Niobrara is identified as the top of the calcareous sediments of the lower part of the Cretaceous section, but no unconformity was observed. The upper limit of the Pierre shale in the Montezuma quadrangle is marked by the irregular surface of the Williams Range thrust fault, which has brought pre-Cambrian rocks onto the upper Pierre. In South Park the marine shale of Montana age is conformably overlain by an unfossiliferous coal-bearing formation that Washburne⁴¹ designated "Laramie." Although abundant coaly fragments are present in the uppermost beds of the Pierre shale in Middle Park, the sandstones directly below the Eocene Middle Park formation contain marine fossils and are of Pierre age.⁴² In the regions where a younger Cretaceous formation is present, it rests conformably on the Pierre shale.

Lithology.—The Pierre shale is about 4,000 feet thick in the Montezuma quadrangle, and its original thickness was much greater. In the Snake River section, which was measured a short distance north of the Snake River near Keystone, the Pierre is 3,975 feet thick, and

the upper limit is the Williams Range thrust fault. Twenty miles northwest of Keystone, about 4,800 feet of Pierre lies beneath the Williams Range thrust fault. Sections made at these places are shown in figure 4.

The formation is predominantly dark olive-brown shale but contains a few thin beds of limy sandstone. It is well exposed on the Snake River west of Keystone and at many places on the Blue River between Dillon and Kremmling. The thin-bedded black or dark olive-brown clay shale that makes up the lower 1,850 feet of the formation contains very few fossils and no persistent beds distinguishable through differences in color or lithology. Above the thick lower shale there are several moderately persistent beds of sandy or shaly fossiliferous limestone. As shown in plate 8, *A*, these beds are from 10 to 50 feet thick and commonly crop out in low ridges or cliffs. Three, four, or five of these limy beds commonly occur within a few hundred feet, interbedded with shale of the same appearance as that found below. Another thick shale member lies above the shaly limestones and is overlain by a persistent sandstone at a horizon about 3,800 feet above the Niobrara. This sandstone is very close to the thrust fault in the region near Keystone, but farther northwest a shale member about 650 feet thick is found above it and is capped by a bed of white sandstone about 100 feet thick. Further details of the lithology are given in the following sections measured at Keystone and at the Palmer ranch, 20 miles to the northwest.

Section of Cretaceous formations on north side of Snake River near Keystone

Algonkian (?) schist, in fault contact with Pierre shale.
Montana group (Upper Cretaceous):

Pierre shale:	Feet
Black fissile shale	20
Black sandy shale	10
Greenish-gray limy sandstone	25
Dark gray sandstone	15
Interbedded shaly gray sandstone and shale	30
Black and dark olive-brown shale	1,400
Greenish-gray sandy shale	200
Thin-bedded fossiliferous limy brownish-gray sandstone, ridge-forming member	120
Fissile gray limy shale	150
*Hard sandy and limy shale ⁴³	30
Black or dark olive-brown and dark-brown clay shales, in part fissile	1,850
Slightly limy brown shale containing fossil fragments, interbedded with blue-black noncalcareous shale	10
Blue-black fissile clay shale	115
	3,975

Colorado group:

Niobrara limestone:

Blue-gray limy shale containing abundant secondary calcite	30
Fissile blue-black limy shale containing several beds of coarse gray limestone 1 to 2 inches thick	30

⁴³ Probably equivalent to bed marked * in the Palmer ranch section.

⁴⁰ Beekly, A. L., op. cit., p. 39.

⁴¹ Washburne, C. W., The South Park coal field, Colo.: U.S. Geol. Survey Bull. 381, p. 309, 1910.

⁴² Lovering, T. S., The Granby anticline, Grand County, Colo.: U.S. Geol. Survey Bull. 822, p. 72, 1930.

Section of Cretaceous formations on north side of Snake River near Keystone—Continued

Colorado group—Continued.

Niobrara limestone—Continued.

Fissile gray limy shale separated from overlying bed by 3-inch layer of white calcite	Feet	40
Shale, largely covered		240
Dark grayish-black thick-bedded dense fossiliferous limestone		10
		350
Benton shale:		—

Thin-bedded bluish-gray limestone grading downward into purplish limy shale	30
Covered, but mostly black shale with bed of conglomerate 10 inches thick at base	340
	370

Dakota quartzite: Massive and medium-bedded fine-grained gray quartzite

47

Section of Cretaceous shales exposed above Palmer ranch, on northeast side of Blue River about 20 miles northwest of Dillon

Pre-Cambrian gneiss thrust over Cretaceous rocks.

Pierre shale:

Dark-gray limy sandstone	100
Massive soft white sandstone	25
Dark sandy shale	25
Black fissile shale	400
Dark-gray limestone	2
Black fissile shale	200
Fissile gray shale	118
Medium-bedded fossiliferous cross-bedded light-brown sandstone	50
Dark-colored shale containing a few thin limy layers near base	1, 100
Thin-bedded brown sandy limestones with thin shale partings	25
Dark-gray shale	225
Medium-bedded gray limy shale	10
Dark-gray shale	10
Thin-bedded, slightly oolitic limy sandstone	10
Thin-bedded grayish-brown limestone	10
Medium-bedded light-brown limestone (cliff-forming)	15
Grayish-black limy shale	15
Medium-bedded brown shaly limestone, a cliff-forming member	10
Black shale	150
Thin-bedded limestone and dark-gray limy shale	125
Medium-bedded light-brown sandy limestone	10
Fissile grayish-black shale	180
*Thin-bedded gray sandy limestone, cliff-forming member, with shale partings ⁴⁴	20
Fissile grayish-black shale with a few $\frac{1}{4}$ -inch layers of limestone at the base	1, 160
	3, 995

Topographic expression.—The soft shales of the Pierre weather into broad valleys and smooth slopes. (See pl. 7, B.) The hard pre-Cambrian rocks that lie on top of the Pierre shale in Tenderfoot Hill, just north of Keystone, and in the ridge east of Soda Creek protect the shale from erosion, but even on their

moderately steep slopes outcrops of shale are rare. The shaly limestones near the middle of the formation form low ridges and cliffs a short distance west of Keystone. These ridges and the subdued topography characteristic of the associated shales are shown in plate 8, A.

Correlation.—The following table lists the fossils found by the writer in making the sections shown above and gives the distance above the Niobrara formation at which they were collected. The fossils were identified by J. B. Reeside, Jr.

Keystone section:		Feet
Macra aff. M. nitidula Meek and Hayden	—	2, 200
Inoceramus barabini Morton	—	2, 200
Baculites ovatus Say	—	2, 200
Cliona sp.	—	2, 300
Inoceramus sagensis Owen	—	2, 200, 2, 300, 3, 930
Baculites ovatus Say var. haresi Reeside	—	2, 600

Palmer ranch section:

Ostrea aff. O. larva Lamarck	—	4, 650
Inoceramus aff. I. barabini Morton	—	3, 800
Pteria linguaeformis Evans and Shumard	—	3, 800
Protocardia subquadrata Evans and Shumard	—	3, 800
Dentalium gracile Evans and Shumard	—	3, 800
Baculites ovatus Say	—	2, 250, 2, 800
Baculites compressus Say (?)	—	2, 250, 2, 800, 3, 800
Inoceramus sagensis Owen	—	2, 250
		2, 800, 3, 800, 4, 650, 4, 800
Vanikoro sp.	—	1, 750
Fish scale	—	1, 750

According to Reeside the fossils listed above are all of Pierre age, and even those from the highest beds are characteristic Pierre forms. Until detailed work is done in the region between Dillon and North Park it seems unsafe to attempt to subdivide the Pierre into the units used farther north, although it is probable that the Steele shale and the Mesaverde formation are present and will eventually be separated. The correlation of the Pierre in several districts in central Colorado is shown in plate 3 of Professional Paper 176.

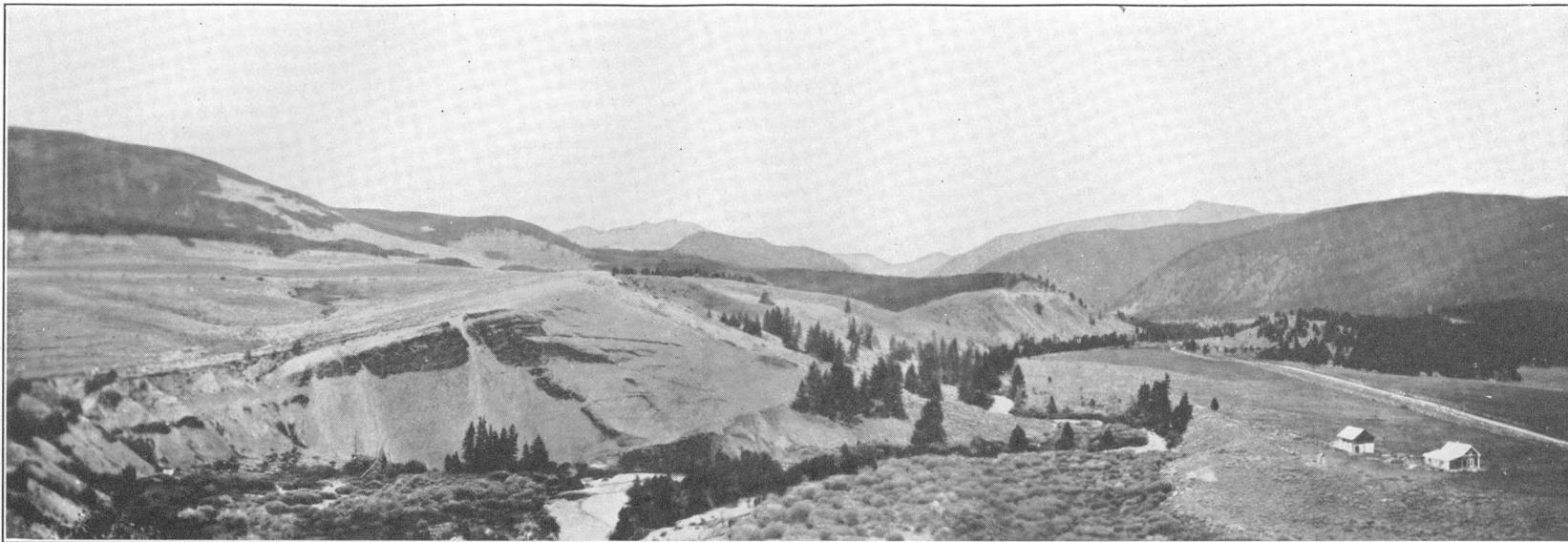
QUATERNARY DEPOSITS AND TOPOGRAPHIC EVOLUTION

Much of the present topography of the Montezuma quadrangle and the surrounding country was developed in Quaternary time, but remnants of earlier land surfaces are preserved in some places. Two Tertiary and three Quaternary erosion cycles are evident, but no deposits corresponding to the Tertiary cycles have been recognized nearby. For convenience of treatment, the different topographic stages and the deposits formed during them will be discussed together.

Eocene land surface.—By the end of Eocene time a well-developed peneplain had formed in the northern part of the Front Range,⁴⁵ where it levels the upturned Cretaceous sediments at the edge of the mountains and is cut by channels containing Oligocene sediments. In the Livermore and Home quadrangles, just south

⁴⁴ Lovering, T. S., Geologic history of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, p. 108, 1929.

* Probably equivalent to bed marked * in the Snake River section.



A. VIEW LOOKING EAST UP THE SNAKE RIVER FROM THE CONICAL SHALE HILL 1 MILE WEST OF THE MONTEZUMA QUADRANGLE.

The bluffs on the north side of the river are formed by calcareous layers in the Pierre shale. The low hill in the right middle distance is part of the terminal moraine west of Keystone. The plain in the foreground and middle distance is made by the outwash gravel from the Wisconsin glacier.



B. VIEW LOOKING SOUTH FROM THE SOUTH END OF TELLER MOUNTAIN NEAR THE CASHIER MINE.

Glacial trenching of the Flattop peneplain is well shown.



A. GLACIAL LAKE AT HEAD OF SMELTER GULCH, VIEWED FROM MOUNT LEWIS.



B. ROCK GLACIER AT HEAD OF STEVENS GULCH.

of the Colorado-Wyoming boundary, this Eocene peneplain, which can be correlated with the nearby Medicine Bow peneplain,⁴⁶ can be traced southward into the Rocky Mountain National Park, where it forms a conspicuous bench nearly 1,000 feet below the well-known "Flattop" peneplain, described by Lee.⁴⁷

The Flattop peneplain, probably developed during early Eocene time, is conspicuous in the high mountains south of the park and has been traced through the Fraser quadrangle into the Montezuma quadrangle by the writer. (See pl. 9.) It is not a horizontal surface nor even an inclined plane. At the edges of the mountains it approaches a tilted plane in its configuration, but near the center of the Front Range uplift, in the Montezuma and Georgetown quadrangles, it is a smooth but irregular surface (see pl. 8, B, and fig. 2) and may be described as a mature hilly upland. In places this upland surface has been modified to a marked extent by Miocene and Pliocene erosion, and in such places it is difficult to define sharply the essentially Eocene land surface:

The late Pleistocene glaciers trenched parts of the Flattop peneplain deeply and produced conspicuous topographic contrasts, as shown in plate 8, B. The smooth, gently sloping surfaces that form the mountain tops in the southwestern part of the quadrangle stand above steep-walled cirques and precipitous slopes that drop abruptly into U-shaped valleys whose floors are from 500 to 1,500 feet below, and remnants of the old upland in the northeastern part of the quadrangle are as much as 3,000 feet above the floors of the glacial valleys.

Basal Eocene beds occur in South Park, but no deposits of later Eocene age are known in or near the quadrangle.

Late Tertiary land surface.—On the east side of the Front Range, in the Georgetown and Denver Mountain Parks quadrangles, a maturely dissected surface lying at an altitude of 7,500 to 8,500 feet forms the edge of the mountains. This surface was described by Lee⁴⁸ as the Rocky Mountain peneplain. It probably developed during Oligocene, Miocene, and Pliocene time and represents the gradual encroachment of a piedmont plain toward the central highland. In most places the much older Medicine Bow peneplain has not been separated from the Rocky Mountain peneplain, although the two are easily distinguished on the east side of the Front Range west of Boulder and near Nederland. As the Medicine Bow surface was first recognized in that locality during the writer's study of the tungsten deposits, after the field work in the

Montezuma quadrangle had been completed, no attempt is made in the following discussion to differentiate the two surfaces. The Rocky Mountain peneplain is not well developed on the west side of the Front Range, but a maturely dissected late Tertiary land surface that is well preserved in the Breckenridge district is here correlated with it. Much of the Rocky Mountain peneplain lies between 10,000 and 11,000 feet above sea level in the southwestern part of the Montezuma quadrangle and is conspicuous in the hilltops west of Browns Gulch. As shown in plate 9, it can be recognized in the hills bordering the North Fork of the Swan River where its altitude is in general a little more than 11,000 feet. On both sides of this stream, about a mile north of Garibaldi Gulch, the relation of the Rocky Mountain peneplain to the Flattop peneplain is well shown. The younger surface is from 400 to 600 feet below the Flattop peneplain and is separated from it by a moderately steep slope. Farther north it is difficult to distinguish the effects of early Pleistocene erosion from those of the late Tertiary.

No deposits corresponding to the Rocky Mountain peneplain erosion cycle are known near the Montezuma quadrangle unless parts of the high-basin debris sheets are of this age.

Early Pleistocene topography.—Early Pleistocene glaciation was widespread in the Front Range, and remnants of the topography carved during this glacial stage can be seen in many places, although later glaciation has destroyed or modified most of the features belonging to this early stage. Many of the high-level cirques that form hanging basins tributary to deeply cut valleys, as well as the upper basins in compound cirques at the heads of glacial valleys, were formed in the early glacial stage which the writer has correlated with the early Pleistocene (Kansan?) glaciation of the plains.⁴⁹ Remnants of the valleys cut in early Pleistocene time are preserved as rock shelves as much as 1,200 feet above the floors of the present valleys. (See pl. 9.) Such rock benches are found at lower and lower levels as they are followed downstream toward the lower limit of early Pleistocene glaciation, and near the terminal moraines of this stage they may be within 100 feet of the present valley bottoms. The moraine-covered terrace 500 feet above the Snake River at Keystone is believed to be the floor of the valley carved by early Pleistocene glaciers. The writer has correlated the 160-foot terrace at Idaho Springs with the post-Kansan or Yarmouth interglacial stage,⁵⁰ although Ball⁵¹ has dismissed the

⁴⁶ Van Tuyl, F. M., and Lovering, T. S., A contribution to the physiographic history of the Front Range, Colo.: Geol. Soc. America Bull., vol. 43, p. 172, 1932.

⁴⁷ Lee, W. T., Peneplains of the Front Range and Rocky Mountain National Park, Colo.: U.S. Geol. Survey Bull. 730, p. 4, 1923.

⁴⁸ *Idem*, p. 5.

⁴⁹ Alden, W. C., and Stebinger, Eugene, Pre-Wisconsin drift in the region of Glacier National Park, Montana: Geol. Soc. America Bull., vol. 24, p. 569, 1913. Alden, W. C., Physiographic development of the northern Great Plains: *Idem*, vol. 35, p. 405, 1924.

⁵⁰ Ball, S. H., *op. cit.* (Prof. Paper 63), p. 84.

possibility that this terrace is Pleistocene, because Clear Creek has cut a canyon in bedrock 600 feet wide and 160 feet deep since its formation. Ball believed that the great size of the canyon proved that the terrace was preglacial. Work by Alden in the northern Great Plains and in Glacier National Park, however, has shown that interglacial erosion in Pleistocene time deepened the major stream valleys 1,000 feet or more. Capps⁵² estimated that Wisconsin glaciation deepened certain stream valleys from 200 to 800 feet in the Leadville quadrangle, just southwest of the Montezuma quadrangle. It thus seems that the writer's correlation of the high terraces and rock benches on Clear Creek with the early Pleistocene glacial stage is in accord with the probable amount of erosion that has occurred. The altitude of the rock benches on the north side of Clear Creek a few miles west of Silver Plume suggests that the bottom of the Clear Creek Valley in early Pleistocene time was about 1,200 feet above the present valley floor, and this is the deepest post-Kansan trenching noted in the quadrangle.

The mature topography of the late Tertiary mountainous upland was characterized by wide, gently sloping valleys, and most of the early glaciers must have been broad but relatively thin. The work of such glaciers would be greater at the sides than at the bottom and would result in forming wide U-shaped valleys that were little deeper than the original stream-cut valleys. Stream cutting in the succeeding interglacial stage probably carved moderately deep, steep-sided valleys and gorges in the bottoms of these broad glacial valleys.

Early Pleistocene deposits.—Most of the material deposited by the Kansan (?) glaciers has been removed by later erosion, but remnants of the early till occur well above the present valley bottoms in several places and are shown on plate 3. Much of this early morainic material is more weathered than the later till and is commonly covered by a heavy growth of pine. The till is made up of unsorted boulders of Tertiary intrusives and pre-Cambrian rocks in a matrix of brownish-yellow sand and sandy clay. The boulders show a great range in size, and some erratics of Montezuma quartz monzonite on the north bank of the Snake River near Keystone are 10 feet in diameter.

The high-terrace gravel deposits of the Breckenridge district were laid down by the glacier-fed streams of the early Pleistocene glacial stage and by the streams of the succeeding interglacial stage. In the Montezuma quadrangle this formation is only meagerly represented and is confined to the drainage basin of the Swan River. The bedrock floor on which the high terrace gravel was deposited is everywhere above the level of the present streams, but its altitude is variable. As shown on plate 3, the high terrace gravel in this quadrangle is only 50 to 150 feet above the streams; a few

miles farther west, however, in the valley of the Blue River, these deposits are as much as 650 feet above the valley floor and cover large areas. They are made up of well-rounded boulders and pebbles and contain little fine sand or clay. Most of the boulders are less than 12 inches in diameter, but some are as much as 30 inches. In the region west of the quadrangle quartzite, porphyry, granite, and schist are the most common rocks present in the high-terrace gravel, but micaceous red grits, red shales, and black shales also occur. Within the quadrangle the micaceous red grits and shales were not observed in these deposits. Many of the boulders are deeply weathered and can be readily broken up with a hammer.

Late Pleistocene topography.—Much of the present topography was carved in the Wisconsin glacial stage, and the most conspicuous features are due to glacial cutting, although moraines and valley trains are abundant. The line of perpetual snow in Wisconsin time was probably near an altitude of 11,000 feet in the Montezuma quadrangle, and valleys heading at lower levels were unglaciated. Frey Gulch, Keystone Gulch, and Soda Creek, in the western part of the quadrangle, are valleys of this type and lack the glacial features so common in most of the other valleys of the region.

Cirques are one of the most striking features of glacial sculpture and are abundant in the high country near the Continental Divide. They are steep-walled rock basins at the heads of streams and were formed by the plucking and abrasion of the ice near the source of former glaciers, where valley deepening from glacial erosion was at a maximum. Compound cirques are common, and the higher cirques in such places are probably relics of early Pleistocene glaciation. The headward erosion of cirques on opposite sides of a ridge may result in impassable knife-edged divides, and many examples of this type of erosion can be found in the quadrangle. The uneven rock floors of the cirques have been filled by lakes in many places. From the summit of Grays Peak, Argentine Peak, or Mount Lewis many of these glacial lakes can be seen gleaming like emeralds at the base of sheer iron-gray cliffs. The tarn and cirque at the head of Smelter Gulch are shown in plate 10, A. Although most of the lakes are caused by the uneven surface excavated by the glaciers, some of them fill depressions in the ground moraine. Swamps are more common than lakes in the deposits left by the retreating glaciers.

Hanging valleys and U-shaped valleys, typical of glacial erosion, are characteristic of the high country, and many features of ice erosion are well illustrated in the quadrangle. The effect of a marked change in the course of a glacial valley on the action of the glacier is well shown in Ruby Gulch, about 3 miles northeast of Montezuma, and is illustrated in plate 7, C. As the movement of the glacier was changed from south to due west the southeast and south side of the gulch bore the brunt of the work of redirecting the mass of

⁵² Capps, S. R., Pleistocene geology of the Leadville quadrangle, Colo.: U.S. Geol. Survey Bull. 386, p. 12, 1909.

moving ice, and the wall of the gulch was hewn almost vertical while the opposite slope of the valley was little affected. The rasplike action of boulders embedded in the moving glaciers smoothed, striated, and channeled the bedrock on the floors and sides of many valleys. Glacial striae are uncommon on the valley walls, but there are many places on the valley floors where they are fresh and well preserved. They can be easily distinguished on the smoothly polished hummocks of bedrock, as at the head of St. Johns Creek.

Late Pleistocene (Wisconsin) deposits.—Most of the valleys are occupied by thin, discontinuous bodies of alluvium, Wisconsin till, and valley-train gravel. The till includes terminal moraines, lateral moraines, recessional moraines, ground moraines, and medial moraines, but these have not been distinguished by separate conventions on plate 3. The poorly sorted material that makes up the drift is little weathered and shows a great range in size and shapes. Sub-angular boulders as much as 20 feet in diameter are intermingled with small pebbles, sandy clay, and small boulders. The till is known to be more than 100 feet thick in some places, but drill records in the till deposits near Breckenridge suggest that locally its thickness is as much as 150 feet.

The coarse gravel of the valley train was deposited by the streams issuing from the foot of the glaciers, and in many places its superposition on the till marks the later part of the glacial stage, when the glaciers were retreating toward the snowy cirques. Glacio-fluviatile deposits of this sort are most widespread on the Snake River between Keystone and Cold Spring. They consist chiefly of moderately well-rounded cobbles, small pebbles, and sand, but small boulders are rather common. The pebbles and boulders are fresh and unweathered, in contrast to those found in the high terrace gravel.

Recent topography.—Since the retreat of the Wisconsin glaciers erosion has modified the topography but little. Canyons from 10 to 30 feet deep have been cut in the bottoms of some of the large glacial valleys; landslides, rock glaciers, and talus streams have been active in some places; small alluvial fans have formed at the mouths of tributary streams in certain valleys; and many small lakes have been formed by beaver dams in the poorly drained ground moraines below 11,500 feet.

Recent deposits.—Thin strips of alluvium border the streams at many places and are commonly covered with a dense growth of Arctic willow. Swampy lake beds, in part of late Wisconsin age, occur in the poorly drained hollows of some ground moraines, notably in Geneva Gulch just east of the quadrangle. Small alluvial fans composed of moderately fine pebbly gravel and coarse sand have formed at the mouths of several side gulches that enter the Snake River

between Keystone and Soda Spring. Landslides are abundant along the oversteepened sides of the glaciated valleys. The largest landslide is on the north slope of Decatur Mountain a short distance east of the Pennsylvania mine. The rasping attack of the glacier as it swung west from the Horseshoe Basin to the main course of Peru Creek was chiefly absorbed by the north shoulder of Decatur Mountain and probably resulted in greatly oversteepening it, and when the supporting pressure of the ice was removed, a large mass of the mountain slumped into the valley. Smaller landslides occur at many other places in the quadrangle and are shown on plate 3. Slowly moving masses of angular rock fragments, generally termed rock glaciers, are forming at the foot of steep ridges in several places. They are most common in the southeastern part of the quadrangle, and the largest and most striking one occurs at the head of Handcart Gulch. The brilliantly colored slopes of Red Cone are covered with small angular fragments of the pyritized bedrock, which are constantly feeding the slowly spreading accumulation at the base. The rock glacier at the head of Stevens Gulch is shown in plate 10, B.

Pyritized slope wash in Handcart and Geneva Gulches and near the head of the Snake River has been the source of local deposits of bog iron ore. As ground water passes over the oxidizing pyrite it becomes rich in iron sulphate, which soon hydrolyzes and forms limonite. The limonite cements the slope wash and ground moraines of the valleys to a depth of 20 feet or more at some places. Most of the limonite contains so much extraneous material that it is almost valueless as an iron ore, although it was used as a flux by the Hall Valley and Geneva Gulch smelters in the seventies. The distribution of the bog iron ore is shown on plate 3. An analysis of some of the material in Handcart Gulch used by the Hall Valley smelter in 1875 showed SiO_2 7.18 percent, Fe_2O_3 67.55 percent, P_2O_5 1.82 percent, CaO 1.22 percent, H_2O and organic matter 22.37 percent.⁵³

The high basins that have been little affected by glaciation have been filled to depths of as much as 100 feet by the gradual downward creep of slope wash from the surrounding hills. Although this process is still going on, most of the material accumulated in Pleistocene time. These high-basin debris sheets are made up of unsorted, angular, more or less weathered fragments, embedded in sand and sandy clay. The slopes of the unglaciated valleys that head below 11,500 feet are covered with slope wash very similar to the high-basin debris sheets. The valley bottoms contain some material ranging in appearance from that characteristic of the high terrace gravel to that indistinguishable from the gravel of the late Wisconsin valley trains.

⁵³ Chauvenet, Regis, The iron resources of Colorado: Am. Inst. Min. Eng. Trans. vol. 18, p. 268, 1890.

CRETACEOUS (?) AND TERTIARY IGNEOUS ROCKS

GENERAL FEATURES

As the true relations of the igneous rocks of the Montezuma quadrangle and their places in geologic history can be appreciated only after a study of the entire Front Range province, the following pages are devoted to a general regional discussion, with paragraphs on the local rocks interposed at appropriate places.

Post-Cambrian igneous rocks are common in the Montezuma quadrangle and, as shown on plate 5, they are part of a belt of porphyries that is coextensive with a belt of mineralization. The late intrusive rocks of the Front Range are found chiefly in a narrow zone extending southwestward from Boulder to Breckenridge. West of Breckenridge the porphyry belt widens toward the southwest and continues across the State to the San Juan mining region. Ball⁵⁴ was one of the first to summarize the occurrences of porphyry in Colorado and, with Spurr and Garrey,⁵⁵ to point out that mineralization and intrusive activity are localized in this northeastward-trending belt. These porphyries were intruded in late Cretaceous (?) and early Tertiary (Eocene) time.

The porphyries have many features in common. Although they show a great range in texture and in mode of occurrence, they are nearly all siliceous or intermediate igneous rocks. Certain types, such as the Lincoln porphyry of the Leadville and Alma districts, are generally found in cross-breaking bodies; others, such as the monzonite of Bald Mountain, in the Breckenridge district, are more commonly found as sills. Certain porphyries have such distinctive features that they are easily recognized as one rock formation in widely separated regions. The Lincoln porphyry, for example, has been correlated with similar appearing rocks in districts 60 miles from the type locality on Mount Lincoln, Park County.⁵⁶ Attempts to correlate other porphyries have been less convincing: thus Ball⁵⁷ has correlated an alaskite porphyry, one of the latest intrusives of the Georgetown quadrangle, with the earliest of the porphyries of the Leadville district, the White porphyry. Although Crawford does not specifically correlate porphyries other than the Lincoln porphyry, he gives a general summary of his interpretation of the igneous history of central Colorado. This summary is in general accord with the conclusions of most geologists who have worked in this region and is as follows: (1) Intrusion of porphyries from great depth; (2) large-scale folding and faulting; (3) intrusion of quartz diorite in small bodies throughout a wide region; (4) batholithic invasion of quartz

monzonite; (5) minor faulting; (6) deposition of minerals emanated from the quartz monzonite magma; (7) a second intrusion of porphyries; (8) more faulting. As the result of additional study throughout a great part of the Front Range and in other parts of Colorado, a slightly more detailed and definite age sequence can now be given.

In order that the reader may have clearly in mind the igneous and structural sequence that should be established in the next few pages, the conclusions are summarized before the general discussion. The post-Cambrian igneous and related structural history of the Front Range is believed to be essentially as follows: (1) Intrusion in early Denver time (lowest Eocene) of sills and dikes of silicic felsites, notably the White porphyry of Leadville and the felsites of the Ward district; (2) gradual vertical uplift of the Front Range region, accompanied by the intrusion and extrusion throughout early and middle Denver time of calcic andesites and potassie basalts such as the interbedded basalts of Table Mountain, near Golden; the Valmont dike, east of Boulder; and the gabbro, diabase, and ultrabasic dikes of the Boulder, Central City, and Georgetown quadrangles; (3) strong folding and thrust faulting at the end of Denver time, preceded and accompanied by the intrusion of monzonitic magma, locally dioritic or granodioritic in composition, such as the Johnson Gulch porphyry of Leadville, the diorite of the Buckskin Gulch stock of the Alma district, the diorite and monzonite porphyries of Breckenridge, the dacite of the Georgetown quadrangle, and the hornblende and biotite diorites of the Central City quadrangle; (4) minor faulting followed by the intrusion of dikes and sills of porphyritic quartz monzonite such as the Evans Gulch porphyry of Leadville, the quartz monzonite porphyry (intermediate type) of Breckenridge, and the Elk Mountain porphyry of the Tenmile district; (5) faulting preceding and accompanying the wide-spread invasion of coarse-grained porphyritic quartz monzonite, mostly in stocks and dikes and rarely in sills, represented by the Lincoln porphyry, the Princeton quartz monzonite of Crawford, the Montezuma quartz monzonite, and the quartz monzonite porphyries of the Georgetown quadrangle; (6) minor faulting and the intrusion of dikes of porphyritic sodic quartz monzonite such as the alaskitic quartz monzonite porphyry of the Georgetown quadrangle and the porphyritic Brainerd quartz monzonite of the Ward district; (7) the intrusion of dikes of sodic rhyolite and porphyritic sodic granite such as the aslaskite of the Georgetown quadrangle and the porphyritic Modoc quartz monzonite of the Ward district; (8) the intrusion of porphyritic granite and rhyolite such as those of the Georgetown and Montezuma quadrangles; (9) the intrusion of alkaline syenites and trachytes such as the alkali syenite and the bostonites of the Georgetown and Central City

⁵⁴ Ball, S. H., op. cit. (Prof. Paper 63), pp. 67-71.

⁵⁵ Spurr, J. E., and Garrey, G. H., *idem*, p. 107.

⁵⁶ Crawford, R. D., A contribution to the igneous geology of central Colorado: *Am. Jour. Sci.*, 5th ser., vol. 7, pp. 365-388, 1924.

⁵⁷ Ball, S. H., op. cit., p. 70.

quadranbles and the trachyte of Sunset, in the Ward district; (10) minor faulting and the formation of gold-silver-lead-zinc-copper ores throughout the mineral belt of Colorado;⁵⁸ (11) the intrusion of felsites and related rocks, such as the rhyolite agglomerate of Leadville, the biotite latite of the Georgetown quadrangle and the biotite andesite of the Bluebird mine, near Nederland; (12) cutting of partial peneplain by the end of Fort Union time (the Flattop peneplain); (13) minor uplift in early Wasatch time and widespread peneplanation during remainder of Eocene time (formation of Medicine Bow peneplain);⁵⁹ (14) marked vertical uplift at end of Eocene time, accompanied by faulting; (15) denudation throughout Oligocene time; (16) volcanic activity throughout the Miocene in the San Juan region and periodically in the southern and north-central parts of the Front Range, locally accompanied by the formation of important ore deposits; (17) denudation and minor volcanism during the Pliocene; (18) faulting and regional uplift in early Pleistocene time, followed by strong erosion.

The igneous activity that commenced early in Denver time and continued through that epoch well into the lower Eocene is not as readily subdivided into separate stages as the summary given above might lead one to believe. As many writers have already pointed out, the porphyritic intrusives are all intimately related to one another and are probably differentiation products of one deep underlying magma. In the long period of time that the magma was active its slowly changing composition was manifested in the changing composition of successive intrusions. Definite age relations established by one type of intrusive cutting another have been recorded for most of the groups given in the foregoing summary, but only in a few widely separated localities. The trend of differentiation has been well shown at some places, and it is noteworthy that this evidence indicates the same sequence as the age relations found in distant parts of the mineral belt. There seems to be good reason to believe that petrographic similarity, where not obscured by alteration, affords an important and moderately trustworthy basis for correlation, but it is used only to supplement the method of comparing definitely established rock sequences.

ESTABLISHED RELATIONS OF THE INTRUSIVES

The earliest record of intrusive activity is found in the lower part of the Denver formation, at about 600 feet above the Laramie formation. Pebbles of light-colored silicic felsites carrying sparse phenocrysts of augite are abundant in the lower beds on South Table

⁵⁸ Burbank, W. S., Revision of geologic structure and stratigraphy in the Ouray district of Colorado and its bearing on ore deposition: Colorado Sci. Soc. Proc., vol. 12, pp. 213-232, 1930.

⁵⁹ Van Tuyl, F. M., and Lovering, T. S., A contribution to the physiographic history of the Colorado Front Range [abstract]: Geol. Soc. America Bull., vol. 43, p. 170, 1932.

Mountain.⁶⁰ The andesite pebbles in the higher parts of the Denver formation are distinctly less silicic and more calcic than those found lower down. Thus, a few hundred feet higher in the section pebbles of the light-colored andesites are followed by dark-colored varieties low in magnesia, which are typical of most of the eruptive material found both in the pebbles and in the interbedded lavas. Still more calcic andesites are reported from a horizon about 1,400 feet above the base on Green Mountain, where Cross⁶¹ found a dense pyroxene andesite containing both augite and hypersthene; this is said to be the lowest observed occurrence of the highly magnesian variety indicated by hypersthene. Interbedded lavas occur in the Denver formation above the horizon of the light-colored andesite pebbles. The analyses given in the table on pages 36-37 show that the basalts are characterized by moderately low silica and high alumina, ferrous iron, magnesium oxide, and calcium oxide.

In the Ward district, a few miles northwest of Boulder, mica dacite and felsite are probably earlier than a diabase dike, which in turn is older than quartz monzonite.⁶² In the Central City quadrangle biotite and hornblende andesites are older than biotite and hornblende diorites.⁶³ In the Montezuma quadrangle augite diorite is earlier than monzonite and porphyritic quartz monzonite. In the Leadville district the White porphyry, a silicic felsite porphyry, is older than all the other post-Cambrian intrusives.⁶⁴ The analyses of the White porphyry of Leadville and the much altered felsite porphyry of the Ward district (nos. 55-57, p. 37) show considerable differences in the composition of these two rocks, which so far as known are the oldest porphyritic rocks in their respective districts. The presence of silicic andesite pebbles in the lowest part of the Denver formation indicates that more acidic rocks preceded the normal and calcic andesites which supplied most of the early sediment to the formation. As the earliest of the porphyritic rocks in the Ward district agree in composition and sequence with the earliest eruptive material in the Denver sediments, they are believed to be of Denver age. Although the White porphyry of Leadville is more silicic than the early felsites of the Denver formation, it is grouped with them because it is the earliest porphyry of the district and is earlier than the post-Denver folding and faulting of the Laramide revolution. The age relations and the similarity in composition of the intrusive augite diorite and diabase of the Front Range to the calcic augite

⁶⁰ Cross, Whitman, Geology of the Denver Basin: U.S. Geol. Survey Mon. 27, pp. 161-171, 1896.

⁶¹ *Idem*, p. 178.

⁶² Worcester, P. G., The geology of the Ward region, Boulder County, Colo.: Colorado Geol. Survey Bull. 21, p. 46, 1920.

⁶³ Bastin, E. S., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U.S. Geol. Survey Prof. Paper 94, p. 52, 1917.

⁶⁴ Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U.S. Geol. Survey Prof. Paper 148, pp. 51-52, 1927. Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, p. 371, 1924.

andesite pebbles and the interbedded basalts of the Denver formation (nos. 44-54, p. 37) suggest that they may be correlated.

The relation of the early diorites and diabases to the rocks of the granodiorite group is shown at few places. In the main tungsten area of Boulder County diabase is clearly older than a calcic dacite.⁶⁵ As the dacite consists chiefly of andesine, orthoclase, biotite, hornblende, and augite with interstitial quartz that Crawford believes to be largely secondary, the rock belongs to the early monzonitic rocks which are included in the granodiorite group for purposes of correlation. As pointed out above, the calcic diorites are earlier than the porphyritic quartz monzonite near Montezuma also. It is worthy of note that in the Middle Park formation, whose lower part is equivalent to the Denver formation, the first pebbles of quartz monzonite porphyry noted by the writer were far up in the section, nearly 5,000 feet above the base, but in the lower beds andesitic material was abundant. The evidence, though meager, seems sufficient to place the calcic andesite and diabase groups as definitely older than the granodiorite and the quartz monzonite groups.

At Breckenridge monzonite and orthoclase-bearing diorite grade into each other and may be considered typical of the monzonite group. They are older than the quartz monzonite porphyry of this district.⁶⁶ Diorite of the same type is older than the Lincoln porphyry (quartz monzonite) of the Leadville, Alma, and Tenmile districts.⁶⁷ In the region from Breckenridge to Como the rocks of the monzonite group were intruded in large masses along the axis of a regional fold that developed during the Laramide revolution. The rocks are involved in much of the faulting that accompanied this orogeny, but some faulting and folding had taken place before their intrusion. Their age is probably later than that of the Denver formation of the type locality, but they may be contemporaneous with the upper part of the Middle Park formation. If the Laramide revolution is regarded as marking the end of the Cretaceous period, the granodiorite rocks should be called the latest Cretaceous rocks in the Front Range, but if, on the other hand, the Denver formation is an early Tertiary (Eocene) formation, as it is at present classed by the United States Geological Survey, the monzonite as well as all other post-Cambrian intrusive rocks of the Front Range were formed in the Tertiary period.

In the Breckenridge district the moderately porphyritic quartz monzonite classed by Ransome as the "quartz monzonite porphyry (intermediate type)" is

⁶⁵ George, R. D., and Crawford, R. D., The main tungsten area of Boulder County Colo.: Colorado Geol. Survey 1st Rept., pp. 23, 28-30, 1908.

⁶⁶ Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U.S. Geol. Survey Prof. Paper 75, p. 71, 1911. Lovering, T. S., Geology and ore deposits of the Breckenridge mining district, Colo.: U.S. Geol. Survey Prof. Paper 176, p. 16, 1934.

⁶⁷ Crawford, R. D., op. cit., p. 371. Emmons, S. F., U.S. Geol. Survey Geol. Atlas, Tenmile district folio (no. 48), structure-section sheets, 1898.

clearly earlier than the Lincoln porphyry.⁶⁸ Recent work in the Mosquito Range south of the Leadville district shows that a porphyritic quartz monzonite similar in appearance to the intermediate quartz monzonite porphyry of Breckenridge cuts a rock that strongly resembles the monzonite porphyry of Breckenridge.⁶⁹ These relations as well as the intermediate texture and composition indicate that the moderately porphyritic quartz monzonites, such as the Elk Mountain porphyry of the Tenmile district and the intermediate quartz monzonite porphyry of the Breckenridge district, are older than the Lincoln porphyry and younger than the rocks of the monzonite group.

In the preceding paragraphs examples have been given to show that the coarsely porphyritic quartz monzonite porphyries, typified by the Lincoln porphyry, are clearly younger than the White porphyry of Leadville, the granodiorite, and the intermediate quartz monzonite porphyries, and that rocks of similar composition to the Lincoln porphyry but of different texture cut basic diorite and diabase. Near Montezuma the large stock of coarsely porphyritic quartz monzonite cuts the Williams Range underthrust fault,⁷⁰ which was formed during the Laramide revolution, and this stock is older than the Flattop peneplain, which is believed to be of early Eocene age.⁷¹ Near Silver Plume quartz monzonite porphyry of finer texture but similar composition is cut by granite porphyry and alaskite porphyry.⁷² In the Leadville district it is cut by rhyolite dikes,⁷³ and in the Tenmile district it is earlier than the rhyolites.⁷⁴ In the Alma district the Lincoln porphyry is earlier than a felsite dike⁷⁵ and a "late white porphyry"⁷⁶ that is probably equivalent to a rhyolite or sodic quartz monzonite in composition. The Lincoln porphyry is cut by veins in many districts, but the sediments that it invades in the Montezuma quadrangle show contact metamorphism. It is evidently older than the main period of ore deposition throughout the mineral belt but is nevertheless genetically related to the mineralization. It is probably early Eocene.

Throughout the mineral belt there are many dikes whose composition is intermediate between that of the quartz monzonite porphyry group typified by the Lincoln porphyry and that of the granite and rhyolite

⁶⁸ Lovering, T. S., op. cit., p. 16.

⁶⁹ Behre, C. H., Jr., unpublished report.

⁷⁰ Lovering, T. S., The Williams thrust fault: Geol. Soc. America Bull., vol. 39, p. 173, 1928.

⁷¹ Lovering, T. S., Geologic history of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, p. 99, 1929.

⁷² Spurr, J. E., and Garrey, G. H., op. cit. (Prof. Paper 63), p. 133.

⁷³ Emmons, S. F., Geology and mining industry of Leadville, Colo.: U.S. Geol. Survey Mon. 12, pp. 198, 350, 1886. Behre, C. H., Jr., Revision of structure and stratigraphy in the Mosquito Range and Leadville district, Colo.: Colorado Sci. Soc. Proc., vol. 12, p. 43, 1929.

⁷⁴ Emmons, S. F., U.S. Geol. Survey Geol. Atlas, Tenmile district folio (no. 48), p. 3, 1898.

⁷⁵ Crawford, R. D., op. cit., p. 371.

⁷⁶ Singewald, Q. D., Preliminary report on the geology of Mount Lincoln and the Russian mine, Park County, Colo.: Colorado Sci. Soc. Proc., vol. 12, p. 396, 1930.

group. In the Georgetown quadrangle sodic quartz monzonite, according to Ball,⁷⁷ is in part contemporaneous but mostly earlier than granite aplite. Porphyritic sodic granite, the granite porphyry of Ball, is younger than porphyritic quartz monzonite at Silver Plume⁷⁸ and is earlier than the ores. Porphyritic sodic granite is also later than the Lincoln porphyry type of quartz monzonite in the Montezuma stock. These structural relations place the sodic rocks intermediate in time between the quartz monzonite and the granite aplite. Though they bear a close relation to the aplite, they are also intermediate in composition between those two rocks and are therefore in keeping with a progressive differentiation into more and more salic facies.

For the purposes of description this intermediate series has been subdivided into the group of sodic quartz monzonites and the group of sodic granites. Although the age of this series is known, the relative ages of the two groups have not been established by structural evidence. The sodic quartz monzonite group, however, because of its composition, is thought to be an earlier differentiate of the quartz monzonite magma and is provisionally regarded as earlier than the sodic granite group.

Dikes and small stocks of porphyritic granite and rhyolite are found throughout the mineral belt of Colorado. Granite porphyry and alaskite porphyry of this group are later than quartz monzonite porphyry near Silver Plume and earlier than ore.⁷⁹ In the Tenmile district the rhyolites of McNulty Gulch and of Chalk Mountain are later than diorite and Lincoln porphyry and earlier than the silver ores of the Grand Union or Silver Bowl mine.⁸⁰ Bodies of granite aplite occur in the Montezuma quartz monzonite stock, and although they nearly everywhere cut across it with cleanly defined contacts, there are some places where the two rocks grade into each other. In these places the granite is probably a local salic derivative of the stock itself and indicates the general course of differentiation of the quartz monzonite magma.

A group of moderately silicic alkalic rocks is found in the Front Range east of the Continental Divide but is unknown in the major part of the Colorado mineral belt between the Georgetown quadrangle and the San Juan region. These rocks are characterized by their high percentage of alkalies, soda and potash together always making up more than 10 percent of the fresh rock, and by moderately high alumina, which always constitutes more than 16 percent. As shown in the analyses of group 9 (p. 36), they have many other characteristics in common. Near Idaho Springs bostonite is cut by "biotite latite" that is also later than

the ores of that district.⁸¹ The bostonites on the other hand, are earlier than both the lead-zinc and the pyritic gold ores of the Central City quadrangle.⁸² Spurr believed that the alkalic syenite of the Georgetown quadrangle was the youngest Tertiary intrusive in that district, because of the fresh appearance of the rock, because hot springs were found at the edge of a small stock of the syenite near Idaho Springs, and because it was not associated with ore deposits.⁸³ However, many of the older rocks have a fresh appearance where they are not cut by veins; the hot spring in the Dyke vein, on the Argo tunnel level, is several miles from the nearest alkali syenite known; and finally the alkali syenite is less than half a mile from some veins. As only two masses of the alkali syenite are known—a small stock and a short dike close by—its lack of direct association with veins is not a strong reason for regarding it as a postmineral intrusive. Its location in the heart of a region where bostonite and bostonite porphyry dikes are abundant and the marked similarity in the peculiarly distinctive composition of the two rocks suggest strongly that they came from the same magmatic source in the same intrusive epoch. The writer believes that the bostonite and the alkali syenite are both premineral. The relations of the bostonites to the ores and to the biotite latite are all that are on record. However, the writer has found that bostonite cuts monzonite porphyry on Nigger Hill, at the western edge of Central City. The monzonite porphyry follows a northeast fissure that has been offset by the northwesterly fault followed by the bostonite porphyry, the northeastern segment of the monzonite porphyry moving about 60 feet northwest of the southwestern segment. The bostonite porphyry is very fresh in spite of its premineral age, but the monzonite porphyry is much altered. The bostonites are thus definitely later than the monzonite porphyries and earlier than the ores of the Central City district.

In the Rosita Hills district, 110 miles south of Idaho Springs, Cross established the order of eruptions for the Rosita volcano.⁸⁴ The successive changes in chemical composition indicated by the rocks in that district are very close to those indicated by the rocks of the porphyry belt that crosses the Montezuma quadrangle. The earliest eruptive rocks, the Rosita and Bunker andesites, were of intermediate composition and were followed successively by more calcic diorite, a more silicic dacite, a still more silicic rhyolite, an alkalic andesite, and finally a trachyte. None of these rocks have the characteristic high alumina and combined alkalies found in the rocks of the alkalic group of the porphyry belt, but some of the andesite that followed the rhyolites contains as much as 10.32 per-

⁷⁷ Ball, S. H., op. cit. (Prof. Paper 63), p. 74.

⁷⁸ Spurr, J. E., and Garrey, G. H., *ibid.*, p. 133.

⁷⁹ *Idem*, p. 135.

⁸⁰ Emmons, S. F., U.S. Geol. Survey Geol. Atlas, Tenmile district folio (no. 48), pp. 3, 4, 1898.

⁸¹ Spurr, J. E., and Garrey, G. H., op. cit., p. 344.

⁸² Bastin, E. S., op. cit. (Prof. Paper 94), p. 101.

⁸³ Spurr, J. E., and Garrey, G. H., op. cit., p. 135.

⁸⁴ Cross, Whitman, *Geology of Silver Cliff and the Rosita Hills, Colo.*: U.S. Geol. Survey 17th Ann. Rept., pt. 2, p. 326, 1896.

cent of combined alkali and 18.40 percent of alumina. The trachyte, latest of the eruptive rocks of the Rosita volcano, is still higher in both alkalis and alumina. The magmatic sequence in this region is clearly parallel to that established in the porphyry belt and is believed by Cross to be of Eocene age. As alkalic rocks are later than rocks of the granite and rhyolite group at Rosita and later than monzonite porphyry at Central City, it seems probable that rocks of group 9 are the latest premineral intrusives in the porphyry belt.

Postmineral igneous rocks are rare in the Front Range. Bastin⁸⁵ found a dike of fine-grained gray biotite andesite that was later than the ore of the Blue Bird mine, near Nederland. Spurr and Garrey⁸⁶ found a fine-grained biotite latite dike that was later than the ore of the Stanley mine, near Idaho Springs. Loughlin⁸⁷ describes pipes of rhyolite agglomerate that are definitely later than the ores in Leadville. All are similar in composition. The biotite latite of the Georgetown quadrangle has a glassy groundmass whose index of refraction is between 1.49 and 1.50; this indicates a glass of rhyolitic composition.⁸⁸ As the groundmass makes up the largest part of the rock, it should be classed as a rhyolite rather than a latite. No detailed description of the andesite of the Bluebird mine is on record, but its general description suggests a rock similar to the biotite latite of the Georgetown quadrangle. The few rocks that are definitely post-mineral are probably close to rhyolites in composition. The analysis of the biotite latite given on page 36 (no. 1) indicates a moderately calcic member of the granite family. All these rocks are older than the Rocky Mountain peneplain, which was developed in Miocene and Pliocene time.

CORRELATION

It is beyond the scope of the present report to make a detailed comparison of all published rock descriptions that bear on the intrusives of the porphyry belt. As most of the petrographic descriptions had to be studied in preparing the classification adopted in this report, a tentative correlation of the porphyries in some of the mining districts of the Colorado mineral belt has been prepared and is given in the accompanying table. The table on pages 36-37 compares most of the published analyses of intrusives from the porphyry belt together with some from Cripple Creek and the Rosita Hills.

PETROGRAPHIC DESCRIPTIONS

In the foregoing pages reasons are given for classifying the intrusive rocks of the porphyry belt into several groups in which rocks of similar composition and age

are considered. All groups are not present in the Montezuma quadrangle, but a brief description of the salient features of each group is given here, in order that the information may be placed on record. The groups are listed below in the order of age, the youngest at the top. The ores are also listed in order to show their position in the sequence.

11. Late silicic intrusives.
10. Ores.
9. Alkalic group.
8. Granite and rhyolite group.
7. Sodic granite group.
6. Sodic quartz monzonite group.
5. Quartz monzonite group.
4. Intermediate quartz monzonite porphyry group.
3. Monzonite group; includes diorite and granodiorite.
2. Gabbro group; includes peridotites, gabbros, calcic diorites, and andesites.
1. Early felsite group; includes rhyolites, dacites, latites, and silicic andesites.

The ages of these groups can be summarized as follows: Groups 1 and 2 are of Denver age, later than the Upper Cretaceous Laramie formation and older than the Laramide revolution; groups 3 to 9 are older than the mineralization of the porphyry belt and are probably all of early Eocene age; group 11 is post-mineral and pre-Miocene.

GROUP 1

There are no early felsites in the Montezuma quadrangle. In other parts of the Front Range rocks of this group are light-colored fine-grained porphyries and in most places are much altered. Phenocrysts make up less than one third of the rocks and are commonly 15 percent or less. They range from 1 to 5 millimeters in length but are usually about 2 millimeters. Small gray laths of plagioclase, near andesine in composition, are the most abundant phenocrysts, but quartz, biotite, and hornblende are common. In the highly altered state characteristic of this group, biotite is usually altered to muscovite or sericite. The groundmass may be partly glassy but is more commonly a very fine, even-grained aggregate of feldspar and quartz. Both orthoclase and plagioclase are usually present in the groundmass, and rarely a little biotite is found. Sericite and calcite are abundant alteration products. Zircon, magnetite, and pyrite are common accessory minerals, but allanite and titanite, so common in the later rocks, do not occur in the felsites, so far as known. Many of the quartz phenocrysts have a border of fine-grained quartz drawn from the groundmass, which is optically continuous with the quartz of the phenocryst. Further descriptions of the rocks of this group are given in the reports of Loughlin,⁸⁹ Bastin,⁹⁰ Crawford,⁹¹ and Worcester.⁹²

⁸⁵ Bastin, E. S., op. cit., p. 101.

⁸⁶ Spurr, J. E., and Garrey, G. H., op. cit., p. 135.

⁸⁷ Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U.S. Geol. Survey Prof. Paper 148, p. 59, 1927.

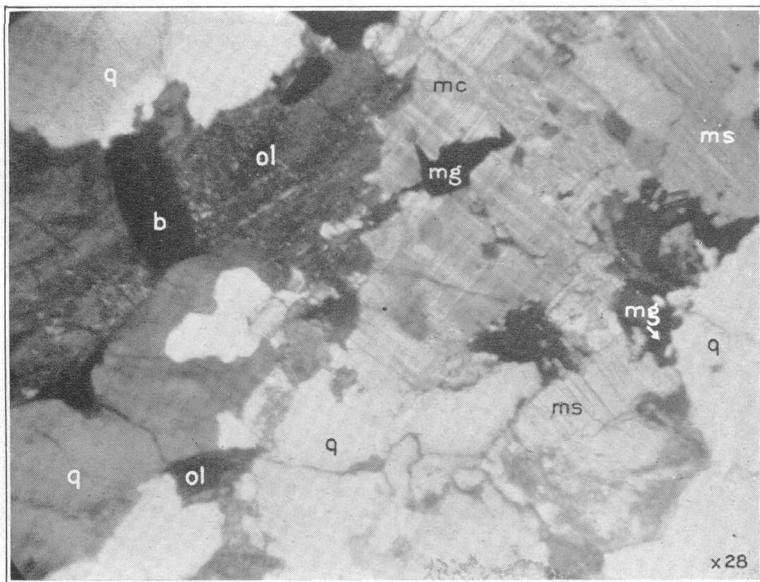
⁸⁸ George, W. D., The relation of the physical properties of natural glasses to their chemical composition: *Jour. Geology*, vol. 32, p. 368, 1924.

⁸⁹ Loughlin, G. F., op. cit., pp. 43-46.

⁹⁰ Bastin, E. S., op. cit., pp. 50-51.

⁹¹ George, R. D., and Crawford, R. D., op. cit., pp. 24-26.

⁹² Worcester, P. G., op. cit., pp. 29, 43, 44.



A. PHOTOMICROGRAPH OF SILVER PLUME GRANITE FROM SANTA FE MOUNTAIN.

The minute cracks in the quartz (q) indicate slight strain. Crossed nicols. mg, Magnetite; mc, microcline; ms, muscovite; b, biotite; ol, oligoclase.



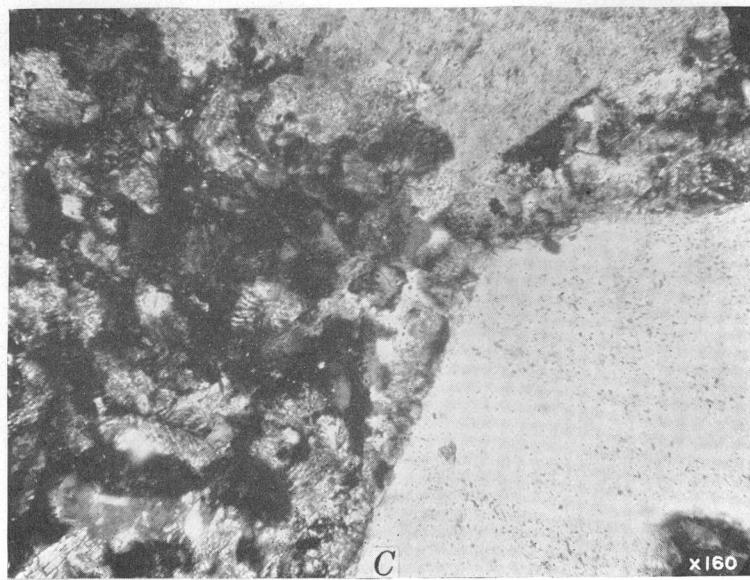
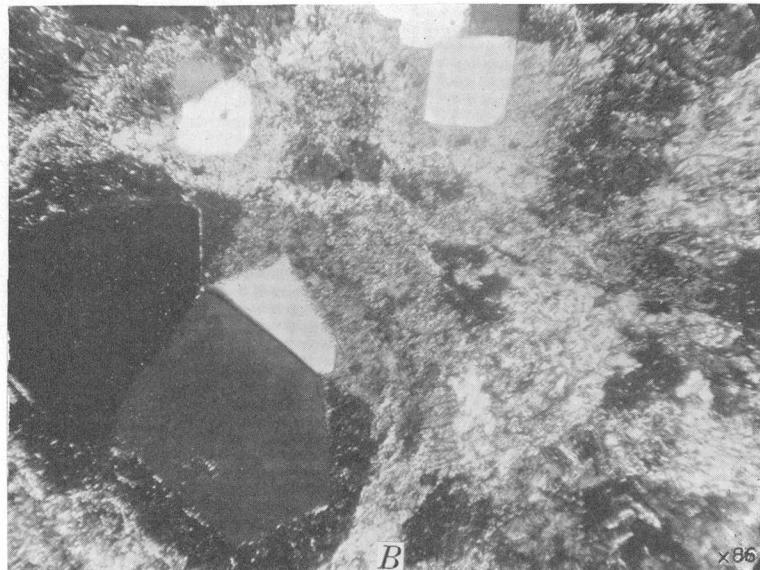
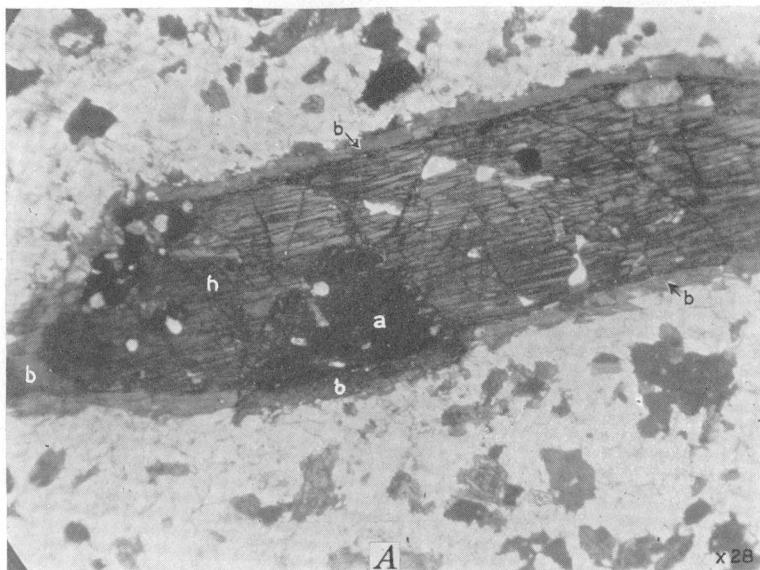
B. PHOTOMICROGRAPH OF AUGITE DIORITE FROM EAST SLOPE OF BEAR MOUNTAIN.

Showing typical network of andesine laths (striped crystals) intergrown with augite (stippled appearance). Black rods of ilmenite abundant. Crossed nicols.

PLATE 12

PHOTOMICROGRAPHS OF ROCKS FROM THE MONTEZUMA QUADRANGLE

- A. Hornblende diorite near mouth of Middle Fork of Swan River. Augite core (a) surrounded by hornblende (h), which in turn is surrounded by rim of biotite (b), indicating reaction of augite with magma of changing composition.
- B. Rhyolite porphyry from dike one-tenth mile north of bench mark 11,905, on wagon road west of Argentine Pass. The phenocrysts of quartz have an optically continuous border of quartz in the fine-grained microgranular groundmass of quartz and orthoclase which surrounds them. Crossed nicols.
- C. Granite porphyry from dike in Horseshoe Basin near foot of trail to Argentine Pass. Micrographic intergrowth of quartz and orthoclase in groundmass; nearly euhedral quartz phenocrysts. Crossed nicols.



PHOTOMICROGRAPHS OF ROCKS FROM THE MONTEZUMA QUADRANGLE.

Tentative correlation of Cretaceous (?) and Eocene porphyries in several districts in the northeastern part of the mineral belt of Colorado, with special reference to the Front Range

	Porphyry group (this report)	Ward district	Nederland district	Central City quadrangle	Georgetown quadrangle	Montezuma quadrangle	Breckenridge district	Leadville district and adjoining region
Vertical uplift at end of Eocene	13							
Early Wasatch uplift	12	(Medicine Bow peneplain)						
Gradual development of Flattop peneplain	11		Ore	Andesite at Bluebird mine	Biotite latite			Rhyolite agglomerate
	10	Ore	Hornblende and biotite andesites	Ore	Ore	Ore	Ore	Ore
	9	Trachyte at Sunset		Bostonite	Alkali syenite Bostonite			
	8				Rhyolite Granite porphyry	Rhyolite and granite porphyritic		Rhyolite and "late White porphyry"
	7	Modoc quartz monzonite			Alaskite Dacite			
	6	Brainerd quartz monzonite			Alaskitic quartz monzonite	Porphyritic sodic quartz monzonite		
	5	Mount Alto quartz monzonite		Quartz monzonite of Apex mine	Quartz monzonite porphyry	Montezuma quartz monzonite	Quartz monzonite porphyry	Lincoln [quartz monzonite] porphyry
	4	Mica dacite porphyry, quartz latite porphyry, and White Raven quartz monzonite		Quartz monzonite			Intermediate quartz monzonite porphyry	Evans Gulch [quartz monzonite] porphyry
	3	Monzonite, latite, diorite, and andesite porphyries	Latite, dacite, and basalt porphyries	Caribou stock differentiates Monzonite Hornblende and biotite diorites		Diorite	Monzonite Diorite	Johnson Gulch porphyry Diorite of the Buckskin Gulch stock in Alma district
Early Eocene (Denver) uplift	2	Diabase and olivine basalt	Pyroxenite Gabbro	Gabbro		Augite diorite		
	1	Felsite	Felsite	Hornblende and biotite andesites				Mount Zion porphyry White porphyry

GROUP 2

The rocks of group 2 vary greatly in texture but are more commonly granular than porphyritic and are generally very uneven grained. Rocks of this group are characterized by abundant plagioclase, generally ranging in composition from calcic andesine to labradorite, but in some places bytownite occurs. Orthoclase is rarely found, augite is common, hornblende and biotite vary greatly in abundance but are usually present, and olivine occurs in the more ferromagnesian rocks of the group. Magnetite and apatite are abundant accessory minerals, and titanite is not uncommon.

In the Montezuma quadrangle augite diorite occurs at many places in the form of small irregular masses and in dikes. Unlike the other late intrusive masses, it is irregularly distributed throughout the quadrangle, as shown on plate 3. The augite diorite is generally a fresh medium-grained dark-colored rock having a slightly greenish cast. Its texture ranges from finely porphyritic to unevenly granular, but the largest crystals are rarely more than 4 millimeters long. The rock weathers to a uniform rusty brown (after prolonged exposure), but in the early stages of weathering the plagioclase phenocrysts stand out as numerous small chalky-gray laths that contrast strongly with the brownish groundmass.

The microscope shows that in the augite diorites andesine and augite are the essential minerals and usually are found in the proportion of 3 to 1. The andesine ranges from $Ab_{55}An_{45}$ to $Ab_{60}An_{40}$ and occurs in moderately fresh appearing laths that reach a maximum length of about 2 millimeters. In the porphyritic varieties the average size of the andesine phenocrysts is about 1 millimeter and of the augite phenocrysts about 0.8 millimeter; the crystals in the groundmass have a considerable range in size, but the andesine laths average about 0.15 millimeter and the augite crystals about 0.10 millimeter in length. The granular augite diorites differ from the porphyries in showing a continuous variation in the size of the grains; although most of the crystals lie between 0.10 and 1.0 millimeter, crystals of any length between 0.01 and 2.0 millimeters can usually be found. In the porphyries the proportion of augite to andesine is about the same in the phenocrysts as in the groundmass, but the phenocrysts are usually fresh, whereas nearly half of the augite originally present in the groundmass is altered to fibrous green hornblende. The andesine commonly shows some alteration to fibrous mica, probably paragonite but is in the main almost unaltered. Titaniferous magnetite is abundant, both as an original constituent and as an alteration product of the augite, and may make up as much as 15 percent of the rock. Titanite occurs as an accessory mineral and as an alteration product of titaniferous magnetite. Rims of titanite surrounding titaniferous magnetite are common in some specimens. The augite commonly occurs in subhedral

simple crystals which are interstitial between the andesine laths, but in some places it poikilitically encloses the andesine. The network of andesine laths typical of the augite diorite is shown in plate 11, *B*.

GROUP 3

The monzonite group includes rocks belonging to the diorite, monzonite, and granodiorite families. No coarsely porphyritic rocks have been found in this group. Most of the rocks are fine-grained porphyritic rocks near granodiorite in composition, but both granular and porphyritic rocks of medium grain are not uncommon. The granular rocks are usually more calcic than the porphyritic rocks and more commonly occur as cross-breaking bodies. The phenocrysts may make up as little as 20 percent of the rock and are commonly from 1.5 to 3 millimeters in length. Plagioclase, biotite, and hornblende are the common phenocrysts, but rarely apatite or quartz also occur as phenocrysts. The plagioclase is generally labradorite, but andesine is not uncommon. The groundmass is chiefly an intergrowth of labradorite or andesine laths with a small amount of interstitial quartz and orthoclase, but some ferromagnesian mineral is usually present also. Apatite is always an abundant accessory mineral, magnetite is common, zircon and allanite are frequently found, but titanite is rare. Distinctive features of this group of rocks are the even texture, the lack of orthoclase phenocrysts, the rarity of quartz phenocrysts except in the dacites, the abundance of gray plagioclase laths about 2 millimeters in length, and the presence of interstitial quartz and orthoclase in the groundmass.

Representatives of the monzonite group in the Montezuma quadrangle include several dikes, which are most numerous in the southwest quarter of the quadrangle. A stock about half a mile in diameter occurs at the mouth of the Middle Fork of the Swan River, just south of the quadrangle. Most of the rocks belonging to this group would be classed in the field as porphyritic hornblende diorite or hornblende monzonite. They are dark gray and medium to fine grained, and the phenocrysts nowhere exceed 5 millimeters in diameter and are nearly everywhere less than 3 millimeters. Hornblende or augite, less commonly biotite, is usually the most conspicuous phenocryst and is associated with smaller but more abundant laths of gray plagioclase. Quartz and orthoclase are not present as phenocrysts. The rocks of this group are generally very fresh and differ markedly in this respect from the granite porphyries.

Under the microscope the diorite and monzonite porphyries show subhedral and euhedral phenocrysts of plagioclase, hornblende, augite, or biotite, in a matrix consisting chiefly of moderately fine grained plagioclase, orthoclase, and quartz. The plagioclase is commonly andesine, but labradorite is sometimes

found. The plagioclase phenocrysts are about 2 millimeters in diameter. The ferromagnesian phenocrysts occur in a variety of ways. The most common of these minerals is hornblende, but it is usually associated with some biotite and augite. In the diorite at the mouth of the Middle Fork of the Swan River some crystals of the hornblende show a central core of augite, and nearly all the hornblende crystals are surrounded by a rim of brown biotite. (See pl. 12, A.) The crystal orientation of augite, hornblende, and biotite is the same, and it is probable that the different minerals represent reaction zones developed during the final stages of crystallization in the dioritic magma and suggest the type of differentiation described by Bowen.⁹³ A short distance farther west, rocks of this group have hornblende phenocrysts partly replaced by aggregates of small augite or diallage crystals, and in some of the dikes on Collier Mountain east of Montezuma hornblende is lacking, and augite phenocrysts as well as some biotite are abundant.

The groundmass forms about 60 to 80 percent of the rock and is also illustrated in plate 12, A. It consists of network of andesine or labradorite laths in a matrix of quartz and orthoclase. Nearly all the quartz is interstitial, but rarely some crystals enclose plagioclase laths. The orthoclase occurs in larger grains and poikilitically encloses both plagioclase and apatite crystals. Apatite, magnetite, zircon, and titanite are common accessory minerals.

GROUP 4

The intermediate quartz monzonite porphyry occurs in the southwestern part of the quadrangle as sills and dikes cutting the Cretaceous shales. It is a moderately light colored gray rock, profusely speckled with small black crystals of hornblende or biotite, or both. Quartz crystals are always visible in the hand specimen and range from 1 to 15 millimeters in diameter but are commonly between 1.5 and 2 millimeters. The gray laths of oligoclase or andesine, which are abundant, are usually between 0.5 and 2 millimeters in length. Superficially the rock resembles the granodiorites, but the presence of the quartz phenocrysts is a distinctive feature that permits its ready identification in the field.

Under the microscope the quartz phenocrysts are seen to be strongly corroded and are commonly surrounded by a thin rim of fine-grained quartz drawn from the groundmass. The rim is optically continuous with the quartz of the phenocryst. The plagioclase occurs in individual subhedral crystals and in aggregates of three or more. The abundant biotite or hornblende occurs in subhedral or euhedral crystals, containing inclusions of apatite and rarely zircon. The groundmass is a microgranular mosaic of quartz

and orthoclase crystals in nearly equal proportions. Magnetite is the most abundant accessory mineral, but zircon and titanite are not uncommon.

GROUP 5

The porphyritic quartz monzonite correlated with the Lincoln porphyry of the Leadville district has many times the volume of all other Tertiary intrusive rocks. It occurs in a variety of forms, but the presence of prominent orthoclase phenocrysts, more abundant but smaller plagioclase laths, quartz, and some ferromagnesian mineral, all of megascopic size, generally suffices to distinguish it from other intrusives. Although porphyritic quartz monzonite occurs in dikes throughout the porphyry belt, by far the largest masses are found in stocks.

One stock and part of another occur in the Montezuma quadrangle. The stock at Montezuma lies in the center of the quadrangle and has a surface area of 16½ square miles. The other stock is in the southwestern part of the quadrangle and extends beyond its borders. It is much smaller but more irregular than the Montezuma stock, and it is impossible to distinguish the cross-breaking mass from sills in many places, but the entire area in which quartz monzonite porphyry occurs is slightly less than 12 square miles. In addition to these two large masses, a few small cross-breaking bodies of irregular shape deserve mention. On Torreys Peak a very irregular body of pinkish-gray medium-grained and porphyritic rock crops out through an area of about 27 acres. It is similar to the Montezuma quartz monzonite in every way except in the size of grain. A slightly larger stock of coarse-grained quartz monzonite porphyry forms a peak, rising to an altitude of 12,500 feet, a quarter of a mile west of Webster Pass. Irregular cross-breaking and sill-like bodies of quartz monzonite porphyry also occur near the head of West Geneva Creek. Aside from these occurrences the porphyritic quartz monzonites are found as dikes that range in length from about 100 feet to slightly more than a mile.

Great differences in texture are found in the rocks of the quartz monzonite group, but no felsitic rocks belonging in this class occur in the Montezuma quadrangle. In the large stocks most of the quartz monzonite porphyry is coarsely porphyritic, and even dikes in which a felsitic groundmass makes up most of the rock show conspicuous quartz and orthoclase crystals from 5 to 12 millimeters in length. In a few places in the Montezuma stock complete gradations from the coarsely porphyritic rock into fine-grained porphyry have been found.

As the rock of the Montezuma stock typifies the coarse-grained varieties of the quartz monzonite group and forms the largest single body of late intrusive rock in the Front Range, it will be described in more detail

⁹³ Bowen, N. L., *The evolution of the igneous rocks*, pp. 60-62, Princeton Univ. Press, 1928.

than the other porphyries. Patton⁹⁴ refers to the rock as the Montezuma "granite", but as orthoclase and andesine occur in about equal proportions (or within the arbitrary limits set for monzonite) it is more appropriately called the Montezuma quartz monzonite.

The Montezuma quartz monzonite is a beautiful stone: at a little distance it appears a dappled pinkish gray, and when studied more closely the abundant large flesh-colored crystals of orthoclase are found to stand in pleasing contrast to the finer-grained gray matrix, mottled with small black biotite crystals. Most of the conspicuous orthoclase occurs in crystals from 15 to 20 millimeters in length, but in some places the crystals are much larger, and a few reach a length of 50 millimeters. Smoky quartz and the abundant gray or grayish-green plagioclase commonly occur in crystals ranging from 3 to 5 millimeters in length. Hexagonal crystals or "books" of biotite about 2.5 millimeters in diameter are plentiful, and the euhedral shape of this mica is characteristic of its occurrence in the quartz monzonite.

Because of the handsome appearance of the rock, its use as a building stone has been suggested. Unfortunately, most of the rock is much jointed, and it might be difficult to find a place where dimension blocks of satisfactory size could be quarried. In most places three or four systems of joints cut the quartz monzonite into rhombic blocks. The jointing appears so regular and is so conspicuous that dips and strikes were recorded at many places, but the results showed that the trend of both minor and major joints varied greatly in different parts of the stock. This lack of concordance suggests that the prominent jointing is not the reaction of the stock to regional compression but is more probably in part the result of forces transmitted through the deeper portions of the solidifying magma and in part the result of slow cooling. The pronounced horizontal sheeting found on Lenawee Mountain is confined to the mountain top.

Under the microscope the coarse-grained granitoid quartz monzonite is found to contain as its essential minerals quartz, orthoclase, andesine, and biotite and to have accessory magnetite, titanite, apatite, zircon, and allanite. Andesine occurs in subhedral laths, which range in composition from $Ab_{67}An_{33}$ to $Ab_{53}An_{47}$ in the thin sections examined. Andesine makes up from 30 to 40 percent of the rock, and is earlier than quartz, orthoclase, or biotite. Quartz is earlier than some of the orthoclase, but in places it is in micropegmatitic intergrowth with orthoclase and is evidently contemporaneous. From 20 to 30 percent of most sections is quartz, which is anhedral, shows a great range in size, and contains many minute fluid inclusions. Orthoclase makes up from 25 to 35 percent of the thin sections studied, but the large crystals that are so

prominent in an outcrop of the quartz monzonite were avoided in selecting material for microscopic work. As the large crystals make up about 10 percent of the rock, the total orthoclase content is correspondingly greater than that observed under the microscope. Most of the orthoclase is anhedral and fresh. The brown biotite, which forms about 10 percent of the rock, is subhedral and contains inclusions of apatite, magnetite, and zircon. It is more or less altered to chlorite and epidote.

Although most of the Montezuma stock is coarsely porphyritic, some small bodies of finer-grained rock occur. Patton mapped these finer-grained porphyries as separate formations, but the writer has included them with the typical coarse-grained Montezuma quartz monzonite because the contact between the two types is nearly everywhere gradational and because their composition is the same. In some places the contact is moderately sharp, but even in those places the finer-grained facies shows a coarsening of grain near the contact. The finer-grained rock probably represents the intrusion of magma late in the quartz monzonite epoch of differentiation. It consists of gray and pink feldspar phenocrysts less than 10 millimeters in diameter and small crystals of quartz and biotite, set in a fine or medium grained grayish-green groundmass. Commonly orthoclase makes up 25 percent of the phenocrysts and about 35 percent of the groundmass. Nearly all the orthoclase phenocrysts are twinned after the carlsbad law. The plagioclase phenocrysts are smaller than the orthoclase but are much more abundant and make up a decidedly larger percentage of the phenocrysts. Most of the plagioclase is andesine, ranging from $Ab_{55}An_{45}$ to $Ab_{65}An_{35}$, but many of the crystals are surrounded by a more sodic border, and locally no andesine is present and the only plagioclase is oligoclase. The quartz phenocrysts are anhedral, commonly occur in aggregates, contain many lines of minute bubbles and fluid inclusions, and rarely show slightly embayed outlines suggesting the beginning of magmatic resorption. The phenocrysts of biotite are either subhedral or euhedral and contain many small inclusions of apatite and in some crystals inclusions of zircon, titanite, or magnetite.

The groundmass is composed chiefly of a xenomorphic mosaic of quartz and orthoclase crystals which poikilitically enclose small plagioclase laths. The plagioclase ranges in composition from andesine to albite-oligoclase, but most of it is sodic andesine. Biotite is moderately abundant in the groundmass, and locally titanite is common; both minerals poikilitically enclose andesine. The accessory minerals, named in the order of their abundance, are apatite, magnetite, titanite, zircon, and allanite.

Although orthoclase, plagioclase, and quartz are usually fresh, the biotite is in general partly or wholly

⁹⁴ Patton, H. B., op. cit., p. 125.

altered. Its most abundant alteration product is chlorite, with which some epidote is usually associated; less commonly rutile and leucoxene appear among its decomposition products. Where the plagioclase has been altered some distance from veins, carbonate was more commonly formed than sericite (or paragonite), but close to veins sericite is abundant.

The porphyritic quartz monzonite stock in the southwestern part of the quadrangle is very similar in its general features to the Montezuma stock. It differs markedly in the number of inclusions of older rock which it carries, however. In the Montezuma stock a few small schist fragments were found, but the stock as a whole is remarkably free from inclusions of older rock. The stock near Tiger is in places so full of fragments of the formations into which it was intruded that it is best described as an intrusion breccia. Inclusions of quartzite are very abundant and range from some that measure less than an inch to xenoliths many yards in diameter. Inclusions of silicified shale and silicified limestone are moderately abundant, and schist is not uncommon. In the regions where the quartz monzonite is relatively free from country-rock fragments it is commonly finer-grained and more porphyritic than the Montezuma quartz monzonite. Under the microscope it shows the same minerals and the same general relations. The quartz phenocrysts are more corroded and have thin borders of quartz drawn from the groundmass added to them in optical continuity. Orthoclase and quartz are more abundant in the groundmass than in the phenocrysts and are micropoikilitic in their relation to the andesine or oligoclase microlites.

The coarsely porphyritic and coarse-grained quartz monzonite of the stocks weathers a pinkish gray or light rusty brown. The large orthoclase crystals remain lighter-colored than the groundmass and weather in relief except where the rock has been hydrothermally altered. The light-colored, slightly protruding orthoclase crystals give the weathered surface a knobby appearance that is distinctive and easily recognized.

The porphyritic quartz monzonite dikes range in color from dark pinkish gray to moderately light greenish gray and in texture from coarsely to finely porphyritic. No felsitic rocks belonging in this group have been found in the quadrangle. In most of the dikes the phenocrysts range from 3 to 10 millimeters in length, but rarely crystals of orthoclase 25 millimeters in diameter can be found. Orthoclase and plagioclase are abundant as phenocrysts, quartz is always present but is usually inconspicuous, and biotite and rarely hornblende also occur as megascopic crystals. The groundmass makes up 25 to 75 percent of the rock.

Under the microscope the relation of the dike rocks to the Montezuma quartz monzonite is more apparent than in the hand specimen. In most of the dikes over half of the phenocrysts are plagioclase, ranging in

composition from andesine to oligoclase, and many of the crystals are strongly zonal. From 20 to 35 percent of the phenocrysts are orthoclase, commonly twinned after the carlsbad law, and most of the remaining crystals of megascopic size are quartz. The quartz is rarely subhedral, more commonly showing embayed outlines indicating magmatic resorption. In the sodic varieties, such as the oligoclase-quartz monzonite porphyries, the corroded quartz crystals generally show added rims of fine-grained quartz in the groundmass, which are optically continuous with the phenocrysts. The rims are locally present in a groundmass that is microgranular but are much wider and more prominent in a micropoikilitic groundmass. Biotite and hornblende are not abundant and are more or less altered to chlorite, epidote, sericite, and magnetite.

The groundmass consists chiefly of quartz and orthoclase, but small amounts of plagioclase, generally near albite-oligoclase in composition, are usually present. The proportion of orthoclase to quartz varies greatly, but rocks having a groundmass in which the two minerals are nearly equal are the most common. The texture of the groundmass is generally microgranular, but micropoikilitic texture is not uncommon, and rarely the quartz and orthoclase are micrographically intergrown. Apatite is the most abundant accessory mineral, but magnetite, zircon, and titanite are also found. The Cretaceous shales in the valley of Soda Creek, near the west edge of the quadrangle, are intruded by sills of quartz monzonite porphyry which have a glassy groundmass, but all dikes and sills in the pre-Cambrian rocks of the quadrangle are entirely crystalline.

Most of the porphyritic quartz monzonite dikes are moderately altered. The feldspars are sericitized, and the ferromagnesian minerals are heavily chloritized. The uniformity of the alteration over wide areas suggests that it was endomorphic and occurred shortly after consolidation, induced by hot solutions emanating from the dikes themselves during cooling. To use a homely simile, the dike rocks were cooked in their own juices. This type of alteration is more and more noticeable in the later silicic rocks.

GROUP 6

The sodic quartz monzonite differs from the rocks of group 5 in being much less silicic and more sodic. Quartz is confined to the groundmass, and the plagioclase is either albite or albite-oligoclase. In color the rocks of this group range from dark gray to moderately light greenish gray, and in texture from very finely porphyritic felsites to porphyries having abundant phenocrysts as much as 5 millimeters in length. Most of the phenocrysts are light greenish-gray tabular crystals of albite. Orthoclase phenocrysts are not uncommon but are nowhere abundant. Hornblende

or biotite is present in most of the dikes but not everywhere in megascopic crystals.

The groundmass is much darker than most of the phenocrysts and is darker in the medium-grained porphyries than in the felsitic varieties. Its chief minerals, named in the order of abundance, are albite, orthoclase, and quartz. The proportions of the minerals vary greatly, but quartz nowhere forms more than 25 percent of the groundmass, and orthoclase commonly ranges between 20 and 50 percent. Many small flakes of chlorite occur in the groundmass and probably indicate the former presence of fine-grained biotite or hornblende. Apatite is so abundant in the groundmass of many of the rocks that it should be classed as an essential rather than as an accessory mineral. Where albite is very abundant, the groundmass commonly has a microtrachytic texture, but where orthoclase is abundant the albite microlites are poikilitically included in the much larger orthoclase crystals. The groundmass of some of the felsites is so finely microgranular that it suggests a devitrified glass.

Most of the sodic quartz monzonite porphyries show marked alteration. The feldspar phenocrysts are sericitized, the minute flakes of mica following crystallographic directions. The phenocrysts of hornblende or biotite are commonly replaced completely by carbonate, epidote, and pleochroic green chlorite.

In the Montezuma quadrangle the sodic quartz monzonite porphyries occur in short dikes, none of which are more than a few hundred yards in length, and are found only in the northeast half of the quadrangle.

GROUP 7

Rocks of the sodic granite group are light gray but generally have a buff or brownish tint. The rocks are porphyritic, and their groundmass is fine grained but is distinctly granular in appearance, even to the naked eye. All of the sodic granite porphyries carry abundant quartz. In most of them the quartz is prominent in both groundmass and phenocrysts, but in some rocks it is largely confined to the groundmass. The latter type can be distinguished from the sodic quartz monzonites by the dominance of orthoclase over albite in the phenocrysts. Dark-colored minerals are not common and are in general greatly altered.

Dikes of the sodic granite porphyry group are abundant in the porphyry belt northeast of the Montezuma stock. Most of them are light-colored felsites and fine-grained porphyries, but close to the Montezuma stock there are some dikes that have abundant quartz and orthoclase phenocrysts from 5 to 10 millimeters in diameter.

Under the microscope the essential minerals are found to be quartz and albite or albite-oligoclase. The proportions of orthoclase and quartz vary widely, but albite or sodic oligoclase generally makes up from

10 to 20 percent of the slide. In some specimens quartz phenocrysts greatly predominate over orthoclase, and the groundmass may be 80 percent quartz; in others orthoclase is much more abundant than quartz in both groundmass and phenocrysts. Both corroded quartz and euhedral quartz may be present in a thin section. The boundary of the quartz phenocrysts is usually sharp, but in the more silicic varieties or those having a groundmass of micropoikilitic quartz and orthoclase, the quartz phenocrysts have an optically continuous border of fine-grained quartz in the groundmass. Orthoclase phenocrysts are subhedral and commonly occur as carlsbad twins. Some orthoclase is perthitically intergrown with albite. Many phenocrysts of albite and sodic oligoclase show broad twinning bands, unusual in such sodic plagioclase. Biotite, where present, is generally partly altered to chlorite. Muscovite crystals 0.5 millimeter in diameter are not uncommon, but as they are invariably intergrown with magnetite, they may be secondary. The groundmass is usually a microgranular mass of quartz, orthoclase, and albite. Micropegmatitic and microperthitic intergrowths of the minerals in the groundmass are common, and in some specimens the plagioclase microlites are micropoikilitically enclosed in the minute anhedral orthoclase crystals.

Fresh specimens are rare. In all the sections examined the feldspars were sericitized, and isolated aggregates of unoriented muscovite crystals about 0.1 millimeter in length occur in them. Epidote and chlorite are common alteration products of the biotite.

Zircon and apatite are the most common accessory minerals.

GROUP 8

Granite and rhyolite porphyries (pl. 12, *B*, *C*) are abundant in the porphyry belt from the Montezuma stock northeast to Jamestown. They are light-colored silicic rocks, finely porphyritic or dense and felsitic. Dark-colored minerals are generally lacking, and wherever phenocrysts are present quartz is prominent and in many places is the only mineral large enough to be seen without the aid of the microscope. Orthoclase is moderately abundant in the phenocrysts of some dikes, and muscovite is sparingly present in many specimens. In most places the diameter of the phenocrysts is from 1 to 2 millimeters, but some quartz crystals are 4 millimeters in length. The microscope shows that quartz phenocrysts having optically continuous borders of fine-grained quartz in the groundmass are present in most of the rocks. The outlines of these crystals are always irregular and show magmatic resorption prior to the addition of the fine-grained rims. The feldspar phenocrysts are seldom fresh; orthoclase is sericitized, and the rare plagioclase is altered to sericite, carbonate, and quartz. The muscovite is probably secondary, as it is streaked and intergrown with fine-grained decomposition products.

The phenocrysts nowhere exceed 25 percent of the rock and usually make up less than 10 percent. Quartz is the chief mineral of the groundmass and is generally twice as abundant as orthoclase. These minerals usually form a microgranular mosaic, but in some of the dense, aphanitic varieties the groundmass is an indefinite mixture of quartz and orthoclase clouded with innumerable minute bubbles and opaque inclusions. Sericite and zoisite are commonly disseminated through the groundmass in moderate amounts. Apatite and rarely zircon are present in small amounts.

The rocks of this group in the Georgetown quadrangle were mapped by Ball⁹⁵ as granite and rhyolite porphyries, and he correlated them with the white porphyries of Leadville because of the megascopic muscovite that is common to both. As indicated earlier, the writer does not believe that the composition or the age relations justify this correlation.

GROUP 9

Rocks of group 9 have not been found in the Montezuma quadrangle, but they are abundant in the adjacent Georgetown and Central City quadrangles. Some of the rocks of group 9 are almost granitoid, but most of them are porphyritic felsites, having a marked trachytic texture. Most of the rocks of this group have a pinkish or purplish tint and where unweathered are generally a light pinkish gray. Anor-

⁹⁵ Ball, S. H., op. cit. (Prof. Paper 63), pp. 75, 76.

thoclase and orthoclase greatly predominate over the other minerals present and in many places together amount to over 95 percent of the rock. Locally aegirite-augite is abundant, or had been abundant prior to alteration, garnet and titanite are present, and oligoclase is common. Quartz, apatite, magnetite, zircon, and fluorite, and rarely biotite occur as accessory minerals. The groundmass of the porphyritic varieties is composed of orthoclase and anorthoclase laths, which have a trachytic arrangement where the phenocrysts are not abundant but have a microgranular texture in the rocks having more phenocrysts than groundmass. Rocks of group 9 occur as small stocks in a few places, but most of them were intruded as dikes, some of which persist for miles.

GROUP 10

Ores; see pages 59-64.

GROUP 11

Rocks of group 11 have not been found in the Montezuma quadrangle. Most of them are glassy rocks that are slightly porphyritic, but in some the groundmass is finely crystalline. The felsitic varieties are light gray; the glassy rocks range from light gray to dark greenish gray. Orthoclase, biotite, and albite or oligoclase are the most abundant phenocrysts, though quartz crystals are not uncommon. Microlites of labradorite are generally present in the glassy groundmass, but as the glass has an index less than 1.50, it is much more silicic than these microlites would suggest. The rocks of group 11 occur as dikes and pipes.

Analyses of intrusive rocks of central Colorado, chiefly from the mineral belt

11. Late silicic intrusive group

No.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O	H ₂ O-	TiO ₂	P ₂ O ₅	MnO	Incl.	Sum	Specific gravity	Reference ^a
1.....	66.44	14.98	1.57	0.43	0.18	2.47	1.12	3.32	4.06	4.60	0.20	0.11	0.13	{ CO ₂ 0.67 S .02 }	100.42	-----	P.P. 63, p. 134.

11a. Comparative group of late (Miocene) alkalic rocks

2.....	58.05	17.66	3.51	1.65	1.55	4.48	5.80	4.06	0.87	0.35	0.91	0.40	0.13	ZrO 0.02	-----	P.P. 54, p. 104.	
3.....	59.38	19.47	1.60	1.19	.36	1.96	7.80	5.83	.69	.11	.58	.08	.15	ZrO .10	-----	Do.	
4.....	54.34	19.23	3.19	2.11	1.28	4.53	6.38	5.14	1.17	.14	1.09	.27	.08	ZrO .07	-----	Do.	
5.....	58.78	20.03	1.87	.49	.16	.83	9.36	5.50	1.57	.31	.29	.03	-----	ZrO .17	-----	Do.	
Average..	57.64	19.10	2.54	1.38	.84	2.95	7.33	5.13	1.09	.23	.72	.20	.09	.09	99.33	-----	

9. Alkalic group

6.....	60.30	18.12	2.45	1.25	0.28	3.89	5.83	5.01	0.77	0.75	0.55	0.25	0.12	{ ZrO 0.01 BaO .26 ZrO .11 }	99.90	-----	P.P. 63, p. 134.
7.....	67.41	16.21	.85	1.14	.15	.14	3.95	7.19	.88	.67	.16	.05	.16	-----	99.65	-----	Do.
8.....	64.82	17.71	1.95	.44	.22	1.03	4.37	6.09	1.17	-----	.20	.05	.10	-----	99.84	2.58	
9.....	65.41	18.78	.94	.72	.16	1.58	5.91	5.41	1.38	-----	Trace	Trace	Trace	CO ₂ .56	100.29	2.621	Colo. Sci. Soc., 6, p. 228. ^b
10.....	63.49	18.40	2.44	1.09	.66	2.30	5.70	4.62	1.04	-----	Trace	Trace	Trace	.16	99.90	2.69	A.R. 17, 2, p. 324.
11.....	58.94	17.19	2.63	1.98	1.52	4.45	4.20	3.90	4.53	-----	.27	-----	.10	-----	99.94	2.65	Do.
Average..	63.40	17.73	1.88	1.10	.50	2.23	4.99	5.37	1.63	.71	.24	.06	.12	-----	99.95	-----	Do.

8. Granite and rhyolite group

12.....	74.45	14.72	-----	0.56	0.37	0.83	3.97	4.53	0.66	-----	0.01	0.28	-----	100.38	-----	M. 12, p. 589.	
13.....	75.07	12.15	1.62	n.d.	.14	.86	4.12	4.57	1.34	-----	.05	-----	100.18	99.92	-----	P.P. 99, p. 969.	
14.....	75.39	13.65	.38	.18	.15	.51	1.84	6.81	1.13	-----	Trace	Trace	Trace	.14	99.99	-----	A.R. 17, 2, p. 324.
15.....	73.11	13.16	.62	.23	.19	.54	2.85	5.10	4.05	-----	-----	-----	-----	.14	100.22	100.22	Do.
16.....	75.20	12.96	.37	.27	.12	.29	2.02	8.38	.58	-----	-----	-----	.03	-----	100.14	100.14	Do.
Average..	74.64	13.33	.60	.25	.19	.61	2.98	5.88	1.55	-----	-----	-----	.13	-----	100.14	100.14	

See footnotes, p. 37.

Analyses of intrusive rocks of central Colorado, chiefly from the mineral belt—Continued

6. Sodic quartz monzonite group

No.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O	H ₂ O—	TiO ₂	P ₂ O ₅	MnO	Incl.	Sum	Specific gravity	Reference ^a
17.....	67.01	18.03	0.66	0.72	0.84	3.99	4.42	3.53	0.91	.....	.....	0.10	0.09	.....	100.40	.....	B. 148, p. 176. Do. ^b
18.....	65.94	16.00	.60	1.74	1.02	2.87	3.85	4.56	1.13	.....	.....	.23	.....	.....	100.26	2.672	
Average..	66.47	17.01	.63	1.23	.93	3.43	4.13	4.05	1.02	.....	.....	.17	.05	.....	99.84	.....

5. Quartz monzonite group

19.....	66.45	15.84	2.59	1.43	1.21	2.90	3.92	2.89	0.84	.....	0.10	0.36	0.09	CO ₂ 1.35	100.09	2.67	M. 12, p. 332. ^b
20.....	68.00	16.21	1.07	1.57	1.05	2.61	3.29	3.88	.92	.....	.21	.09	.....	100.32	2.04	B. 148, p. 176.	
21.....	65.51	17.01	.....	2.79	.90	3.16	3.82	4.67	1.78	.....	.13	.....	.....	100.15	2.666	Do.	
22.....	67.04	14.75	.81	1.95	.94	3.98	3.40	4.06	.19	0.13	1.36	.20	.27	.....	99.76	.....	Colo. G. S., 4, p. 144.
23.....	68.14	15.29	.35	1.66	.26	3.03	3.59	4.07	.39	.40	.36	.17	.12	.....	99.65	.....	P. P. 75, p. 45.
24.....	67.53	15.46	2.18	2.42	.16	3.24	3.24	3.86	.55	.23	.41	.01	.10	.....	99.63	.....	Do.
25.....	65.38	17.54	2.14	1.72	1.51	2.00	3.82	2.98	.89	.20	.50	.....	.....	.....	99.58	.....	Colo. G. S., 31, p. 45.
26.....	64.44	16.07	2.79	1.31	1.70	2.88	3.77	3.04	1.32	.28	.40	.....	.....	.....	100.65	.....	Do.
27.....	66.67	16.72	2.54	.72	1.47	3.03	3.67	3.10	1.05	.13	.30	.....	.....	.....	99.40	.....	Do.
28.....	68.34	16.96	.44	1.02	1.94	3.12	3.25	2.49	1.12	.05	.40	.....	.26	.....	99.99	.....	Do.
Average..	66.87	16.27	1.73	1.72	1.11	3.09	3.58	3.50	.90	.20	.48	.16	.1531	100.06	

4. Intermediate quartz monzonite porphyry group

29.....	67.29	15.78	1.86	1.97	0.72	2.36	3.77	3.55	2.10	.....	None	0.28	0.21	.....	100.16	.....	A. R. 14, p. 227.
30.....	68.10	14.97	2.78	1.10	1.10	3.04	3.46	2.93	1.28	.....	0.07	.16	.09	.....	100.11	2.736	M. 12, p. 332.
31.....	68.91	14.27	.90	.23	.67	.60	1.96	7.15	.43	1.12	.41	.16	.02	.....	100.49	.....	P. P. 148, p. 49.
32.....	64.28	16.99	2.59	2.64	1.13	3.95	3.78	3.51	.25	.07	.49	.32	.14	.....	100.38	.....	P. P. 75, p. 58.
33.....	63.25	16.16	2.60	2.44	1.62	2.99	3.54	3.26	1.85	.63	.50	.30	.....	.....	100.02	.....	P. P. 148, p. 51.
34.....	67.20	14.95	5.10	.....	2.39	.30	4.00	.89	2.13	.....	.08	.70	.....	CO ₂ 0.40	97.45	2.43	Colo. Sci. Soc., 3, p. 357.
35.....	62.51	17.49	2.52	2.80	2.27	5.08	3.31	1.80	.66	.....	.36	.....	.....	.....	99.58	.....	Colo. G. S., 31, p. 45.
Average..	65.94	15.80	2.63	1.60	1.41	2.62	3.40	3.30	1.24	.47	.36	.24	.16	.....	99.24	.....

3. Monzonite group

36.....	57.35	16.20	3.15	4.36	2.41	5.66	4.50	3.39	0.70	0.15	1.07	0.07	0.12	.....	100.55	2.763	P. P. 75, p. 55.
37.....	55.44	14.95	4.37	5.18	3.58	6.12	4.44	2.83	.84	.15	1.22	.49	.22	.....	100.44	2.827	Do.
38.....	60.62	16.74	4.94	3.27	4.08	7.39	3.50	1.97	.92	1.15	.....	Trace	.15	CO ₂ 1.15	100.73	2.768	M. 12, p. 589.
39.....	64.81	15.73	1.68	2.91	2.82	4.22	3.98	1.43	.62	.....	.08	.23	.08	CO ₂ 1.08	100.61	2.740	B. 148, p. 173.
40.....	63.64	18.05	2.14	1.80	1.01	3.36	3.65	4.73	1.07	.....	.43	.18	.46	.....	100.52	2.568	Colo. Sci. Soc., 6, p. 181.
41.....	57.55	16.52	2.68	4.48	1.37	5.85	4.90	2.95	2.15	.....	.24	.83	.....	CO ₂ 3.57	100.21	.....	Colo. Sci. Soc., 7, p. 12.
42.....	53.60	17.01	4.06	4.81	3.54	5.73	3.42	2.08	2.58	.11	1.40	.....	.87	CO ₂ .84	100.05	.....	Colo. G. S., 31, p. 45.
Average..	58.43	16.33	3.20	3.54	2.69	5.48	4.06	2.77	1.27	.22	.74	.30	.3195	100.36	

2. Gabbro group, ultrabasic subgroup (b)

43.....	44.93	18.32	8.70	21.09	0.47	1.41	2.12	0.58	Trace	.....	.....	2.92	.....	.....	100.54	.....	Colo. Sci. Soc., 5, p. 151.
44.....	39.22	4.93	18.12	5.90	3.61	19.20	2.51	.68	.21	.....	.....	3.49	.....	.....	99.20	.....	Colo. Sci. Soc., 5, p. 150.
45.....	22.24	11.78	4.74	3.35	25.00	10.19	3.29	3.64	5.6336	.61	99.62	2.73	Colo. Sci. Soc., 6, p. 109.

Average..

35.46

11.08

10.52

10.11

9.69

10.27

2.64

1.63

1.95

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2.26

.61

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3.34

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Descriptions of the rocks represented by the numbered analyses in the accompanying table are given below. They have been abstracted from the references given in the table, and none are the result of petrographic work done by the writer.

1. Biotite latite, Chicago Creek near Idaho Springs. The groundmass greatly predominates over the phenocrysts and in general is aphanitic. Small phenocrysts of biotite and feldspars are numerous and equally abundant. The minerals found as phenocrysts, in the order of their abundance, are orthoclase, biotite, plagioclase, and rarely brown hornblende.

2. Latite-phonolite, Cripple Creek (Anaconda mine). Ranges in color from dark gray to black and is finely holocrystalline. It is porphyritic and contains prismatic phenocrysts of pyroxene and feldspar 2 centimeters or less in diameter. The feldspar phenocrysts predominate and are chiefly albite or albite-oligoclase. Orthoclase is common and ranges in size from 0.05 to over 1.0 centimeter. Pyroxenes are moderately abundant. Hornblende, biotite, and apatite are always present and in some places are prominent. Sodalite, noselite, and analcrite are generally present and in many places are abundant. The groundmass is compact and dark and locally contains inclusions of hornblende syenite.

3. Latite-phonolite, Cripple Creek (Bull Cliff). Same as no. 2.

4. Syenite, Cripple Creek (Longfellow mine). Light gray and finely granular. Orthoclase, albite, oligoclase, and aegirite-augite are the principal constituents, but orthoclase is by far the most abundant. Much of the pyroxene is surrounded by a zone of greenish-brown hornblende, but hornblende also occurs alone. Sodalite is present in rather large grains, and more or less decomposed nosean occurs in small quantities. Analcite is plentiful in irregular grains and is associated with the feldspars. Extremely minute needles of stilbite (?) penetrate the analcite grains. Biotite, apatite, titanite, and magnetite are common accessory minerals.

5. Phonolite, Cripple Creek. A fresh phonolite from dark gray to greenish. The texture ranges from dense, microcrystalline to porphyritic, but phenocrysts are scarce. Flow structure is almost always present. Most of the phenocrysts are clear glassy feldspar. The groundmass is largely made up of microlites of soda orthoclase. Nepheline makes a large percentage of the rock and sodalite, noselite (and haüynite?) are common. Analcite, aegirite, and aegirite-augite are present in varying amounts in different places. The aegirite is most abundant and in many places is alone. A blue amphibole is present and is generally associated with aegirite.

6. Alkali syenite, Idaho Springs. The texture ranges from one in which the groundmass equals the phenocrysts to a holocrystalline texture. The groundmass is composed chiefly of anorthoclase and orthoclase, but rarely quartz is also present. The phenocrysts are chiefly orthoclase, anorthoclase, pyroxene, and brownish-black garnets; they include also a little titanite. Fluorite is present in the groundmass, and oligoclase is not uncommon.

7. Bostonite, Idaho Springs. A light pinkish-gray felsitic to porphyritic rock. The phenocrysts are commonly small but in some places reach a diameter of 1 inch. The groundmass has a trachytoid texture. The phenocrysts are chiefly alkali feldspars and plagioclase; pyroxene pseudomorphs are common. Between the lathlike anorthoclase crystals of the groundmass are equidimensional wedge-shaped masses of orthoclase and quartz, which have solidified after the crystals of anorthoclase.

8. Trachyte, Sunset. Contains about 25 percent phenocrysts. The texture of the groundmass ranges from microgranular to glassy. The phenocrysts consist chiefly of orthoclase (sanidine) and oligoclase. Small crystals of apatite, ti-

tanite, and octahedrite occur but are not abundant. Small amounts of magnetite, limonite, biotite, zircon, and augite (?) are sometimes found in the groundmass and rarely as phenocrysts. The groundmass consists largely of orthoclase microlites in a glassy base, but it is decomposed, and its composition and structure are difficult to ascertain.

9. Trachyte, Rosita Hills. Occurs in dikes and surface flows. The dikes vary greatly in physical appearance and range from true trachytes to a dark dense porphyry. The phenocrysts are predominantly sanidine crystals, usually less than 1 centimeter in length, but oligoclase is also abundant. Biotite is present though not plentiful. The groundmass, which greatly predominates over the phenocrysts, is ash-gray. It consists largely of fine granular orthoclase, with very subordinate quartz and plagioclase. Apatite and zircon are also present in small amounts.

10. Andesite (dike), Pringle andesite, Rosita Hills. The Pringle andesite occurs in both surface flows and dikes. The chemical composition is the same, although the dike rock is darker, is finer grained, and has a larger percentage of groundmass than the surface flows. The rock is a dark-gray porphyry. Phenocrysts of oligoclase and andesine are more common than orthoclase, although the orthoclase is one of the characteristic minerals of the rock. Biotite is more plentiful than augite, but neither is abundant. Hornblende is rarely present. The groundmass is a coarse-grained mixture of feldspar microliths, augite, and magnetite, and in some places it contains a subordinate amount of quartz.

11. Andesite (flow), Rosita Hills. Same as no. 10 except that it is a surface flow instead of a dike.

12. Rhyolite, northwest point of Chalk Mountain, Leadville. Contains sanidine, plagioclase, and quartz in abundance and a little biotite and magnetite.

13. Nevadite, Summit County, probably from the Tenmile district. The rock is a grayish-white felsite porphyry, containing quartz and glassy white feldspar in moderately large phenocrysts. Some hornblende and albite phenocrysts are also present. The groundmass is a very fine grained intergrowth consisting chiefly of albite, sanidine, anorthoclase, and quartz but contains a small amount of mica and hornblende. An analysis of the white glassy feldspars gave the following results: SiO_2 , 65.49 percent; Al_2O_3 , 18.74; Fe_2O_3 , trace; CaO , 0.39; K_2O , 9.45; Na_2O , 3.53; loss on ignition, 1.30; total, 98.90.

14. Rhyolite, Rosita Hills. The texture of the rhyolites is variable. The rock is generally porphyritic and contains rather large crystals of orthoclase in the granular groundmass. The phenocrysts are commonly quartz and two feldspars. The groundmass is made up of a rather coarse intergrowth of quartz and orthoclase.

15. Pitchstone, Rosita Hills. The pitchstone in this locality is variable in texture, and the color may be red, yellow, green, brown, or black. Small phenocrysts of feldspar are sometimes present. The pitchstone is related to the rhyolites and except for the large proportion of glass present, its mineral composition will probably approximate that of the rhyolites.

16. Rhyolite, Rosita Hills (Round Mountain). Similar to no. 14.

17. Diorite porphyry, Tenmile district (Copper Mountain). Contains oligoclase, hornblende, and biotite phenocrysts in a groundmass of quartz, orthoclase, plagioclase, and magnetite. Zircon, sphene, and apatite are accessory minerals. Small amounts of secondary chlorite and epidote are present.

18. Granite porphyry, Jefferson tunnel, Tenmile district. Contains orthoclase, oligoclase, quartz, and biotite phenocrysts in a groundmass of quartz and orthoclase. Magnetite, apatite, zircon, and allanite are accessory minerals. Chlorite, calcite, and magnetite are present in small amounts as decomposition products of biotite.

19. Lincoln porphyry, summit of Lincoln Mountain, Leadville quadrangle. A coarse-grained porphyritic rock containing phenocrysts of quartz, orthoclase, plagioclase, and biotite in a groundmass of plagioclase, orthoclase, and quartz. The amount of plagioclase in the groundmass is rather small, but most of the phenocrysts are plagioclase near andesine in composition. The orthoclase phenocrysts are large, some reaching a length of 2 inches.

20. Granite porphyry, McNulty Gulch, Tenmile district. Contains phenocrysts of orthoclase, oligoclase, andesine, quartz, biotite, and altered hornblende in a groundmass of quartz, orthoclase, and magnetite. Accessory minerals are titanite, allanite, apatite, and zircon. A small amount of secondary chlorite is present.

21. Granite porphyry, Jefferson tunnel, Tenmile district. Similar to no. 18.

22. Quartz monzonite, Monarch-Tomiche district. The feldspars are the most abundant minerals of the quartz monzonite, and as a rule plagioclase predominates over orthoclase. Quartz is invariably present but nowhere in great quantity and usually occurs in small crystals. Hornblende and biotite are usually associated in about equal amounts. Titanite is a prominent accessory mineral, and apatite, zircon, and magnetite are usually present. The plagioclase is poikilitic in many places and encloses biotite and hornblende.

23. Quartz monzonite porphyry, Browns Gulch, Breckenridge. Has rather large and conspicuous phenocrysts and a rather fine, even-grained groundmass. There are several large phenocrysts of orthoclase, but the plagioclase (andesine) phenocrysts are much more abundant. Quartz phenocrysts are plentiful, biotite is common, and hornblende is rare. The groundmass is composed almost entirely of quartz and orthoclase. Allanite is common and occurs in rather large crystals.

24. Quartz monzonite porphyry, Browns Gulch, Breckenridge. district. Similar to no. 23.

25. Quartz monzonite porphyry, near Halfway, Tarryall district. Moderately porphyritic, finely granular, light to dark gray. Contains orthoclase, andesine-oligoclase, biotite, quartz, and hornblende phenocrysts in a matrix consisting chiefly of quartz and orthoclase. Apatite, titanite, allanite, and zircon are accessory minerals. Plagioclase phenocrysts are more abundant than orthoclase and in some places poikilitically enclose both biotite and quartz.

26. Quartz monzonite porphyry, north of Halfway, Tarryall district. Similar to no. 25.

27. Quartz monzonite porphyry, Little French Creek, Tarryall district. Similar to no. 25.

28. Quartz monzonite porphyry, Mineral Ranch Hill, Tarryall district. Similar to no. 25.

29. Quartz porphyrite, Sugar Loaf Mountain, Tenmile district. The phenocrysts are chiefly plagioclase, biotite, and quartz; the evenly granular groundmass is principally quartz and orthoclase.

30. Gray porphyry, Onota shaft, Johnson Gulch, near Leadville. The mineral composition is almost the same as that of the Lincoln porphyry (no. 19). It is holocrystalline and has large phenocrysts. The porphyry is usually somewhat altered, although it appears quite fresh. Large crystals of orthoclase and small and numerous crystals of plagioclase and biotite are the rule. The groundmass has the same minerals as the Lincoln porphyry, although it is not quite so coarse-grained.

31. Gray porphyry (Johnson Gulch porphyry), Leadville. The color ranges from greenish gray to dark gray. Its essential minerals are orthoclase, plagioclase, quartz, biotite, and hornblende; the accessories are magnetite, apatite, titanite, and allanite. The phenocrysts are plagioclase, a few large orthoclase crystals, quartz, biotite, and hornblende. The ground-

mass in the lighter varieties consists chiefly of quartz, alkalic feldspar, and subordinate and variable amounts of plagioclase. The porphyry is usually much altered, and sericite and chlorite are invariably present; pyrite, epidote, calcite, and siderite (?) are common, and some secondary quartz occurs. Calcite is more abundant in the darker varieties.

32. Quartz monzonite porphyry, Mount Guyot, Breckenridge. Almost equigranular, with little distinction between groundmass and phenocrysts. Plagioclase is the most abundant mineral and is between andesine and labradorite in composition. Orthoclase probably predominates over quartz. Biotite is plentiful, and in places some hornblende is intergrown with it. Titanite, apatite, and magnetite are accessory minerals.

33. Evans Gulch porphyry, Evans Gulch, Leadville. An even, fine-grained porphyritic rock which has from 25 to 30 percent of oligoclase-andesine. Quartz and orthoclase are generally associated in the groundmass. A small amount of albite is also reported. The biotite has been altered to chlorite, and small grains of magnetite are closely associated with the quartz and orthoclase. Apatite and zircon are accessories.

34. Quartz porphyry, Flagstaff Hill, Boulder. Contains moderately large crystals of quartz, feldspars, and biotite in a felsitic groundmass. The feldspars have been badly altered, but it is believed that they were originally sanidine. Quartz is abundant. It is difficult to ascertain the composition of the groundmass because of its decomposed condition, but probably its original minerals were quartz and feldspar (orthoclase or sanidine).

35. Quartz monzonite of Silverheels, head of Little French Creek, Tarryall district. A greenish-gray, moderately fine grained porphyritic rock containing abundant hornblende and labradorite-andesine phenocrysts as well as a few inconspicuous phenocrysts of biotite and quartz. The fine-grained groundmass consists of quartz, orthoclase, and hornblende.

36. Diorite porphyry, Wellington mine, Breckenridge. Has a seriate fabric, and the phenocrysts are rather small. The largest phenocrysts present are hornblende and are accompanied by plagioclase, pale augite or diopside, hypersthene, biotite, magnetite, and apatite. The predominating mineral of the groundmass is labradorite, but quartz and orthoclase are present, and hypersthene is common. Biotite is rare and occurs in very small flakes. Accessory zircon and magnetite are present.

37. Diorite porphyry, Wellington mine, Breckenridge. Essentially the same as no. 36 except for minor alteration. The hornblende has apparently been altered to biotite, and some secondary calcite is present.

38. Porphyrite, Buckskin Gulch, Park County. Dark-colored and fine-grained. Contains abundant unevenly sized hornblende, much plagioclase, and a little biotite. The groundmass is essentially quartz and orthoclase (?). Magnetite and a little apatite are present.

39. Biotite porphyry, North Mosquito Amphitheater, Mosquito Range. Similar to no. 38 except that it contains no hornblende and much biotite. Plagioclase, orthoclase, quartz, biotite, magnetite, apatite, and zircon are present. Small amounts of secondary calcite, chlorite, and pyrite are also present.

40. Andesite, Sugarloaf Mountain, Boulder County. Brownish gray with a ratio of about 33 percent phenocrysts to 67 percent groundmass. The feldspar phenocrysts are the most abundant and form about 20 percent of the rock. The composition and proportion of the different phenocrystic minerals is as follows: Orthoclase and sanidine about 13 percent, plagioclase 7 percent, pyroxene 5 percent, biotite 3 percent, hornblende 2 percent, and magnetite 3 percent. Apatite and titanite are present in very small amounts. The extremely fine grained groundmass is essentially feldspar.

41. Mica andesite, West Sugarloaf Mountain, Boulder County. About one-third of this rock is made up of phenocrysts, and the remainder is a microcrystalline groundmass. About 54 percent of the phenocrysts are sanidine, about 21 percent labradorite, 7½ percent biotite, 4½ percent magnetite, and 0.6 percent titanite. Apatite is present in small quantities. Secondary calcite is abundant, and kaolin (?) and secondary quartz occur in small amounts. The groundmass is largely feldspar but includes considerable magnetite and some limonite.

42. Diorite porphyry, Boreas Pass, Tarryall district. Medium fine grained, dark gray, porphyritic; contains abundant small phenocrysts of plagioclase and biotite. Hornblende is also conspicuous but is less abundant than the other two minerals. The groundmass is holocrystalline and consists chiefly of plagioclase. Some orthoclase may be present, and quartz and apatite are noted as accessory minerals.

43. Basalt, Alum Hill, Boulder County. A dark-colored porphyry, containing moderately large crystals of augite and plagioclase in a glassy groundmass. About 49 percent of the rock is augite, 32 percent is plagioclase, 16 per cent is titaniferous magnetite, 1.6 percent is haüyne, and 1.6 percent is tridymite.

44. Basalt, Alum Hill, Boulder County. A fine-grained greenish-gray rock. The groundmass is a glass and is the matrix of small crystals of plagioclase, augite, some hematite, and a little calcite. No magnesite, titaniferous iron ore, quartz, or apatite were seen.

45. Olivinite, 2 miles southwest of Boulder, Boulder County. Dark gray to purplish. Serpentine nodules are abundant and show a clear resemblance to the original crystalline olivine which they replace. Well-crystallized magnetite is very abundant. Titanite occurs in rather coarse nodules and apparently is not present in the groundmass. The specimen selected for analysis contained a minimum of titanite. Garnet is sparingly present in the form of pyrope; most of it is fresh, but some of it is slightly decomposed. Calcite is apparently primary; some of it is cryptocrystalline, but some occurs as phenocrysts. Both light and dark micas occur meagerly. A mineral that strongly resembles zeolite was also noted.

46. Diabase, east of Sugarloaf Mountain, Boulder County. Contains labradorite, orthoclase, augite, and magnetite, with small amounts of hornblende, biotite, apatite, and secondary chlorite.

47. Augite andesite, pebbles in Denver formation, Table Mountain, Golden. Contains a few augite and andesine phenocrysts in a granular groundmass of oligoclase, orthoclase, quartz (?), and some augite and magnetite.

48. Augite andesite, pebbles in Denver formation, Table Mountain, Golden. Contains andesine phenocrysts, but megascopic augite and biotite, though present, are rare. The groundmass is made up of plagioclase, augite, magnetite, and minor accessories. Ptilolite was also observed.

49. Basalt, Table Mountain, Golden; a flow interbedded in upper part of Denver formation. This basalt is a dense black rock which has many augite and olivine crystals in a dark, dense groundmass. Plagioclase phenocrysts are present though not conspicuous to the unaided eye. The groundmass consists chiefly of plagioclase microlites with orthoclase (?) grains between them. Augite, magnetite, and apatite are also present, and biotite is sometimes found.

50. Augite-mica syenite, North Fork of Turkey Creek, Jefferson County. Dark-colored and coarse-grained near the center of the mass. The predominant mineral is orthoclase, but biotite and augite are common in about equal amounts. The augite has many inclusions of apatite, magnetite, and biotite.

The dark-brown biotite contains many inclusions of magnetite. Apatite is very abundant and locally includes some augite. Magnetite is sparingly present, and quartz is found only in small quantities in the finer-grained varieties of the rock.

51. Valmont dolerite dike, 3 miles east of Boulder, Boulder County. Dark greenish gray and slightly porphyritic. The greater part of the rock is made up of plagioclase, but crystals of augite and olivine are also abundant. Orthoclase and biotite are common, and biotite is moderately abundant. Magnetite and apatite are accessory minerals.

52. Bunker andesite, Rosita Hills. A dark porphyritic holocrystalline rock of compact texture in which the groundmass exceeds the phenocrysts. The chief minerals of the phenocrysts, named in the order of abundance, are feldspars, augite, biotite, and hornblende. The groundmass is made up of feldspars, augite, magnetite, and quartz. Magnetite and apatite occur in small phenocrystic grains.

53. Augite diorite, Rosita Hills. Chiefly labradorite, augite, biotite, and small amounts of olivine. Most of the rock is granular, although locally it is somewhat porphyritic. In the specimen analyzed there was some orthoclase, and where orthoclase is present there is a tendency for hornblende to develop at the expense of augite and biotite.

54. Augite diorite, Rosita Hills. Essentially the same as no. 53 except that it lacks the orthoclase and has a greater amount of olivine.

55. White porphyry (muscovite granite porphyry), quarry in California Gulch, southwest base of Iron Hill, Leadville. The White porphyry is usually creamy white or light gray. It is felsitic but contains a few small, thinly scattered phenocrysts of feldspar and quartz and a few small scales of muscovite and biotite. The feldspar is andesine, and iron oxide and hexagonal crystals of muscovite are occasionally found. The muscovite was regarded as secondary by S. F. Emmons, but Loughlin reports small clusters of muscovite that appear both earlier and later than the quartz, which is believed to be primary. The groundmass is microgranular and consists essentially of oligoclase, orthoclase, and quartz. The oligoclase and orthoclase are about equal in quantity. The quartz is abundant and interstitial among the feldspars. Minute grains of zircon and rutile are rather common, but magnetite and apatite are very scarce.

56. White (Zion) porphyry, Little Harry shaft, Prospect Mountain, Leadville. The essential minerals are plagioclase, orthoclase, and quartz. Orthoclase slightly predominates over plagioclase. Many muscovite leaves are present and contain small crystals of rutile or stout crystals of anatase (?). Zircon is abundant and some biotite is present; magnetite and apatite are very rare.

57. Felsite dike (porphyrite), Niwot mine, Ward district. A light greenish-gray, very fine grained, slightly porphyritic rock in which most of the primary minerals have been greatly altered. Small feldspar phenocrysts and a few chloritized or micaceous needles are visible in the hand specimen. Most of the feldspars were originally plagioclase, but some are not banded and may have been orthoclase. The rock as a whole seems to be an aggregate of kaolinlike minerals, with much secondary quartz. Titanite (?), chlorite, leucoxene (?), rutile (?), mica (?), and actinolite (?), may be present, but the abundant fine-grained silica has greatly altered the original and early secondary minerals. Some pyrite is also present. The specimens analyzed appeared fairly fresh but were obtained close to the Niwot vein, 300 feet below the surface. The analysis indicates much hydration and removal of alkalies, and the CaO is abnormally high.

Summary of averages of analyses, showing approximate composition of the different groups

Group	Epoch 3		Epoch 2							Epoch 1		
	11a	11	9	8	7 ^a	6	5	4	3	2	1	
SiO ₂	57.64	66.44	63.40	74.64	70.55	66.47	66.87	65.94	58.43	35.46	53.25	69.36
Al ₂ O ₃	19.10	14.98	17.73	13.33	15.17	17.01	16.27	15.80	16.33	11.68	19.34	15.00
Fe ₂ O ₃	2.54	1.57	1.88	.60	.61	.63	1.73	2.63	3.29	10.52	3.06	1.59
FeO	1.38	.43	1.10	.25	.74	1.23	1.72	1.60	3.54	10.11	4.28	.89
MgO	.84	.18	.50	.19	.56	.93	1.11	1.41	2.69	9.69	3.28	.58
CaO	2.95	2.47	2.23	.61	1.97	3.43	3.09	2.62	5.48	10.27	6.86	3.48
Na ₂ O	7.33	1.12	4.99	2.96	3.55	4.13	3.58	3.40	4.06	2.64	3.93	2.31
K ₂ O	5.13	3.32	5.37	5.88	5.02	4.05	3.50	3.30	2.77	1.63	3.68	2.08
H ₂ O +	1.09	4.06	1.63	1.55	1.28	1.02	.90	1.24	1.27	1.95	1.24	3.48
H ₂ O -	.23	4.60	.71	—	—	—	.20	.47	.22	—	—	—
TiO ₂	.72	.20	.24	—	—	—	.48	.36	.74	2.26	.63	—
P ₂ O ₅	.20	.11	.06	—	.10	.17	.16	.24	.30	.61	.39	—
MnO	.09	.13	.12	.13	.09	.05	.15	.16	.31	—	.18	.05
CO ₂	.67	—	—	—	.38	.77	.31	.06	.95	.334	—	.71
ZrO	.09	—	—	—	—	—	—	—	—	—	—	—
Sum	^b 99.44	100.40	99.95	100.14	100.02	99.89	100.06	99.24	100.36	^c 100.16	100.12	99.53

^a Calculated as intermediate between groups 6 and 8.^b Late alkaline subgroup.^c Ultrabasic subgroup.

DIFFERENTIATION

The succession of intrusions in the Front Range porphyry belt suggests their derivation from a common magma whose composition was gradually changing during the intrusive period. The course of rock differentiation can be traced rather clearly and can be divided into three epochs—(1) an early epoch marked by ferromagnesian differentiates; (2) a middle epoch marked by moderately to highly silicic differentiates; (3) a late epoch marked by alkalic differentiates.

The earliest rocks (groups 1 and 2) suggest an unusual type of differentiation—the change from an intermediate to a ferromagnesian magma. On the east side of the Front Range this early stage started with a magma whose composition was that of a moderately silicic diorite, but the succession of early intrusives indicates that it gradually grew much more ferromagnesian and locally became highly ferromagnesian. These early intrusions, unlike the later ones, were widespread in the Front Range and were not concentrated in the mineral belt.

After a period of rest a second epoch of differentiation commenced. The early intrusives of the second epoch (group 3) had the composition of diorites, but the successive intrusions show that the magma became steadily more and more silicic. It had successively the composition of a diorite, monzonite, quartz monzonite, sodic quartz monzonite, sodic granite, granite, and alaskite. A great upward migration of magma occurred during the quartz monzonite stage, and the later differentiates represent a comparatively small amount of the material from the magmatic reservoir, and their composition suggests filter-pressed residuum

from the partly consolidated quartz monzonite. Although most of the residual magma progressively changed until it finally had the composition of an alaskite, a part of it or perhaps a deeper magma became more and more sodic. The rocks that formed in the early stage of sodic (alkaline) differentiation are contemporaneous with the granite porphyries of the diorite-alaskite epoch.

During the later part of the second epoch of differentiation the composition of the magma changed from albite-oligoclase-quartz monzonite (group 6) to alkali syenite (group 9). The end of the second epoch of differentiation overlapped the beginning of the third, and the alkalic series that characterized the third epoch apparently represents a late branch of the diorite to granite differentiation.

Some of the details of differentiation are clear and are worthy of consideration. The usual changes in the feldspars occurred. Labradorite, andesine, oligoclase, and albite appear successively in later and later rocks. Quartz and orthoclase are inconspicuous in the early rocks of the second epoch but increase in abundance in later rocks. They are confined to the groundmass in the diorites and first appear as abundant phenocrysts in the quartz monzonite porphyry. By a gradual decrease in the other constituents the rock series move toward alaskite. In the alkalic stage, however, quartz decreases while orthoclase continues to increase. In the sodic differentiates oligoclase changed to albite and still later, through the addition of potash, to anorthoclase.

The ferromagnesian minerals have an interesting history. The augite of the early diorites changed to

hornblende in most places, and the hornblende in turn to biotite. Local reversals of order occurred from time to time, and in some places hornblende became unstable after its formation and changed into augite again. Hornblende is the characteristic ferromagnesian mineral of the diorite and early monzonite, and biotite is characteristic of the quartz monzonites and granite porphyries. However, in some of the albite-oligoclase-quartz monzonite porphyries and sodic granite rocks, hornblende is abundant again. In the more sodic differentiates augite is the chief ferromagnesian mineral. It would seem that the changing conditions of equilibrium were such that the ferromagnesian constituents crystallized successively as augite, hornblende, biotite, hornblende, and augite.

In the section on rock alteration the gradual increase of water during the differentiation of the diorite magma is traced. Apparently the water was concentrated in the granite differentiate while the alkaline differentiate became relatively dry.

ROCK ALTERATION

HYPogene ALTERATION

In general, alteration has been more widespread in the later intrusive rocks than in the older ones. As the later intrusives preceded the ores by only a short interval, there was probably a marked tendency for them and the ore solutions to follow the same channels, whereas the older intrusives may have followed fractures that by the time of ore formation had become tightly sealed. Thus a more frequent occurrence of zones of alteration may be expected in the late than in the early intrusives. Hydrothermal alteration was not confined to the period of ore formation, however, as the metamorphism of the country rock surrounding the porphyritic Montezuma quartz monzonite stock shows that appreciable alteration accompanied its intrusion. As its intrusion was separated from the ore stage by an interval during which alaskite and alkali syenite magmas were formed and intruded, it is probable that rock alteration began feebly in an early stage of the diorite and granite period of differentiation and continued with growing power until it culminated shortly before ores commenced to form. Much of the rock alteration was not related to channels of mineralization, and the evenness of its effects indicates deuterian or endomorphic changes.

Some late albite-quartz monzonite porphyry intruded at the edge of the Montezuma stock shows an unusual type of alteration. The albite phenocrysts are partly replaced along their borders and cleavages by a more calcic feldspar. The alteration was probably effected by calcic emanations from the partly cooled mass of quartz monzonite in the adjacent stock.

The endomorphic as well as the exomorphic changes were made chiefly by watery solutions at high temperatures. The increase of alteration marks the gradual

accumulation of water and other volatile constituents of the magma as it became more and more silicic and potassic. If a water-rich magma were intruded into a pervious fissure, the volatile constituents would move into regions of lower pressure as the molten rock solidified, finding avenues of escape through the shattered or porous material in the fissure zone. If a water-rich magma were intruded into a tightly sealed opening, the volatile material would be trapped with the solidifying rock. Thus, where the volatile fluids could escape little deuterian alteration of the porphyry would occur, although, if a similar porphyry nearby had cooled in contact with the fluids squeezed out during crystallization, it would show pronounced endomorphic changes. The most thorough deuterian alteration occurred in the rocks of the granite group, and, although the rocks of the alkalic groups are greatly altered along channels of mineralization, they show little alteration in other places. It would thus appear that water was segregated with the granite magma during differentiation and that the alkalic fraction was relatively dry. This supposition is substantiated by the occurrence of biotite in the granitic rocks and augite in the alkalic rocks, minerals characteristic of relatively wet and relatively dry magmas respectively.

Aside from the lack of relation to channels of mineralization, deuterian alteration⁹⁶ is commonly marked by coarser-grained secondary minerals than those formed by local hydrothermal alteration, but in many places, especially where the alteration has been intense, the two types are indistinguishable. Where deuterian alteration was feeble, sericite or fine-grained muscovite has replaced the feldspars, chiefly plagioclase, and chlorite has replaced the ferromagnesian minerals. Where the alteration was more intense, the muscovite and sericite are not confined to the feldspars but also appear in the ferromagnesian minerals, which contain more or less chlorite, quartz, epidote, leucoxene, magnetite, rutile, and zoisite. In some places carbonate is apparently contemporaneous with this suite of alteration products, but in most places it is later.

As in many places local hydrothermal alteration affected rocks that had already undergone deuterian alteration and, furthermore, as the hot solutions were not only changing but probably fluctuating in composition, pressure, and temperature, the sequence of alteration products is not everywhere the same. There is nevertheless a fairly definite paragenesis of the alteration minerals. Although sericite and chlorite probably formed in the cooler parts of the contact-metamorphic zone at the same time as the typical contact minerals were developing closer to the stock, in general such minerals as garnet, tremolite, hematite, magnetite, and epidote are the earliest products of exomorphic alteration. Sericitization was active from

⁹⁶ "Deuterian" is used in the sense originally given to the term by Sederholm (Comm. géol. Finlande Bull. 48, p. 142, 1916), for alteration produced during the later stages of the consolidation of a magma.

the time of the intrusion of the Montezuma stock till the period of ore formation. During the early part of this period, and at later stages in places where alteration was not intense, chlorite and epidote actively replaced ferromagnesian minerals. During the later part of the period of sericitization, or locally at an earlier stage in regions where early alteration was intense, fine-grained quartz partly or completely replaced the ferromagnesian minerals and the feldspars. Locally siderite or ankerite was introduced into the country rocks during the solidification of the quartz monzonite porphyry stocks and reacted with magnetite to form pyrite. Sulphur was not given off in large quantities until near the end of the period of sericitization. Then the bulk of the pyrite was precipitated in the veins or replaced the wall rock. During the vein-forming period silicification was the dominant type of alteration, but in some places the wall rocks were replaced to a minor degree by ankerite and impure siderite. Most of these carbonates formed near the end of the period of mineralization. The latest effect of hydrothermal solutions in veins was the introduction of calcite and fine-grained quartz. In many porphyries the calcic feldspars were replaced by calcite and fine-grained quartz, both of which are later than the sericitization of the rock. The absence of clay minerals and iron stains indicates that this alteration was not due to weathering and suggests that it also occurred late in the period of waning hydrothermal activity.

WEATHERING

During weathering the feldspars are converted to carbonates and clay minerals, while the ferromagnesian minerals are gradually changed into limonite, carbonates, and clay. If the rocks are already somewhat altered, weathering is more rapid, and the ferromagnesian minerals disappear much more rapidly than the feldspars. Where all the minerals were fresh before reaching the zone of weathering, some of the dark minerals, such as biotite, are as resistant to weathering as plagioclase. In the coarse-grained porphyritic quartz monzonites that have been hydrothermally altered, the large, slightly altered orthoclase phenocrysts commonly weather more rapidly than the silicified and sericitized plagioclase minerals, especially if they are exposed to slightly acid solutions, and the porphyry becomes pitted on the weathered surface by the removal of the large phenocrysts. Quartz phenocrysts are everywhere more resistant to weathering than the other constituents of the porphyries. Where previously unaltered rocks are exposed at the surface, the plagioclase usually weathers more rapidly than the other minerals, and the phenocrysts of orthoclase and quartz both weather in relief.

In most places in the pre-Cambrian complex there is little difference between the dike rocks and the country rocks in their resistance to erosion or weathering, but

in some of the softer members of the Idaho Springs formation and the Swandyke gneiss the dikes weather in relief. In the sediments west of the pre-Cambrian rocks the porphyries are generally much more resistant to erosion than their country rock and stand up in ridges or hills above the softer shales and grits.

Owing to the abundance of pyrite and other sulfides, the outcrops of veins are commonly less resistant to both weathering and erosion than their country rock, and their surface form is usually a linear depression. The acidity of the soil above pyritic bodies is unfavorable to the growth of many plants, especially aspen and willow, and in a thicket of these trees and shrubs the outcrop of a vein is marked by stunted growth, or, if the soil is thin, by a narrow barren strip of ground.

STRUCTURE

REGIONAL STRUCTURE

The Front Range is an elongate dome extending north from Canon City, Colo., into Wyoming. In the broad pre-Cambrian area exposed in this uplift the most obvious structural features are those developed in pre-Cambrian time, but the effects of the much later Laramie orogeny, so apparent in the bordering Paleozoic and Mesozoic sediments, can also be recognized within the metamorphic complex. The pre-Cambrian rocks that make up most of the Front Range are chiefly granites and schists. The regional pre-Cambrian structure has already been described by the writer,⁹⁷ and only the general features will be considered here. A large mass of granite, the Pikes Peak granite batholith, extends north from Canon City to Georgetown, a distance of about 90 miles. North of the Pikes Peak batholith several smaller batholiths of granite intrude into the schist between Georgetown and Laramie, Wyo., but schist is as abundant as granite. Although the regional structure of the schist is comparatively simple, the minor folds and crenulations are complex. Most of the schist southeast of the mineral belt dips north or northeast, but close to the Pikes Peak granite it is folded into irregular synclines and anticlines. Northwest of the mineral belt a northward-trending anticline extends from Georgetown into Estes Park, and a syncline runs north-northeastward from the vicinity of Breckenridge to Fraser. Within the mineralized belt the schists are folded into a series of sharp synclines and anticlines, most of which trend from east to northeast.

Nearly all the post-Cambrian events that affected the structure occurred in late Cretaceous and earliest Eocene time. They included strong folding accompanied by thrust faulting and related tear faulting; several stages of minor faulting preceding, accompanying, and following the intrusion of quartz monzonite

⁹⁷ Lovering, T. S., The Front Range mineral belt: Colorado Sci. Soc. Proc., vol. 12, pp. 233-268, 1930.

porphyry stocks and dikes; vein formation; and minor postmineral faulting.

Although the Front Range uplift has a distinctly north-south regional trend, it is made up in large part of northwesterly folds arranged en échelon. These folds and their associated faults are the earliest effects of the Laramide revolution. Where deformation was not severe, these northwesterly flexures are open asymmetric folds, but where the mountain-building forces were stronger, the folds are overturned toward the southwest and in many places are broken by reverse faults, downthrown to the west. In the Montezuma quadrangle the west edge of the Front Range coincides with a broken fold of this type. Thrust faults have been found on both borders of the range, but, as shown on plate 5, the largest one known at present breaks this western fold and is known as the Williams Range thrust fault. It has been traced from the Breckenridge district for 50 miles northwestward to Muddy Butte, a short distance beyond Kremmling. Farther northwest it is hidden under Tertiary sediments, and its extreme northern limit is unknown. At its southeast end it passes into an overturned fold that continues southeastward into South Park where it is hidden beneath Pleistocene gravel. This fault, as will be shown presently, is interpreted as an underthrust.

A narrow zone of irregularly spaced but well-alined porphyry stocks trends N. 40° E. across the Front Range from Breckenridge to Jamestown. Nearly all the dikes, sills, and mineral deposits except the Miocene ores of Cripple Creek are concentrated in the region just southeast of the zone of stocks in a northeastward-trending "mineral belt" ranging from 3 to 12 miles in width. Although persistent northwesterly faults extend across the mineral belt and for long distances both northwest and southeast of it, easterly and north-easterly fractures, which include most of the vein fissures, are abundant only in the mineral belt. This belt passes diagonally across the Montezuma quadrangle. The northeasterly course of the zone of stocks and the mineral belt of the Front Range is shown on plate 5. The veins in the mineral belt commonly occupy faults and fissures that strike from northeast to east, but some northwesterly veins have been found. The eastward-trending mineralized faults in the west half of the range show a marked uniformity in the direction of their displacements. So far as known, in all faults of this system the northern walls have moved east almost horizontally. The northeasterly faults commonly show less horizontal than vertical movement, and both reverse and normal faults are common south of the Montezuma stock. As indicated above, the northwesterly faults are commonly reverse faults that dip northeast. The mineral belt comes to the west edge of the range in the Montezuma quadrangle at the place where an overturned fold breaks and passes into the Williams Range thrust fault, and it seems clear that these structural features are related.

The easterly faults of the mineral belt show the presence of widespread horizontal shearing forces, and the Williams Range thrust fault, which dips east-northeast at a low angle, also records the presence of a regional stress that was nearly horizontal. Both types of fracturing are thought to have been the result of a regional compression, for when the overturned fold broke into the thrust fault near Tiger the movement of the fracturing rock masses was greater than in the adjacent folding layers, and strong tearing stresses developed between the areas of thrusting and folding. Thus as one part of the overturned fold broke loose and moved along the thrust fault past the less active part of the fold a transverse shear zone marked by tear faults was formed.

The terms "overthrust" and "underthrust" have been used to indicate which block was believed to be active. In most places, no field evidence has been given that would indicate that one block was more active than the other, and the use of either "underthrust" or "overthrust" as descriptive terms depended largely on the theories of the user. Where the side of a thrust-fault block ends against a tear fault it may be possible to determine whether the upper block was more active than the lower block. If the lower block has been pushed actively under an inert upper block, the movement along the tear fault will not be the same as it would be if the upper block had moved actively over a nearly inert lower block. Points on the active side of the tear fault will be carried past the inactive, or fold, side parallel to the dip of the thrust fault. If the upper block moves over an inert lower block, points on the thrust-fault side of the tear fault will move up the dip of the thrust fault relative to the fold side of the tear fault, whereas if the lower block moves beneath an inert upper block, points on the active side of the tear fault will move down the dip of the thrust fault. Drag of the inert block by the active block would cause the same relative movement in the tear faults bordering both the active and the inert blocks of the thrust fault. As the direction of movement of the tear faults in the mineral belt shows that the north side of each fault moved east while the fold south of the Williams Range thrust fault was overturning to the west, and as this fold is deflected slightly eastward where it adjoins the tear-fault zone, it is probable that the lower block of the thrust fault was more active than the upper block, and thus that the Williams Range thrust fault can, with some assurance, be called an underthrust.^{97a}

Overfolding toward the southwest accompanied by either overthrusting or underthrusting has been common in Colorado northwest of a line extending from Boulder southwest to Gunnison, a line that nearly coincides with the center of the Colorado mineral belt. In a wide zone southeast of this line, persistent steep

^{97a} Lovering, T. S., Field evidence to distinguish overthrusting from underthrusting: *Jour. Geology*, vol. 40, pp. 660-663, 1932.

northerly faults, downthrown on the west, are common, but thrust faults are not found. The southern limit of this zone trends nearly west from the north end of the Wet Mountains to the north end of the San Juan Mountains. Farther south overfolding and overthrusting toward the northeast—a direction opposite to that of the overfolding northwest of the mineral belt—have been common.⁹⁸ Thus, in the Front Range, the mineral and porphyry belts mark the northwestern limit of a transition zone between opposite types of deformation. The broad regional structure, as well as the more local relation of the mineral belt to the Williams Range thrust fault, indicates northeast-southwest shearing stresses concentrated in this belt during the Laramide revolution, in early Eocene time.

As the Montezuma quadrangle is on the western border of the Front Range uplift, where the mineral belt intersects the Williams Range thrust fault, the local structure described below is an excellent sample of the regional geology.

LOCAL STRUCTURE

The major structural elements of the Montezuma quadrangle are shown in figure 5. The metamorphic rocks are greatly broken and intruded by pre-Cambrian granites and Tertiary porphyries, but the axes of the chief folds of the schist have been shown. The Williams Range thrust fault is present in the southwestern part of the quadrangle and passes into an overturned fold near the southern boundary. The fault plane is domed up at the western edge of the large stock of quartz monzonite porphyry near the center of the quadrangle, and a "window" has been cut through the gneiss of the hanging wall by the Snake River and Jones Creek, exposing the underthrust Cretaceous shales.

The mineral belt runs diagonally across the quadrangle from southwest to northeast and, as in other parts of the Front Range, coincides with a belt of porphyries. These major features and the associated structure will be discussed in detail below.

PRE-CAMBRIAN STRUCTURE

Much of the pre-Cambrian granite in the Montezuma quadrangle shows flow structure, especially near the contacts with the schists or gneisses. The parallelism of the tabular feldspars and biotite crystals indicates the direction of movement in the granite masses during their emplacement and is well developed in the Silver Plume granite masses and in the small outlying stocks and bosses of Pikes Peak granite in the southeastern part of the quadrangle. The direction of the flow lines was not systematically studied, as time was lacking for the detailed work that would be required, but several observations were made and

are recorded on plate 3. In most places the flow lines are parallel to the schistosity of the enclosing schists or gneisses, suggesting the intrusion of the granite in sill-like masses, but cross-breaking contacts between granite and schist are common, and here the flow lines are parallel to these contacts in the adjacent granite. In the large mass of Silver Plume granite in the north half of the quadrangle many of the small bodies of schist, and most of the larger bodies, show such marked concordance in the direction of the schistosity that it seems probable that they are roof pendants; on the other hand, the small isolated bodies of schist that show no relation to the regional structure are probably xenoliths that had been stoped from the overlying batholithic cover and were trapped by the solidifying magma. The direction of foliation of the schist masses is shown on plate 3, and the random orientations of the schist inclusions contrast so markedly with the regularity of strike in the roof pendants that they can be easily distinguished.

The general structure of the schists is shown in the cross sections on plate 4. The Swandyke gneiss marks the center of a syncline which is about 5 miles wide near the southern boundary of the quadrangle. Several minor folds occur on the sides of the major syncline, and complex crenulations of small magnitude are present everywhere. The axis of the major syncline runs north through the western part of the Montezuma quadrangle and swings northeast soon after entering the Fraser quadrangle. To the east of the syncline the general dip of the schists is toward the west, but several minor anticlines and synclines have been recognized and are shown on figure 5 and in the cross sections on plate 4. The direction of the schistosity is indicated by short lines on plate 3, where many flexures are shown that are not of sufficient importance to be described here. The larger features are also indicated by this convention and the approximate course of schist beds can be ascertained by studying the direction of the lines.

The most pronounced structural feature in the schist in the east half of the quadrangle is the westward-plunging anticline at the head of West Geneva Creek. Although it is not plainly shown in the cross sections, the abundant measurements of dip and strike and the swing of the lines of schistosity on plate 3 clearly indicate its position and structure. It differs from the northeastward-trending anticlines and synclines north of it in being a comparatively open fold. Dips of 20° to 40° are common in it, whereas farther north in the schist area northeast of Grays Peak the schistosity is generally steep and the folds are almost isoclinal.

As stated elsewhere,⁹⁹ the progressive increase in the degree of metamorphism of the schists as the large

⁹⁸ Oral information from W. S. Burbank and E. N. Goddard.

⁹⁹ Lovering, T. S., Geologic history of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, pp. 67-71, 1929.

pre-Cambrian granite masses of the Front Range are approached suggests that the schistosity was developed during the period of pre-Cambrian batholithic inva-

Locally the structure of the schists appears related to this large granite mass, and in the Georgetown quadrangle the schistosity swings around the nose of the

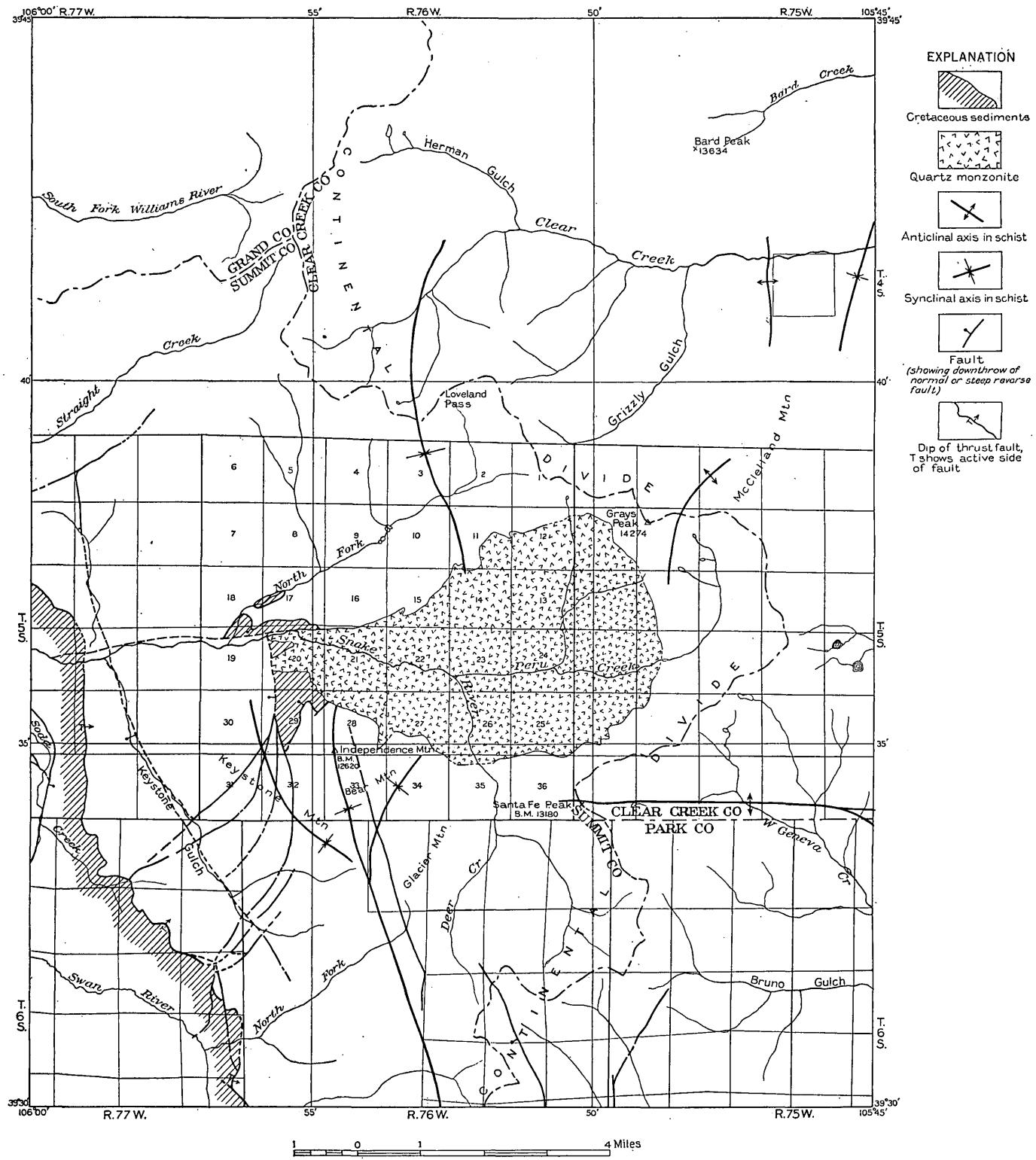


FIGURE 5.—Major structural features of the Montezuma quadrangle.

sion. The crumpling of the sediments, which were metamorphosed into schists and gneisses, was caused by regional forces that were active before and during the formation of the Pikes Peak granite batholith.

batholith approximately parallel to the contact of the two rocks. In that region it dips at low angles away from the granite on the east and north but becomes steep along the west and southwest sides and in many

places shows no parallelism to the granite contact. It is probable that much of the present structure of the schist was developed before the intrusion of the granite and was locally modified by the intrusion.

LARAMIDE STRUCTURE

Williams Range thrust fault.—The Williams Range thrust fault enters the Montezuma quadrangle about a mile northwest of Keystone and follows a south-southwesterly course to the North Fork of the Swan River, where it turns due south and passes into an overturned fold. The schist and gneiss that crop out above the fault generally supply a moderately thick cover of slope wash that creeps over the soft Cretaceous shales underlying the fault and effectually conceals the contact of the two formations. The contact of the sediments and metamorphic rocks was seen at only one place along the western boundary of the pre-Cambrian mass. Near the head of Soda Creek, where the fault crosses the east line of sec. 3, T. 6 S., R. 77 W., some prospect holes were driven into the brecciated fault zone, and about 30 feet of it is exposed. The lowest part of the outcrop is sandy and moderately fine grained and grades up into a breccia that near the top contains angular fragments of granite and pegmatite as much as 5 inches in length. Hematite and green copper stain are abundant in cross fractures. A very prominent sheeting is present that strikes due east, dips 25° – 30° N., and is probably parallel to the fault plane in this locality. Slickensides dipping 46° N. 70° E. were observed, but the grooves and heavy striations, which are very prominent, dip due east at 50° . The shales nearby dip 24° NNE. In most places the sediments west of the fault dip east or east-northeast at 20° to 30° and show no change in dip as the fault is approached. Locally, however, the shale is much disturbed, and in the irrigation ditch 0.4 mile north of Keystone the Pierre dips 50° – 90° E.

Farther south the geology, which is described below, indicates that an overturned fold south of the Middle Fork of the Swan River becomes more and more broken toward the north and passes into the thrust fault near Tiger. Although pre-Cambrian rocks rest only on the Pierre from the place where the fault enters the quadrangle, near Keystone, south to a point about a mile north of Tiger, they abut against fragments of the Niobrara and Dakota formations at several places farther south, as shown on plate 3. On the south bank of the Middle Fork of the Swan River about a quarter of a mile east of its mouth a nearly vertical thin bed of Dakota quartzite lies between schist and a mass of intrusive hornblende diorite, but the contacts are covered. Farther south both the Benton shale and the Dakota quartzite lie between the diorite and the pre-Cambrian rocks, and at Georgia Pass, $2\frac{1}{2}$ miles south of the quadrangle, the sedimentary contact of the Dakota quartzite and the pre-Cambrian

schist is clearly exposed. It is overturned and dips about 65° E.

The eastward continuation of the Williams Range thrust fault for at least 4 miles from its main outcrop at Keystone is shown by a "window" that adjoins the Montezuma stock. Just west of the stock hard, slaty shale crops out for about a mile on the lower slopes of the western spur of Porcupine Peak, near the junction of Snake River and its north fork, $2\frac{1}{2}$ miles east of Keystone. Poorly preserved casts of *Inoceramus* show that the rock is Upper Cretaceous, and its lithology indicates that it is the Pierre shale. It is overlain by the Swandyke gneiss from 200 to 700 feet above the valley floor, and the two formations are separated by an indurated fault breccia about 30 feet thick. The fault surface is very irregular but dips in a general northerly direction as shown in plates 3 and 4. South of this exposure of the fault, on the northwest spur of Independence Mountain, shale is found at much higher altitudes, and the fault crosses the spur about 2,300 feet above the valley of the Snake River. Keystone Gulch is the western limit of the southern mass of shale and almost certainly follows a strong fault. The fault contact descends rapidly as it is followed south from the crest of the Independence Mountain spur, and the shale passes from sight beneath the overlying gneiss in the bottom of Jones Gulch 1.8 miles from its mouth.

Structural relations of the Montezuma stock.—A wedge of the Montezuma quartz monzonite stock projects west into the shale in the valley of the Snake River, and, as shown on plate 3, the thrust fault is cut off abruptly by the stock a short distance east of meridian $105^{\circ}55'$, on both the north and south sides of the wedge. The shale dips away from the quartz monzonite at 10° to 50° , showing that the wedge is near the axis of a domal uplift. It is uncertain whether the difference in altitude of the thrust-fault surface on the two sides of the wedge is due chiefly to faulting or to doming, but the straightness of the north edge of the quartz monzonite suggests that it followed a transverse fault. It is known that the doming of the thrust fault was accompanied by faulting along Jones Gulch, and it seems probable that the dome was also broken by an eastward-trending system of faults either before or accompanying the intrusion of the stock.

The contact of the Montezuma stock and the schists is nearly straight for distances of several miles in some places. On the northern and southeastern sides of the stock the straight-line contacts generally trend N. 70° E., suggesting a preporphyry system of fractures having this trend. It is probable that they represent fractures related to the tear or transverse shear faults of the mineral belt. In most places the contact of the quartz monzonite and the metamorphic rocks is steep, but on the eastern border of the stock the contact dips 45° E. down the southwest spur of Grays Peak, through an observed vertical distance of 1,200 feet. The schist

nearby is badly crumpled and may have been crowded by the intrusion of the stock, but in most places the intrusive rock breaks cleanly across the schistosity of the country rock, and there is no indication that the structure of the schist affected the shape of the stock. The upward bulge of the Williams Range thrust fault at the west end of the stock suggests that the quartz monzonite was intruded near the center of a local eastward-trending anticline, and the primary linear and platy structure of the intrusive and the position of the aplite seams indicate that it was moving upward and N. 80° E. at an angle of about 25° to the horizontal in this locality.

The stock is strongly jointed but has few persistent faults or fissures. As it was intruded after the region had been through the period of stress when the Williams Range thrust fault was formed, it was probably subjected to much milder fracturing stresses than the country rock nearby.

The region northwest of the stock contains almost no dikes of porphyry, but the region southeast of it has many dikes and small irregular masses of porphyry. As pointed out in the discussion of regional geology, this is a relation that exists throughout the porphyry belt of the Front Range; the large stocks of porphyry all occur northwest of the belt of porphyry dikes, which is also the belt where veins are abundant. This relation suggests the presence of subjacent magmatic chambers southeast of the zone of stocks and their absence to the northwest. These chambers were probably the source of the solutions that mineralized the fractures of the mineral belt. The regional position of the Montezuma stock in the northeastward-trending zone of stocks suggests that its intrusion was dependent chiefly on regional shearing stresses between provinces of different types of deformation, rather than on the presence of the thrust fault which it cuts.

Transverse faults and fractures of the mineral belt.—The distribution of the veins and dikes of the mineral belt that extends diagonally across the quadrangle is shown on plate 3. In the northeastern part of the quadrangle they are concentrated in a narrow northeasterly belt extending from Kelso Mountain to Brown Gulch. South of Kelso Mountain the belt is slightly broader, probably averaging about 2 miles wide, and runs almost due south to the head of West Geneva Creek, where it swings southwest and widens greatly. In this part of the quadrangle it would not be recognized as a distinct northeastward-trending belt if it were not considered part of a regional feature. (See pl. 5.)

West and south of the head of West Geneva Creek scattered veins occur in many places, but the largest veins are still concentrated in narrow belts. Near Montezuma the best-known and most productive veins, which on the whole have northeasterly trends, occur in a strip about a mile wide that runs nearly due

west from the head of West Geneva Creek to Glacier Mountain, where it swings sharply south-southeast through Teller Mountain into Hall Valley. The scarcity of veins west of Glacier Mountain is attributed to the fact that the pre-Cambrian in that area terminates downward against the underthrust plastic, impervious Pierre shale, which was an effective barrier to rising ore-forming solutions. The northwestward-trending belt of northeastward-trending veins in the Hall Valley area is probably related to the fault at the east side of South Park, with which it alines and with which the prominent regional north-northwest faults correspond in movement.

It is difficult to obtain information about the movement of faults in the schists and gneisses, as definite horizons are not usually recognized, but in some of the veins and faults the direction of movement was found. Of the many criteria that have been suggested for determining the direction of movement of fault walls,¹ the writer has found that the only trustworthy ones are displacement of recognizable horizons, drag of adjacent layers of schist, interior faulting within a fault zone, curved tension cracks, S-shaped compression fractures in the fault material indicating the relative movements of the two walls, and grooves and furrows cut into hard walls and believed to be parallel to the direction of strongest movement. These criteria have been used to determine the direction of movement in faults of the Montezuma quadrangle.

The premineral faults in the northeastern part of the quadrangle, near Silver Plume, commonly trend east-northeast, and in the Gold Belt tunnel the north wall of the chief vein fissure apparently moved down and east. A few miles to the southwest most of the veins strike north-northeast, and in the Stevens mine the west wall of the vein fissure apparently moved down and north at an angle of about 60° . Most of the veins in the mineral belt farther south also strike north-northeast or northeast, but a few trend east or northwest. In the Pennsylvania vein, about 5 miles south of the Stevens mine, the available data, though not conclusive, suggest that the northwest wall of the fissure moved up and northeast at an angle of about 30° . Near Montezuma the Bell-Meteor Wing vein, the Bullion vein, the Chatauque vein, and the Sts. John or Comstock vein follow reverse faults that dip northwest, and the Silver King follows a normal fault that dips southeast, its southeast wall moving down to the northeast at an angle of about 70° . Thus in the premineral faults near Montezuma for which the movement could be ascertained the upthrown wall was consistently on the north and the angle of movement was moderately steep. This movement was probably expressed by step faulting related to the formation of the east-west anticline associated with the Montezuma

¹ Willis, Bailey, and Willis, Robin, Geologic structure, pp. 132-145, New York, McGraw-Hill Book Co., 1929.

quartz monzonite. The Ida Belle fissure, on the east slope of Jones Gulch, strikes nearly due east and cuts the Williams Range thrust fault. Its north wall moved down to the east at a low angle. If the movement on these faults is representative of the region near them, it seems probable that they were formed in response to a regional shearing stress, modified later by local vertical stresses attending the intrusion of the Montezuma quartz monzonite stock.

Postmineral faults are not common in this quadrangle, but several were observed in Glacier Mountain, south of Montezuma. Most of them have a northerly strike and an easterly dip and are normal faults. Movement along these faults may be as much as 350 feet. (See pp. 85, 102.)

The veins in the southeastward-trending branch of the mineral belt that runs through the Hall Valley area are in transverse relation to a fault zone that is parallel to the schistosity of the Swandyke gneiss in this region and strikes north-northwest. The displacement on the three north-northwest faults in this zone (shown as one fault on pl. 3) is not uniformly in the same direction, but on two of the three faults for which the direction was ascertained the movement was very much greater than on the third, and in these two the west wall moved down and to the south. The veins that are related to the fault zone strike northeast, but the direction of movement of their walls is not known with certainty, although the occurrence of ore in the flatter parts of the Missouri vein suggests that it is a reverse fault in which the northwest wall moved up.

Intrusive relations of dikes and small masses.—With the exception of the Montezuma quartz monzonite stock and the quartz monzonite mass in the southwestern part of the quadrangle, all the Tertiary intrusives occur in relatively small masses. Most of the intrusives north of West Geneva Creek are dikes, but southwest of this stream small irregular-shaped masses are common. The longest dikes in the quadrangle are less than a mile long, and most of them are less than half a mile—commonly less than 1,000 feet. The short length of the dikes in the Montezuma quadrangle contrasts strongly with the great length of those found in the northeastern part of the mineral belt, where Bastin and others have mapped many dikes several miles long. These long dikes strike northwest, and, as already pointed out, fractures trending northwest are probably related to échelon folding and are much more persistent than northeastward-trending fractures. Nearly all the dikes in the Montezuma quadrangle strike from east to northeast, and apparently all the porphyry was intruded along comparatively nonpersistent fissures. Many of the intrusives are parallel to the schistosity of the enclosing schists and gneisses, but because of the steep dip of most of these rocks, the intrusives are regarded as

dikes rather than sills. At the head of West Geneva Creek, however, sill-like offshoots from the irregular mass of monzonite porphyry on Revenue Mountain were intruded between layers of the gently dipping schists not far from the crest of the westward-trending pre-Cambrian anticline described on page 45. In the shale area west of the Williams Range thrust fault sills are more common than dikes, as may be seen in structure section *D-D'*, plate 4. Most of the dikes that are not parallel to the schistosity strike either east or northeast and are nearly vertical. In some places, as in the Burke tunnel, a mile south of Montezuma, porphyry masses are exposed underground that do not crop out at the surface. In other places a dike that dies out along its strike is succeeded by small masses of porphyry in line with it, which are probably upward projections from a continuous mass that at depth follows the same fracture zone as the exposed dike. Similar relations were noted in the adjoining Georgetown quadrangle by Ball,² who concluded that dikes were probably more abundant at depth than at the surface.

GEOLOGIC HISTORY

During pre-Cambrian time, probably early in the Algonkian,³ a thick series of sandy shales was laid down on an unknown basement. After the deposition of these sediments, and in part during the later stages of their accumulation, large masses of basaltic and andesitic lavas were extruded. The sediments and the lavas were strongly folded and metamorphosed into schists and gneisses at the beginning of a great period of batholithic invasion, which followed the period of extrusion.

The earliest rocks of the batholithic period were intruded while the crumpling sediments were being gradually metamorphosed, and at the depth at which these events occurred the heat and emanations from these intrusives were instrumental in changing the sediments into schists and gneisses. Small masses of monzonite, granite, aplite, pegmatite, and quartz diorite were intruded in many places. Most of the early magmas were very fluid and searched out and followed bedding-plane fractures. This lit-par-lit injection of the sediments was widespread but was most intense in the regions later intruded by the granite batholiths. Continued diastrophism and injection accompanied the invasion of a very large mass of granite magma, and many of the earlier intrusives were converted into gneisses during its slow formation. The Pikes Peak granite batholith, which formed at this time (about a billion years ago), is the largest known in the Front Range, and the intrusive activity as well as the metamorphic processes waned markedly after its formation.

² Ball, S. H., op. cit. (Prof. Paper 63), p. 72.

³ Lovering, T. S., Geologic history of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, pp. 73-74, 1929.

After the Pikes Peak granite had solidified, another epoch of granite invasion occurred. The later pre-Cambrian granites and their associated pegmatites of this epoch were intruded at many places in the Front Range. The Silver Plume granite, the Cripple Creek granite, the Longs Peak granite, and the Mount Olympus granite belong to this epoch and represent the latest pre-Cambrian intrusive activity in the Front Range. It is uncertain whether they belong to the last stage of the batholithic invasion of the Pikes Peak granite or to a much later period.

The formation of the late granites was probably accompanied by uplift and was certainly followed by a long period of erosion. By the end of Algonkian time the earlier mountains had been worn down to nearly featureless plains on each side of a slightly higher tract of land, which existed along the site of the present Front Range. This early Front Range highland has remained a positive topographic area ever since and has supplied sediments to the surrounding region many times. The Front Range highland was separated by a broad basin from a similar high area stretching northwest and southeast of the present site of Creede. Sediments of the early Paleozoic systems are not present in the Montezuma quadrangle, but Cambrian, Ordovician, Devonian, and Mississippian sediments were deposited in the basin west of the Front Range highland, a short distance away. Oscillations of the earth's surface resulted in successive invasions and withdrawals of the sea from the lowlands during these periods, but it is improbable that any of these seas covered the Front Range highland. The areas occupied by the sea in each period were much the same, but in general each marine invasion was a little more widespread than the one before.

There is little in the character of the Cambrian, Ordovician, Devonian, and Mississippian sediments to indicate proximity to a rugged land surface, but there is clear evidence of the rejuvenation of erosive agents in the Pennsylvanian. Elsewhere in the Front Range there is evidence of minor warping between these periods,⁴ but apparently no uplift of magnitude occurred until late Mississippian or early Pennsylvanian time, when the Front Range highland was elevated and the adjoining areas were depressed. Thick continental and interstratified marine delta deposits were formed in these troughs during Pennsylvanian and Permian time. The eastern shore line of the Pennsylvanian sea probably passed through the Breckenridge district very close to the southwest corner of the Montezuma quadrangle, and the Permian sediments overlapped it and extended a few miles farther east onto the pre-Cambrian rocks.

Little erosion or diastrophism occurred in this region at the end of the Permian or during the Triassic period, and no sediments of Triassic age are known nearby.

During the later part of the Jurassic period thin marine sediments were deposited along the northern borders of the Front Range, and some sediments of this age have been reported not far from the Montezuma quadrangle. Neither erosion nor deposition, however, was notably active at this time. Still later in Jurassic time the Front Range highland was reduced to a series of low hills rising from broad, nearly featureless piedmont plains teeming with large swamp-loving reptiles. The fresh-water sediments of the Morrison formation were laid down on these plains but did not cover the hills. The Lower Cretaceous sea is not represented in the area.

The Upper Cretaceous sea advanced over the slowly sinking highland and deposited the Dakota sands and shales, but the central part did not subside as rapidly as the margins, and, as in Pennsylvanian and Permian time, a much thicker series of sediments formed along the edge than over the center. The maximum subsidence probably occurred about the middle of the Pierre epoch, and uplift began soon after subsidence ceased. Before the end of Pierre time the central part of the Front Range highland was pushed above the level of the sea, and the recently deposited shales were exposed to erosion. They were reworked into the upper part of the marine Cretaceous, and the Dakota sandstone was also exposed and reworked at many places and was probably the source of much of the sandy material found in the upper part of the Pierre shale and in the Fox Hills sandstone. During the succeeding Laramie epoch the pre-Cambrian core was exposed and was contributing feldspathic sediments to this formation. Before the end of the Laramie the central part of the Front Range highland was elevated well above the surrounding plains. This elevation was probably due to a gentle arching of the whole Front Range highland, forecasting the violent mountain-making movements that occurred early in Eocene time, soon after the Denver epoch. Increasingly rapid uplift and marked volcanic activity followed the Laramie and ushered in the Denver epoch. At this time acidic felsites and gabbro were intruded at many places in the Front Range, and the gabbro dikes found scattered through the Montezuma quadrangle are believed to be of Denver age. At the same time that the highland was being arched, the border lands were being down-warped, and sometime after the end of the Denver epoch a great mass of the earlier sediments was thrust east-northeastward under the pre-Cambrian rocks in the western part of the Montezuma quadrangle. This folding was accompanied and followed by intrusive activity. Sills and dikes of diorite and monzonite porphyries were succeeded by dikes and stocks of quartz monzonite porphyry, which in turn were followed by dikes of more acidic rocks such as the granite and sodic quartz monzonite porphyries. Emanations from the underlying magma formed many metal-

⁴ Lovering, T. S., op. cit., pp. 75-81.

liferous veins, probably under a moderate cover of pre-Cambrian rocks and Tertiary lavas.

The rejuvenation of the streams that accompanied the mountain building at the end of the Denver epoch caused rapid erosion, and it is probable that the volcanic rocks that covered the pre-Cambrian core of the range during most of the Denver epoch were removed over large areas before Wasatch time, developing an imperfect peneplain called the "Flattop" peneplain. Renewed uplift, probably in early Wasatch time, rejuvenated the streams, and by the end of the Eocene erosion had cut a broad bench, known as the "Medicine Bow" peneplain, about 1,000 feet below the level of the Flattop peneplain. Both surfaces were locally halted at some of the places where the little-folded pre-Dakota peneplain was reexposed. It is probable that many of the conspicuously level surfaces of the Flattop peneplain are also remnants of the earlier erosion surface over which the Upper Cretaceous sea advanced at the beginning of Dakota time and which was slowly uncovered by Eocene erosion. Some of the ore deposits in the Montezuma quadrangle may have been within reach of ground water since the early part of the Eocene epoch.

Minor uplift and erosion occurred during Oligocene time but had little effect on the topography near the Montezuma quadrangle. A much greater uplift marked the Miocene, and in many places in the Front Range there was volcanic activity at that time. The rejuvenated streams commenced carving a new erosion surface on the flanks of the range but cut a plain farther back on the east side than on the west side. This surface, known as the "Rocky Mountain peneplain", is poorly developed in the Montezuma quadrangle but

can be recognized at many places. During lower and middle Pliocene time this peneplain continued to develop on the flanks of the higher mountains, while they themselves were carved into a mature mountainous upland. Little erosion occurred in the upper Pliocene, when for the first time since the Triassic, the region was visited by an arid climate. Although unimportant in its effect on the sculpturing of the mountains, this aridity was probably economically important in aiding the enrichment of the ores.

A broad regional uplift raised the Front Range at the beginning of the Quaternary period, and some of the postmineral faults observed in the quadrangle may have been formed at this time. The uplift started a period of vigorous erosion that has lasted to the present. Two major glacial stages followed the uplift, and it is probable that a less extensive glaciation occurred during the interval between them. A great amount of erosion took place in some of the large valleys after the first glaciation, and some of them were deepened as much as 1,200 feet by later stream and glacial erosion. The last glaciers have disappeared in comparatively recent time, and little erosion has been effected by the streams since.

ECONOMIC GEOLOGY

MINERALOGY

MINERALS OCCURRING IN THE QUADRANGLE

All the minerals that are known to occur in the Montezuma quadrangle are listed in the table below, and the mode of occurrence of each mineral is indicated. Additional information is given for many of the minerals on pages 53-58.

Minerals in the Montezuma quadrangle

Mineral	Hypogene					Supergene	
	Regional metamorphism	Igneous rocks	Contact metamorphism	High-temperature deposits	Moderate-temperature deposits	Sulphide zone	Oxidized zone
Alabandite, MnS					×		
Allanite, Ca ₂ [Al.OH](Al,Fe,Ce,La,Di) ₂ [SiO ₄] ₃		×					
Amphibole, CaMg ₃ (SiO ₃) ₄	×	×					
Andesine, Ab ₇ An ₃ (see plagioclase)	×	×					
Andradite (see garnet)	×		×				
Ankerite, (Ca,Mg,Fe)CO ₃					×		
Apatite, (Ca,F)Ca ₄ P ₃ O ₁₂		×					
Argentite, Ag ₂ S						?	?
Arsenopyrite, FeAsS, or FeS ₂ .FeAs ₂					×		
Augite, CaMgSi ₂ O ₆ with (Mg,Fe)(Al,Fe)O ₂ Si ₆		×			×		
Azurite, 2CuCO ₃ .Cu(OH) ₂							
Barite, BaSO ₄					×		
Beegerite, 6PbS.Bi ₂ S ₃					×		
Biotite, (H,K) ₂ (Mg,Fe) ₂ Al ₂ SiO ₃ O ₁₂	×	×	×				
Bismite, Bi ₂ O ₃							×
Bismuthinite, Bi ₂ S ₃					×		
Bismutite, Bi ₂ O ₃ .CO ₂ .H ₂ O							×
Bromyrite, AgBr							×
Calcite, CaCO ₃					×		
Calamine, H ₂ (Zn ₂ O)SiO ₄							×
Cerusite, PbCO ₃							×
Chalcanthite, CuSO ₄ .5H ₂ O						×	×
Chalcedony, SiO ₂						×	×

Minerals in the Montezuma quadrangle—Continued

Mineral	Hypogene					Supergene	
	Regional metamorphism	Igneous rocks	Contact metamorphism	High-temperature deposits	Moderate-temperature deposits	Sulphide zone	Oxidized zone
Chalcocite, Cu ₂ S	—				?	×	
Chalcopyrite, CuFeS ₂			×	×	×	×	
Chlorite							
Chrysocolla, CuSiO ₃ .2H ₂ O							
Clay	×			×	×	×	×
Clinozoisite							
Copper, Cu							×
Covellite, CuS						×	
Cuprobismutite, 3Cu ₂ S.4Bi ₂ S ₃	×		×		×		
Diopside, CaMg(SiO ₃) ₂							
Dolomite, CaMg(CO ₃) ₂					×		
Emplectite, Cu ₂ S.Bi ₂ S ₂					×		
Enargite							
Epidote, H ₂ O.4CaO.3(Al ₂ Fe)O ₃ .6SiO ₂	×		×	×	×		
Epsomite, MgSO ₄ +7H ₂ O		?					×
Fibrolite							
Fluorite						×	
Freibergite, 4(Cu ₂ S.Ag ₂ S) ₃ .Sb ₂ S							
Galena, PbS							
Garnet, 3R''O.R''O ₃ .3SiO ₂ (when R''=Ca, Mg, Fe, Mn; R'''=Al, Fe(Mn), Cr, Ti)	×		×				
Goethite, Fe ₂ O ₃ .3H ₂ O							
Gold, Au						?	×
Goslarite, ZnSO ₄ .7H ₂ O						×	×
Graphite, C			×				
Gray copper, Cu ₈ Sb ₂ S ₇ or 4Cu ₂ S.Sb ₂ S ₃					×		
Gypsum, CaSO ₄ +2H ₂ O						×	×
Hematite, Fe ₂ O ₃		×	×	×	×		
Hornblende, Ca(Mg,Fe) ₂ (SiO ₃) ₂	×	×					
Hypersthene, (Mg,Fe)SiO ₃	×	×					
Ilesite, (Fe,Mn,Zn)SO ₄ .4H ₂ O							
Ilmenite, FeTiO ₃	×	×					
Jarosite, K ₂ O.3Fe ₂ O ₃ .4SO ₄ .6H ₂ O						×	×
Kaolin, 2H ₂ O.Al ₂ O ₃ .2SiO ₂						×	×
Labradorite (see plagioclase)	×	×				×	×
Leucoxene							
Limonite, 2Fe ₂ O ₃ .3H ₂ O							
Magnetite, Fe ₃ O ₄	×	×	×				
Malachite, CuCO ₃ .Cu(OH) ₂							
Manganosiderite, (Fe,Mn,Mg)CO ₃							
Marmatite, (Zn ₄ Fe)S					×	×	
Melanterite, FeSO ₄ .7H ₂ O							×
Miargerite, Ag ₂ S.Sb ₂ S ₃						?	
Microcline, KAlSi ₃ O ₈	×	×					
Molybdenite, MoS ₂					?	×	
Muscovite, KH ₂ .Al ₃ (SiO ₄) ₃ (see also sericite)	×	×					
Oligoclase (see plagioclase)	×	×					
Orthoclase, KAlSi ₃ O ₈	×	×					
Paragonite, NaH ₂ Al ₃ (SiO ₄) ₃					×	×	
Pearcrite, Ag ₆ As ₈ S ₆							
Perovskite, CaTiO ₃	×	×					
Plagioclase, x (NaAlSi ₃ O ₈). y (CaAl ₂ Si ₂ O ₈)	×	×					
Proustite, Ag ₃ AsS ₃						?	
Psilomelane, H ₄ MnO ₅							
Pyrargyrite, Ag ₃ Sb ₂ S ₃						?	
Pyrite, FeS ₂				×	×	×	
Pyrolusite, MnO ₂							
Quartz, SiO ₂	×	×	×	×	×	×	×
Rhodochrosite, MnCO ₃							
Roscoelite, vanadium mica							
Rutile, TiO ₂	×	×			×	×	
Schapbachite, PbS.Ag ₂ S.Bi ₂ S ₃							
Sericite, KH ₂ Al ₃ (SiO ₄) ₃				×	×	×	
Siderite, FeCO ₃							
Sillimanite, Al ₂ SiO ₅	×	?					
Native silver, Ag						?	
Smithsonite, ZnCO ₃							
Sphalerite, ZnS					×	×	
Stephanite, Ag ₅ Sb ₂ S ₃							
Stromeyerite, CuAgS							
Sulphur, S							
Tennantite, Cu ₉ As ₈ S ₇							
Tetrahedrite, Cu ₈ Sb ₂ S ₇	×	×					
Titanite, CaTiSiO ₅ or CaO.TiO ₂ .SiO ₂							
Tourmaline (black)							

Minerals in the Montezuma quadrangle—Continued

Mineral	Hypogene					Supergene	
	Regional metamorphism	Igneous rocks	Contact metamorphism	High-temperature deposits	Moderate-temperature deposits	Sulphide zone	Oxidized zone
Tremolite, $\text{CaMg}_3(\text{SiO}_3)_4$ -----	X		X				
Turgite, $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ -----							X
Wad, mixtures of oxides, chiefly of manganese, with water-----							X
Wolframite (Fe, Mn) WO_4 -----					X		
Zircon, ZrSiO_4 -----	X	X					
Zoisite, $\text{HCa}_2\text{Al}_3(\text{SiO}_4)_3$ -----	X			X			

MINERALS OF THE ORE DEPOSITS

Alabandite.—Alabandite has been found in the Queen of the West mine at the head of Peru Creek, a short distance north-northwest of Argentine Pass.⁵ It occurred in a vein from 1 to 6 inches wide, and small amounts of dolomite, pyrite, and rhodochrosite were associated with it. The rhodochrosite occurred in small crystals lining vugs in the alabandite. The mineral had perfect cubic cleavage and strongly resembled galena except in color and the readiness with which it tarnished when exposed to the air. A single crystal showed the cube and tetragonal trisoctahedron.

Ankerite.—Ankerite is a common gangue mineral in many of the galena-sphalerite veins. Much of it contains manganese and weathers black at the surface. Carbonates of calcium, iron, magnesium, and manganese form an isomorphous series, and although the pure carbonates containing only one base are sometimes found, in most places the gangue is an ankerite containing several base-forming elements. Iron is an abundant constituent of most of the ankerite, and much of the carbonate could be properly called an impure siderite. The ankerite is light pinkish brown and occurs in compact crystalline aggregates which show curved cleavage faces. Much of the ankerite is later than the sulphides and encrusts them or lines vugs in the ore. In many places late ankerite occurs in veinlets ramifying through the sulphides in branching masses. In some veins the ankerite becomes more abundant near the bottom of an ore shoot and may be earlier than the ore minerals. The porphyries near lead-zinc veins are partly replaced by ankerite, and in some places noteworthy amounts of ankerite have been introduced into the walls of the veins.

Argentite.—Argentite is reported from many veins and has been observed in some of the silver ores in the north end of Glacier Mountain. Here it is closely associated with galena, miargyrite, and pyrargyrite, all of which seem contemporaneous. It is found in a gangue of manganiferous ankerite. Argentite is not a common silver mineral in the ores of the Montezuma quadrangle, however.

Arsenopyrite.—Arsenopyrite was observed in the barren quartz between the two ore shoots cut by the fifth level of the Silver Wave mine. It seemed to be contemporaneous with the quartz and with a small amount of pyrite, and all are believed to be earlier than the main period of sulphide mineralization. The arsenopyrite occurred in small irregular grains disseminated through the quartz.

Azurite.—Azurite is an uncommon secondary copper mineral found near the surface of some of the cupriferous lead-zinc ore bodies. It usually occurs in thin coatings on the free surfaces of fractured country rock, and not in contact with other ore minerals.

Barite.—Barite is an abundant gangue mineral of the lead-zinc ores, especially those that contain gray copper. Some barite is found as a late mineral in the veins, but most of the

barite is earlier than the sulphides or contemporaneous with them. Large bladed crystals of barite are conspicuous in the veins of Glacier Mountain, Teller Mountain, and Hall Valley, and some barite is also found in the veins on Revenue Mountain, on the east slope of Collier Mountain, and on the east slope of McClellan Mountain, where it is associated with fluorite. In most of the veins it is unevenly distributed and may occur as solid masses completely filling the vein or in a loose open-textured mass with many other minerals. Quartz is almost universally associated with barite, in part contemporaneous and in part later. Handsome specimens of coarse barite encrusted with quartz, sphalerite, and galena are found at the Sts. John mine, although at this place barite was deposited almost throughout the period of sulphide mineralization. Late barite, which may be supergene, is reported by Ransome⁶ and Spurr⁷ from veins near the Montezuma quadrangle, but none was observed by the writer. Some barite occurs in the Montezuma quartz monzonite porphyry remote from known veins and is comparatively late, but as it is interstitial between quartz and orthoclase, it is believed to be an accessory igneous mineral.

Beegerite.—Beegerite was first described in 1881 by Koenig,⁸ who used material from the Baltic lode, Revenue Mountain, near the head of West Geneva Creek. The beegerite occurred in small well-defined isometric crystals and as a massive light-gray mineral intergrown with quartz. Its specific gravity was 7.273. It contained no silver, although it was probably associated with silver minerals, as the Baltic vein produced silver ore. The analyses of four samples of the beegerite from this vein are given below.

Bi	20.59			
Cu		1.70		
Pb	64.59	64.07	64.60	63.66
S	15.71	14.23		
	100.89			

Bismite.—Bismite is found in the oxidized zone of bismuth-silver ores, where its bright color makes it conspicuous and has caused it to be called the "canary-yellow" by the miners. The principal occurrence known is at the Missouri mine, in Hall Valley, where it formed a noteworthy part of the ore for many years. It was related to a fault that permitted deep circulation of ground water and occurred to a depth of 200 feet from the present glaciated surface of the valley. It was associated with bismutite and a little malachite. The primary bismuth minerals oxidized more readily than chalcopyrite, however, and bismutite and bismite were found in ores containing chalcopyrite that looked fresh and unaltered, although no bismuthinite nor emblectite was present. They had probably been completely oxidized.

⁵ Ransome, F. L., op. cit. (Prof. Paper 75), p. 91.

⁶ Spurr, J. E., op. cit. (Prof. Paper 63), pp. 257-263.

⁷ Koenig, G. A., Beegerite, a new mineral: Am. Chem. Jour., vol. 2, p. 379, 1881.

Bismuthinite.—The primary bismuth mineral bismuthinite occurs in the bismuth-silver veins in the south half of the quadrangle. It is associated with quartz, pyrite, chalcopyrite, and the silver bismuthides emplectite and schapbachite. It is generally found in fine-grained shining lead-gray specks disseminated through quartz, in which small grains of pyrite are moderately abundant.

Bismutile.—Bismutile, the white secondary oxide of bismuth, occurs in the oxidized parts of bismuth-silver veins, and its general relations are those of bismite.

Calamine.—Calamine is not common in the ores of the Montezuma quadrangle but has been observed near the surface in a few veins. It occurs in thin white or colorless crystals in open spaces in oxidized ore. Some of the crystals are chisel-shaped, and others are so thin that they resemble short pieces of glass thread. The calamine is commonly associated with brown iron oxides and is found in small vugs in zinc ore which has been partly replaced by smithsonite. It is always a product of weathering.

Calcite.—Calcite is most common in late supergene veinlets that cut the ores not far from the surface. It is also found in late hypogene veinlets or in well-formed crystals in vugs. It is not abundant, however, and much of the material that resembles calcite is pale ankerite. The ground waters of the region are heavily charged with carbon dioxide and dissolve a large amount of calcium carbonate, which is deposited as a smooth crust where the waters are tapped by underground openings.

Bromyrite.—Bromyrite is reported from the oxidized zone of some of the rich silver veins, such as the Baker mine, but none was observed by the writer.

Brown iron oxides.—Hydrous oxides of iron are most abundant in the bog iron ores of West Geneva Creek, Handcart Gulch, Hall Valley, and the Snake River. These ores consist chiefly of the brown and yellow hydrous oxides, limonite and goethite, but some of the red hydrous oxide, turgite, is also present. Turgite is more common as a stain on the outcrops of veins than in the bog iron, however, and is associated with limonite and goethite in the oxidized parts of veins. An analysis of the bog iron ores is given on page 25.

Cerusite.—Cerousite is the common secondary lead mineral of the veins and is found near the surface. It is generally associated with galena at the outcrops of the veins, as the ore is rarely so thoroughly oxidized that all the galena is gone. In many ores the galena is apparently altering directly to cerousite without an intermediate border of anglesite being present. It is difficult, however, to give a plausible reaction by which the sulphide could be converted directly into carbonate, and it is probable that the galena oxidized to sulphate, which was so readily converted into carbonate that little or none of it remains. Cerousite occurs in small open spaces in the veins to a depth of at least 200 feet and is commonly found in well-formed crystals from 2 to 10 millimeters long.

Chalcanthite.—Chalcanthite has been reported from the upper parts of several of the cupriferous lead-zinc veins of the quadrangle and is said to have been very abundant in the upper part of the Pennsylvania mine. It is not uncommon on the sides of drifts beneath old stopes in moderately dry mines. Well-crystallized chalcanthite forms coatings from 0.1 to 2 centimeters thick on the walls of the fifth level of the Silver Wave mine.

Chalcedony.—Chalcedony is rare in the Montezuma quadrangle. Extremely fine grained quartz, probably in part chalcedonic, is found in some of the thoroughly silicified dikes in the northeastern part of the porphyry belt, and some of the silicified shale near the large stocks of quartz monzonite porphyry is probably replaced by chalcedony. None has been observed in the veins of the quadrangle.

Chalcocite.—Chalcocite is not abundant but has been observed in many ores close to the surface. It has replaced both chalcopyrite and galena, and in every occurrence studied it is clearly supergene. It probably was a common mineral in the enriched surface ores that were eagerly sought and mined 50 years ago. The typical relations of chalcocite to galena and chalcopyrite are shown in plate 13, A.

Chalcopyrite.—Chalcopyrite is the most abundant copper mineral found in the Montezuma quadrangle. It is present as minute blebs and blades in nearly all the sphalerite. (See pl. 13, B.) It also occurs as distinct masses which vein and replace pyrite. Most of the chalcopyrite is massive and rarely shows crystal faces, but in some of the veins, such as the Waldorf, it is found in well-crystallized tetragonal sphenoids in open vuggy ore. Two or more generations of chalcopyrite are present in many veins. Much of the early chalcopyrite is earlier than galena and sphalerite, but some seems to be contemporaneous. This early chalcopyrite is medium- or coarse-grained (pl. 14, A), and in many polished specimens it shows twinning bands in polarized light. The later chalcopyrite is fine-grained and untwinned. Small flakes of gold are sometimes found in the early chalcopyrite but are not invariably associated with it.

Chrysocolla.—Chrysocolla is not common but is sometimes found in the upper parts of veins associated with limonite.

Copper.—Native copper has been reported from many of the veins in the district but has not been observed by the writer in any of the ores. Near the southern breast of the drift on level F in the Pennsylvania mine, however, acid mine waters were attacking iron rails in 1929 and replacing them with spongy native copper. (See p. 93.) An interesting occurrence is reported from Handcart Gulch, where copper is said to have been washed out of the boggy alluvium bordering the stream by placer miners, who believed it to be a "red gold." Its occurrence here is probably explained by the reducing action of organic matter in the boggy alluvium. The water of the creek contains a large amount of iron sulphate, and it is probable that a small amount of copper is also carried in solution. The occurrence and geologic setting are similar to those of the bog copper ores of Cooke, Mont., which have been studied by the writer.⁹

Covellite.—Covellite is rare in the veins of the Montezuma quadrangle but is found with chalcocite in some of the cupriferous lead-zinc veins. Like the chalcocite, it occurs in small veinlets cutting and replacing both galena and chalcopyrite.

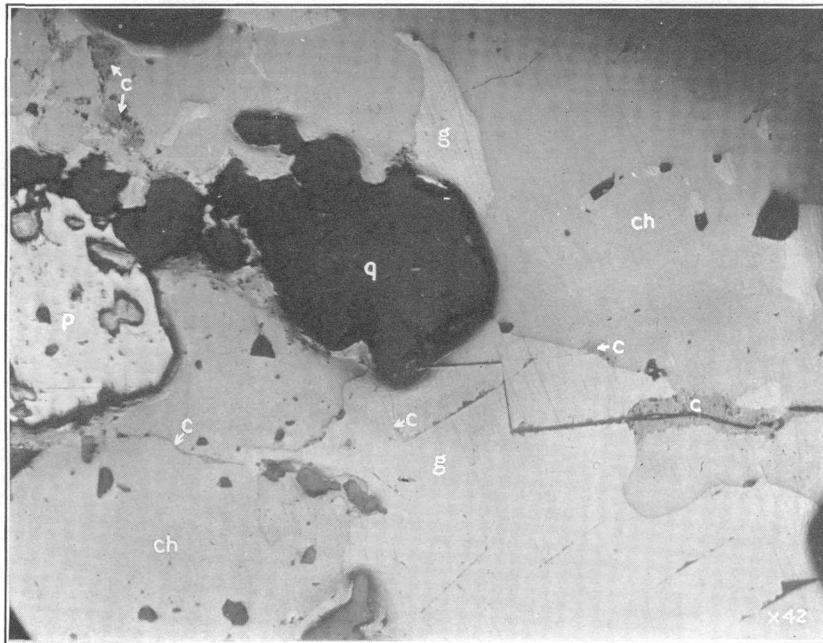
Cuprobismutite and emblectite.—Cuprobismutite is found in the rich bismuth-silver veins in the southern part of the quadrangle. It occurs massive, disseminated through the pyritized quartz of the veins, and in shining steel-gray needle-like crystals projecting into open spaces in the quartz with which it is always associated. Three analyses of cuprobismutite made by Hillebrand¹⁰ in 1883 and one of emblectite are given below.

	Cuprobismutite			Emblectite
	1	2	3	
Bi	60.80	63.42	62.51	62.16
Ag	.89	4.09	9.89	
Cu	15.96	12.65	6.68	18.72
Pb			2.74	
Fe	2.13	.59	.10	
Zn	.10	.07	.07	
S	49.94	48.83	17.90	18.83
	99.82	99.65	99.89	99.71

^a Calculated by Hillebrand.

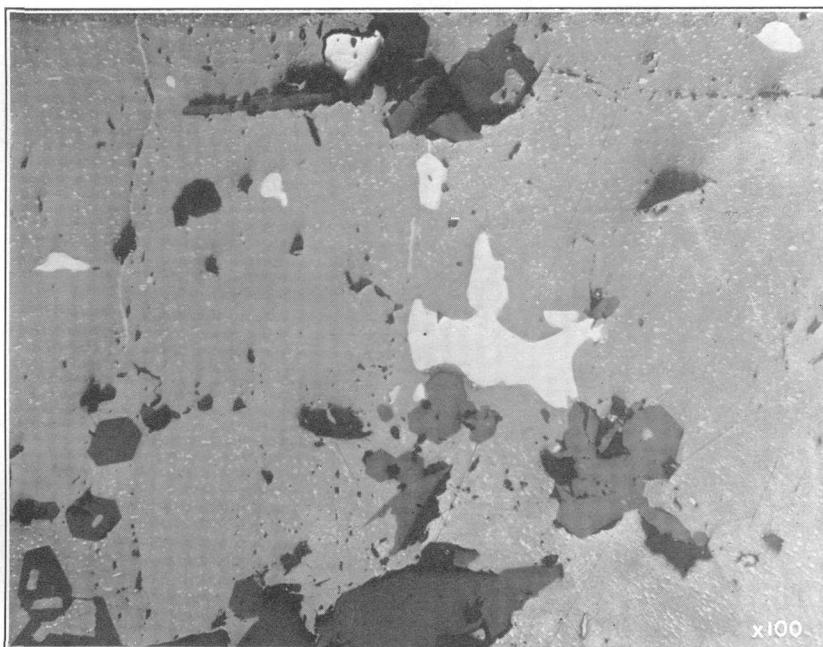
⁹ Lovering, T. S., The organic precipitation of metallic copper: U.S. Geol. Survey Bull. 795, pp. 45-52, 1923; The New World or Cook City mining district, Park County, Mont.: U.S. Geol. Survey Bull. 811, pp. 85, 86, 1929.

¹⁰ Hillebrand, W. F., On an interesting variety of löllingite and other minerals: Colorado Sci. Soc. Proc., vol. 1, pp. 53-55, 1884.



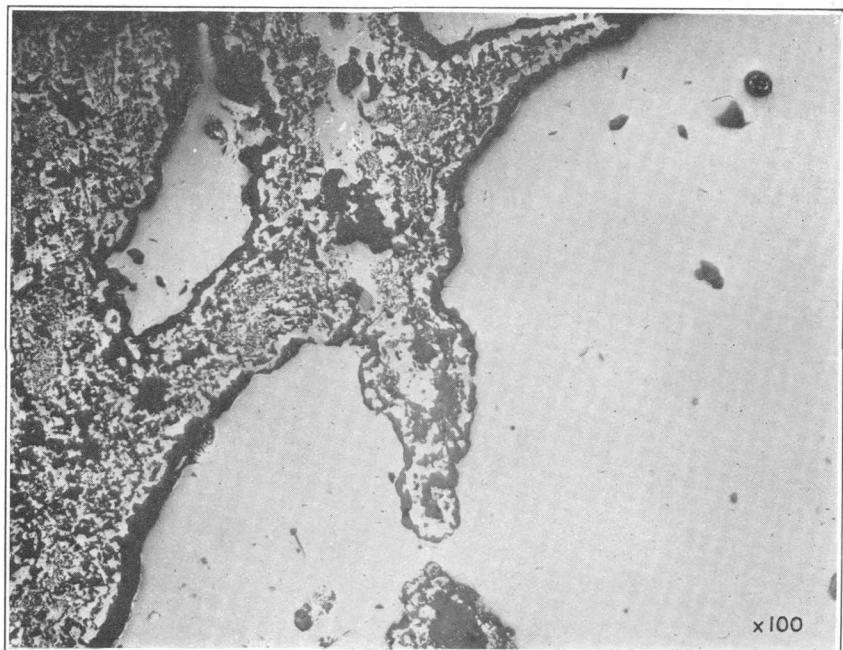
A. PHOTOMICROGRAPH OF ORE FROM LEVEL 3, SANTIAGO MINE.

From gob 800 feet from portal. Illustrates the common relations of chalcocite (c), galena (g), and chalcopyrite (ch). p, Pyrite; q, quartz.

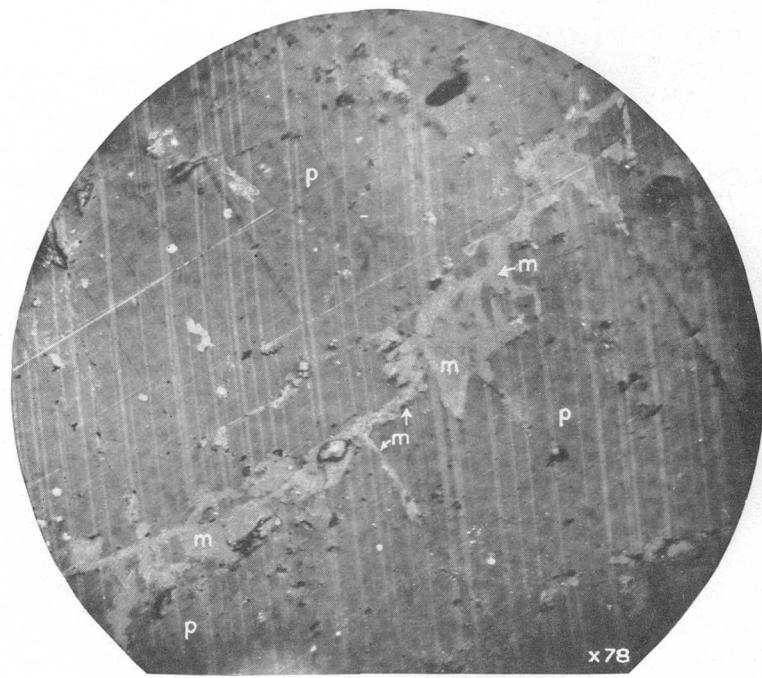


B. PHOTOMICROGRAPH OF ZINC ORE 100 FEET ABOVE MAIN TUNNEL LEVEL, STEVENS MINE.

Showing intergrowth of chalcopyrite (white) and sphalerite (light gray).



A. PHOTOMICROGRAPH OF ORE FROM DUMP OF STAR OF THE WEST NO. 2 MINE, TELLER MOUNTAIN.
Graphic intergrowth of quartz (dark gray) and chalcopyrite (light gray). The quartz is replacing the chalcopyrite but is earlier than galena.



B. PHOTOMICROGRAPH OF SILVER ORE FROM LOWER JERRY TUNNEL.
From vein trending N. 30° E., 320 feet from the portal. Miargyrite (m) replacing twinned pyrargyrite (p). Crossed nicols.

As a small amount of admixed chalcopyrite and sphalerite was present in the material analyzed, in spite of very careful sorting, the iron present was calculated as chalcopyrite and the zinc as sphalerite by Hillebrand, who then calculated the formula of the cuprobismutite from the first three analyses. It is $3RS_4Bi_2S_3$, where R represents Pb and the double atoms Ag_2 and Cu_2 . He concluded that "the needles are a pure sulphobismuthite of copper, and that in the more compact portions of the massive ore silver replaces a portion of the copper, while in some cases a further replacement of copper by lead takes place." The material for analysis 1 came from the Missouri mine, Hall Valley, and occurred as slender, deeply striated needles in open spaces in the ore, where it was associated with chalcopyrite and wolframite in a quartz gangue. Its specific gravity is about 6.31. The material for analysis 2 also came from the Missouri mine and was a dark bluish gray substance without distinct crystal form, intergrown with quartz and a small amount of chalcopyrite. The material for analysis 3 came from Hall Valley and is doubtfully referred to the Missouri mine. It is similar in appearance to the material used in analysis 2, except that no chalcopyrite could be seen in it. Its specific gravity was approximately 6.68. As the material was not examined in polished section, it is possible that the compact material was an intergrowth of argentite, chalcopyrite, galena, and cuprobismutite or bismuthinite, similar to the intergrowths of bismuthinite, galena, and argentite that Loughlin¹¹ found in the Leadville district. The cuprobismutite is very similar in composition to empyelite, and the material gathered in the Missouri mine is the only known occurrence of cuprobismutite. Short believes that the two minerals are identical.¹² An analysis of empyelite from Tannenbaum, taken from Dana's "System of mineralogy", is given for comparison in the table.

Dolomite.—Pure dolomite is not common in this quadrangle, although the impure forms which have been considered under ankerite are abundant. Dolomite occurs in well-formed saddle-shaped crystals in vugs in some of the veins, and in most places it was formed after the sulphide mineralization was complete.

Enargite.—Enargite was not observed by the writer but is reported to have been present in some of the ores found in the Missouri mine in the early eighties.¹³ It occurred as small blades in a quartz gangue and was associated with tetrahedrite, chalcopyrite, and a bismuth mineral.

Epidote.—Epidote is a common constituent of altered rocks in the Montezuma quadrangle. It has been formed by contact metamorphism in calcareous sediments near quartz monzonite porphyry stocks and is a common microscopic constituent of the altered porphyries. (See pp. 42-43, 59.)

Epsomite.—Epsomite is a common mineral in moderately dry mines that have been abandoned for several years. It occurs in thick incrustations on the sides of drifts, generally beneath stopes in veins having an ankerite gangue. It forms in needle-like crystals which are commonly perpendicular or at a high angle to the walls. The crystals are white, and some reach a length of an inch. Epsomite is associated with goslarite in most places.

Fluorite.—Fluorite is a rare gangue mineral except on McClellan Mountain, where it is moderately abundant, and is associated with barite and ankerite.

Freibergite.—Freibergite was found about 1,200 feet below the surface in a vein striking north-northeast in the Toledo tunnel. It is probably contemporaneous with a late generation of chalcopyrite, and both minerals are distinctly later than

galena and sphalerite. The vein has a quartz-ankerite gangue. The freibergite and chalcopyrite are regarded as primary.

Galena.—Galena most commonly occurs in medium-grained anhedral masses but in some places well-shaped crystals are abundant. Rarely do individual crystals measure more than a centimeter in diameter, but in some veins coarse cube galena as much as 5 centimeters across has been found. The well-shaped crystals always occur in open-textured ore and generally line vugs, and in many places they are associated with good crystals of sphalerite, chalcopyrite, and ankerite. Most of the galena in the quadrangle is intergrown with other sulphide minerals, but in some places moderately large masses occur that are nearly free from the other base-metal sulphides. Galena is generally associated with sphalerite, pyrite, and a small amount of chalcopyrite. In many places it is later than these minerals and cuts them in veinlets, but a large part of the galena was contemporaneous with sphalerite and chalcopyrite, though later than much of the pyrite. Galena is common in the oxidized zone and is present at the outcrops of many veins. Nodules of galena surrounded by cerusite are always found in the oxidized zone of the lead veins, and galena also occurs with the cerusite as a loose, open-textured, sandy mass. The galena found in the Montezuma quadrangle is believed to be primary.

The silver content of the galena is variable, and, contrary to the widespread belief that high-grade galena ore is good silver ore, the nearly pure sulphide generally contains less than 20 ounces of silver to the ton. Some late galena is intergrown with silver minerals but is not much more abundant than the silver minerals themselves.

Steel galena has been formed by postmineral movement along some veins, notably the Pennsylvania vein.

Garnet.—A brown garnet is abundant in the contact-metamorphosed sediments near the quartz monzonite porphyry stocks, and a red garnet occurs in the schists of the Idaho Springs formation. The brown garnet is probably the iron-calcium garnet, andradite, and occurs in granular masses associated with epidote and fine-grained quartz.

Goethite.—See Brown iron oxides.

Gold.—Crystalline gold was common in the upper part of the stockworks in the southwestern part of the quadrangle and in the oxidized portion of the veins on Wise Mountain. Several million dollars' worth of gold has been won from the valley of the Swan River by dredging, hydraulic, and sluicing. Many of the lead-silver-zinc veins farther northeast contain moderate amounts of gold, but visible free gold is rare. In most of these veins the gold is associated with chalcopyrite and occurs as small grains in chalcopyrite that was formed later than pyrite and is nearly contemporaneous with galena and sphalerite. Some rich oxidized gold ore is reported to occur in the Star of the West mine, on Teller Mountain, but like the ore on Wise Mountain, the vein did not prove profitable far below the outcrop. Primary gold is a constituent of most of the bismuth-silver ores, where it is probably related to the moderately abundant chalcopyrite.

Goslarite.—Goslarite is formed by the leaching of zinc ores after they have been opened by mine workings and has the same mode of occurrence as epsomite.

Graphite.—Fine-grained flakes of graphite are abundant in the contact-metamorphosed shales at the west end of the porphyritic Montezuma quartz monzonite stock but can be seen only with a microscope.

Gray copper.—Tetrahedrite and tennantite cannot be distinguished in the field, and both are abundant. They have not been found together by the writer, though it is probable that both are present in some ores. The tetrahedrite is generally later than the coarse-grained early chalcopyrite and is commonly later than sphalerite and galena, although in some specimens it appears to be contemporaneous with them. It is

¹¹ Loughlin, G. F., op. cit. (Prof. Paper 148), pp. 170-171.

¹² Short, M. N., Microscopic determination of the ore minerals: U.S. Geol. Survey Bull. 825, p. 104, 1931.

¹³ Cross, Whitman, A list of specially noteworthy minerals of Colorado: Colorado Sci. Soc. Proc., vol. 1, p. 137, 1884.

earlier than the fine grained late chalcopyrite and is also earlier than covellite and chalcocite. All the tennantite observed was definitely a late sulphide. The relations of the tetrahedrite suggest that it was formed slightly earlier in the period of mineralization than tennantite. Gray copper is most commonly found in the quartz-barite ores, where it occurs in small irregular masses that are later than the barite and quartz. These ores usually contain silver, some of which is probably present in the molecules of the gray copper minerals. Apparently pure specimens of dark-colored gray copper from Hall Valley are said to assay 100 ounces of silver to the ton, but assays of light-colored gray copper from the head of West Geneva Creek are reported to show much more silver.

Gypsum.—Gypsum is a secondary mineral that is formed by the action on calcareous rocks of sulphuric acid from decaying pyrite. It occurs in fractures in the black Cretaceous shales near pyritic ores.

Hematite.—Hematite occurs in contact-metamorphosed sediments near the quartz monzonite porphyry stock in the southwestern part of the quadrangle. It is associated with garnet, epidote, fine-grained quartz, magnetite, and some tremolite, pyrite, and chalcopyrite.

Ilesite.—Ilesite was first found in Hall Valley, where it occurred as an efflorescence on the outcrop of the McDonnell vein, and in the oxidized parts of other veins very close to the surface. The material when fresh, according to Cross,¹⁴ is a light transparent green and resembles melanterite, but after it has been exposed to the light and air for some time it loses some of its contained water and becomes white. Its specific gravity is 2.16, and its formula as calculated by Iles is $\text{FeS}_4\text{ZnSO}_4\cdot 5\text{MnSO}_4\cdot 28\text{H}_2\text{O}$, but Cross suggests that the material analyzed had probably lost some water and would need several molecules of water added to the formula given above if it were to correspond to the mineral as found in nature.

Jarosite.—Jarosite has been found in the oxidized ores west of Tiger, in the southwestern part of the quadrangle, but is not common. It is a fine-grained yellowish-brown mineral having a silky luster that distinguishes it from the limonite and jasperry quartz with which it is associated.

Kaolin and the clay minerals.—Kaolin and the other clays are not common gangue minerals, and wherever found their relations to the surface and to the other vein minerals indicate that they are supergene. Clay minerals are common in the fault gouges and in the upper parts of veins where the wall rocks have been attacked by surface water containing acids from the decaying sulphides. Some of the clayey filling of the veins close to the surface carried silver and gold in notable amounts. It is always more or less stained with limonite and ranges from a cream-color to deep reddish brown.

Limonite.—See Brown iron oxides.

Magnetite.—Magnetite is a common accessory constituent of all the intrusive rocks of the quadrangle and is locally abundant in coarse-grained aggregates in some of the pegmatites of the southeast quarter. It also occurs in the contact-metamorphic ores in the southwestern part of the quadrangle, where it is associated with garnet, epidote, fine-grained quartz, tremolite, and hematite.

Malachite.—Malachite is conspicuous but not abundant in the upper parts of the cupriferous lodes. It occurs chiefly as thin crusts on the outcrops of the veins and to a less extent in small veinlets cutting the oxidized ore.

Manganosiderite.—Manganosiderite is locally abundant in the mines on Glacier Mountain. It is found in the lower levels of the Wild Irishman vein and apparently gives way to quartz and barite in the upper levels. Galena is the chief sulphide associated with it, but both sphalerite and pyrite are also present.

¹⁴ Cross, Whitman, A list of specially noteworthy minerals of Colorado: Colorado Sci. Soc. Proc., vol. 1, pp. 140-141, 1885.

Marmatite.—The dark iron-bearing zinc sulphide, marmatite, is abundant in the mines in the Breckenridge district a mile south of the southwestern part of the quadrangle. It also occurs in many of the veins in the quadrangle, but most of the zinc is moderately light colored sphalerite. The marmatite is associated with pyrite, galena, and chalcopyrite. It occurs in medium-grained masses which are later than the pyrite and either contemporaneous or earlier than the galena. Chalcopyrite is intergrown with the marmatite in small blebs and blades, as shown in plate 13, B. The grains of marmatite do not have crystal faces except where they project into open spaces in the ore. Most of the grains are less than 3 millimeters in diameter and are generally smaller than the pyrite and galena with which they are associated.

Melanterite.—Melanterite is not uncommon in old drifts in moderately dry mines, where it forms by evaporation of the sulphate waters that descend through the vein. It forms light-green crusts and stalactites beneath old stopes in the sulphide zone. None has been observed at the surface, but it probably occurs in the oxidized portion of many veins.

Miargyrite.—Miargyrite is one of the most abundant silver minerals in the quadrangle. It is everywhere associated with pyrargyrite, with which it is intergrown. It is present in most but not all of the ruby-silver ores. Miargyrite, like the other ruby-silver minerals, is later than most of the pyrite, galena, and sphalerite but is contemporaneous with a late generation of galena and chalcopyrite. A typical intergrowth of miargyrite and pyrargyrite is shown in plate 14, B. Manganeseiferous ankerite is generally associated with the ruby-silver minerals.

Molybdenite.—Molybdenite is rare but was observed in a quartz vein on the crest of Glacier Mountain a few hundred feet east of the Tiger vein. It has also been found in small sporadic masses in the Montezuma quartz monzonite stock, apparently unrelated to definite veins.

Pearcite.—Pearcite was found in the ore on the dump of the Star of the West No. 2, on the west side of Teller Mountain. It occurs as small blebs scattered through galena. Quartz and tennantite, replacing chalcopyrite, are associated with the galena and pearcite. The minerals are probably primary.

Proustite.—Proustite is a common mineral of the ruby-silver ores but is less abundant than pyrargyrite and miargyrite. It is generally associated and contemporaneous with pyrargyrite, argentite, and late quartz. It is later than siderite and the bulk of the galena and sphalerite. Van Horn¹⁵ describes an interesting occurrence of proustite in the Bell mine, near Montezuma, where all these relations could be ascertained. Argentite and proustite were found for 30 feet along the strike of the vein and for 25 feet along its dip. The vein was about 21 inches wide, and bands of different minerals were symmetrically arranged about a central seam of contemporaneous argentite, pyrargyrite, proustite, and quartz. These minerals were flanked by layers of siderite (manganeseiferous ankerite?), and the siderite by layers of mixed galena and sphalerite. This vein structure shows the same relations of the base-metal sulphides, the carbonate gangue minerals, and the rich silver minerals as those found in a study of the relations of the various minerals in thin section and polished section. Sphalerite and galena are clearly earlier than the ankerite, and the ankerite is earlier than the silver minerals.

Psilomelane.—See Wad.

Pyrargyrite.—Pyrargyrite is a common silver mineral and is present in most of the ruby-silver ores. It is almost everywhere intergrown with miargyrite, forming mutual boundary structures at the edges of small grains. An example of this intergrowth is shown in plate 14, B. The ruby-silver ores are gen-

¹⁵ Van Horn, F. R., Occurrence of proustite and argentite at the California mine near Montezuma, Colo.: Geol. Soc. America Bull., vol. 19, pp. 93-98, 1908.

erally intergrown with quartz, late galena, and chalcopyrite in dark fine-grained masses.

Pyrite.—Pyrite is the most abundant sulphide mineral in the Montezuma quadrangle. It occurs disseminated through altered porphyries and the country rocks of the veins; it is present in the contact-metamorphic deposits near the large stocks; it is abundant in the sericitized rocks of the stockworks in the southwestern part of the quadrangle; and it is the most common mineral of the veins. Unlike galena and sphalerite, most of the pyrite occurs in grains showing distinct crystal outlines, although massive pyrite is not uncommon. It is present in most of the veins but is not uniformly distributed through them, and some bodies of galena and sphalerite ore are almost free from it. In other veins, such as those near Swandyke, quartz and pyrite are almost the only minerals that can be seen. Most of the pyrite is earlier than the other sulphides, but a small amount of late pyrite is present in many places. It is certain that most of the pyrite is primary, but some of the late pyrite may have been formed by descending ground water. The pyrite of the Montezuma quadrangle is rarely auriferous unless chalcopyrite is also present, and the general effect of pyrite is to lower the grade of an ore.

Most of the pyrite has been formed by the introduction of both iron and sulphur, but it is probable that much of the pyrite disseminated through the porphyries of the region has formed at the expense of the original magnetite and the ferromagnesian minerals of the rock, by the introduction of sulphur alone.

Pyrolusite.—See Wad.

Quartz.—Quartz is the most abundant gangue mineral of the ore deposits. Near the west end of the Montezuma quartz monzonite stock a great mass of the Pierre shale has been silicified and now consists of very fine grained dark quartz and a meager sprinkling of contact-metamorphic minerals. In some places clear crystals of quartz occur in openings in the hornstone and are evidently later than the first intense silicification. The early quartz of the veins, however, is moderately coarse grained and is cut in many places by a later generation of fine-grained quartz which was contemporaneous with the deposition of the sulphides. Fine-grained veinlets later than the ore minerals are present in most of the ores (pl. 14, A), and some of them may be supergene. Much of the hypogene quartz contains many minute fluid and solid inclusions, but the abundance of these inclusions varies greatly in different veins and even in different parts of the same vein. The quartz most commonly occurs as interlocking anhedral or subhedral grains having poorly formed crystal faces, though in some of the ores—most commonly those containing barite—a large amount of clear, glassy quartz is present in prismatic crystals from 2 to 8 millimeters in diameter. Most of the vein quartz is free from strain effects, but some in the Sts. John mine shows an unusual border having strain shadows but grading into a clear central grain core. These strain effects probably are the result of movement of the vein walls during mineralization.

Although the amount of silicification in the contact-metamorphosed shales is impressive and quartz is the most abundant gangue mineral of the ore deposits, many of the veins consist largely of sulphides and contain very little gangue. Quartz is relatively more abundant in the low-grade pyritic veins and in the quartz-barite veins than in the other deposits.

Rhodochrosite.—Pure rhodochrosite is rare, but some of the ankerite contains so much manganese that it may be called impure rhodochrosite. Moderately pure rhodochrosite occurs in coarse-grained masses several inches thick in the Jerry tunnel, at the north end of Glacier Mountain. It is associated with pyrargyrite, miargyrite, and argentite but is earlier. Rhodochrosite is reported to be present in the Queen of the West mine, near the head of Peru Creek, where it occurs in vugs in alabandite.

Schapbachite.—Schapbachite may be present in the bismuth ores found in the Grand Trunk and nearby veins, at the head of West Geneva Creek, as an analysis of the ore is reported to be very nearly that of schapbachite. (See p. 79.) None of the bismuth ores from this part of the quadrangle have been seen by the writer, however, and the reported occurrence could not be verified.

Sericite.—Sericite is abundant in the walls of most of the veins and is intergrown with the quartz of many veins. It is also abundant in some gouges, where it may be due to the brecciation of sericitized wall rocks or to the sericitization of a clay gouge. Sericite is an early mineral and was formed at about the same time as the early quartz. Where sericite is abundant it is generally related to channels of mineralization, but in many rocks, especially porphyries, scanty sericite is found some distance from any known occurrence of ore.

Siderite.—Siderite, like the other simple carbonates, is rare, although iron-rich ankerite is very common. As the iron content of the ankerite increases it grades through impure siderite into siderite. Most of the sideritic gangues contain some manganese and weather black when exposed on the dumps of the mine for a few years. Siderite is generally later than the sulphides, but in some places it is contemporaneous with them; it occurs in well-formed crystals and in open-textured granular masses in the veins. Some of the wall rock may be replaced by siderite, but most of the carbonate that has replaced the wall rocks is ankerite.

Silver.—Native silver is moderately abundant in the rich silver ores found near Montezuma, but if native silver has been found in other parts of the quadrangle the writer has not learned of it. In many of the mines on Glacier Mountain wire silver occurs in vugs and is scattered through moderately open textured galena-sphalerite ore that is cut by thin crustified veinlets of pink manganeseiferous ankerite. Wires of silver from 1 to 4 millimeters long occur on the galena, sphalerite, and ankerite. In some places the wires are scattered sparingly through the ore, and in others they occur in compact nests.

Smithsonite.—Thin brownish crusts of smithsonite are sometimes found in the open vuggy ore of the oxidized zone, but secondary zinc minerals are rare in the Montezuma quadrangle.

Sphalerite.—Sphalerite is a common mineral in almost all the ore deposits in the quadrangle and is the most abundant sulphide in many of the ores. It generally occurs in medium-grained masses intergrown with pyrite and galena. It rarely shows good crystal forms unless it occurs in vuggy ore, but open-textured ores are not uncommon in the quartz-barite veins and in the leaner parts of other veins. Most of the sphalerite in the mines near Montezuma is moderately light colored, and some of it is a clear amber-yellow. This light-colored sphalerite is later than the early pyrite and quartz and in most places is contemporaneous with galena or slightly later. Like the other sulphides it is generally earlier than the carbonate gangue with which it is associated in many places. It is everywhere earlier than the silver minerals. In the northeastern part of the quadrangle dark-colored sphalerite is more common than the light-colored variety and has the same relations to the other minerals. In some masses of dark-colored sphalerite there are small amounts of light-colored sphalerite that appear to be later than the dark variety. There is no reason for believing that the abundant light-colored sphalerite near Montezuma is later than the dark sphalerite found on McClellan Mountain, however, and the difference in color is probably due to a local difference in the iron content of the ore solutions during mineralization. In many places in the southwestern part of the quadrangle dark-colored sphalerite is associated with gold ores, but in the region northeast of the stockworks such an association is rare and probably fortuitous where it is found.

Stephanite.—Stephanite is found in some of the ruby-silver ores near Montezuma but is rare in the ores examined by the writer. Stephanite or "brittle silver" is frequently mentioned in mining reports published before 1900, but its identification is not known to have been carefully made, and doubt exists regarding the identity of the mineral called brittle silver by the miners.

Stromeyerite.—Stromeyerite is reported to be the chief mineral in the rich silver veins on Lenawee Mountain, near the center of the Montezuma quartz monzonite stock. An analysis of some ore from the Winning Card vein (see p. 114), quoted by the Montezuma Mill Run, shows a larger proportion of copper to silver than is present in stromeyerite, but it is probable that the ore contained more than one sulphide, and some unobserved chalcopyrite may have increased the total copper content of the specimen analyzed. In the Santiago mine stromeyerite is present in sphalerite-chalcopyrite ore on the fifth level. It is contemporaneous with a small amount of late galena and quartz, the three minerals occurring in small veinlets that cut early chalcopyrite; all are believed to be hypogene.

Sulphur.—Sulphur is sometimes found in the oxidized zone of lead-zinc deposits, where it commonly occurs mixed with earthy masses of cerusite and anglesite.

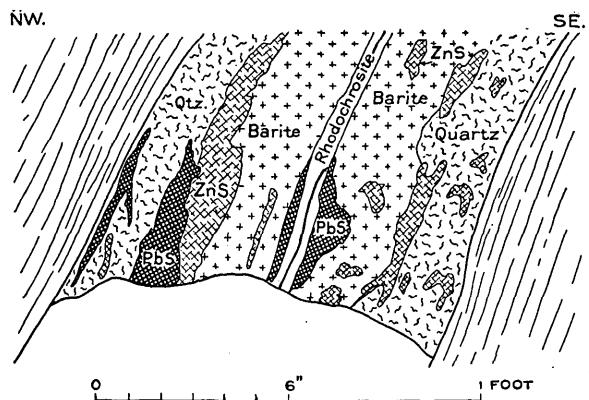


FIGURE 6.—Center of vein in stope on vein 5, Sts. John mine, 700 feet from main crosscut, level 6.

Tennantite.—See Gray copper.

Tetrahedrite.—See Gray copper.

Turgite.—See Brown iron oxides.

Wad.—The outcrops of many veins are blackened by a mixture of manganese oxides. Both pyrolusite and psilomelane have been seen, and it is probable that other oxides are also present. These oxides form fine-grained intergrowths and occur in moderately hard mammillary crusts close to the surface and commonly result from the oxidation of manganeseiferous ankerite or manganosiderite. Much of the secondary manganese occurs as a soft black sooty coat that covers the outcrop of the manganeseiferous veins. This is typical wad and consists of an indefinite mixture of the secondary oxides of manganese and other material.

Wolframite.—Wolframite was identified by Cross in the bismuth ores of the Missouri mine, in Hall Valley, where it made up as much as 2 percent of the ores. It occurred in small crystals intergrown with quartz and cuprobismutite.

PARAGENESIS

Although mineralization may not have taken place throughout the quadrangle at precisely the same time, a study of ores from many different deposits suggests that all were approximately contemporaneous and had very similar sources. The veins as a group show an orderly sequence of events, though all the events

may not be recorded in a particular deposit. The relations of the minerals show that the ores were not injected into the veins but were deposited from solutions that moved upward through the most easily available channels for a considerable length of time.

Sericite, quartz, and pyrite are the earliest minerals directly related to the ore solutions. Some of the quartz and sericite formed almost in place by molecular rearrangement of the original constituents of the rocks, and much of the fine-grained early pyrite resulted from the addition of sulphur to the iron already present in magnetite or some ferromagnesian mineral, such as hornblende. Near major channels of mineralization, however, solutions rich in iron, silica, potash, and sulphur attacked the wall rocks and added these elements. In such places the sericite and quartz are in part earlier than the pyrite and in part contemporaneous. The sericite is largely confined to the walls, but quartz and pyrite occur both as fissure fillings and disseminated in the walls. This epoch of mineralization was followed by an interval during which movement occurred along many veins, resulting in brecciation of the quartz and pyrite. At about this time calcite and manganosiderite were deposited in small amounts in a few places. During the next stage of mineralization moderately coarse grained chalcopyrite was deposited in many veins, and at some places gold is associated with it. Much of this chalcopyrite is twinned, whereas the later chalcopyrite is finer-grained and untwinned. A little sphalerite is contemporaneous with the early chalcopyrite, but most of it is later. A large part of the galena is contemporaneous with sphalerite, but some of it is later. It is probable that galena began to form in notable amounts about the time that the deposition of the early chalcopyrite ceased, and that it continued to be precipitated for some time after nearly all the sphalerite had been deposited. There was little movement during the chalcopyrite, galena, and sphalerite stages, but locally readjustment took place along the veins. The gray-copper minerals, tennantite and tetrahedrite, may have been contemporaneous with sphalerite and galena locally, but most of the gray copper was precipitated during and after the galena stage. Barite is essentially contemporaneous with galena and sphalerite, but its epoch of deposition was probably shorter than theirs. In a few places sphalerite and galena are earlier than barite, in many places they are later, but in most places they are probably contemporaneous. (See fig. 6.) A small amount of quartz was crystallized with the base-metal sulphides, chiefly at the end of the chalcopyrite stage. It is present in small amounts in most veins.

After the deposition of the bulk of the sphalerite, galena, chalcopyrite, and gray copper, ankeritic gangue minerals were deposited. Most of them contain much iron and some manganese. In many places the ankerite stage ended the period of mineralization, but

locally veins were reopened and silver-bearing solutions deposited small amounts of galena, quartz, argentite, native silver, and the silver sulphantimonides and sulpharsenides, such as proustite, pyrargyrite, miargyrite, stephanite, freibergite, stromeyerite, and polybasite. It is probable that bismuth and silver minerals formed in a quartz gangue in the south half of the quadrangle at about this time, but their exact relations to the galena-sphalerite mineralization are in doubt. They may be contemporaneous with the late stage of quartz, which commonly followed ankerite in the galena-sphalerite veins, but they may be much earlier. Fine-grained late chalcopyrite is present in most of the veins, but whether it is primary or secondary is uncertain. It is later than the other primary sulphides but is earlier than covellite and chalcocite.

Briefly summarized, the general order of deposition of the minerals is as follows: (1) Sericite, quartz, pyrite, calcite, manganosiderite; (2) chalcopyrite; (3) quartz, sphalerite; (4) barite, galena, sphalerite; (5) galena, gray copper; (6) ankerite, dolomite; (7) galena, quartz, argentite, silver, miargyrite, stromeyerite, pyrargyrite, freibergite, polybasite, proustite, stephanite, pearcite; (7?) quartz, bismuthinite, cuprobismuthinite, emblectite, schapbachite, beegerite, argentite; (8) chalcopyrite; (9) covellite, chalcocite.

ORE DEPOSITS

The distribution of the veins of the Montezuma quadrangle is shown on plate 3. (See also pl. 15.) The relation of the veins to the mineral belt of the Front Range is considered briefly on pages 44 and 48, and the general features of the mineral belt have been considered elsewhere.¹⁶ Lead-zinc-silver ores are much more abundant than ores of other types, but some gold ore occurs in the southwestern part of the quadrangle, and some bismuth ore is found in a narrow belt extending north from Hall Valley to the head of West Geneva Creek. Most of the ore deposits are fissure fillings, and few ore bodies of economic importance have been formed by replacement. Many of the veins have a shallow enriched zone at the surface, but most of the ore now present is primary and was deposited from hot magmatic solutions during early Eocene time.

The ore deposits are classified according to their origin and mode of occurrence as contact-metamorphic deposits, stockworks, and veins.

CONTACT-METAMORPHIC DEPOSITS

A contact-metamorphic deposit is a high-temperature replacement deposit close to the edge of an intrusive to which it is genetically related. No deposits of this type in the Montezuma quadrangle are commercially important. Contact-metamorphic deposits occur in the southwestern part of the quadrangle be-

tween Browns Gulch and Summit Gulch, and also near the west end of the Montezuma quartz monzonite stock. In both places high-temperature minerals have replaced Upper Cretaceous shale, of Pierre age. In the southwestern part of the quadrangle the most abundant contact-metamorphic minerals are epidote and brown garnet, but dark-green amphibole, pyrite, chalcopyrite, and magnetite are also present. The shale that is most thoroughly replaced consists of a moderately coarse grained aggregate of the brown garnet-epidote-amphibole rock, and the less altered formation nearby is commonly a hard, cherty green shale. Near the Montezuma quartz monzonite stock large masses of the Pierre shale have been silicified, and in much of this hornfels fine-grained garnet and pyrite are visible. Layers consisting largely of medium-grained brown garnet but containing small amounts of pyrite, chalcedonic quartz, tremolite, and sericite were observed a short distance below the Williams Range thrust fault about 0.1 mile north of Cold Spring. Epidote is locally abundant but is much less common than in the southwestern part of the quadrangle. Several prospect pits and tunnels have been put into this metamorphosed shale, and some ore has been found in thin veins, but no ore of contact-metamorphic origin was observed here.

STOCKWORKS

Stockworks are found only in the southwestern part of the quadrangle, in the region studied by Ransome.¹⁷ According to him, the stockworks are thoroughly fissured rocks, generally quartz monzonite, in which the ore occurs in minute veins and thin, discontinuous seams and not in well-defined lodes. The only deposits of this type in the Montezuma quadrangle are in the Cashier, I. X. L., and Hamilton mines. In 1929 they were being exploited by the Royal Tiger Mining Co. Although the writer was not allowed to study these mines or go underground in them, a considerable amount of information has been gathered from various reports and from a study of the region nearby, and it is believed of sufficient interest to be included in this report.

The I. X. L. stockwork, near Tiger, is typical of this group. It is a shattered mass of quartz monzonite porphyry crowded with fragments of the Upper Cretaceous sediments, of which Dakota quartzite is by far the most abundant. Complexly interlacing and crossing fractures cut the porphyry and included fragments and served as channels for hydrothermal solutions. The rocks are strongly sericitized and contain sporadic seams and masses of ore. Sphalerite is the most abundant ore mineral and occurs chiefly in irregular-shaped masses less than an inch in diameter sparsely scattered through the bleached porphyry and quartzite. Thin veinlets of pyrite, chalcopyrite, and sphalerite were

¹⁶ Lovering, T. S., Localization of ore in the schists and gneisses of the mineral belt of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, pp. 234-268, 1930.

¹⁷ Ransome, F. L., op. cit., pp. 143-157.

also observed in the rock that was being milled at the time of the writer's last visit to the property, but no galena was seen. At the time of Ransome's visit, however, he observed pyrite, sphalerite, galena, quartz, and locally some bismuthinite in the veinlets of ore. Some gold and silver are also present. The other stockworks are similar to the I. X. L. in structure and mineralogy but differ from it in that the monzonite porphyry near them contains few inclusions of the invaded sediments. The stockworks were much richer in gold near the surface than below the zone of oxidation. Most of the gold now recovered from them is probably primary.

The Jessie stockwork, which is less than a mile west of the Montezuma quadrangle, and the Hamilton, Cashier, and I. X. L. stockworks occur in a narrow zone trending east-northeastward through Tiger toward the south end of the Williams Range thrust fault. Reference to pages 43-45, where the regional structure is considered, will show that the stockworks are thus directly in the line of shearing that resulted from the underthrusting of the Upper Cretaceous sediments, but, as the quartz monzonite porphyry that contains them is younger than the thrust fault, this coincidence of alignment and position suggests that they probably formed in response to a relatively weak renewal of the shearing stresses that caused the easterly movement of the north walls of so many veins in the mineral belt farther east. As would be expected from the position of the stockworks, the dominant trend of the strongest fracture zones in them is east-northeast, but, in contrast to the area farther east, strong, persistent pre-mineral fractures in the quartz monzonite porphyry are comparatively rare.

VEINS

Types and distribution.—The strike, dip, and general distribution of the veins in the Montezuma quadrangle are shown on plate 3. Most of the veins strike northeast or east-northeast and dip northwest, but some of them dip steeply southeast. Veins striking nearly east are not uncommon, and a few trend northwest. The most productive veins in the quadrangle have a north-northeasterly trend and a steep westerly dip, most of them striking between N. 15° E. and N. 35° E. Their relation to the regional structure is discussed on pages 44 and 48.

In the northeast quarter of the quadrangle lead-zinc-silver veins greatly predominate over other types. Most of them consist chiefly of galena, sphalerite, and pyrite, with small amounts of copper and silver minerals, and have a quartz gangue. On Mount McClellan, however, both barite and fluorite are also present, and in some of the veins in this locality manganiferous ankerite or rhodochrosite is common, though not as abundant as quartz. In the veins in the south half of the quadrangle, especially near the eastern part of the mineral belt, argentiferous gray copper (tetrahedrite)

is much more common than in the veins farther north, but here, too, galena, sphalerite, and pyrite are the most abundant ore minerals. Although quartz is generally the most common gangue mineral, barite is abundant in the southeastward-trending branch of the mineral belt that runs from Hall Valley to Glacier Mountain. In the southeast quarter of the quadrangle, especially in Hall Valley and in the mountains at the head of West Geneva Creek, veins containing bismuth and silver minerals are common, and these minerals are generally associated with chalcopyrite in a quartz gangue. Low-grade pyritic gold veins occur in the mountains near Swandyke, close to the southern border of the quadrangle. A few veins occur in the hanging-wall block of the Williams Range thrust fault north of the North Fork of the Swan River, although this area is underlain by the underthrust Upper Cretaceous shales. These veins have been valuable chiefly for their galena. The veins in the southern part of the Montezuma quartz monzonite stock are zinciferous and consist chiefly of pyrite and sphalerite but contain moderate amounts of galena in a quartz-ankerite gangue. Farther north in the stock sporadic veins containing rich silver ores occur.

Possible centers of mineralization.—Centers of mineralization are commonly centers of intrusive activity as well. The largest intrusive mass in the quadrangle is the Montezuma quartz monzonite stock, and some ores have a rude zonal arrangement around the southern part of this mass. As a rule, the veins in the southern part of the stock contain more pyrite and sphalerite than the veins outside the stock or within it but farther north and were probably formed at higher temperatures and pressures. Most of the rich silver ores in the Montezuma district are scattered irregularly through a belt about a mile wide, which borders the stock on the south from Glacier Mountain to Revenue Mountain, where it swings north and west into the stock, passing through Cooper Mountain and on into Lenawee Mountain. Barite and gray copper become common in the lead-zinc veins just south of the rich silver ores in Glacier Mountain and Revenue Mountain.

It is possible that the veins on McClellan Mountain are related to a center of mineralization to the west, between Kelso Mountain and Torreys Peak, where there is a marked concentration of intrusives, as shown on plate 3. Rich silver ores were found in the Baker mine, on the southern part of Kelso Mountain; galena-sphalerite-quartz-ankerite veins occur on McClellan Mountain, a short distance to the east; and veins of gray copper, fluorite, and barite are common a little farther northeast on the same mountain.

The low-grade pyritic ores of Wise Mountain, near the south border of the quadrangle, may be related to the center of mineralization which produced the gold deposits near Tiger.

The veins near Clear Creek, in the northeastern part of the quadrangle, are probably related to the center of mineralization near Silver Plume, a short distance east of the quadrangle.

Mineral associations.—Galena, sphalerite, pyrite, and quartz are found in nearly all the ore deposits of the Montezuma quadrangle and are much more abundant than the other minerals. The variations of the less abundant minerals, however, give certain ores a distinctive appearance that suggests their inclusion in groups by themselves. Copper minerals are the most abundant of the minor constituents of the ores and occur in most of the veins of the quadrangle. Copper is usually present in negligible amounts, but in some places it contributes materially to the value of the ore. In addition to the value of the copper itself, the common association of gold and silver with chalcopyrite and of silver with tetrahedrite and tennantite makes the presence of these minerals especially welcome to the miners. The gray-copper minerals examined by the writer contain comparatively small amounts of combined silver, however, and most of the silver in these ores occurs as separate minerals, usually a silver sulphantimonide or silver sulpharsenide. The light-colored gray copper contains more silver than the dark-colored gray copper, pure specimens of which are reported to assay only 100 ounces of silver to the ton. Copper-bearing veins containing chalcopyrite and little or no gray copper commonly have a quartz or ankerite gangue; the gangue of veins in which tetrahedrite or tennantite is abundant generally consists largely of quartz and barite with moderate amounts of manganeseiferous ankerite. Galena-sphalerite ores containing barite and gray copper, which are abundant in Hall Valley, Teller Mountain, and Glacier Mountain and on the eastern slope of McClellan Mountain, have heretofore been regarded unfavorably because of the difficulty of separating barite from them. Such ores can now be treated successfully by flotation, however. The galena-sphalerite ores containing chalcopyrite and having a quartz-ankerite gangue are common from the south end of McClellan Mountain southwest to Glacier Mountain and include most of the veins that have been successfully exploited in the past.

The most abundant silver minerals are miargyrite, pyrargyrite, proustite, and stromeyerite and are commonly associated with a manganeseiferous ankerite or rhodochrosite gangue. Some silver veins, such as those of the American Eagle and Winning Card mines, in the Montezuma quartz monzonite stock, contained little galena and sphalerite and consisted essentially of stromeyerite and gray copper in a quartz gangue. In the lead-zinc veins on Glacier Mountain, a short distance south of the stock, native silver, pyrargyrite, proustite, miargyrite, and argentite are the most common silver minerals, although locally freibergite, polybasite, stephanite, and pearcrite occur. The silver

minerals are later than the bulk of the lead-zinc-iron minerals and are not disseminated evenly through the galena-sphalerite ores with which they are associated. They are usually concentrated in rich shoots, whose occurrence is independent of the amount or kind of the earlier base-metal sulphides in the vein.

All the bismuth-silver veins found on the southeast or east side of the mineral belt contain silver and gold. Generally the silver is chemically combined with bismuth in emplectite or schapbachite. The moderately common occurrence of galena-sphalerite ores in the bismuth-silver veins may be fortuitous, as bismuth-silver ore shoots occur alone in many places and were apparently formed at a different time from the lead-zinc ores. Quartz, pyrite, and chalcopyrite are usually found in the bismuth-silver ores, less commonly tetrahedrite and galena, and very rarely barite and ankerite.

Veins of massive pyrite, or pyrite and quartz, occur on Wise Mountain, in the southern part of the quadrangle. Some of these veins carried rich gold ore at the surface, but none of them are known to contain commercial ore more than 25 feet below their outcrop. The gold and silver content of the massive unoxidized pyrite is reported to be uniformly less than \$3 a ton. (See p. 75.)

The gold ores near Tiger are briefly discussed on pages 59-60.

Relation of ore to depth.—In most of the lead-zinc veins sphalerite and pyrite increase with depth. The bottom of an ore shoot may be marked by an abrupt change into pyrite and quartz or the appearance of barren ankerite that completely fills the vein. Galena is commonly much more abundant in the upper part of a vein than in the lower part, but it is a persistent mineral and occurs throughout many ore shoots. In the veins containing notable amounts of copper the copper content generally increases slightly with depth. Where both chalcopyrite and gray copper are present, chalcopyrite usually becomes relatively more abundant in the lower levels and gray copper decreases. In most of the veins, however, the amount of copper is small, and there is little relation between depth and the copper content or minerals of the ore. The silver content of the ores does not seem to be related to depth from the surface nor to distance from the bottom of the lead-zinc ore shoots, although in Glacier Mountain the ores are generally richer in silver in the lower part of the ore shoots than in the upper part. In the Bell mine, on the east slope of the mountain, ruby silver occurs at an altitude of 11,600 feet, about 130 feet below the surface, but farther northeast on the same vein ruby silver and native silver occur at an altitude of about 10,500 feet, about 300 feet below the surface. On the west side of the mountain ore containing ruby silver and native silver was found at an altitude of about 10,900 feet, 700 feet below the surface,

and low-grade unoxidized galena and sphalerite containing sporadic streaks of gray copper extended from the surface to this rich shoot of silver ore. The history of the Stevens mine, on McClellan Mountain, suggests that the upper part of the ore shoot was richer in silver than the ore now exposed on the lower levels, and that the silver content of the ore gradually decreased with depth. In some of the veins nearby, however, rich silver ore was found near the surface but changed abruptly into lower-grade ore from 100 to 200 feet below the outcrop. It is probable that most of the silver ore now known in the quadrangle is not related to the surface. The conclusion that most of the silver ore is primary is supported by field evidence and by the relations of the ore minerals found during their microscopic study. (See pp. 53-58.)

Enrichment.—The writer has recently discussed at some length¹⁸ the problems of enrichment of the ores in a supplemental report on the Breckenridge district. Part of that district is included in the Montezuma quadrangle, and the conclusions reached are applicable to the region treated in the present report. It will be unnecessary to repeat the evidence given in the report on the Breckenridge district, and only the general conclusions are given below.

The relations of rich gold ore to postmineral bedding-plane faults on Farncomb Hill clearly show that these pockets are secondary. In many veins in the Montezuma quadrangle the surface ores carry rich secondary gold and silver minerals, but these ores bottom at much shallower depths in the pre-Cambrian rocks than they do in the later sedimentary rocks in the western part of the quadrangle. It is improbable that noteworthy enrichment has extended more than 100 feet below the surface in any of the veins in the gneisses and schists in the quadrangle, although in a few places silver enrichment may extend to a depth of as much as 300 feet. No secondary galena or sphalerite has been recognized in the mines studied, and if present they make up an inconspicuous amount of the total lead-zinc ore.

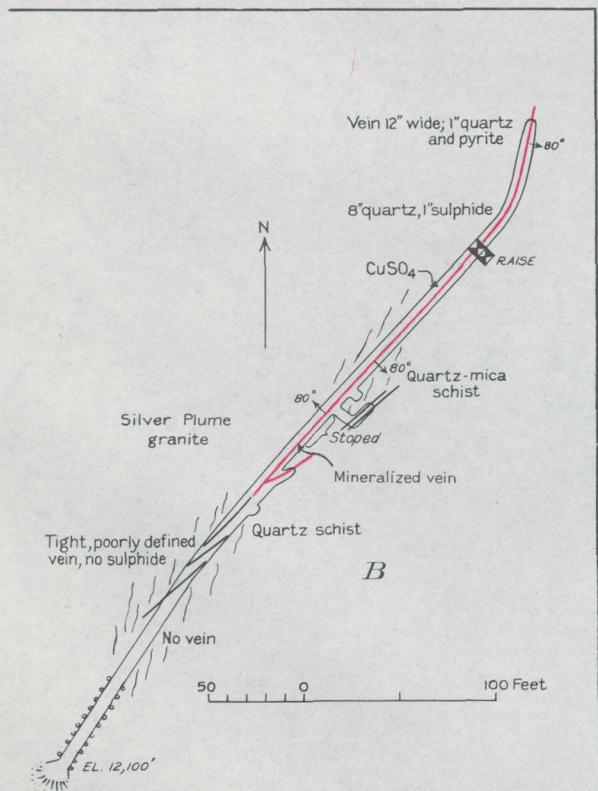
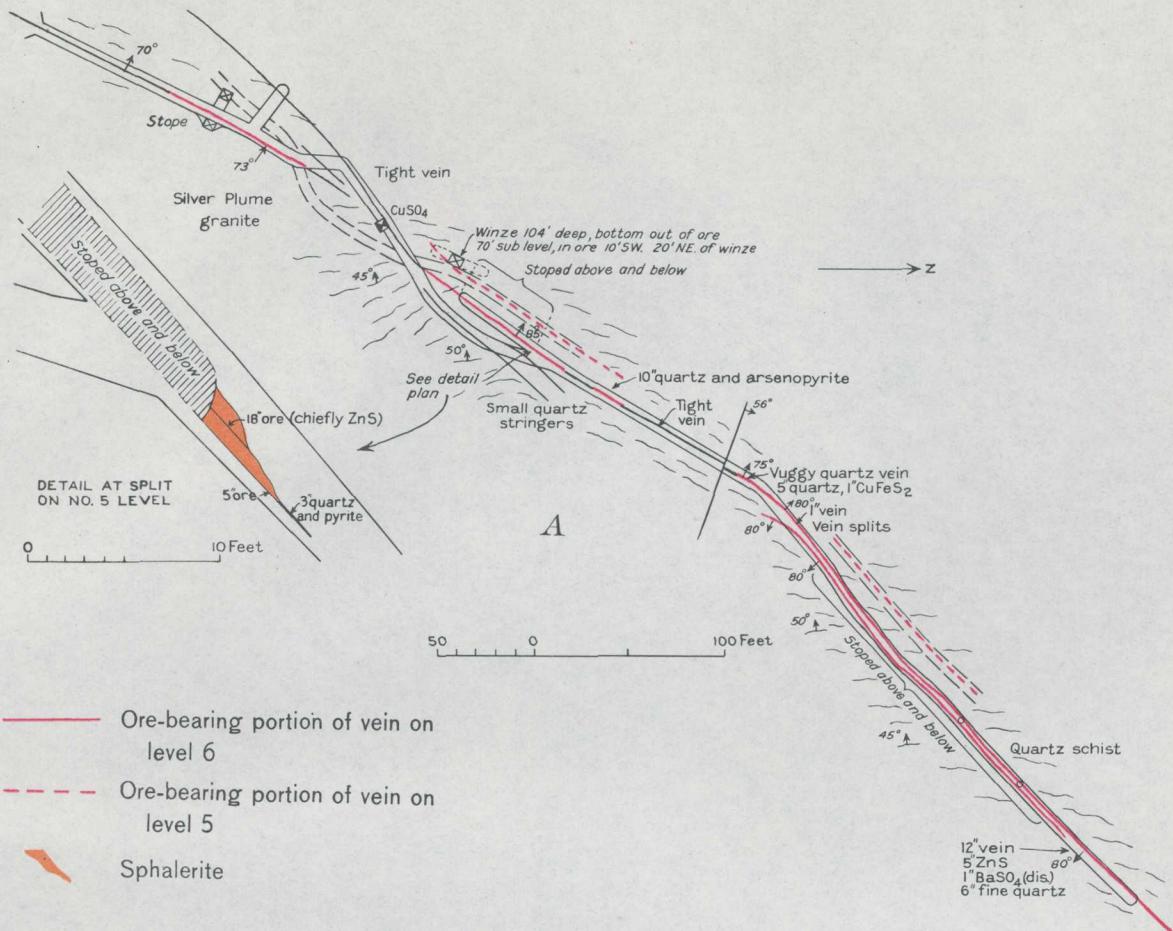
Surface enrichment of the ores has been extensive only where the present surface coincides closely with that of the Flattop peneplain or the Rocky Mountain peneplain. In some veins that crop out on the Flattop peneplain or only slightly below it, such as those on Wise Mountain, in the southern part of the quadrangle, rich gold ore was limited to a depth of 25 feet from the surface, below which the ore turned abruptly into very low grade pyrite. In ores that crop out on the early Pleistocene surfaces, such as the stockworks in the extreme southwestern part of the quadrangle, rich secondary gold ore was found at the surface and gradually passed downward into much lower grade sulphide ore. The enrichment of the veins in the rugged parts

of the mineral belt that have been subjected to late (Wisconsin) glaciation is insignificant, although there is commonly a shallow zone at the surface where the vein contains some secondary ore richer in gold and silver than the primary ore a short distance below.

Dimensions of ore shoots.—The largest individual ore shoots range from 600 to 1,100 feet in strike length and are known to have a vertical extent of 400 to 850 feet. In some of the mines the ore shoots have a greater strike length than vertical extent, but in other mines these relations are reversed. The ore shoot of the Stevens mine was about 600 feet long and 850 feet or more deep. The ore shoot of the Santiago mine was followed for 1,100 feet along the strike and exploited to a depth of 700 feet. The ore shoot of the Pennsylvania mine was about 800 feet long and 400 feet deep. In the Sts. John mine the Comstock ore shoot probably had a maximum strike length of 1,300 feet, and the ore has been mined to a depth of 700 feet, but the bottom of the shoot is not known to be reached by the deepest level. Several ore shoots occur in some of the largest and most continuous veins, and some of these veins have been productive for over a mile in length. The ore shoots are not related to the present surface, although most of those that are known crop out. Several of the small ore bodies near Montezuma occurred in blind shoots and were discovered during underground exploration.

Vertical range of ore deposition.—Although the greatest known vertical range of ore in a single shoot is only 850 feet, the vertical range of ore deposition was certainly much greater. The galena-sphalerite ore of the Pilot vein, near the mouth of Jones Gulch, occurs at an altitude of about 9,500 feet, and similar ore in the Ida Belle vein, less than a mile to the south, occurs at an altitude of about 11,600 feet. As the Pilot vein is at the contact of the Montezuma quartz monzonite stock, it might be expected that both temperature and pressure were greater than at the Ida Belle vein, which is about 2,000 feet from the contact. The ore in the Pilot vein, however, shows no evidence of higher temperatures or pressures and is very similar in appearance and mineralogy to that in the Ida Belle. Sphalerite ore occurs in the bottom of the valley of the Snake River near Montezuma at an altitude of 10,000 feet in the Fisherman vein, and galena-sphalerite ore is found at about 10,350 feet in the Jumbo, Waterloo, New York, and other veins. Less than a mile south of Montezuma galena ores occur in the Cooley and other lodes near the top of Glacier Mountain at an altitude of about 12,000 feet; about 1½ miles southeast of the town galena ore was found in the Silver Wave vein, at the crest of the range, in the saddle between Sullivan Mountain and Santa Fe Peak, at 12,850 feet. Ore was mined from the Blanche vein, in the valley bottom directly below the Silver Wave, at about 11,250 feet. The ores from the Silver Wave

¹⁸ Lovering, T. S., Geology and ore deposits of the Breckenridge mining district, Colo.: U.S. Geol. Survey Prof. Paper 176, pp. 28-32, 1934.



EXPLANATION

- Barren fissure, fault, or vein less than 1 inch wide
- Strike and dip
- Strike and vertical dip
- Strike of schistosity
- ZnS, sphalerite
- CuFeS₂, chalcopyrite
- CuSO₄, copper sulphate
- BaSO₄ (dis.), barite disseminated
- Timbered drift

PLAN OF SILVER WAVE MINE, COLLIER MOUNTAIN, LEVELS 5 AND 6 (A), AND OF LOWER TUNNEL, LUCKY BALDWIN MINE, COLLIER MOUNTAIN (B)

and the Blanche are similar and consist chiefly of galena, sphalerite, pyrite, and chalcopyrite. In this region the evidence shows that the ore minerals were deposited through a vertical range of at least 2,000 feet and suggests that they extend through a vertical range of 3,000 feet or more. There is little doubt that many undiscovered blind ore shoots exist in the district, although it is questionable whether they can be discovered and mined cheaply enough to justify exploration for them.

The vertical range of the ore in the mineral belt a mile east of the Montezuma quadrangle, near Silver Plume, is known to be 2,500 feet. Many of the ore shoots there had a depth of over 1,200 feet, and a few contained ore through a vertical range of 1,800 feet. On McClellan Mountain, near the Stevens and Santiago mines, ore has been found at various places from an altitude of about 11,500 feet to about 13,000 feet.

In considering the observed vertical range of ore in the Montezuma quadrangle it is difficult to appraise the importance of the fact that, with few exceptions, all the ore bodies have been discovered because they cropped out at the surface. In the mineral belt the difference in altitude between the valley bottoms and the ridges above them is commonly less than 2,000 feet; and as only a few ore shoots are more than 500 feet deep, it is evident that the observed vertical range of ore could hardly be more than 2,500 feet under the most favorable circumstances and that it would generally be less. However, the most productive veins are concentrated in several small areas in the mineral belt, and in some of these localities similar changes in the ore are found at approximately equal altitudes, suggesting vertical zones of ore deposition; in other places the changes of ore with depth show zonal relations to certain centers of intrusion. These facts suggest that the bottoms of the larger ore shoots indicate the bottom of the zone in which important masses of ore were deposited nearby.

Localization of ore.—As the ores of the veins are fissure fillings, the localization of the ore is related to the physical character of the wall rocks, the irregularities of the vein, and the position of the vein in the mineral belt. The chemical composition of the walls of a vein has little influence on the localization of ores in the Montezuma quadrangle. The reaction of the rocks to the regional stresses of early Tertiary time determined the size and shape of the openings along the faults that later became veins. On their journey from the magma to the surface the ore solutions had to take the easiest possible route, and thus the most open fractures would generally serve as the conduits for the largest amount of metallizing fluid.

Hard, brittle rocks, such as pegmatite, granite, porphyry, and gneiss, are the common wall rocks of the persistent ore shoots, and soft, plastic rocks, such as mica and hornblende schists, seldom form the walls.

The intersection of two fractures was more likely to be open than either fracture at a distance from the crossing, and the well-known localization of ore shoots at the intersections of veins or near the junctions of branching veins indicates that the solutions found an easy way to the surface along such openings. The occurrence of ore where there are marked changes in the dip or strike can usually be correlated with an ancient open space caused by the movement of the irregular walls of the fault. If the north wall of an eastward-trending vein has a large horizontal compo-

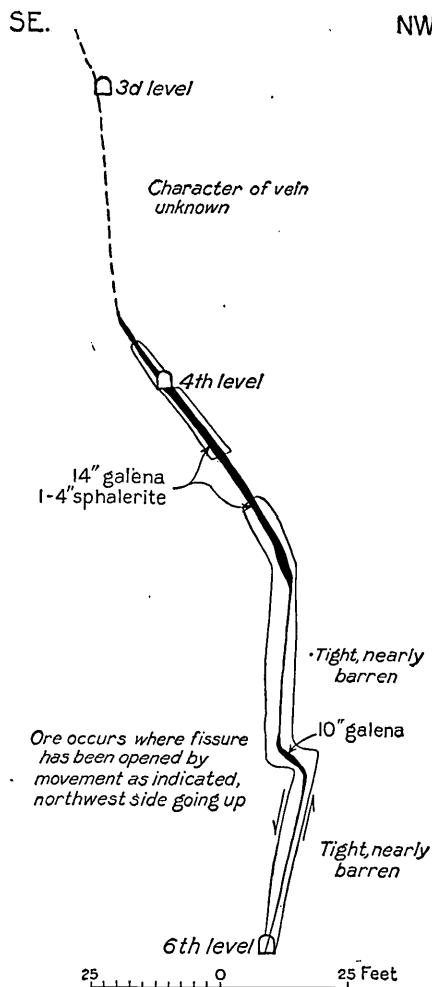


FIGURE 7.—Section along raise in Bell mine, level 6, on south branch of main drift, 930 feet from portal; raise 175 feet from main drift.

ment of movement toward the east, the vein should tighten where it swings northeast and open where it bends southeast, and ore shoots are most likely to occur in the eastward- or southeastward-trending segments. The occurrence of the ore shoots in the Bell vein suggests that to such a structural history may be ascribed in part the localization of the ore. (See p. 72 and pl. 17.) If the horizontal component of movement was small, ore tends to occur in the steeper parts of a vein that follows a premineral normal fault and in the flatter parts of a vein that follows a premineral reverse fault. The cross section of the Bell

vein shown in figure 7 illustrates the relation of change in dip to ore occurrence in a vein filling a premineral reverse fault.

In the complex pre-Cambrian mass many different kinds of rock may be traversed by one fissure. The schistosity of the metamorphic rocks may be crossed by the fissure at a large angle in some places and trend parallel to it in others. A fault cutting a strong rock tends to open well-defined fissures, which usually narrow on passing into a weaker rock. If the fault trends parallel to the schistosity of the wall rock, it commonly loses its identity as a single fracture, and the movement is distributed over several parallel or interlacing slips, forming a sheeted zone. Unless the direction of the vein or the schistosity changes, such a sheeted zone is not likely to contain good ore in schist, although it may be productive in gneissic and granitic rocks. This relation is illustrated at the Silver Wave mine, near Montezuma, shown in plate 16. The schistosity there is parallel to the vein in some places and crosses it at an angle in others. The ore shoots occur where the vein breaks across the schistosity of the wall rock.

The relation of fissuring to kind of wall rock becomes increasingly important with increasing depth. Close to the surface, open fissures may be common even in poorly consolidated clays and sands, but with increasing depth the fractures in such materials become tight, although open fissures may be abundant in stronger rocks much farther below the surface. Similarly, in the region under consideration, open fissures do not persist to as great depths in the relatively weak schists as in the stronger gneisses and intrusive rocks. Accordingly, in any one district profitably worked veins in schist are likely to be more numerous at high than at low altitudes. For these reasons, it seems advisable to confine deep explorations to the stronger rocks.

SUGGESTIONS FOR PROSPECTING

The occurrence of ore shoots reflects the presence of fissures that were open at the time of mineralization and within reach of mineralizing fluids. As the ores were formed by emanations from the deep parts of the porphyry masses, ore deposits should not be expected to occur far from the places where porphyry is moderately abundant. Search for new veins should be confined to the porphyry belt (see pl. 3) and should be concentrated in the areas where earlier prospecting has shown that productive veins exist. The structure and bedrock of the region determined the size and continuity of the openings followed by the rising ore solutions, and persistent veins should be sought in hard, brittle rocks such as granites and gneisses; conversely, shale, biotite schist, or other weak rocks are unfavorable to the occurrence of strong veins. As the quartz monzonite porphyry stocks were intruded after much of the regional folding and faulting had been accomplished, they are less thoroughly fractured than the

rocks nearby, and persistent veins are rare in them. Minor fractures in a stock, however, may be the weak continuations of reopened major fissures in the country rock nearby. In many places, as at the Quail mine, it would be well to follow ore-bearing veins from a stock into the enclosing rock, if the distance is not too great, in the hope that the vein would be stronger in the older rocks. However, if the invaded rock is an exceptionally weak rock, the vein is more likely to narrow than to widen where it leaves the stock.

In considering any vein that has been partly explored, great attention should be given to the structure of the region nearby, in the hope of finding some of the conditions favorable to the localization of ore that have been discussed on pages 63-64. The vein material may also yield valuable indications of probable changes in mineral content if considered with reference to the mineral associations characteristic of certain types of ores. (See pp. 58, 61.)

If many periods of brecciation are shown in an apparently barren but strong vein, the chance of finding an ore shoot somewhere in it is much better than in a barren vein which apparently was never reopened after the barren filling was deposited; thus a study of the paragenesis of the gangue and the ore may be very significant.

Alteration of wall rock, as shown on pages 42-43 has been effected by solutions that were active before, during, and after ore deposition. The early alteration has little relation to ore channels, as is shown by the widespread formation of chlorite and epidote in the porphyry belt. Garnet, magnetite, hematite, and fine-grained quartz have formed early in the period of mineralization near some of the large quartz monzonite porphyry stocks that are closely related to centers of mineralization. Sericitization preceded and accompanied ore deposition and is strongest in gold districts. It was commonly related to mineralization channels, though not necessarily to ore shoots. Pyritization and silicification of the wall rocks also preceded and accompanied ore deposition. Small amounts of carbonates were formed through a long period of time, but most of the carbonate gangue is later than the galena-sphalerite ore stage. The replacement of wall rocks by siderite and ankerite was very common near strong lead-zinc-silver veins but rare near gold veins. Post-ore carbonates (generally calcite) are not commonly related to channels of mineralization and are abundant constituents of only a few altered rocks. Alteration to clay minerals took place after ore deposition. Rocks slightly replaced by any of the above-named minerals can be found throughout the mineral belt, but strong or complete replacement by sericite, ankerite, pyrite, or quartz generally indicates proximity to a channel of ore deposition.

Geophysical methods of prospecting may show the presence of additional ore shoots in a productive vein. As the structural conditions are decidedly adverse to

the use of the seismic methods, and as the topography and small size of the ore bodies make it impossible to use the torsion balance or pendulum apparatus, and as the abundance of magnetite in the country rock would give misleading results with a magnetometer, the electrical methods are the only ones that offer much hope of success.¹⁹

FUTURE OF THE DISTRICT

With the exception of the placer gold found in the valley of the Swan River, in the southwestern part of the quadrangle, most of the production of Summit, Park, and Clear Creek Counties has come from mines outside of the Montezuma quadrangle, and that of the quadrangle has come largely from a few productive veins. About 15 mines have produced more than 1,000 tons of ore, but most of the mines described on pages 68-116 have produced much less. Although the low production figures are in part due to the small size of most of the ore shoots thus far explored, many veins have proved unprofitable because of the high cost of transportation and mining or the lack of successful ore treatment by adequate mills. The reserves of high-grade shipping ore are small, but there are many veins that will yield comparatively small but profitable amounts if mined by lessees. There are probably no veins in the quadrangle rich enough to repay investors in a heavily capitalized stock company.

It is probable that several veins contain sufficient ore of milling grade to warrant their exploitation. Some of the quartz-barite-lead-zinc ores, although previously exploited at a loss when treated in a gravity separation mill, could be profitably concentrated in a flotation mill, as proved by the successful operation of the Whale flotation mill. There may be some bodies of milling ore in or near McClellan Mountain that are sufficiently extensive to justify consideration, although the deep snow of the long winters in this region and the difficulties of avoiding mill-tailing contamination of the streams are factors which must be considered in addition to the grade of ore and the cost of transportation and milling. Much of the ore in the veins of the Montezuma quadrangle has a comparatively low proportion of gangue. Although this is very favorable to mining and permits quick and easy hand sorting of the high-grade ore, the scarcity of extensive bodies of gangue containing disseminated sulphides suggests that much of the ore that may be milled in the future will be the mixed sulphide ores that are almost valueless as mined but may be separated by differential flotation. Most of the few flotation mills that have been built to treat the ores of the Montezuma quadrangle are of the same design and have been notably unsuccessful, although tests on these ores in the standard types of flotation units, such as those in the experi-

mental mill of the Colorado School of Mines, have been entirely successful.

The most notable occurrences of low-grade ores are the auriferous disseminated zinc-lead ores found in the stockworks west of Tiger. The average grade of these ores is low, however, and they have not been commercially successful. As they must be mined by underground methods and crushed to small size before treatment at the mill, it is impossible to exploit them as cheaply as the low-grade "porphyry coppers" with which they are supposed to be comparable. Thus far the cost of producing a pound of ore from the low-grade disseminated ores near Tiger has been more than its selling value. Until the cost of mining and milling can be materially decreased, or until the price of lead, zinc, silver, and bismuth becomes higher than it was from 1915 to 1930, there is little reason for believing that the low-grade disseminated gold-silver-zinc-lead-bismuth ores of the stockworks can be profitably worked.

HISTORY OF MINING

The first wave of prospectors that rushed through the east side of the Front Range in 1859 and 1860 was intent on the discovery of gold, and only gold. Most of the early production came from placers, and it was not until the rich oxidized gold ore of the lodes near Central City had been mined for some time that silver was reported in them. As silver became of more and more economic importance as a part of these gold ores, prospectors began to hunt for argentiferous lodes. In 1863 a prospector named Coley left Empire and went south to Kenosha Pass, thence northwest to Georgia Pass, and up the North Fork of the Swan River to Glacier Mountain, where in the spring of 1864 he found the first silver lode to be discovered in Colorado. On his return to Empire he mentioned his discovery, and in September of that year a party of three men set out from Empire with the avowed purpose of finding silver in the high mountains between them and Breckenridge. According to Hollister,²⁰

Early in September 1864, Gov. R. W. Steele, James Huff, and Robert Layton started out of Empire in search of silver, "which", says Governor Steele, "we supposed to exist in and around the range near the heads of the southwestern branches of Clear Creek, where the same interlock with the heads of the Snakes." Two or three days found them in camp on Huff Gulch, where the Argentine cabins now stand. Next morning Huff went directly up the long eastern slope of McClellan Mountain, Steele and Layton going up Huff Gulch to the right, and all intending to meet on the summit somewhere, and if they should find nothing, seek a pass through on to the Snakes. It happened that Huff passed over the "cropping" of what was afterward called the "Belmont lode", which occurs well up on the ridge and is scattered over a considerable area. He picked some of it up, and upon exhibiting it to his comrades, they all agreed that it was silver ore or blossom and that they need go no further. Opening the ground slightly, they got a few pounds from the vein in place, took it to Central City, and had

¹⁹ Holland, C. A., Geophysical methods of prospecting: Colorado School of Mines Quart., vol. 24, pp. 1-163, 1929.

²⁰ Hollister, O. J., The mines of Colorado, pp. 252-253, Springfield, Mass., 1867.

it assayed, with results varying from \$200 to \$500 per ton. * * * Next year there was a rush to the spot. A district embracing the sources of the south fork of South Clear Creek and the north branch of North Platte was laid out and called "Argentine." The lodes generally assayed high in silver, and during the succeeding (last) winter, several eastern and some home companies were organized rather for the purpose of prospecting and acquiring property by discovery than for working the mines for their profits.

The discovery of silver in the Argentine district caused widespread prospecting in the region nearby and led to the discovery of the highly productive deposits at Silver Plume and Georgetown, as well as those on McClellan Mountain and Kelso Mountain and those in the Snake River drainage basin, to the west. The Baker and Belmont were the most important mines opened in the Argentine district at this time and were worked successfully for many years. Furnaces were built at Graymont and Georgetown to treat their ores, and after a few years of discouragement the developments of these two mines encouraged a second rush to the district in 1869 and 1870. The Stevens vein was probably found in 1869 and commenced a long period of productivity in spite of the high cost of transportation. The completion of a railroad to Graymont in 1885 further stimulated mining in the Argentine district, but the panic of 1893 caused silver mining to become almost dormant throughout the quadrangle. However, the mines on McClellan Mountain were again producing a moderate amount of ore by 1900, and for several years they shipped ore over a narrow-gage railroad that had been built from Silver Plume to the top of McClellan Mountain, primarily as a scenic route for tourists. This railroad was abandoned when automobiles became common, and little mining has been carried on here since.

After the first intensive search for silver ore in 1865 comparatively little was done in the western part of the Argentine district until 1879, when two settlements, Chihuahua and Decatur, were made in the valley of Peru Creek, a few miles northeast of Montezuma. In 1882 Chihuahua, at the mouth of Chihuahua Gulch, had 54 buildings and was the home of many prospectors who were exploring veins in Cooper Mountain, Brittle Silver Mountain, and Morgan Peak. The lack of important discoveries in the next few years discouraged the men, however, and after the town was destroyed by a forest fire in 1889 it was never rebuilt. Decatur, about a mile east of Chihuahua, is in the path of snowslides from Ruby Mountain, and in 1930 only two houses were intact, but the piles of crushed and broken lumber marking the former location of buildings suggested that the town may have been as large as Chihuahua. During the eighties a small furnace was built here and some ore from the mines in the Horseshoe Basin was treated. It was closed about 1889, and since that time the town has been almost abandoned. The Pennsylvania mine, directly south of Decatur, has been one of the most

productive in the quadrangle. The vein was discovered in 1879, and the mine reached the zenith of its production about 1893 and was one of the few properties that were steadily operated during the lean years that followed the panic of 1893. The mines in the Horseshoe Basin have never been operated continuously for more than a few years at a time, but intermittent work at different mines has resulted in some activity in this region every few years since 1865.

Although the first silver ore discovered in Colorado was found on Glacier Mountain early in 1864, no further prospecting was done there until 1865, when the Argentine rush carried a wave of eager prospectors into this region. The Comstock and many other veins were found, and in the next few years mills and smelters were erected for treating the ores. The long haul necessary to take the ore to Denver or Blackhawk induced the mining companies to build a toll road up the Snake River to Webster Pass and down Handcart Gulch and Hall Valley to the North Fork of the Platte River. For many years this road was the chief freight route from Denver to the Snake River mining district. In 1869 a toll road was built from Georgetown to Montezuma by way of Argentine Pass, and a few years later another toll road was completed over Loveland Pass. The latter road was abandoned about 1883. All these roads were supported by charges against wagons and stock using them. The tolls ranged from 5 cents a head for loose stock or pack trains to \$1 for a team and wagon. About 1883 the counties bought the Argentine Pass toll road for a public highway, but little money was spent on its upkeep, and it was soon impassable for teams and wagons. The completion of a railroad to Dillon in 1883 simplified the problem of transportation greatly, and most of the freighting since has been done on the valley road between Dillon and Montezuma.

The first settlement at Montezuma was made in 1865, and the town has been continuously occupied ever since. It was incorporated in the fall of 1881 and was the center of much activity during the next few years. According to the first issue of its local newspaper, the Montezuma Mill Run, June 24, 1882,

We now have two commodious hotels—the Summit House, by L. C. Preston, and the Rocky Mountain House, by J. R. Newman; several restaurants and boarding houses; three stores; three saloons; two blacksmiths; one shoemaker; and mechanics in abundance. * * *

Montezuma claims the first discovery of silver in Colorado. As early as 1863 a prospector by the name of Coley living in Empire, near Georgetown, made prospecting trips over Kenosha Pass and then over Georgia Pass; up the North Swan, over the pass at the head of Bear Creek, and on Glacier Mountain made the discovery of silver.

* * * * *

The lode from which he took the first silver is now the property of the Sts. John or Boston Silver Mining Co. The crude furnace in which he smelted the ore is still to be seen on Glacier Mountain, within 1,000 feet of the Sts. John property.

The first lode discovered after Coley * * * was called the Harrisburg, now the Little Annie. It was discovered and located by W. P. Pollock, John Christian, and —— Pratt. The ore cropped out of the ground, and the vein could be traced by its outcroppings for 500 or 600 feet.

Shortly after the location of the Harrisburg, prospecting became general, and in rapid succession other lodes were located. In 1865 Ed. Guibor came to the camp, built his cabin where the Sts. John now is, and prospected Glacier Mountain, located the Potosi and an extension of the Coley lode; later the Herman and Bell lodes. John T. Lynch and Pratt discovered the Tiger and Tiger Extension lodes in 1865. In 1866 J. T. Lynch discovered the Sukey lode, now the Silver King. He organized a silver-mining company, and they built the Sukey mill to treat the ore. They worked the property until 1869, lost the vein or ran off from it, and then abandoned the property altogether. In 1866-67 prospecting was energetically carried on. "Doc." King and Captain Short organized the first mining company and put up a mill in 1867. The Bell was discovered in 1866 by William Bell, and about that time the Chataqua was discovered by H. M. Teller and G. H. Bull. The Sts. John property was discovered by John Cullom and bought by the Boston Silver Mining Co., who began work in 1867; erected their mills later. In 1868 Captain Ware took charge of the works, and now there is no more completely developed mine in the State. The work done by Captain Ware shows that a master hand directed it.

The first gray copper discovered was in the Coley Extension, and the first ruby was found in the Potosi in 1867.

The Silver Wing was discovered in 1867 by W. P. Pollock, George Link, Mike Dowd, and Charles Breese. The property was bought by the St. Lawrence Silver Mining Co. They erected a substantial mill and tried to reduce the ore by chlorination by Ayers' improvement on the Stedefelt furnace. It did not prove a success, and the work was abandoned.

The Woodchuck, Walker, and other lodes were discovered in 1869 and 1870.

* * * * *

The mines spoken of thus far are on Glacier Mountain and * * * are those discovered before 1870. Since then there have been discovered the Centennial Buckeye, Alabama, Old Timer, Eureka, St. Joe, Harrison, Silver Prince, Silver Princess, Zula King, Wild Irishman, Lady Green, Mendenhall, Lily, Bonanza King, Silver Ledge, and Silver Ware.

On Collier Mountain the first lode discovered was the Cooper, then the Old Settler by Joe Duffield in 1865, then the Lancaster by Bob Espey. * * * The Hannibal, Waterman, Washington, and Morgan were discovered afterward. Besides these there are scores of other properties that will undoubtedly prove to be valuable when developed.

On Teller Mountain, immediately south of town, are to be found the Cashier, Star of the West, Star of the West No. 2, Iowa, Radical, and other properties. The Cashier is probably one of the best-paying mines in the county, if not in the State. The Star of the West, owned by J. Harvat, of Georgetown, is very prominent for its richness; assays as high as 22,000 ounces in silver and 70 ounces gold per ton have been obtained from the ore taken from it. The Star of the West No. 2 bids fair to rival the original in richness.

On Independence Mountain, west of Bear Mountain, is the Great Republic, discovered by Jonas Conwell and Joe McKinney, * * * [also the] Dom Pedro, discovered by O. Milner. The Hunki Dori was discovered in 1880 by Penry, Murphy, Dougherty, and Keogh. The Ida Bell was discovered in 1880. Besides these there are other valuable properties on the same mountain.

The Erickson mine and other good properties are at the head of Keystone Gulch and near the head of Bear Creek.

Several veins were discovered near Montezuma in the eighties and small lots of ore were taken from many of them. Mining waned steadily after 1888, however, and since that time most of the activity has been due to the sporadic exploitation of various properties by stock companies. Some mines—the Sts. John, Bell, and a few others—produced ore continuously for several years at a time, but most of them did not. Further details of the mining history in this district can be found in the descriptions of the individual mines (pp. 68-116).

About 1871 baritic lead-silver ores were found in Hall Valley and at the head of West Geneva Creek and almost immediately were acquired or leased by a British syndicate, the Hall Valley Silver-Lead Mining & Smelting Co., Ltd. Halltown was built in Hall Valley about half a mile south of the quadrangle, and soon elaborate equipment was installed for treating the ores. Three Piltz blast furnaces were erected but were unsuccessful because of the high percentage of barite in the ores. In 1874 and 1875 a reverberatory furnace 64 feet long and a wet concentrator were installed to dress the ore and roast it before smelting. Because of its high specific gravity, the barite could not be separated from the sulphides in the mill, and the whole enterprise was abandoned.²¹ Remnants of the wooden tram, 4 miles long, that connected Halltown with the mines at the head of the valley can still be seen, but Halltown itself has been obliterated. After the failure of the English company the mines were operated individually by private owners or by lessees, and some ore has been shipped almost every year since. Several unsuccessful attempts were made to concentrate the baritic ores by gravity mills prior to 1917, when a flotation mill was built that successfully separated the barite from the sulphides. This mill was shut down in 1921 and has not been operated since. Aside from the concentrates produced by this mill (see p. 114) practically all the ore shipped from the valley has been high-grade silver ore that was sorted by hand. No large-scale operations have been carried on in Hall Valley since 1876, but several of the mines, chiefly the Whale and Missouri, have produced considerable ore. The baritic veins in Revenue Mountain, near the head of West Geneva Creek, supplied some of the ore so disastrous to the Halltown smelters, but nevertheless, after the failure of the English company, a smelter was built at the mouth of Smelter Gulch to treat this baritic ore. The smelter was operated in 1880 and 1881 but had difficulty in obtaining ore sufficiently low in barite to smelt successfully and was soon abandoned.

The auriferous gravel of the Swan River Basin, in the southwestern part of the quadrangle, was discovered

²¹ Jernegen, J. L., Jr., The Whale lode of Park County, Colo.: Am. Inst. Min. Eng. Trans., vol. 3, pp. 352, 356, 1875; Notes on a metallurgical campaign in Hall Valley, Colo.: Idem, vol. 5, pp. 560-575, 1877.

in 1859 or 1860, and the gulches draining into the main valley were soon yielding much placer gold. The deeper gravel of the main valley was not successfully worked till after 1905, when dredging emerged from a 7-year period of experiment and failure into one of steady and profitable production. The thin but extraordinarily rich gold veins of Farncomb Hill, about a mile south of Brewery Hill and just south of the quadrangle, were discovered about 1879 or 1880, and a few years later the stockworks west of Tiger were found. The latter deposits were producing oxidized gold ore before 1890 and were profitably mined until after 1900. As they were followed deeper and the low-grade primary ore became more and more abundant, it was found increasingly difficult to work them at a profit. These properties were acquired about 1912 by the Royal Tiger Mines Co., and since then much time and money have been spent in an effort to prove that the low-grade ores were of commercial grade.

THE MINES

Of the many veins discovered in the Montezuma quadrangle before 1891, during the years when silver was worth more than \$1 an ounce, some yielded little or no ore, while others yielded more than 100,000 tons. Most of the mines have long been inactive, however, and only a very few were accessible when the writer studied the region. Nearly all the veins, large and small, have been the subject of optimistic prospectuses as enthusiastic promoters strove to capitalize both fact and legend. Some of the veins justify further exploration, but the size of the ore bodies mined in the past and the opportunities for finding rich bonanzas or large and profitable bodies of milling ore in the immediate future are commonly overestimated. Many veins whose total production is less than 5 tons have been the nominal object of exploitation of stock companies capitalized for \$500,000 or more. The writer has searched the files of the local papers—the Montezuma Mill Run, the Georgetown Miner, and the Georgetown Courier—for mining news of the region and has supplemented this information by much gathered from men who have been resident in the quadrangle for 40 to 50 years. Some material is also quoted from the reports by R. W. Raymond on mining in the States and Territories west of the Rocky Mountains, and from the reports of H. C. Burchard, Director of the Mint. As noted in the text, manuscript reports by examining engineers have also been used for a few mines to supplement other information. It seems worth while to have these data set down, even though some of the veins described are small and unimportant. Many of them have been the basis for highly speculative and overcapitalized stock companies, and it is hoped that the information in the following pages will help the mining investor as well as the mine operator.

ADDER

The Adder vein is on the northern slope of Glacier Mountain, about half a mile southwest of Montezuma. It was opened in the eighties but had no recorded production until 1919, when 5 tons of lead-silver ore was shipped by Todd & Hatton. As shown below, the mine has been intermittently productive since that time. Two adits aggregating about 300 feet and a shaft about 20 feet deep were made before 1890, and in 1919 the shaft was deepened 15 feet, and a short drift was turned on the vein. In the next few years the shaft was deepened to 85 feet and another level turned. In 1929 about 100 feet of drifts were reported in the shaft workings, but the mine was inaccessible.

The country rock of the vein is the Swandyke gneiss, which strikes N. 30° E. The vein is said to run N. 45° E. and to be nearly vertical. The ore is from 4 to 12 inches thick, according to the Colorado Mining Directory for 1883, and consists of quartz, galena, and silver minerals.

Production of Adder vein

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)
1919.....	5	.....	258	899
1923.....	8	.....	542	1,417
1924 (Adder, Denver, and Register).....	23	0.10	1,192	7,290

No production in 1901-18, 1920-22, 1925-28.

ALTOONA

The Altoona vein is on the west slope of Glacier Mountain near the Wild Irishman mine and is opened by a few shallow shafts and short adits, at an altitude of about 11,500 feet. It was located in 1881 and produced a small amount of silver-bearing gray copper and galena ore during the eighties. The vein strikes northeast and carries from 4 to 8 inches of galena and gray copper in a quartz gangue. According to the Colorado Mining Directory its total production prior to 1883 was 20 tons, but during the next few years it probably produced about 10 tons more.

AMERICAN EAGLE (ELIZA JANE)

The American Eagle vein, or, as it is locally known, the Eliza Jane, is on the crest of Lenawee Mountain, $2\frac{1}{2}$ miles north of Montezuma, at an altitude of about 12,500 feet. It is opened on the northwest slope of the valley of the stream that empties into Snake River near U.S.L.M. Adrian, and is a short distance southwest of the Winning Card mine. It was located in 1880 and produced some very rich silver ore in the next few years. In 1881 4 tons of "gray copper ore" was shipped that netted \$500 a ton, and during 1882 and 1883 the mine was working but its production is not recorded, although the Georgetown Courier for October 1, 1883, notes that this mine "shipped over 3 tons of first-class ore in the last 2 weeks." In 1884, 2 carloads (about 27 tons) netted the lessees \$9,000; in 1885, 20 tons netted \$6,000, and in 1886 3 tons of unknown value was shipped. There was no production during 1887 and 1888, and the mine is not listed later. Silver was the only metal in the ore for which the lessees received pay. The total production of the mine was probably about 85 tons of ore averaging about 350 ounces of silver to the ton. Little is known of the vein except that the character and occurrence of the ore were very similar to those of the Winning Card, which is described on pages 114-116. The ore seam was from 1 to 6 inches wide and contained galena, gray copper, quartz, and a silver mineral that was probably stromeyerite.

ATLANTIC

The Atlantic vein is on the west slope of Collier Mountain, about a mile east-southeast of Montezuma. It lies between

altitudes of 12,000 and 12,500 feet. It was located in 1873 and yielded about 50 tons of silver-bearing galena ore before 1883, but very little has been shipped from it since that date. The total production is probably about 75 tons. The Atlantic is said to be a quartz vein from 4 to 18 inches wide and contains galena locally. The shipping ore assayed about 60 percent of lead and from 50 to 100 ounces of silver to the ton. The vein trends northeast toward the Sarsefield mine, a short distance away, and may be the southwestern continuation of the Sarsefield vein.

BAKER

The Baker lode is on the east slope of Kelso Mountain, $6\frac{1}{2}$ miles northeast of Montezuma, west of the Stevens mine, at an altitude of about 12,000 feet. No work has been done on it since about 1885, but the mine was one of the most productive in the Argentine and Silver Plume mining districts in the seventies. The lode was discovered in 1865, during the rush caused by the discovery of silver in this region late in 1864. In spite of the desertion of the district in 1867, 1868, and 1869, the Baker was developed steadily, and during the winter of 1869-70 communication was maintained with Bakersville (Graymont) without difficulty, and a team and sled was able to make frequent trips between the town and the mine. The use of teams instead of pack trains reduced the cost of transportation about \$3 a ton. In 1869 the Baker Co. completed its reduction works at Bakersville, and in 1870 two shoots of good ore were opened, and for a short time the reduction works smelted from 15 to 65 tons a month. In July 1871 the Bakersville smelter was completely destroyed by fire. This was at the height of its activity, and production fell off immediately. The Baker was listed by Raymond as one of the chief mines worked during 1873, but little ore was shipped after 1874, and the mine was idle during the later seventies. Some work was carried on in the early eighties by the British Queen Mining Co., but no production is recorded for this time. According to the Georgetown Miner for January 19, 1871, the total bullion produced in 1870 was \$27,567.97, or about 21,321 ounces of silver. In January 1872 the total bullion produced in the past year was reported to be \$4,509, or about 3,487 ounces of silver. Incomplete records for 1874 indicate that over 1,000 ounces of silver was produced in that year.

According to Hollister,²² the two principal veins, called the north and south crevices, strike N. 72° E. and N. 60° E. and dip 65° and 85° N.

"They are traced and disclosed by many prospecting pits, showing bodies of uncommonly rich ores, varying in width from 20 inches to 20 feet. The crevices consist of sulphuret and bromide of silver and argentiferous galena, all these ores being more or less interspersed within the vein matter of quartz and feldspar. Samples of ore taken from these crevices yielded by assay as high as \$800 to \$2,000 per ton. At the junction of the north and south crevices a tunnel has been commenced which shows a large body of ore 7 feet in width. * * * Samples of all the different tunnels and surface pits, pulverized, and equal weights of each mixed together. This average ore yielded by assay gold \$6.11, silver \$69—\$75.11 per ton of 2,000 pounds. * * * Two tons of the ore, unselected, undressed, and without roasting, was smelted last winter, yielding 25 pounds of silver, coin value \$422.90, and 1,500 pounds of lead, at 10 cents a pound, \$150. About 3 miles above the right fork and 2,000 feet up from the creek occur the John Brown, United States Coin, and Mammoth Lodes, parallel and within 50 feet of each other, standing above the surface, the Mammoth assaying \$60 a ton for 30 inches, the Coin \$200 a ton for 18 inches in width, and the Brown \$350 for 16 inches. Some ore from the Brown has been smelted—they are all argentiferous

galena—and the lead riches, of which the yield is nearly one-half the weight of the dressed ore, assays about \$1,000 per ton."

In 1869, according to King,²³ the Baker was one of the most thoroughly developed properties in the region, but the amount of ore found had been disappointing. The width of the vein averaged about 3 feet and locally was as much as 15 feet, but the ore seam was not continuous. The ore consisted of galena, sphalerite, and silver minerals and occurred in pockets and chimneys. The chief gangue mineral was quartz, but fluorite was abundant in all but the uppermost of the three levels.

In 1871, according to Raymond,

"The Baker * * * opened to a depth of 320 feet; worked by three adits, 187, 212, and 420 feet long, all connected by a shaft, extending to a depth of 168 feet below the third level. The mine is in good ore above the first level. The ground between the first and second levels is entirely worked out, and between the second and third levels nearly so. Though nine-tenths of all the ore found in the lode was on the footwall, the deep shaft has been sunk on the hanging wall, and no ore was found beyond a depth of 60 feet. This summer a crosscut was started toward the footwall, which, at a distance of 10 feet from the hanging wall, struck a vein of solid ore $2\frac{1}{2}$ inches in width and assaying \$650 per ton. Here again, as in all instances where true fissure veins have been sunk upon to greater depth, it has been proven that the ore continues downward, though of

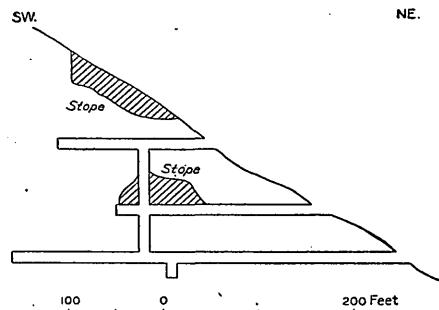


FIGURE 8.—Longitudinal section of Baker mine, 1869.

course varying in richness as well as thickness, and sometimes pinching up entirely for some distance. In the stope above the first level there is a vein of ore, varying from 2 to 10 inches, yielding ore of \$200 (mill assay). The stope between the second and third carries from 1 to 6 inches of \$130 mill ore. Below the third level no ore has been taken out except in sinking the shaft. The driving of levels preparatory to taking out ore was just contemplated when the company's mill was destroyed by fire. This accident stopped operations for a considerable period. Next year a deep tunnel, gaining over 400 feet below the third level, is to be started to facilitate cheap working."

In 1883 the mine was developed by four levels, all connected by a 200-foot shaft. A partial section of the workings taken from Raymond's report for 1869 is shown in figure 8.

The country rock of the mine is Silver Plume granite, quartz-biotite schist, and injection gneiss cut by many dikes of granite and rhyolite porphyry. The average width of the Baker vein is said to be about 16 inches, and the ore a short distance below the surface consisted of stephanite, silver-bearing galena, and chalcopyrite in a quartz gangue.

BALTIC AND REVENUE

The Baltic and Revenue veins are opened by the Britannic tunnel, on the southwest slope of Revenue Mountain at the head of West Geneva Creek, 3 miles east of Montezuma. There are several other workings on the veins of this group, including a shaft on the Revenue vein that has its collar on the Continental

²² Hollister, O. J., Mines of Colorado, p. 260, Springfield, Mass., 1867.

²³ King, Clarence, U.S. Geol. Expl. 40th Par. Rept., vol. 3, pp. 599-600, 1870.

Divide at an altitude of about 12,600 feet. The altitude of the Britannic portal is about 12,125 feet.

The property is accessible from Grant, about 11 miles to the southeast. A good automobile road runs as far as the foot of Kirby Gulch, 7 miles from Grant, and is passable for cars for 2 miles more, and a wagon road continues to a point within half a mile of the Britannic tunnel, which is on the main trail from West Geneva Creek to Cinnamon Gulch.

The Baltic and Revenue veins, discovered in 1872, were famous in the seventies, and the ruins of a smelter erected to smelt their ores in 1879 can still be seen at the foot of Smelter Gulch. Some of the ore produced by the veins was sent to the Hall Valley smelter in 1873-75, at the time the mines in Hall Valley were being exploited by the Hall Valley Silver-Lead Mining & Smelting Co., Ltd. In his report for 1874 Raymond says: "It has been opened for about 400 feet and to a depth of about 65 feet and carries a very regular seam of galena and gray copper, averaging about \$120 per ton in silver." After the failure of the Hall Valley enterprise the mines in the valley of West Geneva Creek produced almost nothing until 1880, but during this time the Britannic adit was driven, and drifts were turned from it on many of the veins that were cut. In 1881 the

tained an average dip of 45° for the remaining 75 feet of the winze shown in the cross section in figure 9. The vein below the 250-foot sublevel is said to consist largely of barite with moderate amounts of chalcopyrite and dark-colored sphalerite but has small amounts of quartz, galena, and gray copper. The vein was followed 600 feet west from the Britannic adit, and the ore shoot continued for about 500 feet of this distance and was stoped as much as 150 feet above the tunnel level, according to James Kimberly. East of the winze the ore became very pyritic, and little work was done in that direction. The ore pinched so markedly above the Britannic level that the ore shoot may properly be considered a blind one, although the vein itself crops out. The shoot is said to have had a pronounced pitch to the northeast, but the amount of pitch could not be given. According to the Georgetown Miner for August 16, 1879, the Baltic vein had 8 inches of solid gray copper ore on the tunnel level, and the winze showed 12 inches of yellow copper (chalcopyrite) and galena ore. The stope on the Revenue vein 100 feet above the tunnel showed 14 inches of pyrite, galena, yellow copper, and gray copper ore.

The Revenue vein strikes about N. 55° E. and dips about 75° NW. The Britannic tunnel cuts it about 200 feet beyond the

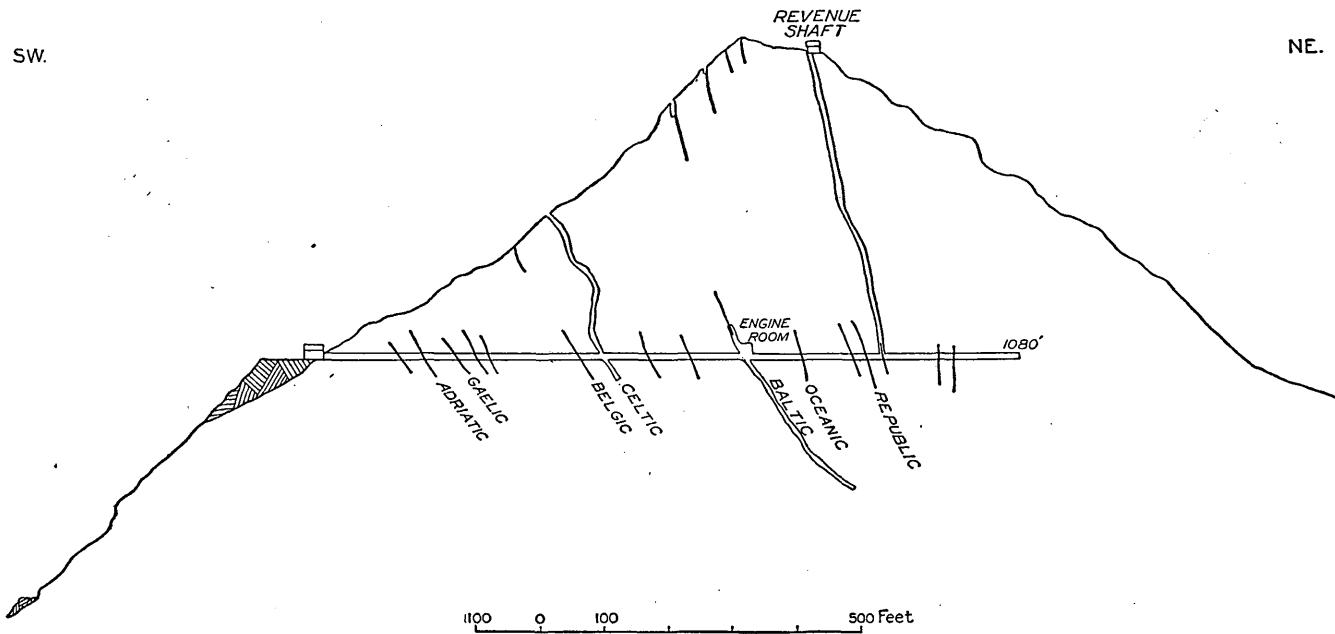


FIGURE 9.—Cross section along line of Britannic tunnel, looking northwest.

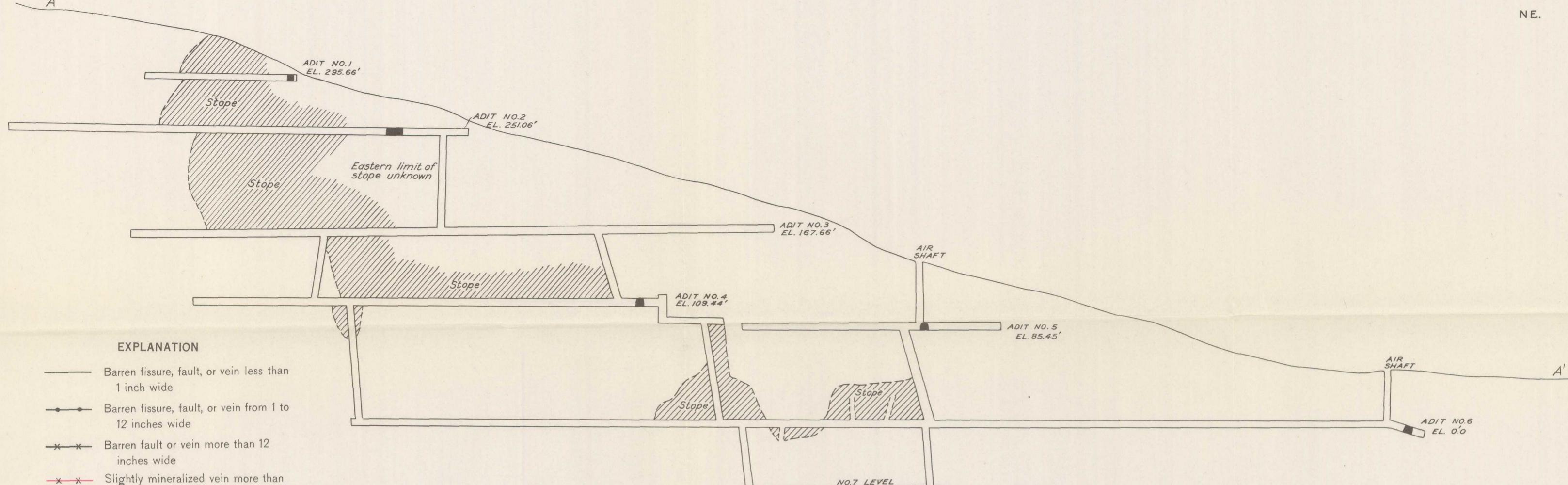
Geneva mining district is credited with a production of \$30,000, and in the next year with \$7,000; most of this was probably produced from the Revenue and Baltic group of veins. The district as a whole is not mentioned again, but in 1887-91 the Baltic is listed as a producer and is given credit for a production of \$1,300 in gold and \$69,132.93 coin value in silver, a total of \$70,432.93. The production records during the nineties were very poor for all the mines in Colorado, so that it is not surprising that no further production is recorded for the Baltic, although miners in the district state that some ore was mined. Six carloads are said to have been shipped from the Baltic in 1898, and two carloads more in 1902. Because of the long haul to the railroad, all ore shipped from this region has had a tenor of \$50 or more to the ton. Except for two small shipments from the Revenue vein, no ore is known to have been shipped from this group since 1902.

The Baltic vein strikes northeast and dips 45° to 75° NW. The steep dips occur in the upper part of the vein, and as it was followed downward from the Britannic tunnel level the dip changed from 65° to 55° and maintained this angle for nearly 200 feet, below which it flattened still more and main-

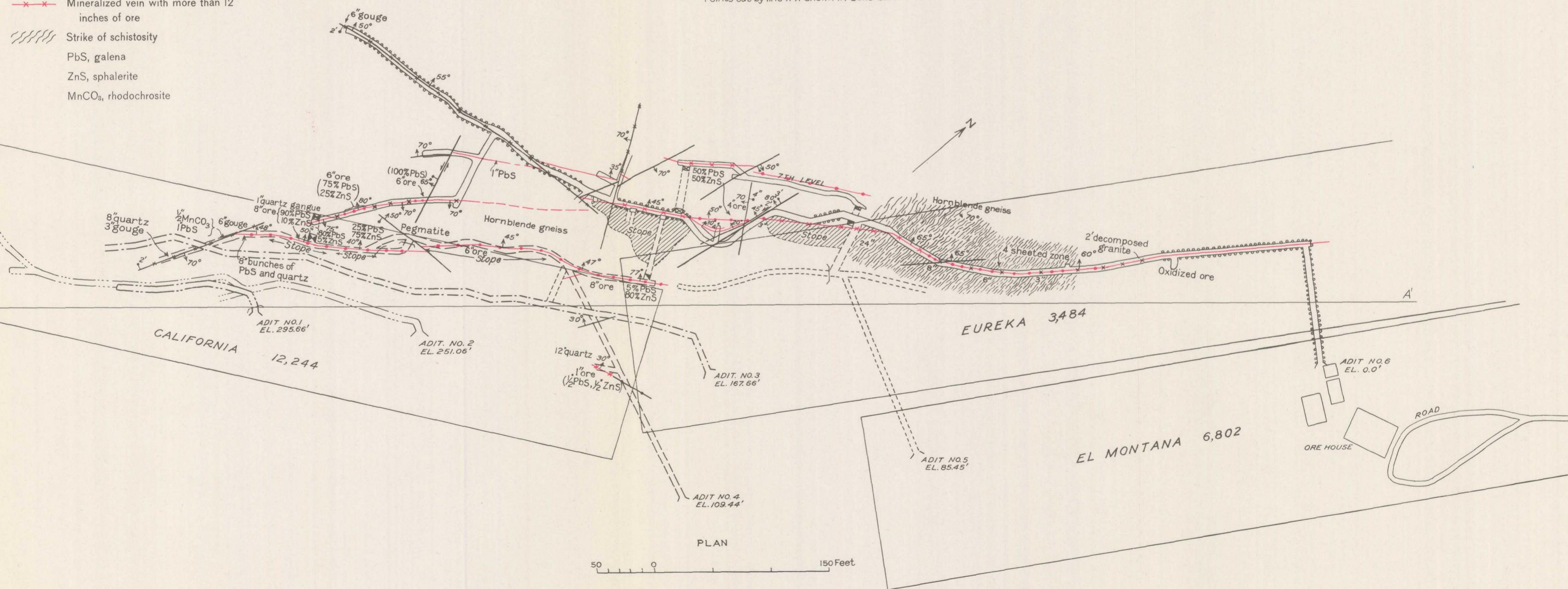
Baltic vein and is connected to the surface by a shaft 455 feet deep. The vein is somewhat narrower than the Baltic and averages about 6 inches in width. It contained a higher proportion of gray copper than the Baltic, and near the surface it had a high percentage of galena. The silver content of the ores of the Baltic and Revenue group increased with the content of gray copper. The gold content, which was locally high, increased with the content of chalcopyrite. The country rock of the veins is largely injection gneiss and quartz-sillimanite-biotite schist, striking northeast and dipping at an average angle of about 55° NW. Small dikes of monzonite and quartz monzonite porphyry are common on the surface and were probably found underground in some of the workings. The veins appear to be essentially parallel to the schistosity, and the cause of the localization of the ore shoots is not known.

Emmons²⁴ notes that a specimen of ore from the Baltic mine was "ore and gangue, pyrite, chalcopyrite, blende, fahlerz (gray copper), and a little galena in siliceous gangue; occasional pink calcite crystals."

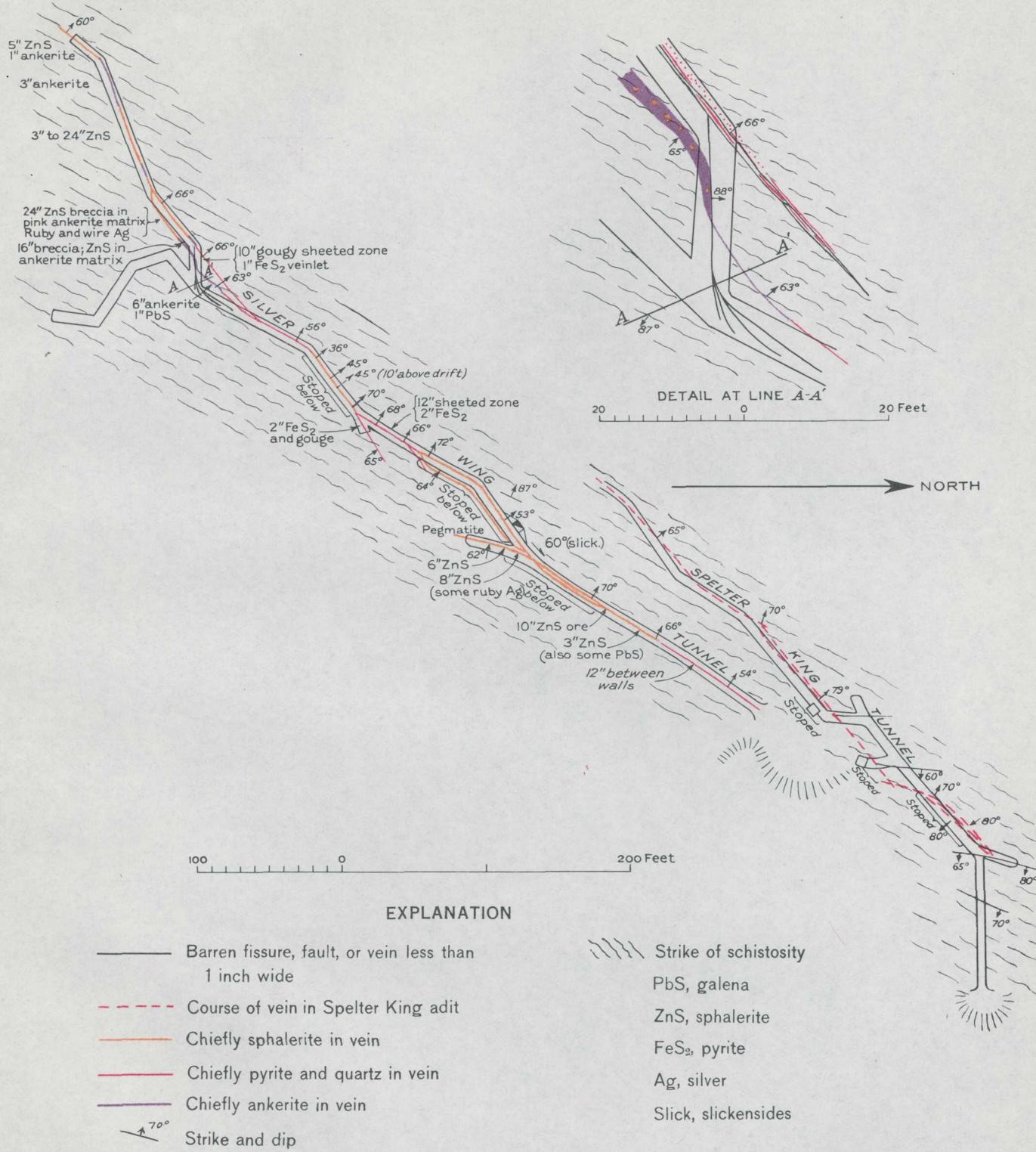
²⁴ Emmons, S. F., Tenth Census, vol. 1, pp. 77, 188.



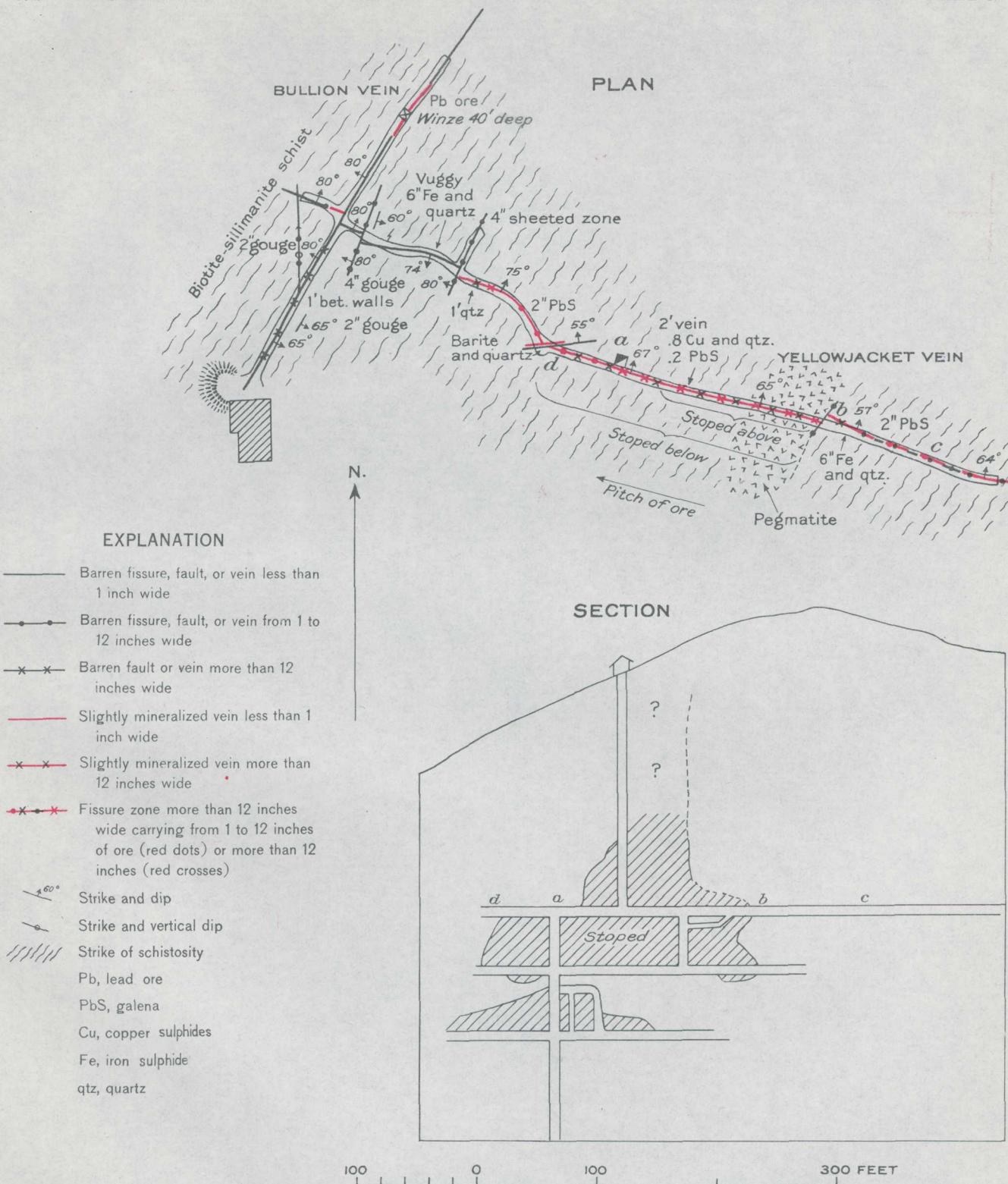
SECTION AND PROJECTION
Points cut by line A-A' shown in solid black



PLAN AND LONGITUDINAL SECTION OF BELL MINE, SOUTH OF MONTEZUMA

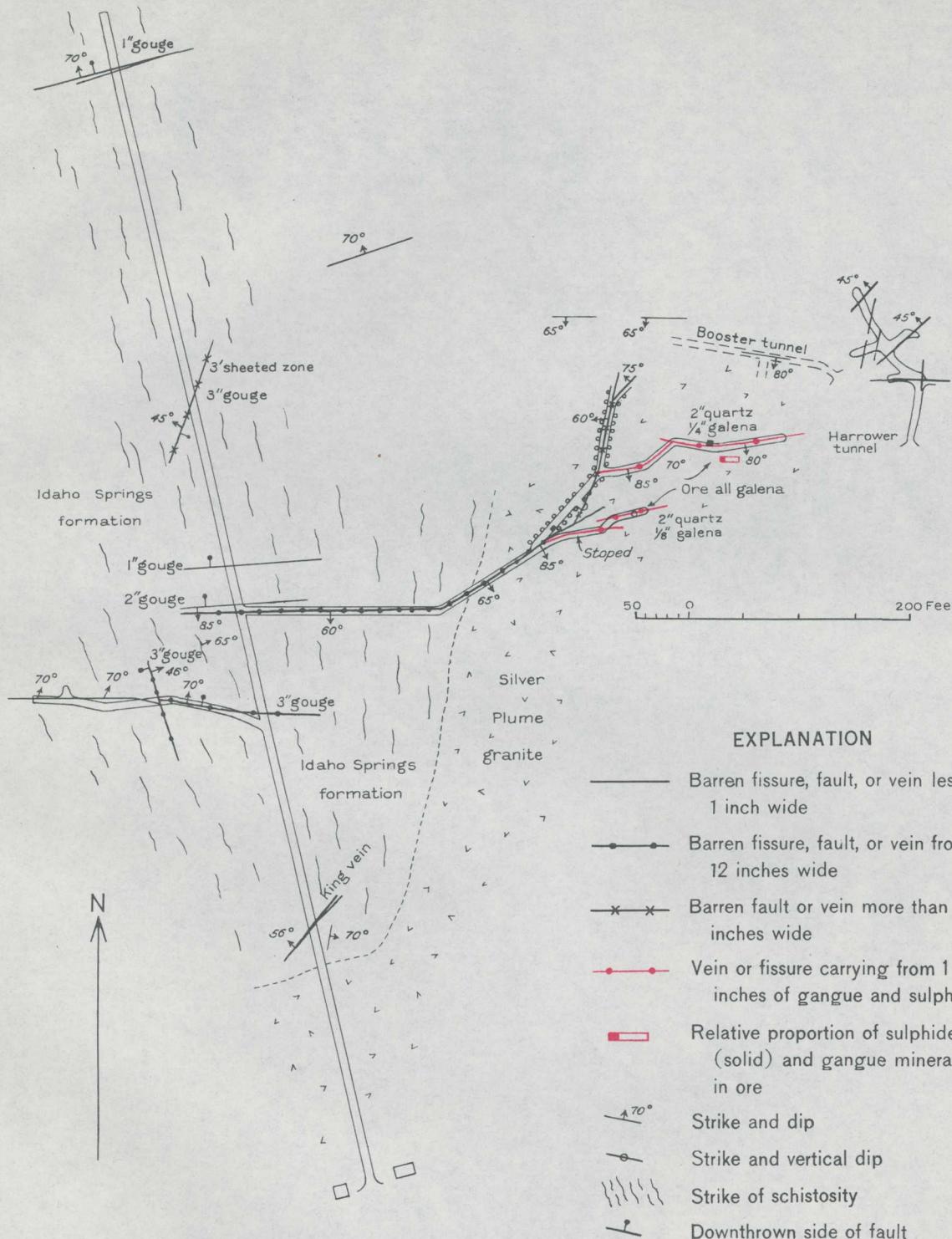


PLAN OF SILVER WING AND SPELTER KING TUNNELS,
GLACIER MOUNTAIN

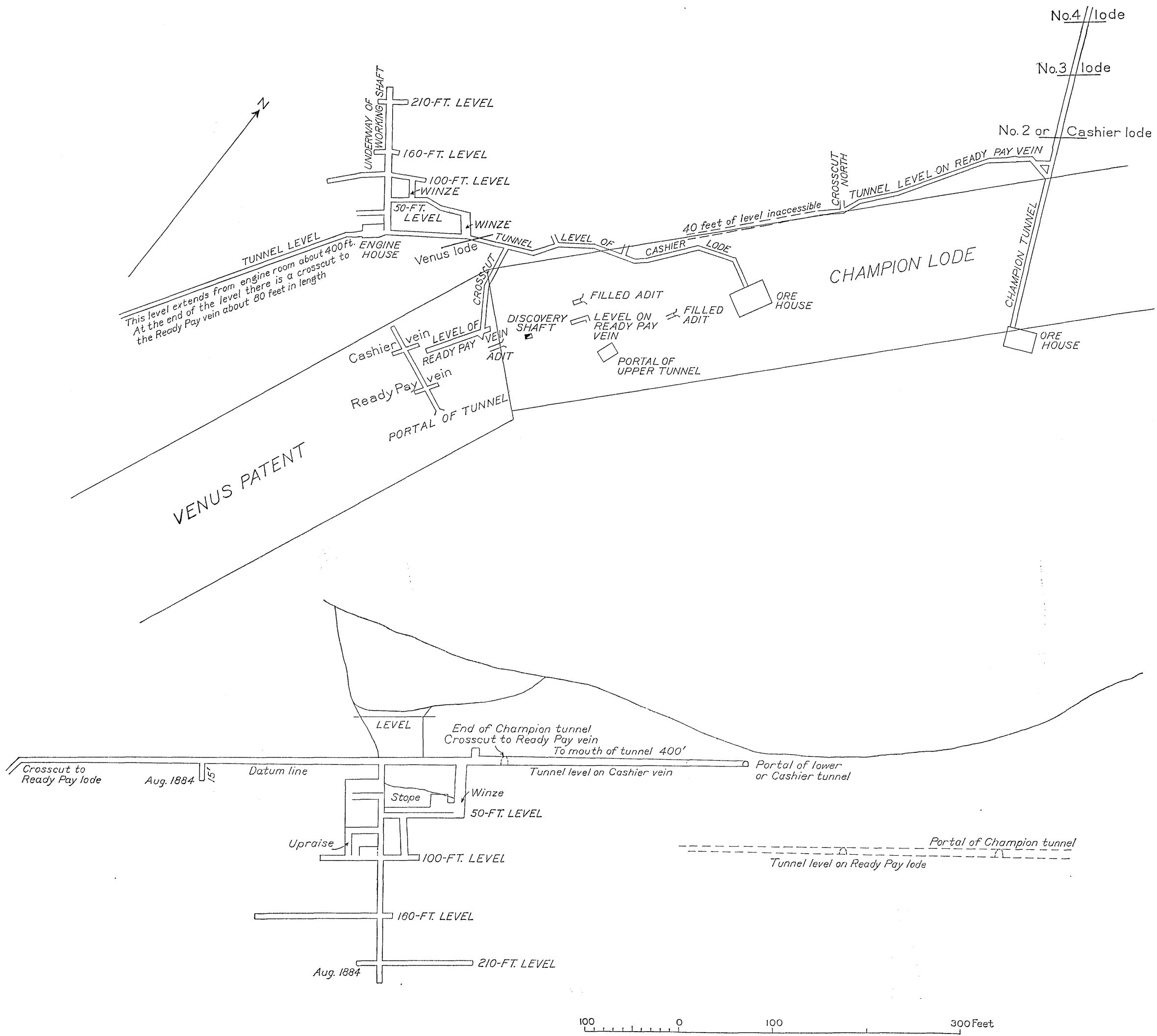


a, Pb generally between Cu and hanging wall. Winze 185' deep, all reported in ore, average 3' wide.* b, 1 foot quartz, very vuggy and carrying CuFeS_2 sphenoids. c, Pocket of ore 6' long and barren streaks 20'. d, Sheeted zone, 4'-6', narrow Pb and Cu veins.

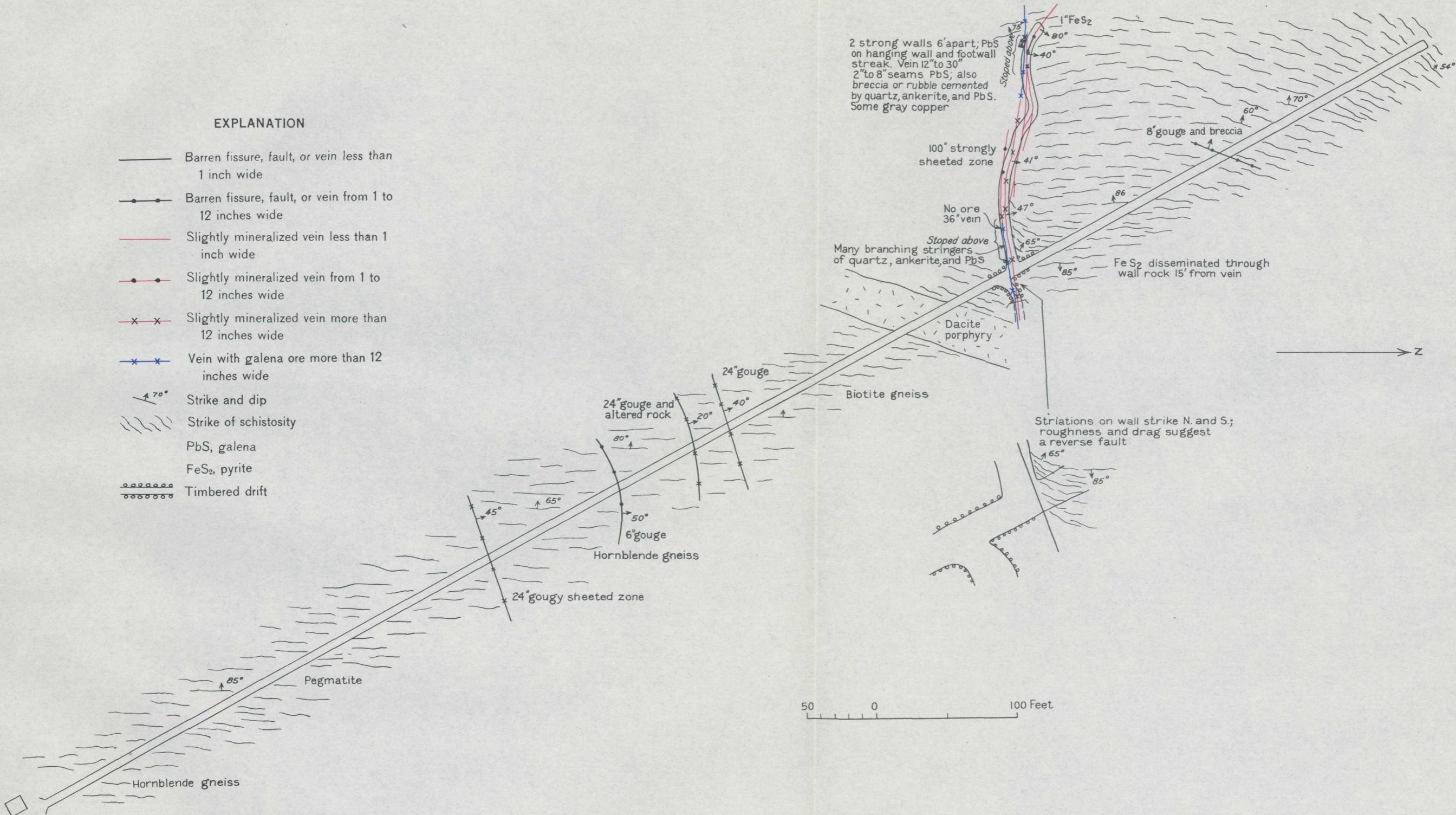
PLAN AND SECTION OF BULLION MINE, NEAR MONTEZUMA



PLAN OF BUSTER TUNNEL, NEAR SILVER PLUME MTN.



PLAN AND VERTICAL PROJECTION OF CASHIER AND CHAMPION MINES.



PLAN OF MAIN (LOWER) ADIT, CHATAUQUE MINE, GLACIER MOUNTAIN, 1929

The incomplete production figures given below are all that have been found.

Production of Baltic and Revenue veins

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)
Baltic:					
1887	(?)		10,450		
1888	(?)	62.89	9,158		
1889	(?)		10,378		
1890	(?)		10,603		
1891	(?)		8,018		
Revenue: *					
1876	1		41	673	
1878	45	1.31	6,266		5,063
1880	52	60.62	17,825		21,057
1881	43	54.02	12,055		13,345
1887-89	30				
1911	2	.08	328	569	98
1919	14	.36	900	2,398	2,443
1927	4		300	1,635	703

* No record available for 1877, 1879, 1883-86, 1890-1900; no production in 1901-10, 1912-18, 1920-26, 1928.

BELL, METEOR, AND WING

The California, Sunburst, Meteor, and Wing claims, on Glacier Mountain, are on the lode commonly known as the Bell vein. The original discovery was made by William Bell on the California claim in 1866, and the ground was taken up as the Bell East and the Bell West. These claims were not patented, but the portions of the vein which they covered were steadily worked until about 1893. The ground was relocated in 1897 by John and Frank Burke, who patented the claims in 1899 as the California and the Sunburst. The Silver Wing claim was located about 1870, and the original claim was 3,000 feet long and 50 feet wide. This claim, as surveyed, failed to keep the apex of the vein between its side lines for more than 300 feet from the discovery shaft, and the Burkes located the Meteor claim on the ground between the California and the place where the vein crossed the side lines of the Silver Wing claim, thus gaining control of the apex for nearly 4,500 feet.

The California and Sunburst claims were sold to the Cleveland Mine Development Co. in 1902. Work was carried on until the summer of 1903, and mixed lead-zinc ore was found on the no. 6 tunnel level. Work was then discontinued, and little or no work was done until 1925.

In 1924 H. B. McGowan, of New York City, obtained a lease and bond on the Sunburst, California, Meteor, and Silver Wing claims. He obtained the services of G. H. Short (formerly associated with George Graham Rice as manager of the Idaho Copper Co.) in driving a crosscut adit, which was expected to tap the vein under the Meteor claim. The adit failed to reach its objective and is said to have caved within a few months of the time that work was discontinued. It was inaccessible at the time of the writer's first visit to the district, in the fall of 1926.

McGowan defaulted a payment in May 1925 and lost his lease. In the later part of the summer Short bought the California and Sunburst claims from the Cleveland Mine Development Co. and organized the Bell Silver Mining Co. in Salt Lake City. The property was worked by Short and his associates from September 1925 until December 1926, and lessees operated it during the winter of 1927-28.

The Silver Wing adit was advanced about 250 feet by Short in 1924, at the time that this property was under lease to McGowan, and at the same time a raise was made in ore, but little stoping was done. No other work has been done in this adit since that time (1924-29).

The chief workings of the Bell mine are above 11,600 feet on the east side of Glacier Mountain, about a mile south of Montezuma. As shown in plate 17, there are about 3,000 feet of drifts and crosscuts in six adits and a short sublevel. The lowest

adit, no. 6, has its portal a short distance above the ore house at the terminus of the wagon road that leads to the Bolivar mill, half a mile south of Montezuma.

The vein trends northeast, and the general dip is about 65° NW. The surface of the vein is flexuous, and its course varies from N. 30° E. to N. 70° E. in some places, but in most of the workings it is not far from N. 40° E. The inclination of the vein is more irregular than its course, commonly ranging from 40° to 80°, but in places it is vertical and may even dip steeply southeast. The vein everywhere cuts across the schistosity of the Swandyke gneiss, which is the prevailing country rock. A small body of granite is cut near the entrance of the lowest adit, but hornblende and biotite gneiss seamed with pegmatite make up the wall rocks of the vein in the rest of the accessible parts of the mine. The gneiss strikes nearly due north and dips 50°-75° E. About 480 feet from the portal of adit 6 the Bell vein is cut by a normal fault striking N. 10° E. and dipping steeply west. The fault zone is about 3 inches wide and has offset the vein about 5 feet. Another normal fault striking in the same direction but dipping east offsets the vein a few feet about 600 feet from the portal. A short distance beyond this fault the drift swings west on a sheeted water-bearing fault zone about 24 inches wide, which contains a seam of gouge 6 inches wide. This fault dips 55° N. and apparently moved the southwestern part of the Bell vein about 15 feet east. This fault is also recognized on level 4, where its displacement is only about 10 feet. The vein is apparently terminated on level 4 by a northerly fault dipping 70° E. and marked by a seam of gouge 3 inches thick. The plan of the upper levels, now inaccessible, suggests that this fault occurs in them also and that the vein was not found west of it. If this fault is normal, like the other faults having a similar strike, the Bell vein should be found by turning north after passing through the fault, but exploration has not been carried out in that direction. A few small northwesterly normal faults, later than the northerly faults, have been mapped but do not persist from one level to another.

The ore seam of the Bell vein ranges from 3 to 24 inches in width but is commonly from 4 to 12 inches. Except where the vein dips southeast, the ore streak is remarkably free from gangue and consists chiefly of light-colored sphalerite and galena. (See fig. 10.) Sphalerite strongly predominates in the northeast half of the workings, but galena is more abundant than sphalerite in the southwest half. This change in the character of the ore is apparently unrelated to depth and is a lateral rather than a vertical change. Gray copper is uncommon, but a small lens occurred in the vein on level 6. Very little gold has been found, but the vein is noted for its rich silver shoots. The most common silver-bearing minerals observed are pyrargyrite and miargyrite, or dark ruby silver, but argentite and proustite are not uncommon. Wire silver is said to occur sparingly, but none was seen by the writer. The ruby silver occurs in lenticular masses in the center of the vein and is abundant in some places for distances of 20 to 30 feet along the drifts. The largest mass of which there is an authentic record was described by Van Horn.²⁵ (See p. 56.)

In most of the vein the ore occurs in a single seam, but in some places where premineralization movement developed many strong branching gouge seams and slips between the main walls of the vein, or where small parallel or branching fissures occur near the main premineral fault, several sulphide veins may follow the strongest of the premineral fractures. In some parts of the vein the introduction of the sulphides into the broken ground resulted in irregular masses of ore, which themselves have the misleading appearance of being badly faulted, as is illustrated in figure 10. The ore shoots are lentic-

²⁵ Van Horn, F. R., Occurrence of proustite and argentite at the California mine near Montezuma, Colo.: Geol. Soc. America Bull., vol. 19, pp. 93-93, 1903.

ular and are related to the changes in dip and direction of the vein. A steep dip or a strike near N. 30° E. is distinctly unfavorable for the occurrence of ore shoots, and conversely a

SE.

NW.

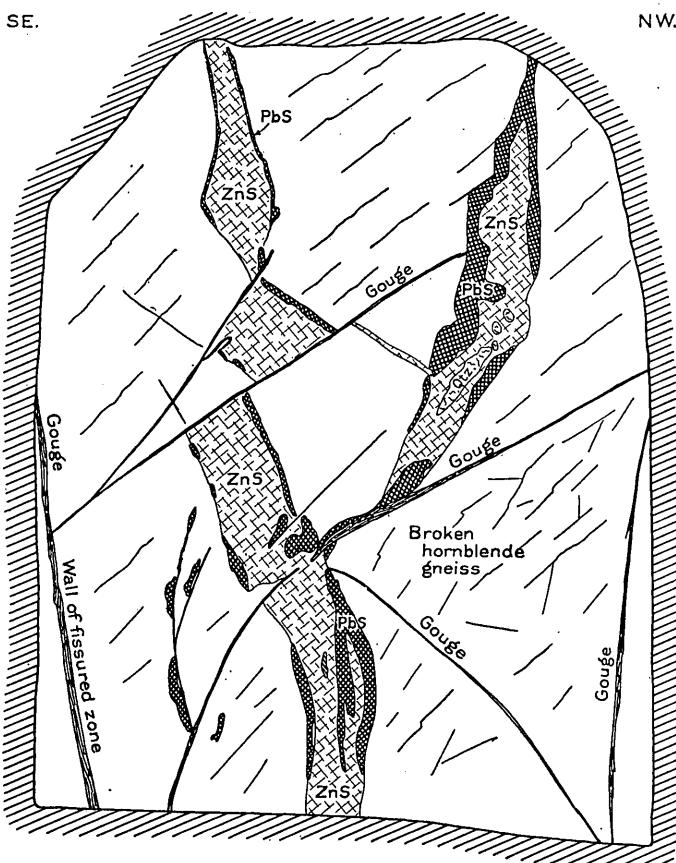


FIGURE 10.—Mineralization of broken ground in premineral fault zone. Apparent postmineral fault (upper left) is seen to be premineral (upper right).

gentle dip or a strike close to N. 45° E. is usually found where ore shoots occur. The cross section of the raise near the breast of adit 6, where the vein dips at more than 60° , coincides with a change in the course from N. 35° E. to N. 55° E., but the junction of the vein with other premineral fissures may have had some effect on the richness of the ore.

About 100 feet from the portal of adit 4 a vuggy quartz vein 12 inches wide was found that contains a small amount of galena and sphalerite. The vein strikes N. 70° E. and dips 30° N.; this dip and strike if maintained would cause it to intersect the Bell vein on level 6 about 650 feet from the portal, where a rich pocket of ruby silver was found. At this place a sheeted zone in the footwall of the Bell vein strikes N. 70° E. and dips 35° N., suggesting that the vein found in adit 4 was a factor in localizing ore at its junction with the Bell vein. The intersection of a strong gouge fissure striking N. 75° E. and dipping 55° N. with the Bell vein in the southwestern part of level 6 apparently had no effect on the localization of ore, although the strike and dip of the fault indicate that it is probably a continuation of the Wild Irishman vein zone. Although the fault is later than the Bell fissure, the relations are not clear enough to allow a decision as to whether the fault is later than the ore in the Bell vein. It is possible that this fault and the Bell vein fissure are both premineral. The S-shaped fractures in the Bell vein shown in figure 11 suggest that the ore was deposited in a reverse fault.

The Silver Wing or Wing adit and the Spelter King adit, half a mile northeast of the Bell mine, close to the Bolivar mill, are shown in plate 18. The Wing adit, 135 feet above the Spelter King, is about 700 feet long. Several ore shoots have been found in this adit; the first, 170 feet long, and the second, 60 feet long, have been stoped, but little ore had been taken from the other shoots in 1928, and the character of the ore was well shown.

The country rock is a biotite gneiss of the Swandyke gneiss, and its prevailing strike is about N. 25° E. It dips steeply east near the portal of the adit, but in the southwestern half of the workings it dips steeply west. Although the vein strikes parallel to the gneiss for short distances, it everywhere cuts across the schistosity because of its much gentler dip. The general course of the vein in the Wing and Spelter King adits is N. 50° E., and its average dip is about 65° NW. Although it is well defined and the miners followed it without much difficulty, it branches, splits into closely spaced parallel fissures, pinches into a tight, narrow seam of quartz and pyrite in some places, and swells into a sulphide vein 24 inches wide in others. In the first two ore shoots most of the ore left is massive light-colored sphalerite, carrying a small amount of galena, but a shipment made from the Wing in 1907 consisted of 36 tons of galena ore containing 35 percent of lead and $23\frac{1}{2}$ ounces of silver to the ton. Shipments from the Spelter King indicate that the zinc ore carries only about 15 ounces of silver to the ton. However, some rich pockets of ruby silver and native silver were found in a few places, usually at the beginning or end of an ore shoot and close to the intersection of a branching fissure. About 525 feet from the portal of the Wing adit some high-grade silver ore was seen by the writer. As indicated in plate 18, some movement occurred in this part of the vein after the deposition of the sphalerite, which occurs as a breccia about 24 inches wide, cemented by manganiferous ankerite. The cementation is not complete, and the vein is moderately open and vuggy in this place, and many of the vugs contain abundant wire silver, which was apparently one of the latest minerals.

The ore solutions did not find a single gaping fissure during the formation of the Bell vein, but rather a northeastward-trending fissure zone through which the ease of travel was much

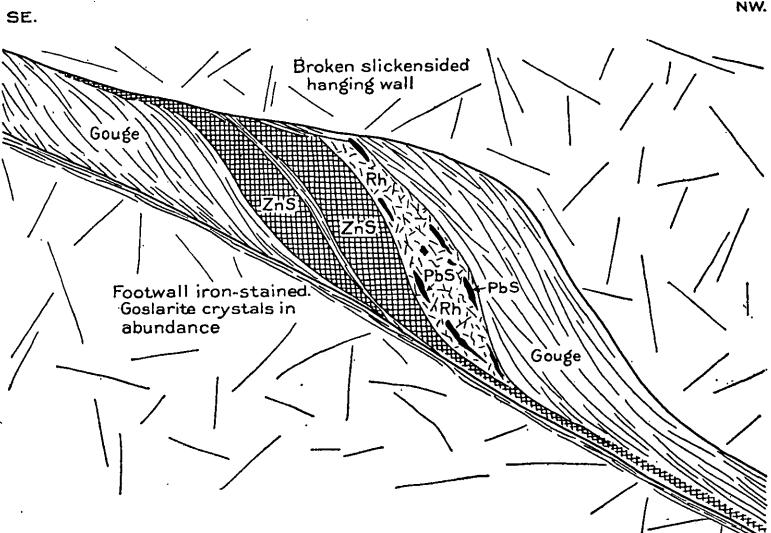


FIGURE 11.—Vein following S-shaped fracture cleavage of premineral reverse fault 80 feet beyond second winze on level 6, Bell mine. Rh, Rhodochrosite.

greater in some directions than in others. As shown in figure 11, reverse faulting caused the formation of this fissure zone. Movement of the hanging wall upward over the footwall tended to create an opening wherever the dip of the walls

flattened, and thus it is not surprising that in general the solutions found the more gently dipping parts of the vein more open and accessible than the steeply dipping parts. The dip of the vein in the Spelter King adit is steeper than in the Wing, and the localization of ore seems directly related to the occurrence of cross fissures.

The study of the Bell vein brings out the discontinuous character of the ore shoots common in the veins of the Montezuma quadrangle. The occurrence of many shoots separated by weakly mineralized or barren places on the vein is evident from the maps, and it is probable that several ore shoots similar to those already worked exist between the Wing adit and the Bell mine.

The available production figures are given below, but they are fragmentary and incomplete prior to 1902.

Production from Bell and California groups

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)	Zinc (pounds)
Prior to and including						
1882 "	1,000		25,000	900,000		
1883 "	300		7,500	270,000		
1884 "	40		1,000	36,000		
1885 "	90		2,250	81,000		
1886 "	155		3,875	139,000		
1887	125		3,831			
1888	100		1,468	85,765		
1889	(?)		1,342	83,428		
1890	(?)		2,941	187,556		
1891	(?)		1,253	49,980		
1925	281	3.45	3,220	159,772	527	176,249
1926	766	10.06	12,640	439,957	3,312	441,668
1927	31	.30	610	34,005		
1928	37	.38	649	37,802		

* Estimated.

No record available for 1892-1900; no production in 1901-24.

BELMONT (GUS BELMONT, JOHNSON)

The Gus Belmont was the first recorded lode in Colorado, although it was discovered several years after mining became active in the Central City district. It is close to the crest of McClellan Mountain, a few hundred yards northwest of the Santiago mine and 6½ miles northeast of Montezuma. The mine is well above timber line and lies at an altitude of about 13,000 feet. Rumors of the existence of silver-bearing lodes in this region, caused by the discovery of silver on Glacier Mountain, south of Montezuma, early in the summer of 1864, led to systematic prospecting for silver in September of the same year. Gov. R. W. Steele, James Huff, and Robert Layton left Empire in search of silver and on September 14 discovered the outcrop of the Belmont vein, from which they took several pounds of ore that averaged \$827.48 a ton in gold and silver, chiefly silver. The next year there was a rush to the region, and many other veins were discovered. After a year of only moderate success most of the prospectors deserted the district, but both the Belmont and the Baker mines worked steadily through this period of depression. In 1870 their developments encouraged a second rush to the district, and nearly all the known veins in the Argentine district were discovered before the end of the following year. A small custom stamp mill, driven by water power, was built on Leavenworth Creek, about 3 miles southeast of the Belmont vein, and operated intermittently for many years. Although known as the International mill and built to treat the ores of both the International and the Belmont lodes, most of the ore put through the stamps in the years from 1870 to 1872 was bought from the Belmont. According to the Georgetown Miner for November 10, 1870, 11½ tons of ore from the Belmont yielded \$113 at the coinage value of silver, and in February 1871 this paper noted that the "Belmont was in a large body of ore running \$694 a ton." In his report for

1873 Raymond noted that "this, one of the principal mines of the district, worked during the year."

The Belmont was not patented under its original name, and there has long been a dispute over the exact location of the original Gus Belmont lode. An excerpt from the Georgetown Courier for April 3, 1884, definitely indicates that it was relocated as the Johnson: "The Johnson * * * has been leased and will commence work as soon as snow melts and the building is repaired. This is an excellent piece of property and produced a great deal of fine ore when worked as the Belmont." The same paper on February 19, 1885, noted that the Johnson had from 2 to 3 inches of ore on the lower level, which was sorted into two grades of ore. The first-class ore ran 200 ounces of silver to the ton, and the second-class ore 100 ounces. Some ore from 1 to 6 inches wide was reported as present in the upper levels. The property was worked steadily by lessees until 1893 and produced a few tons of ore running from 100 to 200 ounces of silver to the ton. The vein had not been worked for many years when visited by the writer in 1927 and was inaccessible. The lode probably strikes northeast and is near the southeast side of a small stock of Silver Plume granite, but so far as known is lies entirely within the granite.

According to the Colorado Mining Directory the mine had produced prior to 1883 \$300,000 from "galena and sulphurets in a quartz gangue", which assayed, when sorted, from 50 to 200 ounces of silver to the ton. In 1883, according to the same authority, it was developed by 4 tunnels aggregating 976 feet and by 2 shafts aggregating 163 feet.

BLANCHE

The Blanche vein is on the southwest slope of Collier Mountain, a short distance north of the Silver Wave mine, and lies between 11,000 and 12,250 feet above sea level. It was located in 1874 and yielded some ore during the eighties but has not been worked since 1890. The known production has been 3 carloads (about 40 tons) in 1883, averaging \$50 a ton; 30 tons in 1885, netting \$1,950; and an unknown amount in 1888, netting \$544.23 in lead and silver. The mine was worked during 1884 and produced about 40 tons of ore; it is not listed as a producer in 1886 or 1887 by the Montezuma Mill Run and was probably idle during those years. Its total production is about 125 tons of lead-silver ore, averaging about 35 ounces of silver to the ton and 35 percent of lead. It was opened by two adits aggregating about 400 feet and a shaft 85 feet deep. The shipping ore was 14 inches wide and contained quartz, gray copper, galena, and sphalerite. The vein where exposed in the lower workings, a quarter of a mile north of the wagon road to Webster Pass, strikes N. 57° E. and dips 58° NW. Here it is about 2 feet wide and contains abundant quartz and a seam of sulphide 3 inches thick. Galena is slightly more abundant than either chalcopyrite or sphalerite, which are present in nearly equal amounts. The vein swings northeast a few hundred feet from the lower adit and strikes N. 35° E. as far up the slopes of Collier Mountain as it has been traced. The available figures for production are as follows:

Production from Blanche vein

	Ore (short tons)	Silver (fine ounces)	Lead, wet assay (pounds)
1883	40	1,400	28,000
1884	40	1,400	28,000
1885	30	1,050	21,000
1888	(?)	196	4,765

No record available for 1880-87.

BOND

The Bond is a small prospect in Warden Gulch about three-quarters of a mile south of Peru Creek. The vein contained

about 3 inches of gold and silver bearing quartz, and in 1882 a small amount of ore was sold to the Chihuahua mill.

BRITTLE SILVER

The Brittle Silver group, which includes the Boston, Brittle Silver, Little Nell, Peary, and White Sparrow claims, is on the north slope of Brittle Silver Mountain, slightly below an altitude of 12,000 feet, about half a mile south of Peru Creek. The country rock in this region is the Montezuma quartz monzonite. The veins are from 3 to 15 inches wide and contain galena, gray copper, "brittle silver" (stephanite), and a small amount of gold. The ore is said to average about 100 ounces of silver to the ton, but the only known statement as to the production of the property, a carload of about 14 tons in 1885, does not include the value of the ore. There was no production in 1887 and 1888, and although there was some in 1889 the figures were confidential and were not published.

BUDA

The Buda is on the south slope of Cooper Mountain, about 2½ miles northeast of Montezuma, well above timber line, at an altitude of about 12,000 feet. It is developed by a shaft about 25 feet deep and an adit said to be about 300 feet long. It was located in 1880 but produced nothing until 1886. In that year 8 tons of silver-lead ore was shipped, and in the next 3 years about the same amount was produced each year, but only the figures for the value are on record; these are given below. The ore came from a narrow vein 3 to 6 inches wide, containing quartz, pyrite, sphalerite, galena, and some silver and gold.

Production of Buda mine

[Estimate by Montezuma Mill Run]

	Ore (short tons)	Gold	Silver	Lead
1886	8			
1887	(?)	\$0.80	\$273	
1888	(?)	.97	359	\$6,194
1889	(?)		127	8,111

BUENA VISTA

The Buena Vista is on the south slope of the high western spur of Collier Mountain, about 1,000 feet northwest of the Sarsefield mine and a mile east of Montezuma. The adit by which the mine is developed is at an altitude of about 12,000 feet. In 1889 it produced an unrecorded amount (probably about 6 tons) of lead-silver ore, valued at \$1,077.82; no other record is available. It did not produce prior to 1887 but is locally credited with an output of about 35 tons during the late eighties. The tonnage of ore in 1889 is not given but was probably about 6 tons. The vein trends east-northeast and has a narrow quartz-galena seam.

BULLION

The Bullion mine is on Collier Mountain, about a mile southeast of Montezuma, at an altitude of about 11,800 feet, 1,400 feet above the Snake River. It has an aerial tramway connecting the main level of the mine with a wagon road in the valley bottom, but the cables were dismantled in 1928, and in 1929 the only method of reaching the mine or moving supplies to it was over a steep trail.

The Bullion vein was discovered by the Tyler brothers about 1870, and the Yellowjacket vein, from which nearly all the production of the mine has come, was discovered shortly afterward. The two claims were sold to Colonel Williams, who slowly developed the mine in the eighties and nineties and sold ore to the local smelters. Unfortunately little record of the amount could be found, but in 1882 2 tons of galena and gray copper ore was sold to local smelters for \$290 a ton. The Mayhem Investment Co. bought the Bullion mine from Williams about 1900

and entered on an extensive development program. Several thousand tons of ore was produced in 1902-3 after the construction of the Bullion tram. About 1903 some money was obtained from the Jackling interests to finance a tunnel starting near the foot of the tram to tap the Yellowjacket and other nearby veins at depth. No work was done on the proposed adit, and in 1904 the loan was foreclosed and the Bullion mine became one of the assets of the Florence smelter. When the Cripple Creek Short Line and the Florence smelter were sold to the Golden Cycle Co., the Bullion mine became the property of that corporation, which still owned it in 1933. In 1907 H. B. Clifford became interested in the mine and shipped 200 tons of ore to various mills for treatment, in order to obtain information on the best method of beneficiation before erecting a mill near the mine. The operations were stopped during the panic of 1907 and were not again resumed by Clifford. A carload of ore was shipped by a lessee, Charles Dunn, in 1926, but so far as known no other work was done in the interval between 1907 and 1929.

The underground workings of the mine are shown on plate 19. The main adit was driven on the Bullion vein and a cross drift turned on the Yellowjacket vein about 150 feet from the portal. A winze was sunk 40 feet on the Bullion vein, but no sublevels were turned. On the Yellowjacket vein a winze 185 feet deep connects the cross drift with sublevels 45 and 100 feet below it. As shown on plate 19, much of the ground above the first sublevel has been stoped. A small underground hoist serves the winze but is probably inadequate to lift rock economically from the bottom of the present winze. The bottom of the winze is dry, but the air in it would not support combustion, and the present writer was unable to examine the lower workings of the mine.

The country rock of the region consists of quartz-biotite schist and quartz-biotite-sillimanite schist, which trend N. 35° E. and dip about 65° SE. The Bullion vein strikes parallel to the schist and dips parallel to it south of the Yellowjacket vein but becomes vertical and then dips steeply to the west a short distance north of the Yellowjacket. For most of its length the Bullion vein is a barren sheeted zone about 12 inches wide, containing a 2-inch seam of gouge; about 230 feet from the portal, however, a thin seam of galena is visible for about 50 feet, beyond which the vein again becomes barren. The winze on the galena ore apparently failed to find encouraging ore below the adit, and no further work was done on the Bullion vein.

The Yellowjacket vein strikes about N. 75° W. and dips about 65° N. in its productive portion; it dips very steeply to the north or south in the nearly barren segment exposed in the first 100 feet east of the Bullion drift. The Bullion vein faults the Yellowjacket vein and displaces the western segment about 10 feet north of the eastern segment. Two faults parallel to the Bullion and with similar displacements cut the Yellowjacket vein 20 and 100 feet east of the Bullion drift. West of the third fault the Yellowjacket vein is about 6 inches wide and contains only a few short, narrow lenses of vuggy quartz incrusted and intergrown with pyrite. East of the third fault the vein, which is much wider but largely quartz, bends to the southeast. Thin seams of galena appear in the walls of the drift about 60 feet beyond the fault and gradually converge to a junction with the main quartz vein near a small eastward-trending quartz-barite vein 100 feet east of the fault. Beyond this place the vein resumes its normal course and widens to 24 inches of siliceous lead-copper ore. As shown on plate 19, this ore shoot is about 240 feet long, and much of it has been stoped. The ore shoot extends to the surface but is much shorter at the outcrop than in the main drift. The shoot is stoped 100 feet below the level, and the bottom of the winze is reported to be in ore. The vertical dimensions of the ore shoot undoubtedly exceed the horizontal dimensions somewhat. East of the ore shoot the vein has been followed for 150 feet and consists largely of vuggy

quartz, carrying short, narrow lenses of galena or chalcopyrite separated by barren stretches 20 to 30 feet long.

In the ore shoot the main vein is a persistent seam of quartz from 15 to 30 inches wide, carrying abundant chalcopyrite and locally containing small amounts of bismuth and a high silver content. A seam of galena which, according to observation and report, generally lies between the copper-bearing quartz and the hanging wall of the vein, is said to be much more variable in width than the copper ore, pinching to a width of 1 inch in some places and swelling to a maximum of 20 inches in others. The galena is nearly free from sphalerite in all the ore seen.

The occurrence of the ore shoot in the Yellowjacket vein, which cuts across the schistosity of the country rock, and the weakness of the mineralization in the Bullion, which is essentially parallel to the foliation of the schist, are in harmony with occurrences of ore in other veins nearby. It is probable that further exploration of the Yellowjacket vein would prove the existence of other ore shoots similar to that exposed in this mine.

The production record of the Bullion so far as it is known is given below. It is incomplete but probably gives the bulk of the production, as comparatively little ore is reported to have been sold before 1900.

Production of Bullion mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)
1881-----	2	-----	224	-----	-----
1885-----	4	-----	-----	-----	-----
1886-----	10	-----	-----	-----	-----
1887-----	10	-----	-----	-----	-----
1907-----	200	-----	4,500	141,176	-----
1926-----	30	0.70	749	1,393	3,996

No record available for 1882 and 1889-1900; no production in 1883-84, 1888, 1901-6, 1909-25, 1927-28.

BUSTER

The Buster tunnel is in the northeastern part of the quadrangle, on the north side of Clear Creek about 2 miles west of Silver Plume. The main tunnel is at an altitude of about 9,800 feet and is connected with the main highway by a short wagon road. As shown on plate 20, there are two short adits above the main tunnel, but the writer did not visit them. The Buster tunnel has been driven N. 14° W. for about 1,100 feet, and two drifts have been turned from it, one to the east and one to the west. The tunnel is in Silver Plume granite for the first 200 feet, but the rest of it, as well as all the west drift, is in schist and gneiss of the Idaho Springs formation. Several fissures and faults trending east or northeast were cut, but none were mineralized in the schist. The east drift enters granite about 200 feet from the main tunnel, and the fissure which it follows splits into several branches a short distance farther east. Two of these branches strike nearly east and dip steeply south and are mineralized. A few mine cars of ore is reported to have been found at the crotch where these branches left the northeast-trending master fissure, but the veins where seen by the writer were less than 3 inches wide and consisted chiefly of quartz. Thin seams of galena were present in the quartz and in places widened to half an inch.

CABLE

The Cable mine is on the northeast slope of Glacier Mountain a few hundred feet northwest of the King tram and about a quarter of a mile south of Montezuma. It was located in 1881, patented in 1882, and actively developed through two adits in the next few years. It was a regular shipper in 1882-85, producing a total of about 100 tons of ore. The vein is said to be from 5 to 8 inches wide and to contain quartz, galena, and some

gray copper. It strikes northeast and is essentially parallel to the schistosity of the hornblende gneiss of the Swandyke gneiss, which is the country rock.

CARRIE

The Carrie mine is on Wise Mountain between the North and Middle Forks of the Swan River, at the head of Garibaldi Gulch. In 1929 the workings were inaccessible, and the buildings were in poor repair. The mine is said to have produced a moderate tonnage of gold ore prior to 1900, and a trial run of 1 ton of ore in 1905 netted 2 ounces of gold and 10 ounces of silver. At that time the mine workings included a tunnel 900 feet long, a 90-foot shaft, and 3,000 feet of drifts. The mill and the portal of the tunnel are near timber line at an altitude of about 11,750 feet. According to C. M. Snyder, who worked in many of the mines near Swandyke before 1900, the Carrie, in common with several other veins on the top of Wise Mountain, contained rich gold ore in the shallow oxidized zone close to the surface, but profitable mining ceased at a depth of about 25 feet. The heavy pyrite found below this depth carries almost no lead, copper, or zinc, and the value of gold and silver as recorded in several assays was between \$2 and \$4 to the ton.

The rich surface showings of the Carrie, Blackhawk, and De Soto encouraged the Carrie Mining Co. to drive its lower adit to prove the veins at depth. Thomas Griffith was employed as superintendent in the late nineties, and after cross-cutting many strong but very low grade pyritic veins and drifting on some of them to points known to be directly below rich surface ore, he recommended the closing of the mine. Work was accordingly discontinued in 1902, and almost no work has been done since.

The Carrie and the other veins on Wise Mountain strike a little north of east and are almost vertical. The country rock consists of granite gneiss and quartz monzonite porphyry, both of which are impregnated with pyrite. The top of Wise Mountain is only slightly below the general level of the early Eocene Flattop peneplain, and the free gold found in the shallow oxidized zone on the top of this mountain is probably the result of enrichment. No similar concentration of gold was found in the pyritic lodes exposed on the glaciated flanks of the mountain.

CASHIER (CHAMPION)

The Cashier mine is on the southeastern slope of Teller Mountain, 1 1/4 miles due west of Webster Pass and 3 miles south of Montezuma. It is opened by four adits between altitudes of 12,000 and 12,450 feet, where the vein cuts the crest of Teller Mountain. In 1929 most of the workings were inaccessible. The Cashier vein was discovered in the early seventies by Dickson Southworth, who worked the mine until about 1880. In spite of its isolated position, the rich silver ore enabled Southworth to make a profit from his small-scale operations, and during his tenure of the property 54 shipments were made by pack train to the smelters at Blackhawk. The records were preserved in a report made by G. K. Sabin, who was subsequently in charge of the property, and are given on page 76. Southworth shipped in all 108 tons 312 pounds of ore, assaying over 200 ounces of silver to the ton, which netted him \$20,736.16, or \$192 a ton after the smelting charges of about \$25 had been deducted. The Cashier & Champion Mining Co., incorporated in Colorado in 1882, with Sabin as superintendent, developed the property extensively in the next 10 years. The ore was moved by pack train to the head of Hall Valley, about a mile south of the mine, and hauled by wagons from that point to the railroad at Webster, 7 miles away. The cheaper transportation enabled Sabin to ship lower-grade ore than Southworth, and in the report referred to above, which unfortunately is not dated, he states that under his management the property had then produced 710

tons 1,927 pounds of ore, yielding \$63,349.83, giving an average price of \$89.10 a ton after deducting the smelter charges of about \$25 a ton. According to the Colorado Mining Directory for 1883, the Cashier shipped 320 tons in 1881 and 250 tons in the first 8 months of 1882. The same authority states that the Cashier & Champion Mining Co. was organized by the New York & Colorado Mining Syndicate Co. (incorporated in Colorado in 1880), whose avowed object was the purchase of mines and prospects and their development for sale and for the organization of new companies under its control. After the mine had been opened up in the early eighties and the veins exposed sufficiently to indicate the nature and probable extent of the ore, production is said to have stopped, and Munson²⁶ lists the mine as a nonproducer in 1887. Production was resumed about 1889, however, and in 1890, 1891, and 1892, according to men who were freighting ore from the mine at that time, the Cashier was a shipper. An estimate of 300 to 400 tons of ore during this period of production was made by one of these men. This figure is probably approximately right, as in 1889 Munson²⁷ records a total production of \$4,688.68; as the ore commonly averaged about \$90 a ton, about 52 tons, or one-quarter of the estimated production, would have been produced that year. No production is known from the Cashier after 1892. The exact amount of underground development work is unknown, but, as shown in plate 21, it is more than 2,000 feet and includes a 230-foot winze on the lower adit.

The country rock of the Cashier vein is the Swandyke gneiss, which strikes about N. 25° W. and dips 70° W. The vein breaks across the schistosity of the gneiss and strikes northeast and is said to dip steeply northwest. The ore is reported to be from 2 to 24 inches wide and to average about 12 inches. It consists of galena and gray copper in a quartz gangue containing some barite. According to the Montezuma Mill Run for March 10, 1883, the lower and main adit starts on the vein in the Champion claim and follows it through the Champion end lines into the Cashier claim, 300 feet from the portal. At the end lines there is a crosscut 100 feet long to the Ready Pay vein, which contains some galena and gray copper in a quartz gangue. At 200 feet beyond the crosscut there is an inclined winze on the Cashier vein that follows it to a depth of 230 feet below the level. The ore was continuous to the 100-foot level, where a short crosscut to the southwest had 3 feet of massive barite in the breast. At 70 feet southwest of the winze on the 160-foot level the breast of the drift was in good ore, and the 230-foot level was also in good ore. The ore was continuous from the top to the bottom of the winze, according to Mr. Oliver, the editor of the Mill Run, and ranged from 10 to 36 inches in width, with an average of about 20 inches. It consisted chiefly of gray copper, quartz, and barite.

According to a report by E. N. Riote in 1882, the lower adit goes into the hill almost at right angles to the vein and strikes it 80 feet from the portal "and then turns and runs in on the vein. The vein here is small and poor but becomes enriched very soon without widening, and much ore was taken out above the tunnel. This pay shoot lasted for 40 feet or more and then pinched out, apparently leading southward and downward. After passing a barren zone of 20 or 30 feet, the vein again becomes rich and widens, and the top of a new pay shoot was struck. This shoot did not reach the upper level and was not of great extent in that direction. To prospect it a winze was sunk near its commencement, and another 80

feet therefrom—the first one to a depth of 50 feet and the second to a depth of 100 feet. They were connected by a drift from the bottom of the first winze. All along these openings the vein is very rich, widening in places to 18 inches of the richest and 4 feet of the average ore."

According to a manuscript report by L. B. Carpenter dated 1900, the Cashier lower adit goes west into the hill and cuts the vein 20 feet from the entrance. The adit was caved 200 feet from the portal at the time of his visit, however. An 18-inch seam of lead ore was found 40 feet from the portal of the tunnel and was thought to be a "sort of feeder to the main vein." The Comstock tunnel, 140 feet below the Cashier lower tunnel, was open for its entire length of 500 feet. "At a point 300 feet from the mouth it encountered the Cashier vein, and a small stope was started, which shows a streak of about 2 feet of good-looking lead ore. * * * In another place ore is showing in a crosscut to the north, 400 feet from the mouth. This streak is small, however, and would not pay to prospect."

Incomplete production figures for the Cashier and Champion are given below.

Production of Cashier and Champion claims

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)
Cashier:					
1876	3	557			
1877	57	11,686			9,086
1878	35	6,321			5,032
1879	17	4,012			2,558
1880 ^a	28	b 5,767			b 4,557
1881 ^a	311	b 31,381			b 24,841
1882 ^a	372	b 35,730			b 29,775
1883	150				
1889	(?)	126.75	1,599.89		
1892	(?)		6,614		
Champion:					
1876	(?)		14	68	
1880-82 (see Cashier).					
1886:					
Glacier	20				
Warden Gulch	10				
1888	(?)	19.35	20,352		
1889	(?)		46,784		
1891	(?)		5,364		
1892	(?)	32.12	10,001		

^a Includes Champion.

^b Estimated by comparison with production in 1878.

^c Less than half a ton.

Cashier, no record available for 1884, 1888, 1890-91; no production in 1885-87. Champion, no record available for 1877-79, 1883-85, 1887; no production in 1890.

CHATAUQUE

The Chatauque mine is on the east slope of Glacier Mountain, about 1½ miles south of Montezuma. Its lower workings are about 400 feet above Deer Creek, at an altitude of about 11,000 feet. Several buildings in poor repair are clustered around the portal of the lower adit, at the end of a fair wagon road to Montezuma. Most of the production of the mine came from two upper adits about 400 (?) feet above the lower workings.

The vein was discovered by Giol Ball and H. M. Teller in 1866. In 1879 the mine was acquired by the Montezuma Silver Mining Co., which held it for many years. By 1870, according to Raymond, 100 tons of silver ore averaging 363 ounces to a ton had been extracted. According to Frank and William Burke, a small amount of ore was stoped and shipped by them as lessees in 1883. In 1884 and 1885 a moderate tonnage of ore was shipped, according to J. R. Southerland, who worked in the mine during those years. A record of the production from 1887 to 1892 is given below. The Chatauque is said to have produced little or nothing in the next 10 years, and no production is known from 1902 to 1929.

²⁶ Munson, J. C., Report of the Director of the Mint upon the precious metals in the United States during the calendar year 1887, p. 159, 1888.

²⁷ Idem for 1889, p. 153.

Production of Chatauque mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)
1870	100			
1883	75			
1884	28			
1885	10			
1887	15			
1888	(?)		188	9,381
1890	(?)	110.00	10,368	300,726
1891	(?)	4.52	202	
1892	(?)		390	28,522

* Estimated.

No record available for 1886 and 1889.

The accessible part of the lower workings is shown in plate 22. The main adit extends N. 29° W. for 1,130 feet from the portal and intersects the Chatauque vein at a distance of 790 feet. The western drift on the vein is 175 feet long and was still accessible in 1929, but the eastern drift, said to be 400 feet long, was caved a few feet east of the main adit.

The country rock is chiefly the biotite gneiss facies of the Swandyke gneiss, but thick layers of pegmatite and hornblende gneiss are common in the first few hundred feet of the adit. The schistosity strikes from north to N. 30° E. and dips 70°-90° W.; the prevailing strike is N. 10° E., and the average dip is about 80° W. A dike of dacite porphyry about 30 feet wide, parallel to the foliation of the gneiss, is cut by the main adit about 75 feet south of the vein, which it intersects east of the accessible part of the drift. The Chatauque vein strikes from N. 80° E. to due east and dips 40°-50° N. It is a strongly sheeted or brecciated zone from 2 to 10 feet wide, and the drag of the gneiss shown in plate 22 suggests that it is a premineral reverse fault. The ore is chiefly galena, but small amounts of gray copper and sphalerite were seen. As illustrated in figure 12, the galena occurs in branching veins and stringers, or as a breccia cemented by pink manganeseiferous ankerite and quartz. In the two ore shoots exposed in the west drift the gray copper, which is the silver-bearing mineral of the mine, was confined to the brecciated type of ore. In the westernmost ore shoot the brecciated ore is about 25 inches wide and appears to grade into the branching seams of galena illustrated in figure 12. Intermineralization movement on the vein was probably carried partly by the ore shoot and partly by the barren slips in the sheeted zone; and the ore solutions were more active in the open brecciated parts of the vein than in the tight seams of the sheeted zone. The Chatauque is a strong vein and breaks across the foliation of the country rock, but the exposures of the vein were too small at the time of the writer's visit to serve as an indication of the strength of its mineralization.

According to the Montezuma Mill Run, the chief workings in 1883 consisted of a shaft, an adit 173 feet vertically below the collar of the shaft, and the lower tunnel, which was 1,000 feet long at that time. The upper adit tapped the vein through a crosscut 150 feet long and followed the vein for over 100 feet. The ore shipped in the next few years came from stopes above the upper adit. The lower tunnel was supposed to be short of the Chatauque vein and was driven 130 feet farther in 1885 in an effort to reach the vein. The Mill Run states that a strong vein was cut at 725 feet and was supposed to be the Franklin vein. There was a "fine streak of mineral in the breast of the west drift, but it is not solid." The breast of the northeast drift did not impress the editor of the paper so favorably. Both breasts were about 35 feet from the main crosscut tunnel at the time of his visit.

CHRYSLITE

The Chrysolite vein is in Warden Gulch, about 2 miles east of Montezuma. It was discovered about 1884 and produced about 15 tons of galena ore, carrying 15 ounces of silver to the ton, in 1887 and 1888. The vein is said to have a maximum width of 24 inches, but it could not be seen at the time of the writer's visit.

CLARION

The Clarion vein is on the west slope of Collier Mountain, about 2 miles southeast of Montezuma, between the Bullion and Silver Wave mines, at an altitude of about 12,200 feet. It was located by William Howell in 1880 and slowly developed in the eighties and nineties. A small amount of ore was produced during this time, chiefly from a chimneylike shoot about 40 feet long discovered in 1884. Most of the production was made prior to 1893 and is shown below. This ore was chiefly galena but contained a small amount of gray copper and assayed from

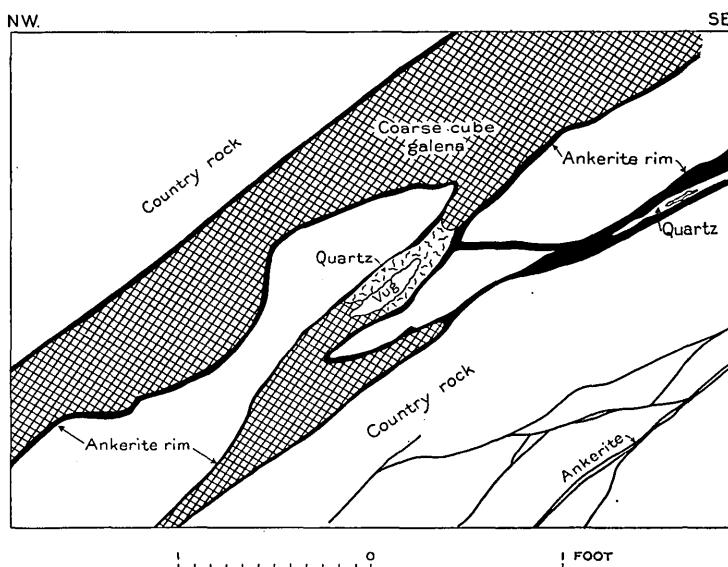


FIGURE 12.—Chatauque vein, west stope, looking east. Footwall streak.

40 to 100 ounces of silver to the ton. The mine probably produced nothing in 1892-1901, but a shoot of lead ore was found in driving an adit in 1902, and about 25 tons of ore was produced from the drift. As shown below, the ore taken from this shoot carried much gold, averaging about 30 ounces to the ton. The Clarion was worked intermittently until 1918 but has been idle for the last 10 years.

Production of Clarion mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)
1885	2				
1886	12				
1887	5	1.20	316	5,232	
1888	50				
1889	(?)		321	4,574	
1890	(?)	1.00	569	8,166	
1903	41	12.30	2,449	25,427	
1906	7	.84	385	3,592	149
1910	11	3.00	863	6,028	223
1911	6	5.13	487	3,934	
1916	18	1.66	523	5,368	868
1917	15	.63	413	11,011	812

* Estimated.

No record available for 1891-1900; no production in 1901-2, 1904-5, 1907-9, 1912-15, 1918-28.

COLEY (COALY)

The Cöley is noteworthy as the first silver-bearing vein to be discovered in the State of Colorado. It is on Glacier Mountain at an altitude of about 11,800 feet, a little less than a mile south of Montezuma. The vein was discovered by a Mr. Coley in July 1864, but little work was done in the district until the following year. It was chiefly valuable for the interest in the silver-bearing lodes that it excited. In the mint report for 1883 Burchard states that the mine had yielded but a very small amount of bullion and had been worked little save by open cuts along the surface. A carload of silver-lead ore was shipped from the claim in November 1883, but the value of the ore is unknown. No other record of production has been found. The vein strikes northeast and is in the Swandyke gneiss.

COMMONWEALTH

[See Santiago and Waldorf]

CONGRESS

The Congress mine is on the north side of Peru Creek at an altitude of about 11,500 feet, about $3\frac{1}{4}$ miles east-northeast of Montezuma. The mine is opened by two adits about 75 feet apart vertically and is connected to a wagon road by a steep wooden tram. The lower level is more extensive than the upper level and is shown in plate 23. The known production of the property is small and has come from small rich pockets of lead-silver-gold ore. According to the Georgetown Courier for November 29, 1888, the vein was 3 feet wide in some places, and the mine shipped 2 cars of ore running \$350 a ton in 1888 and had some ore assaying 700 ounces of silver and 5 ounces of gold to the ton. The available production figures follow.

Production of Congress mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)
1888	(?)		207	1,906	
1889	(?)		1,012	18,540	
1890	(?)		726	16,724	
1891	(?)	1.26	516	3,345	
1892	(?)		376	2,484	
1922	88	1.80	1,051	3,429	
1923	3		62	1,393	86

No record available for 1893-1900; no production in 1901-21, 1924-28.

As shown on plate 23, the vein strikes N. 20° E. and dips 50° W. It is from 2 to 30 inches wide, and for much of its length it consists of vuggy seams of quartz and pyrite cutting bleached quartz monzonite. In places it carries vuggy masses of galena, which contain considerable silver and gold, but unfortunately the ore bodies are lenticular along both dip and strike. The vein is very close to the contact of the quartz monzonite stock with the schists, and the course of the vein would carry it out of the granite in a short distance. The mine workings are entirely within the quartz monzonite stock, and though it is improbable that the vein carries good ore far into the schist, there is a distinct possibility that ore may be found in the vein where it crosses the contact of the two rocks.

COPENHAGEN

The Copenhagen vein is on the west slope of Independence Mountain, about $2\frac{1}{2}$ miles west of Montezuma, at an altitude of about 11,500 feet. It is about 800 feet south of the Ida Belle mine and is accessible by the same trail and road. It was discovered by Hans Brandt in 1886, and by 1888 he had driven four adits on the vein aggregating about 800 feet. In 1887 6 tons of ore was shipped, netting \$297 in silver and \$3 in gold. The property is listed as a nonproducer in 1888 and is not again

mentioned in the statistical reports of the State. According to the Montezuma Mill Run there was in 1887 a maximum width of 14 inches of massive galena ore in the mine, and in 1888 it notes that 4 inches of good ore had been found in most of the lower level.

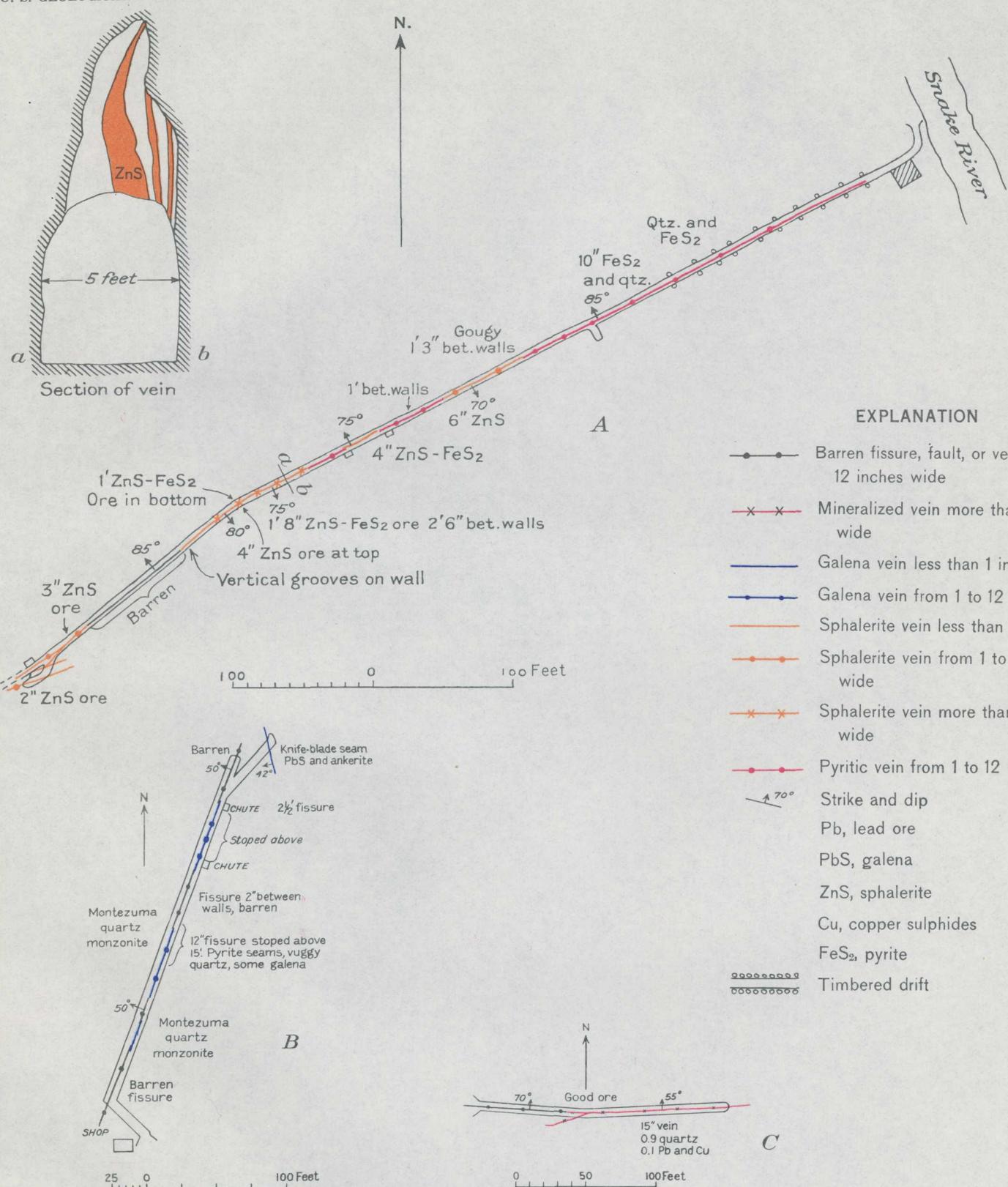
The vein strikes nearly due east and is vertical. The adits have long been caved, but the ore on the dumps indicates that the vein was from 1 to 12 inches wide and consisted of galena, sphalerite, and quartz. The greatest width of solid galena observed was 3 inches. The vein is parallel to the Ida Belle and like it cuts Swandyke gneiss that has been thrust-faulted onto black Upper Cretaceous shale, which crops out conspicuously on the lower slopes of the mountain. The general relations are shown in the cross sections of the Ida Belle mine in figure 15. As the best ore in the Ida Belle was found where the vertical vein crossed the brecciated contact of the Cretaceous shale and the overthrust Swandyke gneiss, it is probable that the best ore in the Copenhagen would be found in a similar structural setting. The dip of the overthrust fault carries the contact of the shale and the overlying hornblende gneiss downhill south of the Ida Belle mine, and the lowest adit on the Copenhagen vein is about 250 feet above the place where the contact of the shale and the gneiss comes to the surface. However, as the overthrust fault dips southwest in this region, the lower adit would cut the fault if continued far enough east. No shale was found on any of the dumps, and it is evident that the fault was never reached by the old workings.

DELAWARE

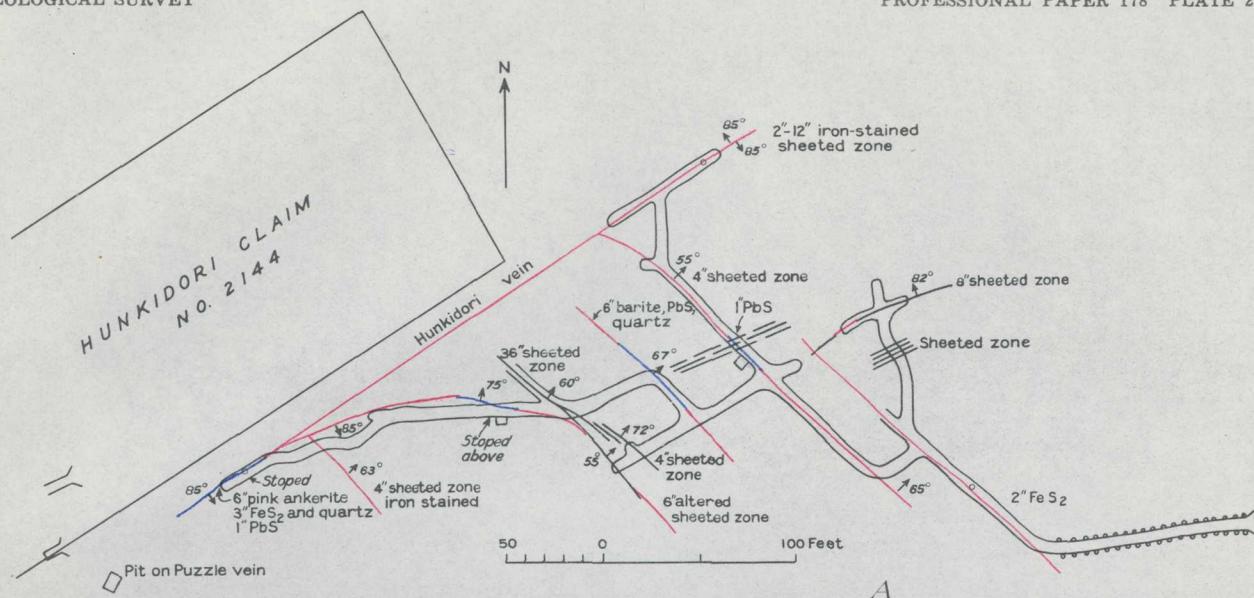
The Delaware, Delaware Extension, and Sunrise claims are on the north slope of Decatur Mountain near the mouth of Cinnamon Gulch, about 3 miles east of Montezuma. The Delaware vein was discovered in 1879 by William Mendenhall and J. F. Sypher, and development was started the same year. By 1883 about 800 tons of ore had been shipped, and the underground workings included an adit about 400 feet long and a shaft 165 feet deep, from which three levels had been turned, aggregating about 400 feet. Unfortunately the mine was in a district where no reports on production were maintained, and the amount of ore removed is unknown. It is said to have been a steady producer in the eighties, but is not mentioned by Munson in his reports for these years. In July 1884 it was producing 3 wagonloads of ore a day (probably about 8 tons). It was not mentioned by the local paper of Montezuma during the next few years, but it is safe to say that the total production exceeded 1,000 tons. The vein was several feet wide and contained from 6 to 36 inches of galena, gray copper, and chalcopyrite in a quartz gangue, assaying in shipments from 25 to 600 ounces of silver to the ton. The Delaware vein is the southwestern extension of the Pennsylvania vein, and the reader is referred to the description of that vein on pages 93-95 for a discussion of the general geology.

DON PEDRO

The Don Pedro is on the east slope of Independence Mountain, a few hundred feet south of the Hunkidori mine and about 2 miles west of Montezuma. It was discovered in 1874 by — Smith, John Lynch, and Joseph Love but was little worked until 1880. Most of its development was the work of Oliver Milner and Joseph McKinney from 1880 to 1887, and no record of production for later years has been found. It was opened by four adits along the vein, of which the lowest was about 200 feet long. The vein strikes northeast and dips about 50° NW. The ore streak was from 6 to 12 inches wide and contained galena and gray copper in a quartz gangue. The inaccessibility of the deposit discouraged development, as most of the ore required concentrating before it could be profitably shipped. Only carefully sorted ore was loaded on the mule



PLANS OF FISHERMAN VEIN, ON SNAKE RIVER (A); CONGRESS MINE,
RUBY MOUNTAIN (B); AND STAR OF THE WEST No. 2 MINE,
TELLER MOUNTAIN (C)



EXPLANATION

— Barren fissure, fault, or vein less than 1 inch wide

—●— Barren fissure, fault, or vein from 1 to 12 inches wide

—*— Barren fault or vein more than 12 inches wide

— Mineralized vein

—- Mineralized vein with many barren stretches alternating with lenses of ore

— Galena ore

 Strike and dip

— Strike and vertical dip

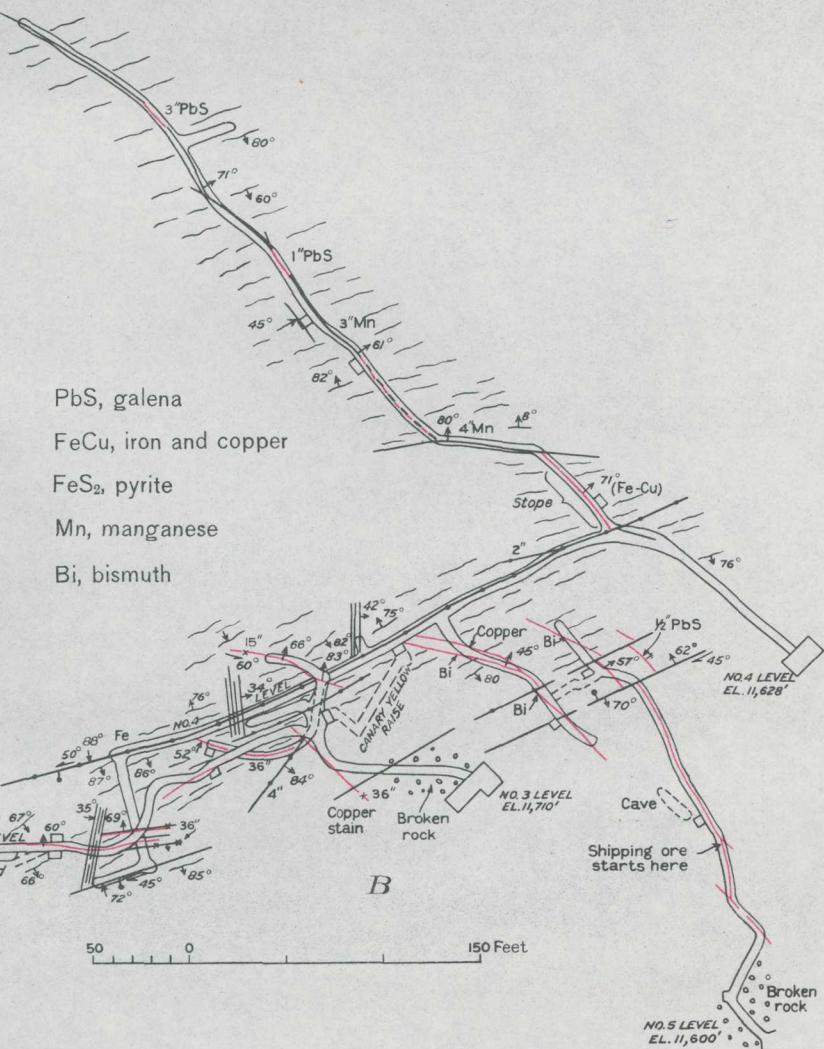
 Strike of schistosity

 Downthrown side of fault

 Grooves and slickensides

 Sheeted zone

 Timbered drift



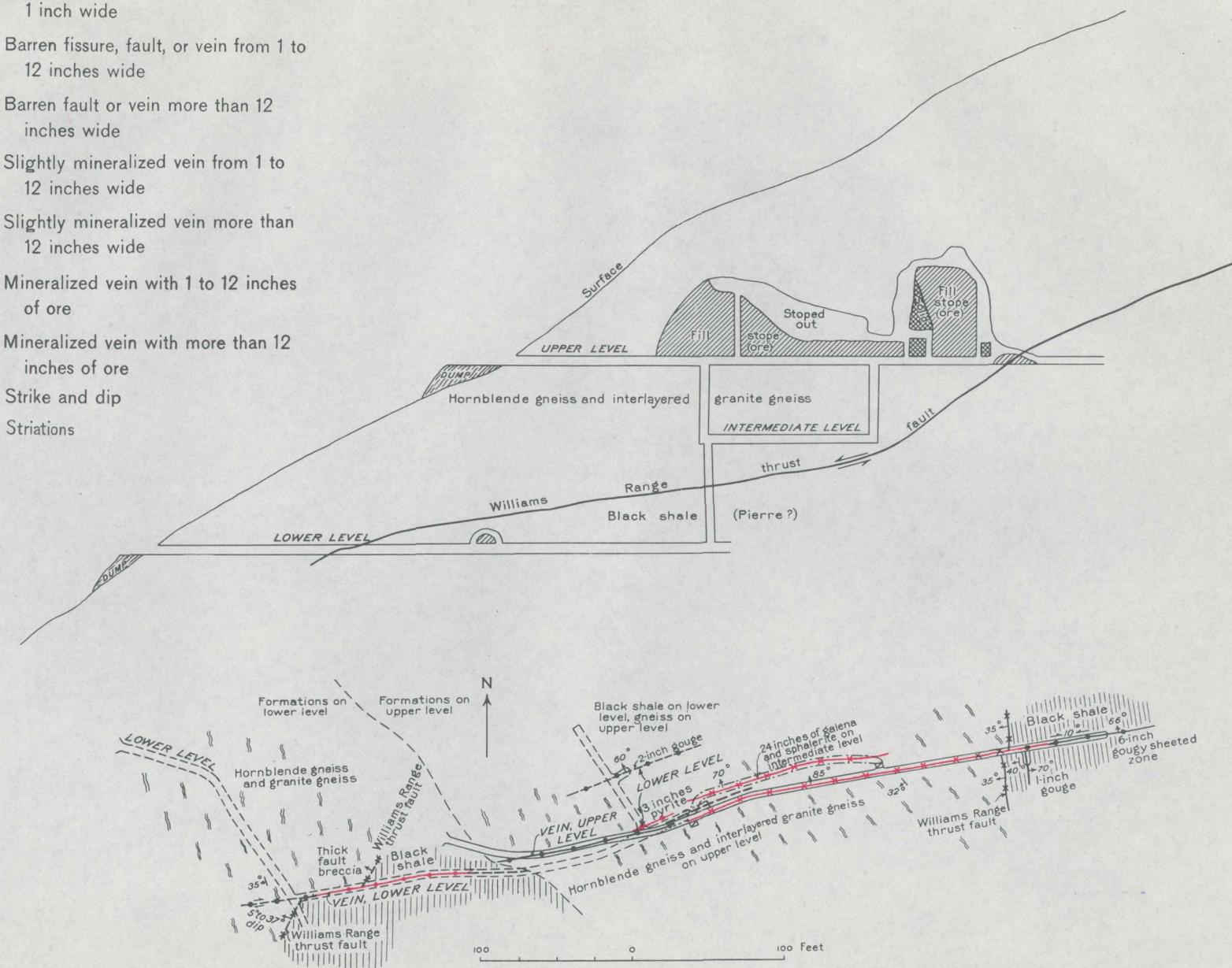
PLANS OF HUNKIDORI MINE, GRIZZLY GULCH (A), AND MISSOURI MINE, HALL VALLEY (B)

EXPLANATION

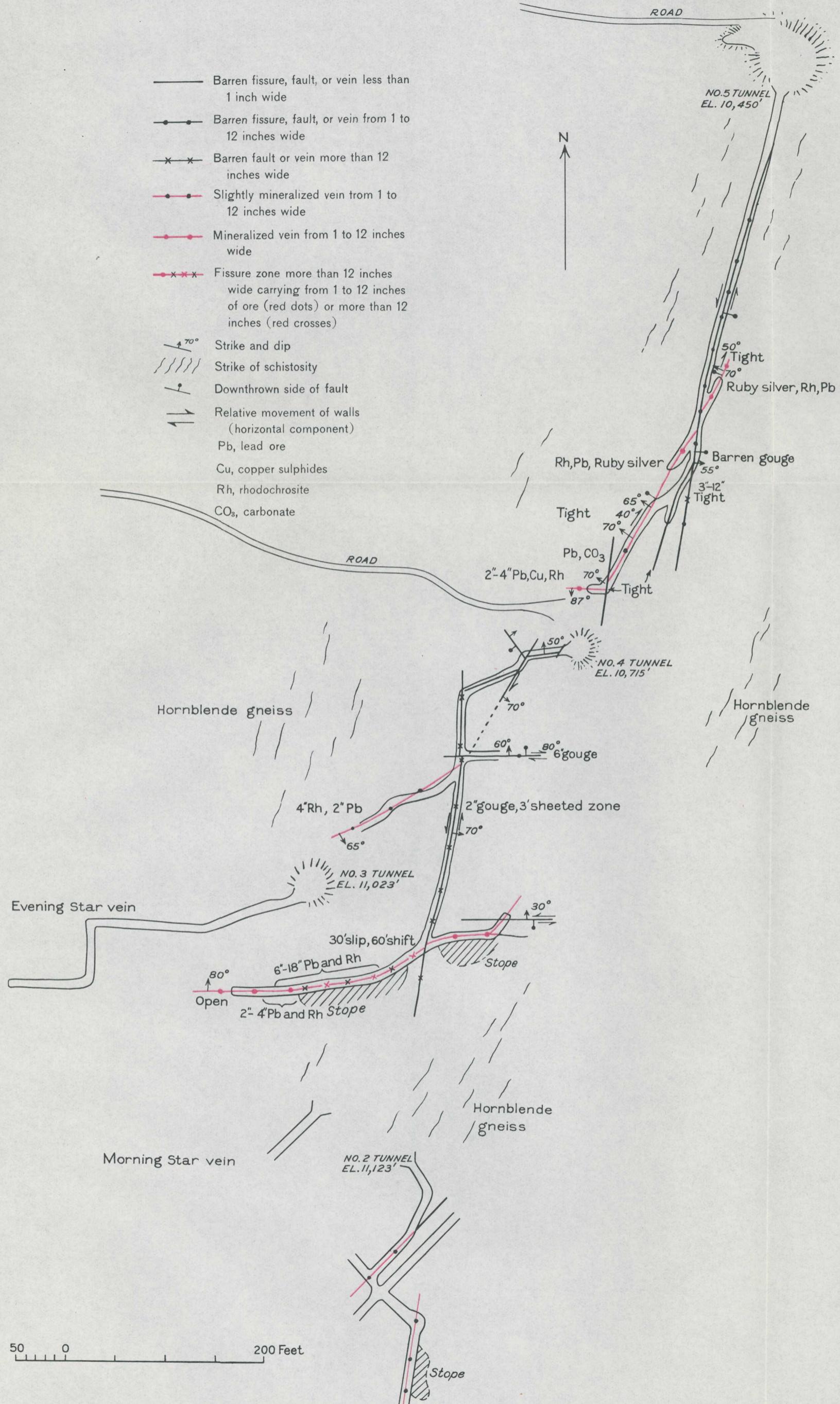
- Barren fissure, fault, or vein less than 1 inch wide
- Barren fissure, fault, or vein from 1 to 12 inches wide
- ×— Barren fault or vein more than 12 inches wide
- Slightly mineralized vein from 1 to 12 inches wide
- ××— Slightly mineralized vein more than 12 inches wide
- Mineralized vein with 1 to 12 inches of ore
- ×— Mineralized vein with more than 12 inches of ore

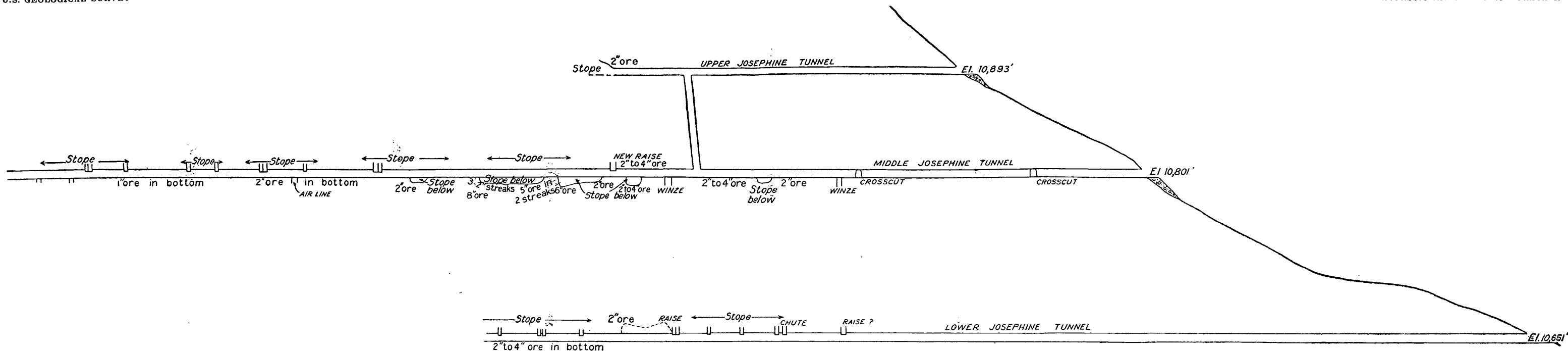
↗ 70° Strike and dip

↖ 10° Striations

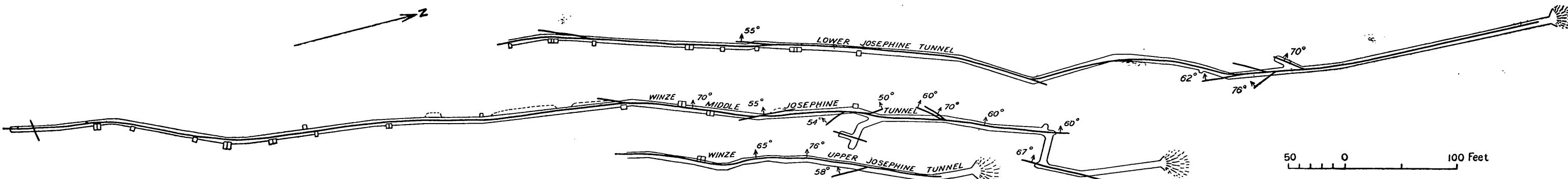


PLAN AND SECTION OF IDA BELLE MINE, JONES GULCH





SECTION



PLAN

JOSEPHINE MINE, KELSO MOUNTAIN.

train and taken to Keystone, the nearest shipping point. In September 1882, according to the local paper, "the last shipment of 30 sacks was 4,060 pounds and ran 72 ounces per ton in silver and assayed 62 percent lead." The total production of the mine during the eighties was probably about 50 tons.

ERICKSON

The Erickson is 3 miles southwest of Montezuma, on the southwest slope of Keystone Mountain, at an altitude of about 12,000 feet. It was discovered by J. B. Erickson in July 1880 and was worked from 1884 to 1888. During this time a shaft 125 feet deep and an adit reported to be about 250 feet long were driven on the vein. In 1885 20 tons of lead ore netted the owners \$600, and in 1886 37 tons of unknown value was shipped. This is probably the total production of the property. The vein strikes N. 45° E. and is nearly vertical. Most of the ore produced came from stopes above the 125-foot level of the shaft, but the ground was so heavy that the stopes became dangerous, large masses of ore and waste caving daily with little warning, and in 1888 work in them was abandoned. The ore in these upper workings was largely galena and reached a maximum width of 18 inches; in the adit, some distance lower on the vein, the ore seam was much narrower and contained as much zinc blende as galena. The galena ore is reported to assay about 25 ounces in silver to the ton. The country rock of the region is the Swandyke gneiss, which strikes from north to northeast and is nearly vertical but dips steeply to the west in many places. The vein is on the line of tear faulting that formed when the Williams Range underthrust broke the overturned fold a short distance north of Tiger. (See p. 44.)

FISHERMAN

The Fisherman workings are about half a mile north-northwest of Montezuma, at an altitude of 10,040 feet, a few hundred feet south of the high bridge on the main road from Montezuma to Keystone. The vein was discovered in the late eighties, but no production is recorded until 1905, and miners are agreed that it produced less than 150 tons before 1900. Its total production does not exceed 300 tons and is probably somewhat less. Sphalerite is the chief mineral in the vein, but galena is locally abundant. The vein is entirely in Montezuma quartz monzonite and strikes N. 45°-65° E. Its average dip is nearly vertical, but steep northwest and southeast dips are common. As shown in plate 23, the ore occurs in lenticular swellings in the vein, and the best shoot exposed is at the place where the course of the vein changes from N. 63° E. to N. 45° E. and the vein dips 75° SE. As shown in plate 23, however, the ore pinches very abruptly a short distance above the drift but is 20 inches wide at the top of the drift. Very little gangue is present in the ore, but a few fragments of partly replaced monzonite were observed in a wide seam of sphalerite. The minerals present, named in the general order of abundance, are dark-colored sphalerite, pyrite, galena, quartz, and arsenopyrite. Galena is distinctly later than the pyrite and sphalerite, and the sphalerite is also earlier than most of the quartz. The character of the ore is shown by the available production figures, as follows:

Production of Fisherman mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Zinc (pounds)
Prior to 1900.	100-150				
1905.	20	3.62	1,360	14,118	
1906.	27	1.11	1,012	34,944	14,202
1907.	21	1.74	279	13,176	5,250
1908.	3		45	2,941	

^a Estimated.

^b Represents concentrates from 100 tons of milling ore.

No production in 1901-4, 1909-28.

GLENDALE, GRAND TRUNK, TREASURE VAULT, AND ISRAEL WILLIAMS

The group of claims comprising the Glendale, Grand Trunk, Treasure Vault, and Israel Williams crosses the crest of the high spur from Collier Mountain that leads to Silver Mountain, and it laps down into the valley of West Geneva Creek on the south and into Warden Gulch on the north. The claims are about 2 miles east of Montezuma and lie between 12,000 and 12,750 feet above sea level. They have been explored by openings in both West Geneva Valley and Warden Gulch, but their production has been small. The Glendale produced 5 tons of ore in 1887; 3 tons in 1888, which netted \$438 for the silver; and an unknown amount in 1889, which brought \$96.97 for the silver. The Israel Williams produced 50 sacks (about 2 tons) of silver ore in 1885 and a small amount of ore in 1886 and 1888. The Treasure Vault, according to Raymond's report for 1874, "contains bismuth-silver ores and at the time of its discovery created considerable excitement. Several other veins of the same character have been found, and it is now known that there is a well-defined belt of lodes carrying ores of this metal at the head of Geneva Gulch. They have a uniform course nearly north and south, crossing the others, and give every indication of more recent formation. As yet they have produced but little beyond specimens, but their location and the poverty of their owners will easily account for that. During the last

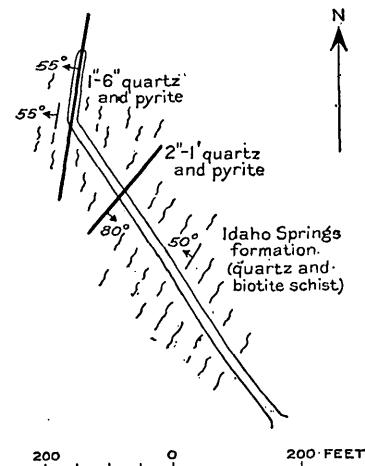


FIGURE 13.—Grand Trunk adit, Geneva Gulch.

summer about 1,500 pounds of slide found on the slope below the Hidden Treasure, and supposed to have come from it, were taken to Georgetown and sold at the rate of \$400 per ton. The ore has been examined and approaches in its analysis very nearly that of the mineral schapbachite."

No production is recorded for the Treasure Vault claim, which adjoins the Glendale and is on the same vein, although the Georgetown Courier for November 11, 1883, states that "the Buffalo lode, extension of the Glendale, mill run gave, first class, 495 ounces; second class, 445 ounces; third class, 112.8 ounces; and fourth class, 43.2 ounces silver per ton. * * * The run netted over \$900 clear. * * * [The vein has] a solid pay streak of 8 inches." According to the Colorado Mining Directory for 1883, this vein had ore from 10 to 40 inches wide, which carried quartz, galena, gray copper, and bismuth, and from 25 to 2,500 ounces in silver to the ton.

The Grand Trunk adit is at the head of West Geneva Creek, at an altitude of 12,000 feet. A sketch map of the tunnel is shown in figure 13. Although the adit is roughly parallel to the Grand Trunk claim, no vein was observed in the adit having a course approaching that of the claim. A vein striking N. 40° E. and dipping 80° SE. is cut about 400 feet from the portal, and another vein striking N. 10° E. and dipping 55° W. is cut about 200 feet farther north. The first vein is from 2 to 12 inches wide and is chiefly quartz, but pyrite is abundant. The

second vein is from 1 to 6 inches wide and is of the same general character as the first. The country rock of the mine comprises Silver Plume granite and schist and injection gneiss of the Idaho Springs formation, which strikes about N. 10° E. and dips about 55° W. There are small stopes on the veins, and about 2 tons of ore has been sacked and was on the dump in 1928. This ore was open and vuggy and consisted of galena, light-colored sphalerite, and barite.

GOLD BELT AND HAMILL

The Gold Belt and Hamill tunnels are in the northeastern part of the quadrangle on the south side of Clear Creek, about 2 miles west of Silver Plume. As shown on plate 3, the Gold Belt has an altitude of about 9,625 feet, and the Hamill, a short distance southeast of it, about 9,800 feet. Both are easily accessible by automobile from Silver Plume. The mines were not working in 1928 and 1929, and the writer was able to make only a cursory examination of one of them, the Gold Belt. It is developed by a tunnel about 3,000 feet long, which runs south-southeastward into the base of Ganley Peak. Several carloads of ore was found in a vein cut by the tunnel 1,600 feet from the portal. This vein strikes N. 80° E. and dips 80° S. In places the south wall swings away from the north wall until it strikes about N. 70° W., and in such places there is a wide zone of crushed rock. Slickensides dip about 70° E., and the drag of the schist walls indicates that the south wall has moved upward. There was no indication of ore in the vein on the tunnel level, but a raise tapped the bottom of the ore shoot a short distance above. The vein is chiefly in schist and gneiss of the Idaho Springs formation, but locally it cuts Silver Plume granite, and this rock made the walls of the ore shoot.

A quartz monzonite porphyry dike was cut by the main tunnel about 3,000 feet from the portal, and drifts were turned northeast and southwest along its contact with the granite, which there forms the country rock. The contact was feebly mineralized, and one small pocket of ore was found that contained a few thousand pounds of lead and zinc sulphide.

The available production figures follow.

Production of Gold Belt and Hamill tunnels

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Zinc (pounds)
Hamill tunnel:					
1924.....	336	0.40	32,160	25,386	68,247
1925.....	439		36,972	31,075	
1928.....	7		1,034	953	2,640

Dry smelting ore

Mary Etta group (includes Gold Belt, Mary Etta, Silver Plume tunnel, and others):	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Zinc (pounds)
1901.....	2	7.00	358		
1902.....	2	2.79	183		
1911.....	8	.12	1,353	404	
1912.....	22		2,137	1,796	
1913.....	33		2,172	3,022	
1914.....	5	.37	242	74	
1920.....	1		174	61	
1922.....	43		1,215		
1923.....	683	.16	47,749	57,077	

^a Includes 14 tons of concentrates containing 0.40 ounce of gold, 4,894 ounces of silver, and 3,528 pounds of lead. Concentrates were produced from 30 tons of milling ore.

No production in 1901-23, 1926-27.

Production of Gold Belt and Hamill tunnels—Continued

Lead smelting ore

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Zinc (pounds)
1912.....	8	0.02	1,844	1,240	
1913.....	6		789	1,593	
1914.....	88		8,806	27,481	
1921 (Gold Belt).....	3	.09	542	582	
1923.....	92	.23	13,984	18,078	
1927 (probably from Silvery Stream).....	6		1,074	1,145	3,585
1928.....	16		2,219	2,433	7,298

Zinc smelting ore

1915.....	27		1,590	22,260
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Dry concentrates

	Concen- trates (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Zinc (pounds)
Mary Etta group:					
1914.....	4		117	364	
1923.....	26	0.74	1,763	2,350	

Lead concentrates

1914.....	48		5,498	59,579	
1920.....	4	4.05	362	1,595	
1921.....	5	.82	1,158	1,215	
1922.....	39	.87	3,280	4,604	
1923.....	99	7.52	12,383	15,287	
1925 (probably from Silvery Stream).....	20	.97	1,045	4,372	10,082

Zinc

1914.....	208		6,952	10,960	178,115
1923.....	58		998	4,380	46,630

Lead-zinc

1914.....	3		213	571	2,556
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Ore to concentrating mills from Mary Etta group

	Short tons		Short tons
1914.....	2,040	1922.....	195
1920.....	40	1923.....	615
1921.....	20	1925.....	108

^a Lead-zinc ore.

^b Dry silver ore.

HANCOCK

The Hancock is on the northeast slope of Glacier Mountain, close to the crest, at an altitude of about 11,700 feet, about half a mile southwest of Montezuma. The vein was discovered about 1881 but is not mentioned as a producer by the local paper. The workings were inaccessible in 1929. The vein strikes about N. 30° E. and is reported to carry galena in a quartz gangue.

HANNIBAL

The Hannibal vein is on the west slope of Collier Mountain and is exposed in adits and open cuts between altitudes of 10,750 and 11,540 feet. The lower adit is a mile south-southeast of Montezuma and can be reached by automobile over the secondary road that continues south from the foot of the Bullion tramway. The vein was discovered in 1880, and an

adit was driven near timber line for a distance of 330 feet before the end of 1883. There is a small stope in this adit not far from the portal, and it is probable that some ore was shipped from this place in the early eighties, but no production is recorded. The lower adit has been driven by Thomas Sharpe since 1906, but no ore had been obtained from it up to the end of 1929. The total production of the property probably does not exceed 25 tons.

A map of the lower adit is shown in figure 14. At 220 feet southeast of the portal a branch drift turns to the east, but it was bulkheaded in 1929 and could not be examined. The main drift continues southeast to the Hannibal vein, which is cut 280 feet from the portal. The country rock of the entire adit is quartz schist of the Idaho Springs formation, which strikes northwest and dips about 50° SW. The vein strikes about N. 88° E. and dips about 85° N. The vein in the breast of the lower adit in 1929 was from 6 to 8 inches wide and consisted chiefly of quartz seamed with pyrite, but a few thin veinlets of manganeseiferous ankerite from 6 to 12 inches long cut the quartz and pyrite. A few grains of galena were also found. Seams of massive pyrite from one-eighth to 1 inch in thickness are abundant in the wall rock near the vein.

In the upper workings the vein contains from 1 to 7 inches of galena, but very little work has been done, and it is difficult to estimate the extent of the ore. However, the vein can be traced easily for half a mile and as it cuts across the formation and is essentially parallel to the Yellowjacket vein of the Bullion mine, it probably also contains some workable chimneys of ore. Additional prospecting should be done on the vein near its intersection with other veins.

HARRISON

The Harrison vein is on the west slope of Glacier Mountain at an altitude of about 11,200 feet, half a mile southwest of Montezuma. The vein was discovered in the early seventies, but little work was done on it until 1883. From that year until 1890 the vein was worked and produced a moderate amount of lead-silver ore. According to Burchard's report for 1883, "The Harrison, the property of the Gem City Mining Co., on the eastern slope of Glacier Mountain, that has been idle so long on account of litigation, has finally settled all dispute and is now one of the big producers of this section. The developments * * * are two tunnels * * * on the vein * * * and three open cuts * * * and the discovery shaft, * * * aggregating 200 feet. Ore is shown in all the workings and improves with depth * * * being gray copper and galena which averages about 60 ounces of silver per ton."

These workings are on the west side of Glacier Mountain and were inaccessible at the time of the writer's visit. One adit on the steep northeastern face of the mountain was open in 1927, but no ore was found in it. The tight barren fissure that was followed southwest from the portal split into two barren seams in a short distance. Both branches were explored for about 100 feet, but no ore was found in either branch.

According to James Southerland, the Harrison produced most of its ore in 1888 to 1890, and all of it came from the shaft sunk on the west slope of the mountain some distance above the adit described above. The ore was nearly solid galena, but some quartz and barite were present. The vein in the shaft strikes northeast and dips steeply northwest. The known production of the mine is given below.

Production of Harrison mine

	Ore (short tons)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)
1883	50	3,000	-----	-----
1884	15	-----	-----	-----
1887	4	395	2,944	-----
1889	(?)	1,570	13,905	-----
1890	(?)	5,146	41,778	-----
1918	2	23	1,434	8

No record available for 1885-86, 1891-1900; no production in 1888, 1901-17, 1919-28.

HERMAN

The Herman vein is on the west slope of Glacier Mountain near the head of St. Johns Creek, at an altitude of about 11,700 feet, 2 miles southwest of Montezuma. It was located in 1875, patented in 1881, and developed during the early eighties but has not been worked since 1890. It is listed as a "heavy shipper" by the local paper in 1882 and 1883. It shipped in 1884 and 1885 but was a nonproducer in 1886-88 and is not again mentioned in the reports examined by the writer. Its

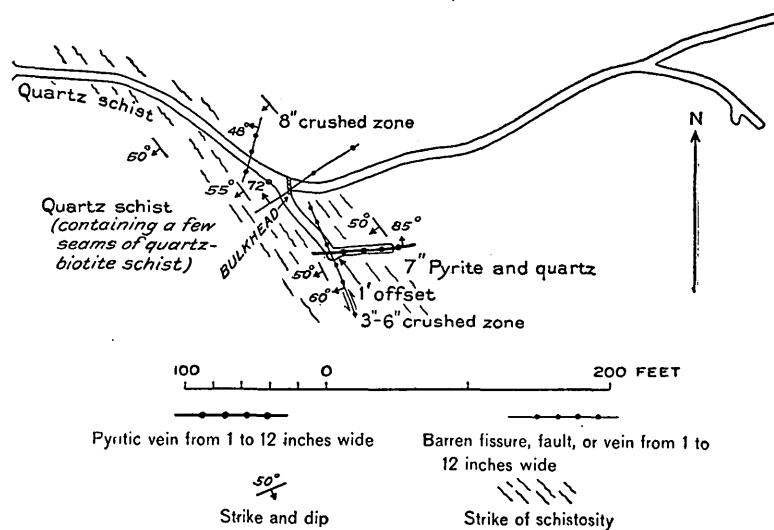


FIGURE 14.—Hannibal vein, lower adit.

total production is probably about 115 tons of lead-silver ore, worth at the time of production about \$85 a ton. According to the Colorado Mine Directory for 1883, the Herman vein was 5 feet wide and had a "pay streak 20 inches wide"; the ore contained galena, gray copper, ruby silver, silver glance, and quartz, assaying about 18 percent of lead and from 75 to 200 ounces to the ton in silver. In Raymond's report for 1883 he notes that the Herman had been shipping some ore and that the "crevice is about 6 feet wide, and all the crevice matter pays for shipment, the average grade being between 60 and 70 ounces silver per ton. This is probably the largest ore body in the district, and with development will probably be one of the largest producers."

The vein is parallel to the Wild Irishman and about 100 feet south of that vein. The country rock is the Swandyke gneiss, which strikes N. 35° E. and dips 70° E.

HUNKIDORI

The Hunkidori mine is on the east slope of Independence Mountain, in Grizzly Gulch, $1\frac{1}{2}$ miles due west of Montezuma, at an altitude of about 11,200 feet. The vein was discovered in July 1880 by Messrs. Penry, Dougherty, Murphy, and

Keogh. The first work was done about 1,500 feet southwest of the present adit portal, at an altitude of about 11,550 feet. This adit was driven 110 feet but had to be abandoned because of the constant caving of the roof. Another adit was driven 660 feet farther northeast at a lower level, and most of the ore shipped from the mine came from this adit. In 1882 the Montezuma Mill Run reported that this adit had been driven 280 feet and that "the first mineral in this level was struck at a distance of 84 feet from its mouth and continues to improve steadily for 40 feet, where a fault occurs in the crevice, and a crosscut was driven 15 feet south, which exposed a vein which was drifted on for 72 feet. This vein shows mineral the greater part of this distance, and in the breast of the drift the pay streak is 2 inches wide in the top and 12 inches wide in the bottom. The breast of the main drift is not in pay at present, but the crevice matter is rapidly improving, and there is no doubt but that another body of mineral will soon be struck. In the ore house there are about 75 tons of very clean, fine-looking mineral. No stopping worth speaking of has been done."

The lowest adit, in which all the recent work has been done, was started in 1882. There are no maps of the upper levels, but the lower workings and the geology of the mine are shown in plate 24. The Hunkidori commenced shipping small lots of ore by pack train in 1882 and has been intermittently productive since that time. According to the Colorado Mine Directory for 1883 the vein of the Hunkidori at that time was 22 inches wide and contained galena, gray copper, and quartz, and the sorted ore averaged 40 percent of lead and 157 ounces to the ton in silver.

Production of Hunkidori mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)
1882.....	20			
1883.....	10			
1885.....	10			
1886.....	1			
1889.....				
1890.....	(?)		471	11,367
1911.....	2	0.11	67	1,922

No record available for 1884, 1891-1910, 1912-28; no production in 1887-88.

The country rock of the lower workings is Montezuma quartz monzonite, but the vein crosses into hornblende gneiss a short distance southwest of them. Most of the ore produced by the property probably was mined near the contact of the monzonite and the gneiss and was between gneiss walls. As shown on plate 24, there are two distinct fracture systems in the monzonite, both of which are mineralized. The principal vein is the Hunkidori, which strikes N. 57° E. and dips 85°-90° S. In its barren parts it is an iron-stained sheeted zone from 2 to 12 inches wide; where it carries ore the vein consists of quartz, manganiferous ankerite, pyrite, galena, and a small amount of zinc blende and ranges in width from 10 to 30 inches. There are several other fissures in the mine, most of which strike northwest. Most of them are iron-stained, some of them carry pyrite, some carry both pyrite and galena, and in one of them a seam of barite and galena 6 inches wide was seen. Little gouge is present on any of the fissures; instead, there is a strongly sheeted structure or a zone of slightly crushed and altered rock. At the breast of the adit in 1928 the vein showed evidence of repeated movements during the period of mineralization. Dark-colored quartz containing abundant pyrite disseminated through it had been brecciated and cemented by pink manganiferous ankerite. Seams of light-colored quartz apparently contemporaneous with the galena that is disseminated through it follow the wall of the vein, but the relation of the quartz to the other minerals was not evident.

The vein appears much stronger and better mineralized as it is followed southwest; the occurrence of the productive ore body in the upper level close to the contact of the monzonite and the Swandyke gneiss suggests that the ore in the lower adit will be found to improve as the drift is pushed southwestward to the contact of these two formations.

IDA BELLE

The Ida Belle vein is on the west slope of Independence Mountain about 3 miles west-northwest of Montezuma, at an altitude of about 11,450 feet. A steep road, which is passable with difficulty for most automobiles, leads from the Dillon-Montezuma highway 2 miles east of Keystone to the lower cabins of the Ida Belle in Jones Gulch, at an altitude of about 10,250 feet. The mine workings are connected with the lower cabin by a steep trail, and supplies and ore are packed by burros or horses over this trail. A very good trail also leads from the lower cabins directly down Jones Gulch to the Dillon-Montezuma highway, and a trail from the mine to Montezuma runs along the north slope of Independence Mountain past the Hunkidori mine.

The Ida Belle vein was discovered in 1880 and developed by three adits in the next few years. The mine shipped steadily during most of the eighties but never in large amounts. It is not credited with any production between 1889 and 1916 and was undoubtedly idle during most of that time. The known production is given below.

The upper adit was not accessible in 1928, and only the two lower adits are shown on plate 25. Both adits are about 440 feet long. A winze 125 feet deep, 165 feet from the portal of the upper adit, connects it with the lower adit. An intermediate level 50 feet below the upper drift has been driven 110 feet east from the winze. As shown in the longitudinal section in plate 25, some small stopes have been made above the lower and upper workings, but in 1929 very little ore had been removed between the two levels. Most of the upper adit is on the Ida Belle vein, which strikes about N. 80° E. and dips 65°-90° N. but averages about 85°. The lower adit in part follows the vein and in part follows a barren fissure a few feet south of the main vein.

Production of Ida Belle mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)	Zinc (pounds)
1883.....	50					
1884.....	50					
1887.....	• 30					
1888.....	(?)	3.39	739	33,353		
1916.....	11	.56	223	11,275	45	
1917.....	37	5.16	588	23,610	82	
1922.....	29	.70	385	13,823		6,565
1923.....	• 30	10.37	340	18,930		4,338
1924.....	8	4.70	114			
1928.....	28	4.40	366	19,069	47	

• Estimated.

• Includes 22 tons of lead ore, containing 6.30 ounces of gold, 340 ounces of silver, and 16,850 pounds of lead.

No record available for 1885-86, 1889-1900; no production in 1901-15, 1918-21, 1925-27.

The most prominent geologic feature of the mine is the Williams Range thrust fault, which separates the pre-Cambrian gneiss and the Upper Cretaceous shale. This fault, as shown on page 47, has a horizontal component of movement of at least 4 miles. Its regional relations are indicated in cross section C-C', plate 4. The fault breccia is from 40 to 70 feet thick in the Ida Belle mine and dips 5°-40° W., averaging about 16°. The Ida Belle fissure offsets the thrust fault, and the contact of the shale with the overlying brecciated gneiss is accordingly found from 5 to 40 feet farther east on the north side of the vein than on the south side. Slickensides and

grooves on the walls of the vein in the upper adit dip 10° E. and suggest that most of the displacement was horizontal. The movement along the Ida Belle fissure formed a gougy, sheeted zone from 2 to 6 inches wide in the shale, a crushed and sheeted zone from 24 to 60 inches wide in the breccia, and a fissured zone from 12 to 45 inches wide in the overlying gneiss. The mineralization of this vein, as would be expected, was strongest in the thrust-fault breccia and weakest in the shale. The ore observed in the thrust-fault breccia close to the contact of the shale was much better than that 50 feet above and was commonly about 24 inches thick. Both galena and zinc blende are present, and there is little waste in the ore close to the contact. The character of the ore 50 feet above the shale and breccia contact is shown in figure 15. Most of the ore between the shale walls is pyritic, but some galena ore occurred in places close to the contact of the thrust-fault breccia. Although it is possible that other ore bodies are present in the baked shale east of the present workings, the geology of the region suggests that the best ore will probably be found close to the contact of the shale and the overlying breccia and will pitch about 15° or 20° W.

INDEPENDENCE

The Independence vein is on the southeast slope of McClellan Mountain, a few hundred feet northwest of the Santiago mine and about $6\frac{1}{2}$ miles northeast of Montezuma, at an altitude of about 12,300 feet. The workings were inaccessible in 1927. The date of the discovery of the vein is not known, but in 1877 it was located as the Independence and subsequently patented under that name. According to the Colorado Mining Directory for 1883 the Independence had produced about \$300,000 prior to that year, and it is known to have been productive from 1883 to 1890.

The amount of development work is indicated by Burchard's report for 1883, as follows:

"The Independence has been one of the best-paying mines in this locality and is developed by a main tunnel 710 feet in length, having a depth of 400 feet at the breast. On this tunnel are four shafts 35 to 80 feet in depth. In one shaft, at a depth of 60 feet, is a drift 100 feet west, showing in a streak of mineral 4 to 8 inches of galena, which mills 70 ounces of silver per ton. The best-paying ore just now comes from a stope about 125 feet from the tunnel mouth and 60 feet above it, now under lease to J. B. Johnson. At 440 feet is a pay streak from 6 to 12 inches wide that mills from 216 to 316 ounces of silver per ton. Four hundred feet from the mouth of the tunnel is a winze connecting the main level with the next level, 110 feet above. In this level the streak is from 3 to 5 inches, milling about 80 ounces per ton."

The vein is mentioned frequently by the Georgetown Courier in the eighties, and the comments suggest that it was one of the best shippers in the East Argentine district during that period. Shipments of 1 to 12 tons at a time are often mentioned, and the average tenor of the ore was apparently well above \$100 a ton. Silver was the chief valuable constituent, but in some places the gold content was also noteworthy.

The vein has been worked several times since 1890, but very little is known of these later operations. As shown in figure 16, the vein has been cut several hundred feet below its outcrop by drifts from the Tobin and Waldorf adits. According to A. A. Atkins, formerly general manager of the Imperial Mines Co., no ore was found in the vein where it was cut on the Waldorf tunnel level at an altitude of about 11,650 feet, although ore had been mined from it on the Tobin tunnel level, about 300 feet above.

The vein strikes northeast and dips about 80° NW. The vein is in Silver Plume granite and is a sheeted zone from 4 to 12 inches wide carrying galena, pyrite, and a small amount of sphalerite in a quartz gangue. The ore shipped in the eighties assayed from 70 to 300 ounces of silver and from a quarter of an ounce to $3\frac{1}{2}$ ounces of gold to the ton. If the mine has produced since 1904, the figures of production are probably included in those of the Waldorf group.

IOWA

The Iowa is on the north slope of Teller Mountain, about $2\frac{1}{2}$ miles south of Montezuma. It was discovered in 1880 and developed by several shallow shafts. It is credited with a production of 50 tons in 1883 by the Colorado Mines Directory, and in 1885, according to the Montezuma Mill Run, it shipped 10 tons of ore, which netted \$500. No other production is recorded for the property. The shipping ore is said to have come from a vein 17 inches wide carrying galena in a quartz gangue and assayed, when sorted, 50 percent of lead and 25 ounces of silver to the ton.

JERRY, EQUITY, DENVER, AND CELTIC

The Jerry tunnel is on the northeast face of Glacier Mountain, about a quarter of a mile southwest of Montezuma, at an alti-

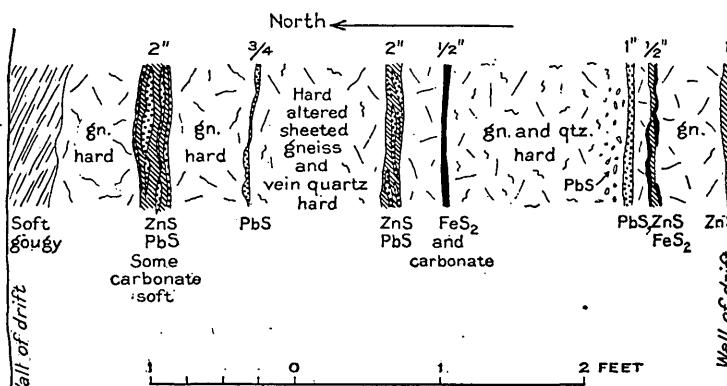


FIGURE 15.—Diagrammatic section of Ida Belle stope.

tude of about 10,450 feet, and the Equity adit is about 265 feet above it. These tunnels were started in the eighties to cut the Mark Twain Extension at depth, but most of the development work was done by the Jerry Mining Co. and the Washington Gold Quartz Mining Co. in 1922 to 1925. As shown on plate 26, the only vein that was stoped to any extent was the eastward-trending vein cut by the Equity adit, although a few carloads of ore was shipped from the northeasterly vein found in the lower workings. The production of the property is given below.

Production of Jerry, Equity, Denver, and Celtic veins

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)	Zinc (pounds)
1900 (Jerry group)-----	3	-----	171	2,935	-----	406
1903-----	3	-----	744	2,007	-----	-----
1904 (Jerry group)-----	4	0.08	278	1,533	-----	-----
1908 (Jerry group ?)-----	2	.03	154	719	-----	283
1918-----	14	.34	407	2,078	28	-----
1919-----	11	.20	351	3,334	31	-----
1921-----	51	1.50	1,239	18,599	-----	1,026
1923 (Denver and Celtic)-----	46	.80	1,190	12,600	-----	-----
1924 (Denver and Celtic)-----	16	-----	92	807	-----	-----
1925 (Denver and Celtic)-----	32	1.40	1,267	16,860	-----	-----

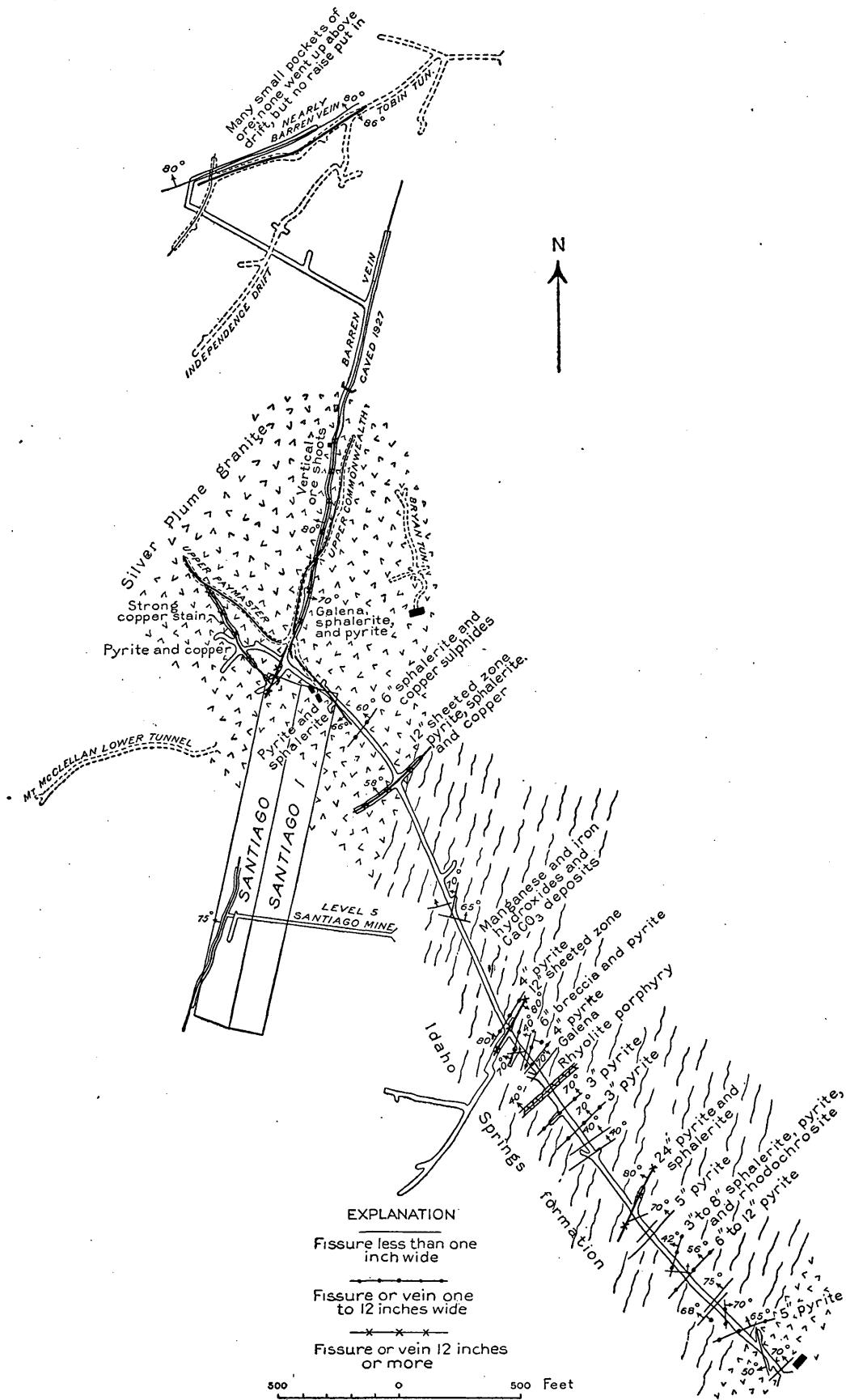


FIGURE 16.—General relations of Santiago, Commonwealth, Independence, Tobin, and Paymaster workings and geology of Waldorf tunnel.

Production of Jerry, Equity, Denver, and Celtic veins—Continued

	Ore to concentrating mills (short tons)	Concentrates produced (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)	Zinc (pounds)
1923 (Denver and Celtic).....	637	55	2,38	2,271	30,678	236	11,968
1924 (Denver and Celtic).....	(?)	83	.88	1,159	12,202	—	40,879

No production in 1901-2, 1905-7, 1909-17, 1922, 1926-28.

The country rock of the mine is hornblende gneiss and pegmatite of the Swandyke gneiss. The gneiss strikes about N. 15° E. and dips steeply east. On the lower level a barren fault parallel to the schistosity of the gneiss was followed by the adit. About 320 feet from the portal a thin northeasterly vein is cut by this fault and is displaced about 15 feet, the eastern segment moving north. The vein is largely rhodochrosite from 1 to 4 inches wide, but some galena and sphalerite are also present. Locally ruby silver can be seen, and a rich pocket of silver ore is said to have occurred near the intersection of the vein and the fault. About 100 feet from the portal of the upper level a fault was cut which is parallel to the one on the lower level and is probably part of the same fault zone. It was followed south to the Denver and Celtic "veins", from which most of the ore shipped from the Jerry mine was produced. As shown on the map, the two veins are faulted portions of one eastward-trending vein that has been cut by the northerly fault, the eastern segment moving north of the western segment. The horizontal slip between the displaced segments is about 30 feet, but the shift between the undisturbed parts of the vein beyond the influence of the fault is nearly 60 feet. The dip and strike of the western part of the vein west of the fault would make it crop out near the center line of the Denver claim, and the dip and strike of the eastern segment of the vein would throw its outcrop close to the center line of the Celtic claim. In the Jerry workings this vein was from 6 inches to 2 feet wide and consisted largely of galena and rhodochrosite; sphalerite and quartz were also common, and ruby silver occurred locally.

JOSEPHINE

The Josephine mine is on the north slope of Kelso Mountain, about 7 miles north-northeast of Montezuma and 5 miles by road from Silver Plume. As shown on plate 27, the vein is opened by three adits at altitudes of 10,893, 10,801, and 10,651 feet. These adits have been driven southward into the mountain 320, 1,090, and 960 feet respectively but were inaccessible at the time of the writer's visit. The Josephine vein was located in 1876, and the upper and intermediate adits were driven 60 and 120 feet before 1883, but most of the development work has been done since 1900. The mine probably produced little before 1905, but as shown in the production table below, it has been an intermittent producer of lead-silver ore since that year.

The Josephine vein strikes about N. 12° E. and dips about 67° W. The country rock includes Silver Plume granite and schists and gneisses of the Idaho Springs formation. According to O. B. Wilmarth, the main vein is well defined and was easily traced past the junctions of several minor branch veins and cross veins. The vein filling in the barren stretches between ore shoots is reported to be chiefly quartz, but the ore is remarkably clean and free from gangue. The average width of the ore in the stopes is said to be about 1 foot, although its width ranges from 1 to 30 inches. Galena is the chief ore mineral, and some sphalerite, pyrite, and chalcopyrite are also present.

Production of Josephine mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)	Zinc (pounds)
1906.....	43	—	1,721	4,376	—	—
1907.....	25	35.02	376	28,835	—	—
1908.....	28	1.98	336	26,359	—	—
1909.....	249	17.28	3,034	371,205	—	—
1910.....	246	33.94	3,227	256,332	722	—
1911.....	175	14.49	2,219	251,295	—	—
1912.....	162	30.27	2,889	196,747	1,830	9,861
1913.....	410	40.51	5,509	514,496	2,001	—
1914.....	476	29.57	4,391	325,997	565	—
1915.....	120	15.49	1,385	112,080	—	13,643
1917.....	107	7.61	1,743	139,785	—	—
1919.....	7	1.28	82	8,390	—	—
1926 (Josephine group, Hoodoo mine).....	11	.62	127	14,905	—	549

No record available for 1889-1900; no production in 1901-5, 1916, 1918, 1920-25, 1927-28.

JUMBO

The Jumbo mine is on the north slope of Morgan Peak, about 1 mile east-northeast of Montezuma. It is developed by three adits—two short ones several hundred feet above Peru Creek and a much longer, lower adit at an altitude of about 10,820 feet a short distance above the wagon road in the valley bottom. The property was discovered in the late eighties and is said to have shipped about 100 tons of lead ore in 1888 and about 25 tons in 1900. This ore was found in the upper adits, and in 1905 some work was done on them, but the ore exposed contained too much zinc to allow shipping without concentration. The upper adits were then abandoned, and the lower adit was driven during 1906-9. In 1914 the property was taken over by the Philadelphia Mining Co. and was operated in conjunction with its Toledo mill, about halfway between the mine and Montezuma. During 1914 and the next 4 years 6,798 tons of ore was produced and all but 38 tons was milled. Most of it can be credited to the Jumbo, although a small amount was obtained from other sources. The lower adit is said to extend almost due south into Morgan Peak for about 1,100 feet. The ore obtained from this level was chiefly zinc blende but contained a small amount of galena. The vein averaged about 6 inches in thickness, but in some places reached 1 foot. Most of the ore came from a single stope, which is said to be about 300 feet long and about 100 feet high. The ore exposed on the dump is massive sphalerite with a little pyrite between quartz walls. Some galena is present but is not abundant. The ore in the upper adits contained a notable proportion of galena, and the sphalerite present was very loose-textured and light-colored. Copper minerals are not conspicuous in the ore, but some tetrahedrite and chalcopyrite are microscopically intergrown with the dark-colored sphalerite from the lower adit. The country rock of the entire mine is Montezuma quartz monzonite.

The following are incomplete figures on the Jumbo mine and the Philadelphia group:

Production of Philadelphia Mining Co.

[Includes Waterloo, Philadelphia, Little Jumbo, Collier Mountain group, Rosen-garten tunnel, and Colorado-Toledo]

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)	Zinc (pounds)
1915 (see also milling ore).....	24	0.89	260	9,468	328	11,099
1917.....	14	1.23	137	3,154	411	9,598

Production of Philadelphia Mining Co.—Continued

	Ore to concentrating mills (short tons)	Concentrates produced (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)	Zinc (pounds)
1914.....	150	64	2,06	632	20,768	486	32,683
1915.....	500	162	7.71	1,332	43,513	830	74,000
Waterloo.....		13	.88	138	8,162		
1916.....	5,658	943	35.46	7,065	193,878	2,802	444,094
1918.....	490	27	.81	113	1,346	108	
Waterloo.....		20	1.55	269	3,150	182	

No production in 1901-13, 1919-28.

KELSO

The Kelso mine is on the north slope of Kelso Mountain at an altitude of 10,800 feet, about $6\frac{1}{4}$ miles north-northeast of Montezuma. The early history of the property is not known, but in 1926-29 it was worked by the Kelso National Mining Co., of Georgetown. At the time of the writer's visit no ore had been produced, but several tons of silver-lead ore was shipped in 1927 and 1928. As shown in plate 28, the country rock of the mine is schist and injection gneiss.

The ore occurs in northwestward-trending veins and is much better where the walls of the veins are gneiss than where they are schist. Although the workings expose many fissures and faults striking from north-northeast to east, the only ore seen by the writer was in fissures belonging to a branching vein system striking N. 10° - 40° W. Some of the north-northeast faults are younger than the northwest veins. The ore was from 1 to 8 inches wide and contained chiefly galena and pyrite and minor amounts of light-colored sphalerite in a quartz and ankerite gangue. The upper tunnels were not accessible at the time of the writer's visit, but the veins which they followed are probably the same as those exposed in the southeastern drifts of the lower tunnel workings, the southern drift following the Kelso vein, and the drift 75 feet to the northeast following the National vein. As these two veins dip toward each other they probably join about 150 feet below the level, and an ore shoot may occur at this junction. No ore shoot was found where the National vein branched from the North Kelso on the tunnel level, however, but at this place, as shown on the map, the two veins were in schist, which is a less favorable wall rock than the gneiss.

Production of Kelso mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Zinc (pounds)
1920.....	2	0.24	15	2,090	
1921 (Mount Kelso).....	6	.32	41	3,720	
1925.....	43	8.42	521	47,844	
1926 (Kelso National).....	15	7.60	210	17,414	1,612
1927 (National).....	32	8.80	626	46,032	1,931

No production in 1901-19, 1922-24, 1928.

KITTY OWSLEY

The Kitty Owsley vein is on the east slope of McClellan Mountain, about $1\frac{1}{2}$ miles north of the Waldorf mine and $7\frac{1}{4}$ miles northeast of Montezuma. The portal of the lower tunnel has an altitude of about 11,850 feet. The mine was inaccessible in 1927, and little is known of its history. The vein is said to be parallel to the Kitty Owsley claim and if so strikes about N. 20° E. The ore on the dump is chiefly brecciated sphalerite in a quartz-barite gangue and came from a vein at least 7 inches wide in places. The country rock is Silver Plume granite, but the strike of the vein would carry it into the Idaho Springs

formation a few hundred yards north of the tunnel. Incomplete production figures follow.

Production of Kitty Owsley mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead, wet assay (pounds)	Copper, wet assay (pounds)	Zinc (pounds)
1912.....	49	6.28	272	27,528		28,115
1913.....	23	2.06	163	12,661		11,430
1917.....	6	1.47	129	6,141		
1918.....	36	3.21	788	29,725	72	
1921.....	1	.11	18	616		

No production in 1901-6, 1908-11, 1914-16, 1919-20, 1922-28.

LANCASTER

The Lancaster vein is on the southwestern spur of Tiptop Peak, about half a mile east of Montezuma, and was developed by three adits at altitudes of about 11,400 to 11,700 feet. The property has long been idle, but it produced a small amount of ore in the eighties. It is credited by the Colorado Mine Directory with a total production of 210 tons prior to 1883 and produced 1 ton of ore in 1886 and \$185.11 in lead ore in 1888. No other production for the mine is on record. In 1883 the three adits were 165, 260, and 15 feet long, and little work has been done since that time. The vein strikes nearly due east and is entirely in the Montezuma quartz monzonite. It is reported to be a fissured zone about 4 feet wide, containing a vein of galena about 5 inches thick. The ore, when sorted, assayed 55 percent of lead and 34 ounces of silver to the ton.

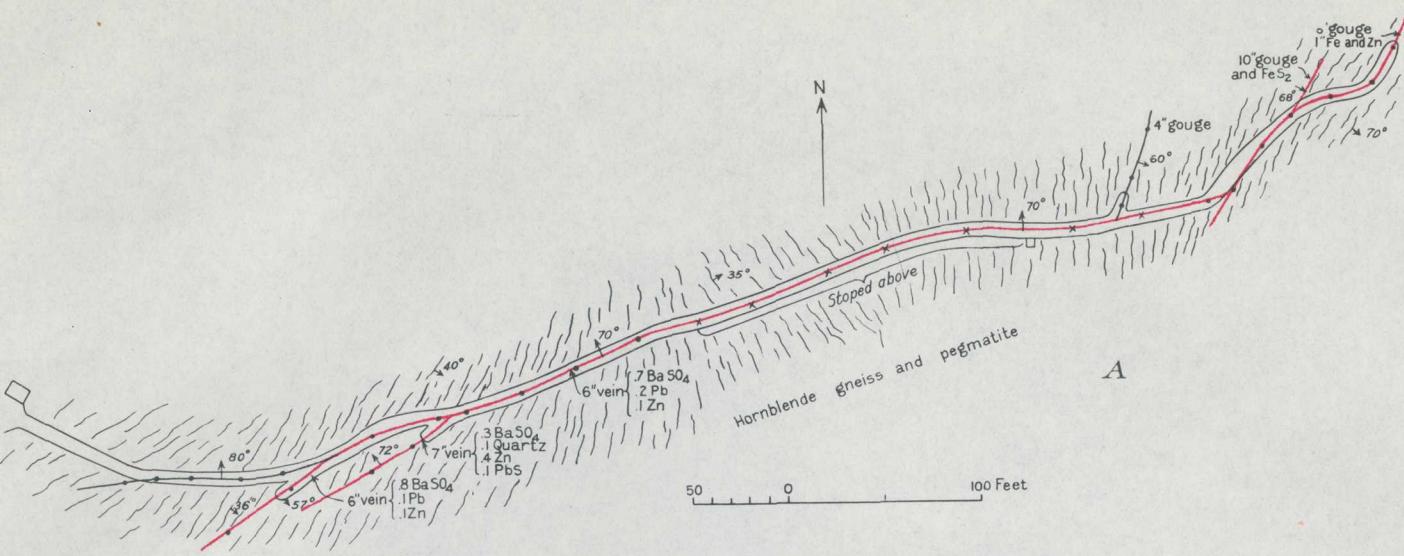
The occurrence of the ore was probably similar to that of the Morgan mine, a few hundred feet south of the Lancaster, described on pages 90-91.

LUCKY BALDWIN

The Lucky Baldwin claim is immediately southwest of the Silver Wave claim (see p. 108) and is probably on the extension of the Silver Wave vein. It has two adits on it at altitudes of 12,000 and 12,060 feet. The upper adit was not accessible in 1929, but both adits are driven northeast to the end line of the claim, and the lower one was examined and is shown on plate 16. It is 425 feet long and follows the vein for 310 feet of this distance. The country rock of the vein comprises Idaho Springs formation and Silver Plume granite; both quartz schist and quartz-biotite-muscovite schist are present and strike about N. 10° E. and dip steeply west. The vein strikes northeast and dips steeply northwest or southeast. It was first cut about 110 feet from the portal in quartz schist and is thin and poorly defined until it passes into Silver Plume granite, 160 feet from the portal. The vein gradually widens in the next 30 feet, and there is a stope about 25 feet high and 30' feet long 200 feet from the portal. There are no other stopes on this drift, but the vein is well marked and is from 6 to 12 inches wide. Most of the vein is quartz, however, and the chief sulphide is pyrite; some chalcopyrite occurs, and in places the walls of the drift are copper-stained. Small amounts of galena and sphalerite were noted in the drift, and some lead-zinc ore was found on the dump.

MAID OF ORLEANS

The Maid of Orleans vein is on the southeastern spur of Lenawee Mountain, and the chief workings are at the foot of the mountain, in the valley of Peru Creek about $1\frac{1}{4}$ miles north-



EXPLANATION

— Barren fissure, fault, or vein less than 1 inch wide

—●—● Barren fissure, fault, or vein from 1 to 12 inches wide

—*—* Barren fault or vein more than 12 inches wide

— Mineralized vein with less than 1 inch of sulphide

—●—● Mineralized vein with 1 to 12 inches of sulphide

—*—* Mineralized vein with more than 12 inches of sulphide

- - - - Approximate position of vein in upper adit

~~~~~ Granite gneiss and injection gneiss

↙<sup>170°</sup> Strike and dip of bedding

~~~~~ Strike of schistosity

↙ Downthrown side of fault

PbS, galena

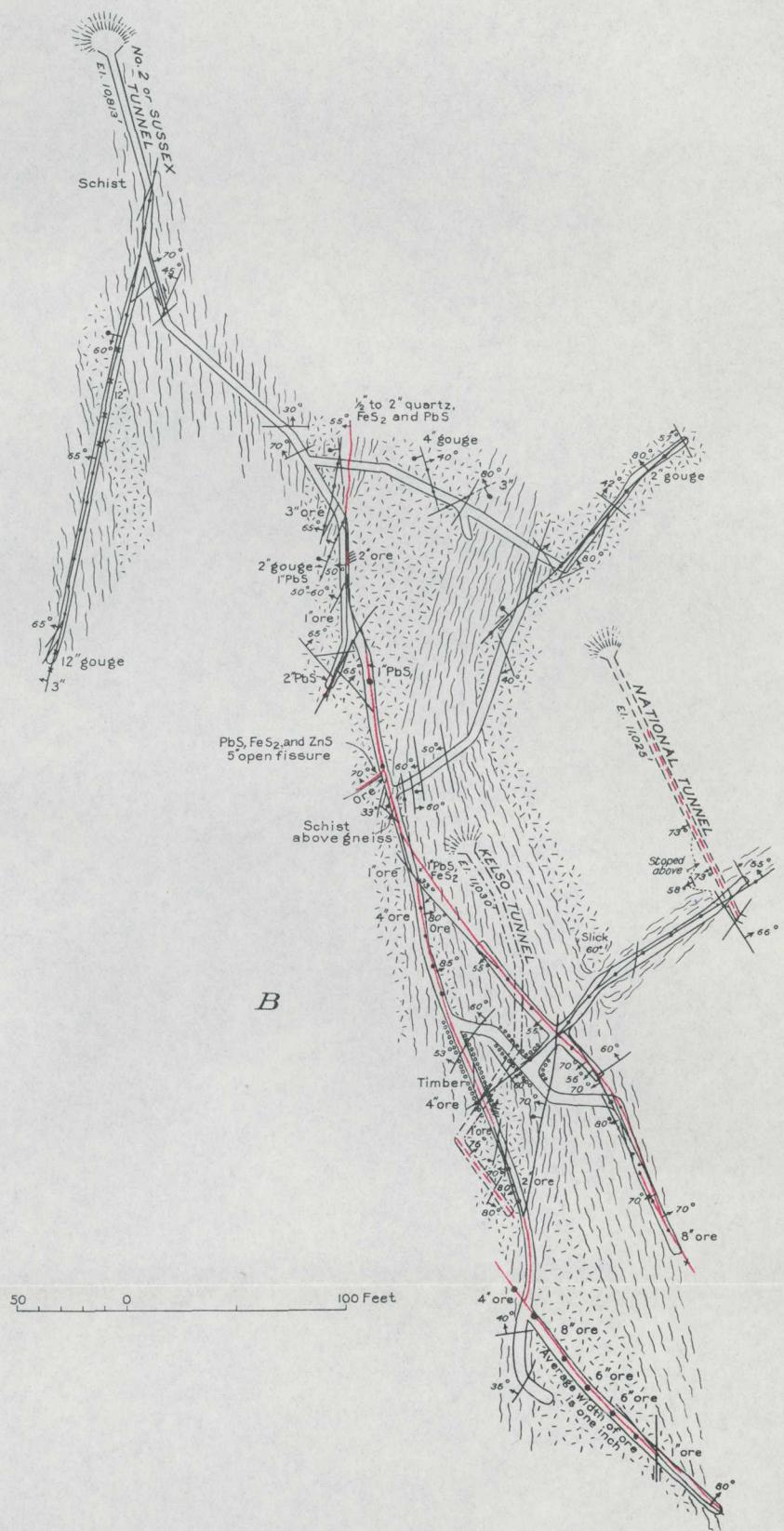
ZnS, sphalerite

FeS₂, pyrite

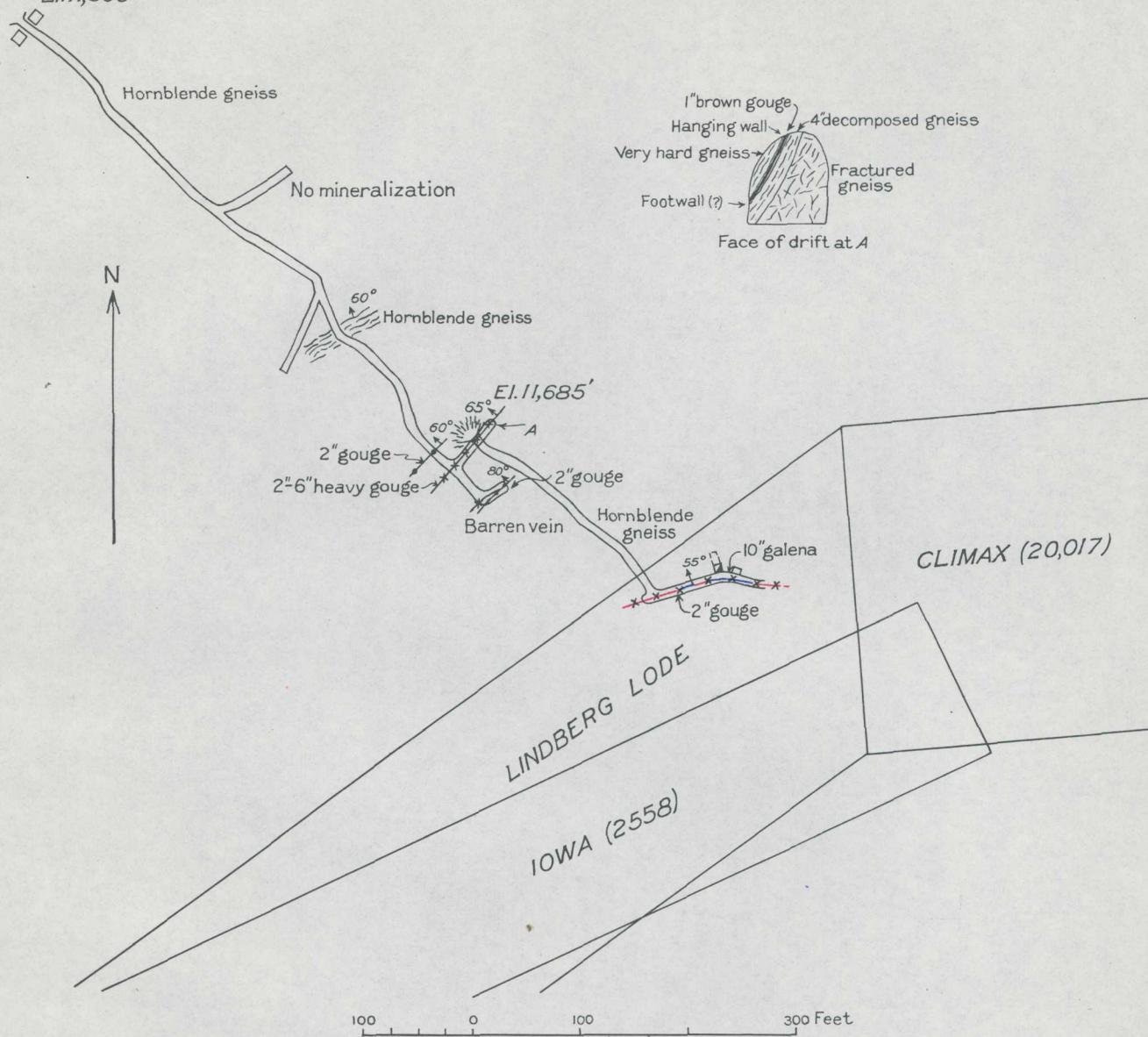
BaSO₄(dis.), barite disseminated

~~~~~ Timbered drift

~~~~~ Slick, slickensides



PLANS OF MORE WORK TUNNEL, GLACIER MOUNTAIN (A) AND KELSO MINE, KELSO MOUNTAIN (B)

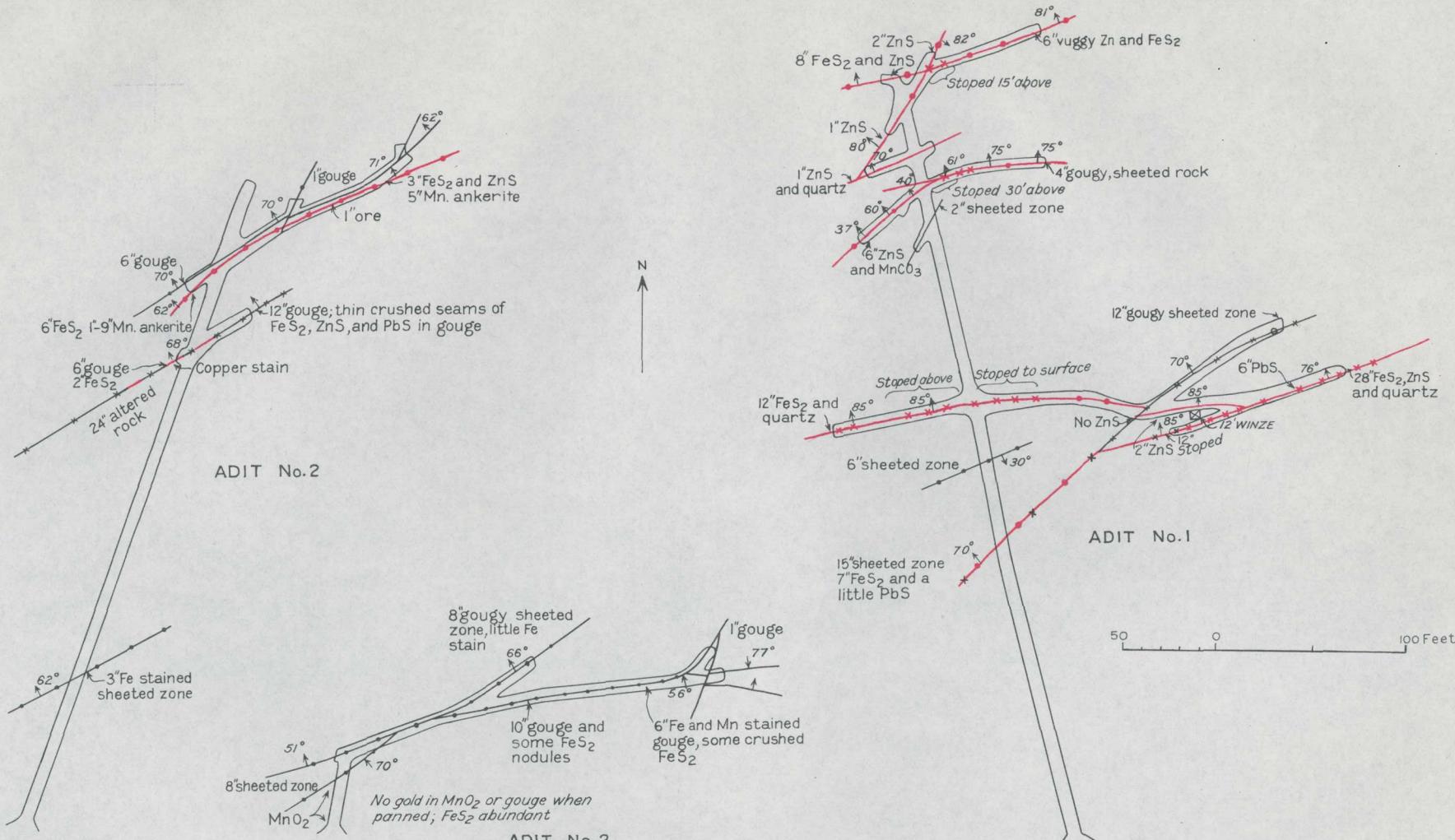


EXPLANATION

- Barren fissure, fault, or vein from 1 to 12 inches wide
- ×— Barren fault or vein more than 12 inches wide
- x— Slightly mineralized vein more than 12 inches wide
- ×— Vein more than 12 inches wide with galena ore

↙ 70° Strike and dip

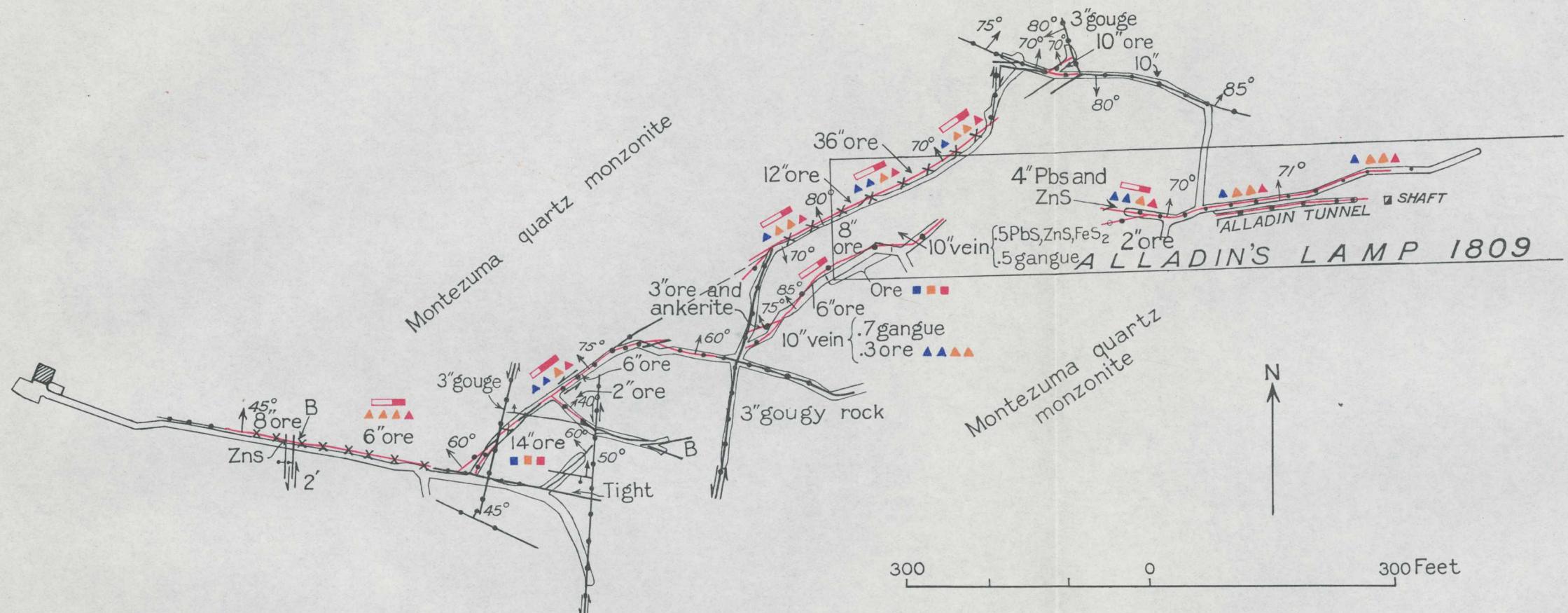
PLAN OF MOHAWK MINE, TELLER MOUNTAIN



EXPLANATION

- PbS, galena
- ZnS, sphalerite
- Fe, iron
- FeS₂, pyrite
- Mn, manganese
- MnO₂, manganese oxides
- MnCO₃, rhodochrosite

PLAN OF MORGAN MINE, MONTEZUMA
(Relative position of adits not shown)



EXPLANATION

— Barren fissure, fault, or vein less than 1 inch wide

—●— Barren fissure, fault, or vein from 1 to 12 inches wide

—*— Barren fault or vein more than 12 inches wide

—●— Mineralized vein from 1 to 12 inches wide

— x — Mineralized vein more than 12 inches wide

▲ ■ Composition of ore, 25 percent represented by a triangle, 33½ percent represented by a square

blue, galena; yellow, sphalerite; red, pyrite

B Barren of galena-sphalerite ore

— Relative proportion of sulphide (solid) and gangue minerals in ore

—^{180°} Strike and dip

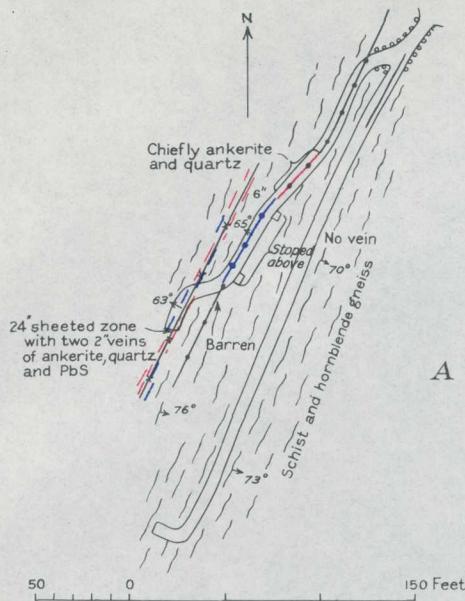
— Strike and vertical dip

PbS, galena

ZnS, sphalerite

FeS₂, pyrite

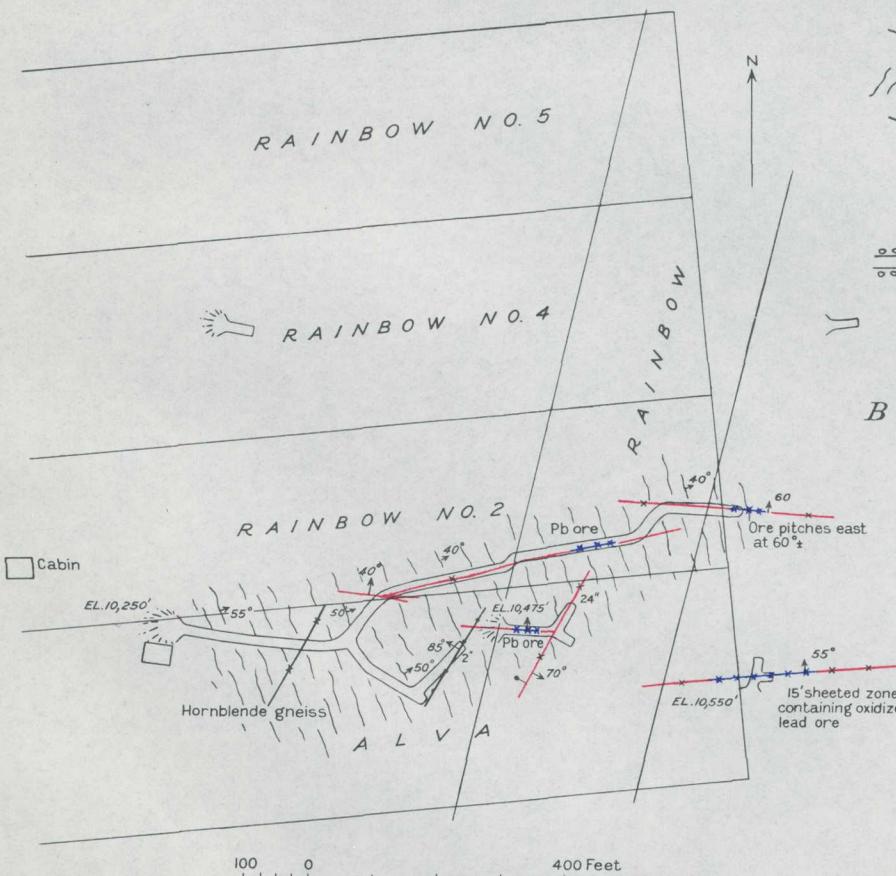
PLAN OF NEW YORK TUNNEL, MONTEZUMA, 1929



A

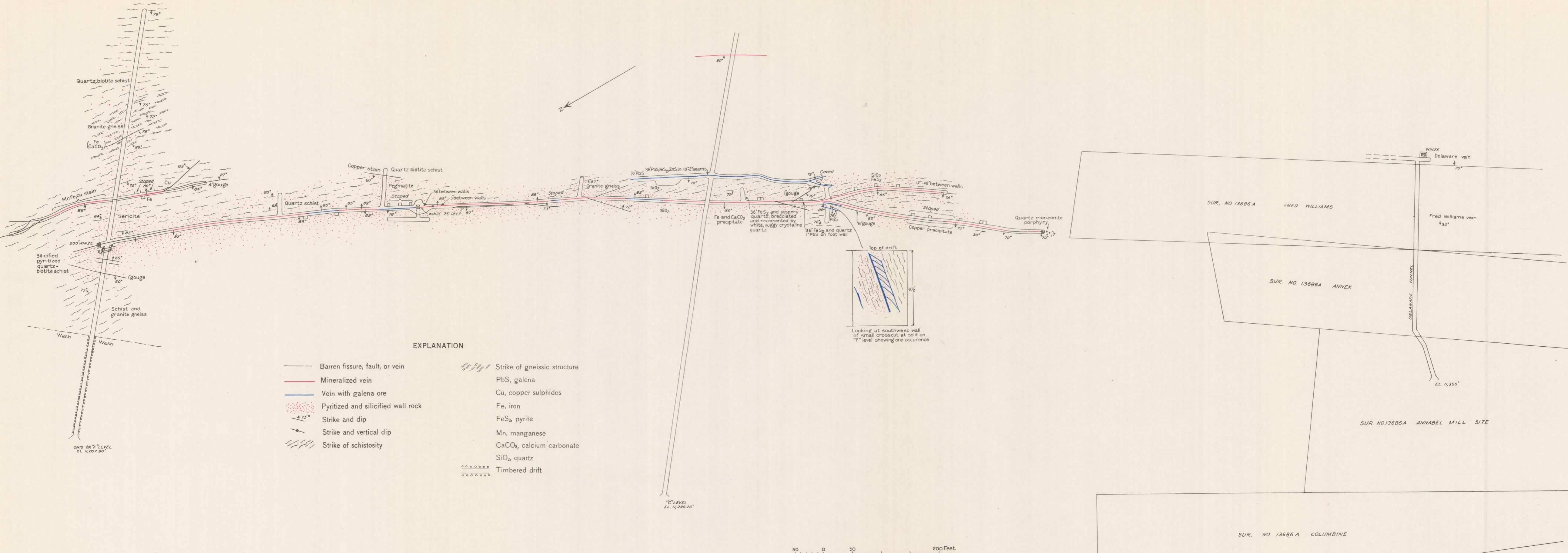
EXPLANATION

- Barren fissure, fault, or vein less than 1 inch wide
- Barren fissure, fault, or vein from 1 to 12 inches wide
- *— Barren fault or vein more than 12 inches wide
- Mineralized vein from 1 to 12 inches wide
- *—*— Mineralized vein more than 12 inches wide
- Vein with galena and ankerite from 1 to 12 inches wide
- *—*— Vein with galena ore more than 12 inches wide
- /— Strike and dip
- ///— Strike of schistosity
- /— Downthrown side of fault
- Pb, lead
- PbS, galena
- Timbered drift



B

PLANS OF OLD TIMER MINE, GLACIER MOUNTAIN (A), AND RAINBOW MINE, KEYSTONE GULCH (B)



east of Montezuma. The shaft by which the mine was worked is on the north side of the creek at an altitude of about 10,300 feet, but it was full of water at the time of the writer's visit. The vein was discovered in 1882 and worked during the eighties, but no production has been made since 1888, so far as is known. Several carloads of ore were shipped in 1885, about 2 tons of ore in 1887, and about 13 tons of ore in 1888; the total production of the mine was probably about 50 tons of silver ore worth about \$60 a ton. According to the Colorado Mining Directory for 1883 the Maid of Orleans vein was "a fissure varying in width and containing pockets of galena, copper pyrites, and sulphurets, assaying from 50 to 150 ounces silver per ton." The ore on the dump in 1929 was pyritic quartz containing a small amount of sphalerite and apparently came from a vein about 6 or 8 inches wide.

Production of Maid of Orleans mine

| | Ore (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) |
|-----------|------------------|--------------------|----------------------|--------------------------|
| 1885..... | 35 | | | |
| 1887..... | (?) | 0.28 | 64 | 1,221 |
| 1888..... | (?) | 3.23 | 223 | 7,589 |

No record available for 1886, 1889-1900; no production in 1901-28.

MARK TWAIN AND ST. ELMO

The Mark Twain and St. Elmo claims are on the northwest slope of Glacier Mountain and are developed by several adits and a shaft 225 feet deep, whose collar is a short distance west of the crest of the mountain, at an altitude of about 11,400 feet. The lower adit, called the St. Elmo tunnel, has its portal on the west slope of the mountain about 500 feet below the collar of the shaft and may be reached from Montezuma over a wagon road that leaves the St. Johns Creek road about half a mile west of the town. The Mark Twain vein and the St. Elmo tunnel site were located in 1881, and work was begun on both at once. The tunnel was driven 550 feet and cut the Mark Twain and St. Elmo veins; the St. Elmo vein was followed northeast and southwest for an aggregate distance of about 500 feet. Stopes from 45 to 60 feet high and about 40 feet long are said to be present in these drifts, but, as shown in figure 17, little of the property was accessible in 1929. In sinking the shaft on the vein, ore was saved and shipped, and several hundred feet of drifts were driven from it, but little stoping was done, and the property remained idle from about 1892 until 1918, when the St. Elmo tunnel was rehabilitated by the St. Elmo Mining Co. A crosscut from the main tunnel was driven and is said to cut the Mark Twain vein 266 feet from the portal. The mine shipped ore in 1881, 1882, 1883, 1884, 1887, and 1889, but produced nothing in 1885, 1886, and 1888. According to Burchard's report for 1883,

"The Mark Twain is now developed with capacity for working 150 men in the stopes, but on account of the railroad not supplying sufficient number of cars only about 14 men have been employed. The developments consist of a crosscut tunnel 400 feet long, cutting the Mark Twain and St. Elmo veins. On the Mark Twain lode is a shaft 205 feet deep and an aggregate of 630 feet in levels. The pay streak averages 8 inches wide of galena and gray copper, carrying about 140 ounces of silver per ton. The workings are supplied with T-rails, ventilators, etc. Charles Buckland is manager. The Mark Twain extension has been worked during the year."

There is no record of production since 1890. The Mark Twain vein strikes northeast and dips steeply to the northwest in the upper part of the shaft, where the shipping ore was found. At 50 feet above the bottom of the shaft the vein bends and dips southeast at a steep angle.

Production of Mark Twain and St. Elmo mines

| | Ore (short tons) | Silver (fine ounces) | Lead, wet assay (pounds) |
|--|------------------|----------------------|--------------------------|
| 1882..... | 50 | | |
| 1882 (Cable and Mark Twain)..... | 30 | | |
| 1883..... | 40 | | |
| 1883 (Cable and Mark Twain Extension)..... | 10 | | |
| 1884 (Cable and Mark Twain)..... | 50 | | |
| 1885 (Cable and Mark Twain)..... | 10 | | |
| 1887 (St. Elmo)..... | 431 | | 2,311 |

No record available for 1886, 1888-1900; no production in 1901-28.

MISSOURI

The Missouri mine is near the head of Hall Valley, about 4 miles south of Montezuma and half a mile south of the Whale mine, at an altitude of about 12,100 feet. The substantial cabins of the mine can be reached by automobile from Webster, 9 miles to the southeast, although in 1928 the road was very steep in places and more suitable for wagons than trucks or cars.

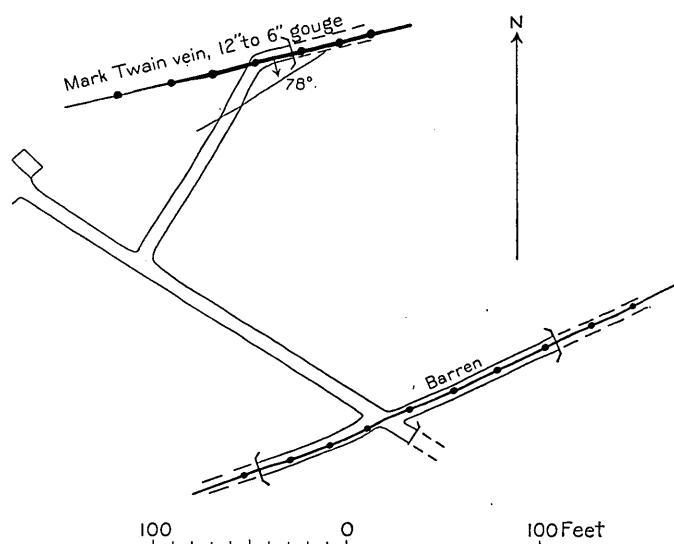


FIGURE 17.—St. Elmo tunnel, Glacier Mountain, 1929.

The Missouri lode was discovered in the late seventies and developed by several adits and a few shallow shafts. Burchard in 1882 says:

"The Missouri is one of the prominent mines in Halls Gulch. The developments consist of shafts and about 500 feet of tunnels upon the vein. The fissure is 30 feet wide, as proven by a crosscut run from the level when in about 240 feet. The ore streak is from 6 inches to 3 feet wide and runs in bismuth, silver, gray copper, copper pyrites, and iron. The ore also carried gold, running from a trace up to 11 1/4 ounces. Mill runs at Argo gave from 150 to 219 ounces of silver per ton, with 0.6 ounce in gold and 10 percent copper."

In his report for the next year Burchard says:

"This mine has an established reputation as a producer, having shipped considerable ore up to the past season. Developments consist of a shaft and about 600 feet of tunnels on the vein. The fissure is from 20 to 25 feet wide, pay streak from 4 1/2 to 22 inches wide; average value of ore 125 ounces silver, and carried as high as 10 ounces gold. This ore carries silver, gold, copper, iron pyrites, and bismuth, also gray copper; but very little lead in this ore, which is rather strange, as every mine in the camp carries lead to a great extent."

In 1884 there was much activity in Hall Valley, and the Montezuma Mill Run in that year noted that the Missouri

mine was furnishing 5 tons of concentrating ore daily to the Quincy Milling & Reduction Works. In 1887 the paper noted that the Hall Valley smelter was unsuccessful and that there was little activity in the gulch. There is no record of any activity at the Missouri between 1887 and 1920, when C. M. Snyder took over the property. The known production of the mine is given below.

Production of Missouri mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet
assay
(pounds) | Copper,
wet
assay
(pounds) | Zinc
(pounds) |
|------|------------------------|--------------------------|----------------------------|-----------------------------------|-------------------------------------|------------------|
| 1920 | 65 | 0.40 | 2,051 | 1,802 | 7,221 | |
| 1921 | 15 | 7.69 | 744 | | 1,408 | |
| 1922 | 13 | 11.80 | 1,838 | 491 | 540 | |
| 1923 | 73 | 54.81 | 9,176 | 3,056 | 5,979 | 906 |
| 1924 | 23 | 5.90 | 1,127 | 1,596 | 3,192 | |
| 1925 | 55 | 50.39 | 5,973 | 3,570 | 5,306 | 692 |
| 1926 | 2 | 17.66 | 444 | 162 | 169 | |
| 1927 | 23 | 47.60 | 1,887 | 915 | 2,333 | 412 |
| 1928 | 27 | 2.42 | 912 | 14,611 | 2,620 | 2,917 |

No production in 1901-19.

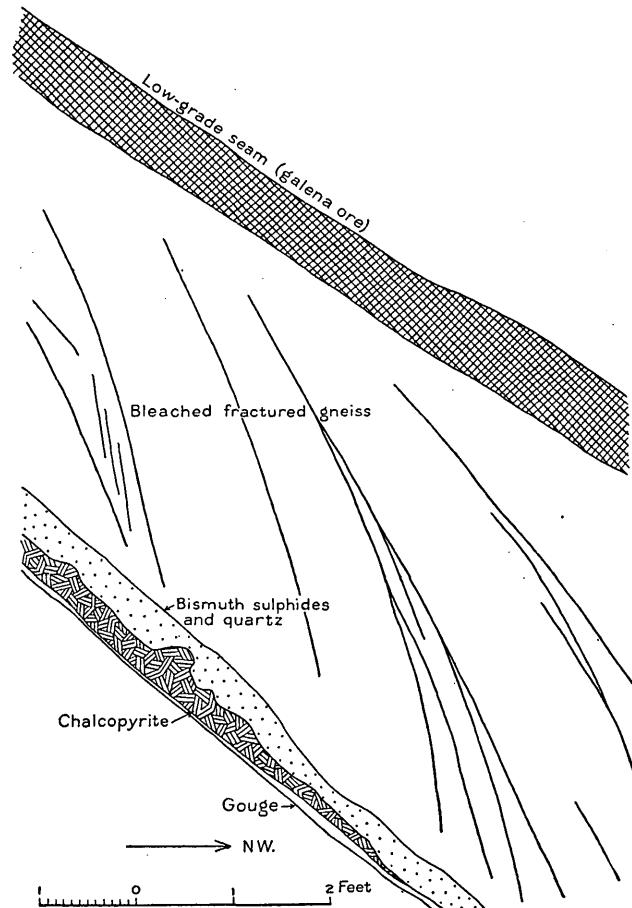


FIGURE 18.—Occurrence of ore in Missouri mine, 10 feet above level 5.

In 1928 the mine was developed by three accessible adits at altitudes of 11,600, 11,628, and 11,710 feet. As shown on plate 24, there are about 2,100 feet of drifts on the three levels and 150 feet of winzes. Most of the work from 1923 to 1928 was done below the upper adit, locally known as tunnel 3, and the bulk of the production has come from the vein opened by adit 5.

The country rock of the mine is hornblende and injection gneiss of the Swandyke gneiss. The schistosity strikes about N. 25° W. in most of the mine and dips 65°-85° E. The gneiss

is cut by several strong bedding-plane faults that are later than the vein fissures, although not certainly later than the vein fillings. The strongest of these northwesterly faults was found 110 feet from the portal of adit 4 and is probably the same as the fault found 120 feet from the portal of adit 3. No veins have been found that cross this fault. The Laclede vein, on the west side of the fault, bends to the north as it approaches the fault; on level 4, 350 feet from the portal, a westward-dipping vein flattens notably as it goes into the fault from the east; the northwestward-dipping Missouri vein ends abruptly to the west at the fault, but no drag was observed; the Leftwick vein was not found on level 4 until after the fault had been passed, but beyond it was followed with little difficulty for 400 feet. Grooves and striations on the walls in adits 3 and 4 are consistent and dip 45°-50° SE. Although the data are incomplete, it is believed that the east wall of the fault moved downward and southeast past the west wall, but the amount of displacement is not known. The only ore shoot that justified stoping on the Leftwick vein in the 400-foot drift on level 4 was found close to its junction with the northwesterly fault. The mineralization of the Missouri vein was weak where it was first cut by adit 5 but became stronger and stronger toward the fault, and the best ore occurs within 100 feet of the fault. Small masses of ore have been found in many other veins in the mine, but all of them are close to the northwesterly fault. These facts suggest that the northwesterly fault was an ore channel and was instrumental in localizing ore shoots in the veins which it intersects.

The Missouri mine is the only one in the Montezuma quadrangle where the occurrence of bismuth ore could be satisfactorily studied. The Missouri vein contains lead and bismuth ore, but the bismuth is generally distinct from the lead. The Missouri vein strikes N. 20°-50° E. and dips about 45° NW., although locally steeper and flatter dips occur. As shown in figure 18, the lode is a wide sheeted zone and carries ore chiefly on the footwall. On level 4 the ore shoot extends from the main northwesterly fault to a point about 140 feet northeast, where the workings broke into hillside wash. On level 3 the ore shoot was barren gouge for the first 15 feet northeast of the fault, but farther northeast the ore was continuous to the surface. The ore close to the fault was highly oxidized, and the raise from level 4 to level 3 at the southwest edge of the ore shoot close to the fault is known as the "Canary-Yellow raise" because of the brilliantly colored oxide of bismuth that was abundant here. The ore rapidly graded into sulphides northeast of the fault, and there was little evidence of oxidation even at the surface. Near the fault, however, white and yellow oxides of bismuth are conspicuous as far down as the ore shoot was explored in 1928. The occurrence of the oxidized ore so close to the bottom of a heavily glaciated valley suggests deep oxidation in preglacial time. Remants of an ancient land surface, the Eocene Flattop peneplain, are well preserved in the summits of the mountains bordering Hall Valley on the west and north. Reconstruction of this ancient peneplain over the valley suggests that the surface may have been as much as 700 feet above level 4, but it is probable that Hall Valley had been cut a few hundred feet below the peneplain before the end of Tertiary time. Oxidation along favorable channels may have reached a depth of several hundred feet in late preglacial time, and the acceleration of deep ground-water circulation caused by glacial trenching during Pleistocene time may have been one cause in effecting the oxidation of the ore.

The sulphide ore occurs in two well-defined seams known as the high-grade or footwall streak and the low-grade or hanging-wall streak. There is everywhere a thin seam of gouge between the high-grade ore and the solid rock wall; the low-grade streak is separated from the underlying high-grade streak by 1 to 40 inches of gouge or highly altered sheeted rock and vein

matter. The thickness of the footwall ore seam ranges from that of a knife blade to a maximum of 12 inches but is generally between half an inch and 5 inches, averaging about 3 inches; the thickness of the low-grade seam ranges from 6 to 36 inches and is usually about 15 inches. Where unoxidized the chief minerals of the high-grade streak are clear, fine-grained quartz, "bismuth-silver", and bismuthinite, but locally chalcopyrite and galena are present. (See p. 54 for an analysis of the mineral called "bismuth-silver.") Wherever chalcopyrite is present in the footwall seam it is said to be always below the bismuth-bearing quartz and to lie on a thin seam of gray talcous gouge. Bismuth is almost wholly confined to the footwall streak, but some bismuth was found in the hanging-wall ore above the third level. Here the copper content of the hanging-wall streak decreased as the bismuth content increased. The chief minerals of the hanging-wall streak are quartz, pyrite, chalcopyrite, and a dark-colored gray copper. Locally galena is abundant, reaching a thickness of 24 inches in some places (fig. 19); barite also occurs locally and usually is associated with galena. Near the main northwesterly fault the high-grade streak was completely oxidized to the white and yellow oxides of bismuth, but the hanging-wall streak, though heavily stained with malachite, contained fresh chalcopyrite. Chalcopyrite is more abundant on the upper levels than on the lower levels, and the dark-colored gray copper is more abundant between levels 4 and 5 than elsewhere in the mine. Ore rich in chalcopyrite contains more gold and silver than the gray copper and lead ores. Pure galena assays about 18 ounces of silver to the ton, and the dark-gray copper assays about 100 ounces. The high-grade ore commonly contains from 5 to 10 percent of bismuth, 1 to 8 ounces of gold and 100 to 1,200 ounces of silver to the ton, and a few percent of copper. The analysis of two shipments of

and at the place where it again flattens to its normal dip there is a large wrinkle in the footwall, as illustrated in figure 20. The ore decreased to a thin, nearly barren seam as the vein steepened and disappeared near the crest of the hump caused by the wrinkle in the wall; on the other side of the hump, however, the trough contained a mass of very high grade bismuth sulphide ore about 5 feet long, 4 feet wide, and 12 inches thick in the center. The axis of the trough pitches

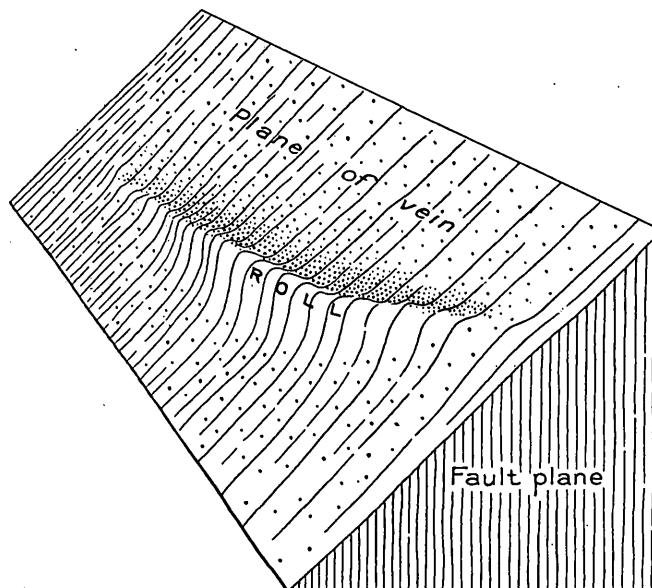


FIGURE 20.—Occurrence of ore in "roll" in Missouri mine.

about 30° NE., away from the main northwesterly fault. The thinning and disappearance of the ore where the dip steepened and the occurrence of a rich pocket where the vein flattened strongly suggest that the Missouri vein occupies a premineral reverse fault. On level 5, as shown in figure 19, the occurrence of the thickest mass of solid galena in the low-grade streak is coincident with a marked flattening of the ore seam.

Little could be seen of the ore occurrence in the other veins of the mine, and most of the information obtained is recorded on plate 24. The ore in the Leftwick vein was chiefly galena, gray copper, and chalcopyrite in a quartz-barite gangue. The width of the ore ranged from 3 to 24 inches and was commonly about 6 inches. Some ruby and native silver are reported from the upper levels. The total development on this vein is unknown, but in 1883 there were six adits on the vein aggregating 2,000 feet.

High-grade bismuth ore is said to have been shipped from the northward-trending vein opened by the southern workings of level 3. This drift, like most of the others in the mine, is very wet, and aside from a heavy copper stain in the walls of the drift near the old stopes little could be seen. According to the miner who worked this part of the mine in the eighties, the vein in the breast was chiefly barren gouge, but at the raise 90 feet north the vein carried 12 inches of good ore, which pinched to a seam of gouge a short distance farther north but widened to pay ore in 20 feet and continued as such for 100 feet. Most of this ore shoot has been stoped above the level, but it is reported that the large amount of water present compelled the miners to abandon the winze near the center of the ore shoot before any ore had been taken out below the level. The ore is said to be very similar to that in the Missouri vein farther north, consisting of a vein of low-grade ore against the hanging wall and one of high-grade ore on the footwall.

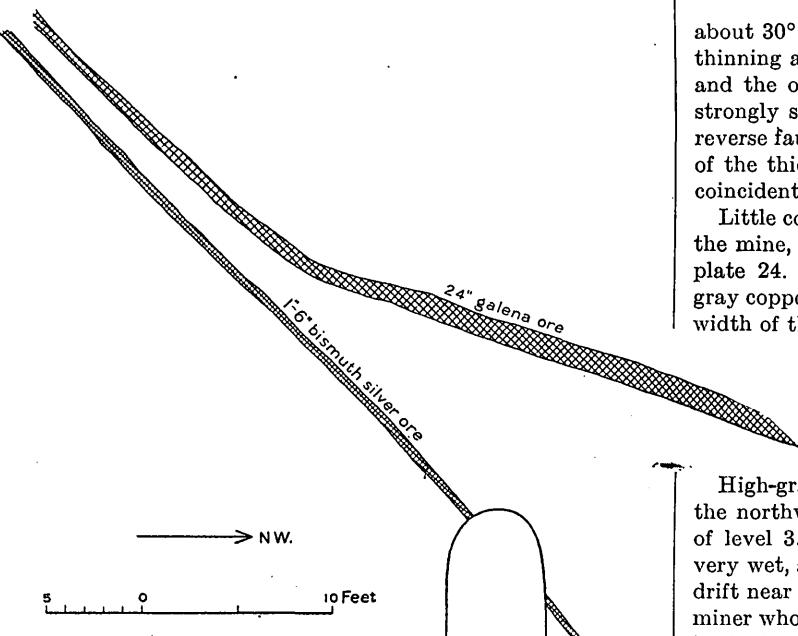


FIGURE 19.—Relations of "low grade" (galena) ore seam to "high grade" (bismuth) ore seam, level 5, Missouri mine.

high-grade ore showed (a) 22 percent of bismuth, 3.80 ounces of gold and 280 ounces of silver to the ton, and 3 percent of copper; (b) 10 percent of bismuth, 8 ounces of gold and 260 ounces of silver to the ton, and 3 percent of copper.

An interesting structural feature was associated with the richest pocket of bismuth ore in the mine. About halfway between levels 3 and 4 and 30 feet northeast of the main northwesterly fault the Missouri vein becomes much steeper,

MOHAWK

The Mohawk mine is on the northwest slope of Teller Mountain at an altitude of about 11,500 feet, about 2 miles south of Montezuma. There is no road to the mine, and the ore must be packed over a trail to the Chatauque mine road on Deer Creek, which it joins 1½ miles from Montezuma. The vein was discovered in 1880 by John Sundragger and was a steady but small shipper during most of the eighties. The known production of the property is given below.

The mine has two accessible adits, as shown on plate 29. The portal of the lower adit is about 175 feet below the upper adit, and all the production has come from the upper level. The country rock of the district is the Swandyke gneiss, which strikes about N. 30° W. and dips 50° SW. The Mohawk vein strikes slightly north of west and dips steeply to the north. It is a fissured zone from 1 to 5 feet wide and contains from 4 to 24 inches of quartz and galena. The lead ore occurs in chimneys separated by nearly barren masses of quartz. The ore shoot being worked in 1928 was about 70 feet long and had been proved to a depth of 30 feet below the level. The ore carries little silver and no copper, a shipment of 37 tons averaging about 9 ounces of silver to the ton and 42 percent of lead.

Production of Mohawk mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead, wet
assay
(pounds) |
|------|------------------------|--------------------------|----------------------------|--------------------------------|
| 1882 | 10 | | | |
| 1883 | 45 | | | |
| 1884 | 45 | | | |
| 1886 | 58 | | | |
| 1887 | (?) | | 144 | 9,604 |
| 1888 | (?) | | 110 | 12,388 |
| 1889 | (?) | | 537 | 55,619 |
| 1925 | 37 | 0.60 | 339 | 31,202 |

No record available for 1885, 1890-1900; no production in 1901-24, 1926-28.

MORE WORK

The More Work vein is on the west side of Glacier Mountain 1 mile south-southwest of Montezuma, and is only 500 feet north of the main adit of the Sts. John mine. The property is developed chiefly through an adit whose portal has an altitude of about 11,050 feet. Some stoping has been done on this level, and about 50 tons of ore is known to have been shipped. The history of the mine was not ascertained. As shown in plate 28, the vein strikes N. 60°-80° E. and dips about 70° N. The country rock is hornblende gneiss of the Swandyke gneiss; it strikes east-northeast to west-northwest and dips 35°-70° E. The unstopped portions of the vein are from 5 to 12 inches wide. Barite is the most abundant mineral in the vein, but galena and sphalerite together make up more than half of the vein in many places. Quartz is also common. The branching character of the vein, shown in plate 28, makes its course difficult to foretell in advance of development work. The vein will probably be cut off a short distance east of the 1929 breast by the northerly fault, which terminates the Comstock vein (no. 5 vein) of the Sts. John mine a few hundred feet south. As this is a normal fault, the eastern continuation of the More Work vein is some distance south of the western segment.

Production of More Work mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead, wet
assay
(pounds) | Zinc
(pounds) |
|------|------------------------|--------------------------|----------------------------|--------------------------------|------------------|
| 1910 | 5 | | 194 | 2,913 | |
| 1917 | 35 | 0.17 | 700 | 7,765 | 21,645 |
| 1919 | 10 | | 303 | 462 | |

No production in 1901-9, 1911-16, 1918, 1920-28.

MORGAN

The Morgan mine is on the south slope of Tiptop Peak about half a mile east of Montezuma. It is developed by three adits between altitudes of 10,975 and 11,205 feet and is reached by a steep wagon road from the town. The mine was worked in the eighties, but only a small amount of ore was shipped. It has produced a few carloads of ore intermittently since 1900 but has never been worked for many years at a time.

Production of Morgan mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead, wet
assay
(pounds) | Copper,
wet assay
(pounds) | Zinc
pounds) |
|------|------------------------|--------------------------|----------------------------|--------------------------------|----------------------------------|-----------------|
| 1889 | (?) | | | 23 | 1,738 | |
| 1901 | 4 | | | 40 | 5,647 | |
| 1917 | 70 | 1.25 | 401 | 14,952 | 662 | 47,689 |
| 1919 | 3 | .10 | 27 | 3,034 | | |

No record available for 1890-1900; no production in 1902-16, 1918, 1920-28.

The Morgan mine is typical of many small mines in the Montezuma quartz monzonite and is therefore discussed in some detail as representing a type. The underground workings, aggregating about 1,800 feet, and the geology are shown in plate 30. The country rock of the entire property is the Montezuma quartz monzonite. The lowest adit contains no stopes, and no ore was observed in it. The drifts follow strong gouge fissures, which are heavily stained with manganese dioxide near the surface. A short distance underground the fissure filling is a light-colored talcous gouge, which is more or less stained with limonite. This gouge was reported to have a high gold content, but the writer found none, although he panned several pounds of it. The heavy residue at the end of the operation proved to be crushed pyrite, and no doubt it is this mineral that has given the iron-stained appearance to the gouge. As shown in plate 30, the main fissure, striking about N. 80° E. and dipping 55° N., cuts and displaces a fissure that strikes N. 55° E. and dips 65° NW. The movement indicates that the main fissure is a normal fault.

The intermediate adit has been driven close to the mine buildings, which include a boarding house, smithy, and compressor house. The adit cuts three fissures which are almost parallel and strike about N. 60° E. and dip 62°-70° N. The first fissure, 80 feet from the portal, is a barren iron-stained sheeted zone about 3 inches wide. The second fissure, 180 feet farther in, is marked by 2 feet of altered sheeted rock, 6 to 12 inches of gouge, and 2 to 4 inches of sulphides, most of which are badly crushed. A drift follows this vein 40 feet, and a seam of crushed pyrite from 2 to 3 inches wide persists throughout this distance. A seam of severely crushed zinc blende from half an inch to 2 inches thick is also present most of the distance, but the galena occurs sporadically in a few crushed lenticular masses 1 to 2 inches wide and 2 to 5 feet long. The third fissure contains a sulphide vein from 4 to 15 inches wide under a hanging wall of gouge from 1 to 8 inches wide. As shown in plate 30, the sulphide vein turns out of the drift away from the gouge seam 10 feet southwest and 100 feet northeast of the main crosscut. It is probable that postmineral movement developed the gouge, and that the movement was only locally confined to the vein. Manganiferous ankerite is about as abundant as the sulphides in the vein. The ankerite occurs as solid seams from half an inch to 5 inches thick, parallel to the sulphide. The sulphide is predominantly pyrite, but light-colored sphalerite is also abundant. Sporadic bunches of galena were observed, but none were large enough to be stoped.

The upper adit has produced all the ore that has been shipped. The veins that have been stoped are nearly parallel

and strike N. 75° - 80° E. and dip 60° - 80° N. In some places they send off northeastward-trending branches, and in others they are crossed by small veins that strike N. 35° - 55° E. Stoping ore commonly occurs at the intersections of cross veins or where a branch vein forks from the main easterly veins. In the widest vein cut by the adit, however, a chimney of ore that extended to the surface is not related to the intersection of fractures on this level. This vein consists chiefly of quartz and pyrite, but sphalerite is also abundant, and lenticular bunches of galena are common. The ore is from 2 to 28 inches wide. The next vein, about 120 feet farther north, is much flatter and varies greatly along both the dip and strike. In the exposed part of the vein the chief mineral is manganeseiferous ankerite about 6 inches wide. Thin layers of pyrite and sphalerite occur in the ankerite, generally in crustified layers. The vein at the breast of the adit in 1929 was chiefly quartz and pyrite but carried abundant sphalerite at its intersection with a cross vein about 20 feet east. This vein is about 8 inches wide and is open and vuggy in many places. Very little ankerite was observed in it.

NEW YORK AND ALLADINS LAMP

The New York mine is on the southeast edge of Montezuma at an altitude of about 10,350 feet. Several veins have been cut by the New York tunnel, the largest of which are the New York and the Alladins Lamp. The Alladins Lamp was discovered in 1882 by Oliver Milner, and some ore from it was shipped in 1888 and 1926, as shown below. No production has been recorded from the New York vein, and little is known of its history.

Production from Alladins Lamp vein

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Copper
wet assay
(pounds) | Zinc
(pounds) |
|-----------|------------------------|--------------------------|----------------------------|---------------------------------|------------------|
| 1888..... | (?) | | | | |
| 1926..... | 25 | 0.86 | 67
115 | 762
9,164 | 6,839 |

No record available for 1880-1900; no production in 1901-25, 1927-28.

The underground workings are shown in plate 31. The country rock of the mine is Montezuma quartz monzonite, and it is cut by northeasterly and easterly mineralized fissures and northerly barren fractures. The northerly fractures are nearly vertical and are later than the mineralized fissures, but the displacements of the faults are small, and many of them do not persist along their strike for more than a few hundred feet. The New York vein is the best-mineralized vein in the mine and has been followed for about 900 feet. It strikes northeast and dips about 70° NW. In some places it is barren, but for most of its length it carries sphalerite, galena, and pyrite in a quartz-ankerite gangue. The ore seam is generally from 4 to 10 inches wide, but in the main shoot, about 1,000 feet from the portal of the tunnel, the vein is from 10 to 36 inches wide for a distance of about 300 feet. No stoping had been done here in 1929, but a raise 60 feet high showed the ore to be 24 inches wide for this distance above the drift. Channel samples taken at many places on this ore shoot are said to average about 35 percent in combined lead and zinc. The lead and zinc are nearly equal in most samples, but in some of them one metal is as much as five times as abundant as the other. The ore in the Alladins Lamp vein is from 3 to 6 inches wide and is similar to the ore in the New York vein. Most of it carries about 10 ounces of silver to the ton, but assays of 20 ounces have been obtained from some places.

The ore in the New York vein is the largest and most continuous body of ore which the writer has seen in the Montezuma quartz monzonite. It contains so much zinc and iron

that it could not be shipped unless these constituents were separated from the lead, and in 1929 there were no successful flotation mills near Montezuma. The ore shoots are not found at the junction of fractures, as in the Morgan mine, but on the contrary the ore becomes poorer in most places where two fractures intersect. A strong, well-mineralized fissure commonly splits and branches at its junction with another vein, and both become nearly barren. It is probable that the stresses that produced most of these premineral fractures in the Montezuma quartz monzonite were relieved by many small fractures where major fissures crossed. The lack of mineralization at the junctions would thus be explained by the poorer channel for circulation afforded in these parts of the veins. The lack of continuity of the veins and the branching character of the fractures are shown in plate 31.

OLD SETTLER AND WATERLOO

The Old Settler vein is on the east slope of Collier Mountain directly east of Montezuma, and the western part of the vein, known as the "Waterloo", has its lower dump within the limits of the town site. The Old Settler was discovered by Joseph Duffield in 1865 and worked intermittently through the seventies and eighties. Raymond's report for 1870 states that the Old Settler was developed by a tunnel 260 feet long and that the ore streak, which assayed from 20 to 100 ounces of silver to the ton, was 2 feet wide and contained galena, sphalerite, gray copper, and pyrite. There is no recorded production from the property, but it is said to have shipped a small amount in the seventies. The vein is well exposed in a small cut on the Waterloo claim, a short distance east of Montezuma, but the workings were inaccessible in 1929. The vein strikes N. 60° - 65° E. and dips steeply to the north. Where it is exposed it is about 12 inches wide and consists predominantly of galena, sphalerite, and pyrite in a quartz gangue. The sulphides are much more abundant than the quartz; galena and sphalerite are present in about equal amounts and are more abundant than the pyrite.

OLD TIMER

The Old Timer lode is on the northeast slope of Glacier Mountain, about half a mile south of Montezuma. The chief adit is at an altitude of about 10,600 feet, a few hundred feet south of the Silver King tram. The Old Timer was discovered in 1881 by Messrs. Benight and Robbins. Several years earlier the St. Lawrence Mining Co. had driven a tunnel 300 feet on a barren vein parallel to the Old Timer and only about 15 feet away. This old drift was used by Benight and Robbins, who drove crosscuts from it to their vein. Two other adits were driven on the vein, and a few carloads of lead-silver ore were shipped in the next few years. The known production of the mine is given below.

In 1882 the local paper noted that the lower level was 100 feet long and carried a wide quartz vein streaked with galena, and that in the upper adit, then about 70 feet long, 12 inches of nearly solid galena had appeared in the breast. The galena carried a small amount of wire silver in some places. According to the Colorado Mining Directory for 1883, the ore when sorted assayed from 100 to 225 ounces of silver to the ton and about 30 percent of lead. Little work has been done on the property since the eighties, and its total production has been small.

The country rock of the vein is the Swandyke gneiss, which strikes N. 20° E. and dips about 75° E. The vein strikes north-northeast and dips about 70° NW. As shown in plate 32, only one short stope has been made on the vein. At the ends of the stope the vein has 6 inches of galena and manganeseiferous ankerite, but the ore on the dump suggests a vein from 6 to 10 inches thick consisting chiefly of galena and quartz. The

galena is disseminated through the quartz and is associated with a moderate amount of light-brown sphalerite. A little pyrite is present but seems confined to the wall rock. Barite and manganosiderite are present in many of the specimens lying on the dump and appear earlier than the sulphides and quartz.

Production of Old Timer mine

| | Ore
(short
tons) | Silver
(fine
ounces) | Lead, wet
assay
(pounds) |
|-----------|------------------------|----------------------------|--------------------------------|
| 1881..... | 5 | ----- | ----- |
| 1882..... | 15 | ----- | ----- |
| 1883..... | 5 | ----- | ----- |
| 1887..... | (7) | 80 | 5,362 |

No record available for 1884-86, 1889-1900; no production in 1888, 1901-28.

ORPHAN BOY

The Orphan Boy is on the east slope of Morgan Peak near the head of Warden Gulch, about a mile east of Montezuma. It is developed by three adits between altitudes of 11,800 and 12,100 feet. The vein was discovered before 1875, but the exact date is not known. It was worked intermittently from 1875 to 1890, but little work has been done on the property since then. The mine produced 45 tons of ore in 1881, 100 tons in 1887, and an unknown amount that yielded 378 ounces of silver and 1,894 pounds of lead in 1889. According to the Colorado Mining Directory for 1883, the Orphan Boy was developed at that time by a drift 150 feet long and a crosscut tunnel 125 feet long. The ore was reported to be galena in a quartz gangue, assaying when sorted from 10 to 40 ounces of silver to the ton and about 35 percent of lead. The vein was said to be from 10 to 30 inches wide.

PAYMASTER

The Paymaster mine is in Horseshoe Basin a quarter of a mile north of Falls Gulch and about 4½ miles northeast of Montezuma. The shaft is at an altitude of 12,050 feet and was partly filled with water in 1929; the adit has an altitude of 11,725 feet and was inaccessible when the writer visited it. The Paymaster vein was discovered in the late sixties, and its ore is briefly mentioned by Raymond in his report for 1870. The activity of the Argentine district in 1870, caused by the developments on the Baker and Belmont veins, encouraged prospecting in Horseshoe Basin, and some work was done on the Paymaster at that time, but it was not until 1879, when the claim was relocated, that active development was undertaken. In the next few years an 80-foot shaft was sunk on the vein, and a few hundred feet of drifts were driven. A three-story mill was completed in 1882 and was joined to the mine by a tramline 1,300 feet long. The Paymaster, Silver Ball, and Seven-thirty claims, all on the same vein, were patented in 1881.

The recorded production of the mine is small. Some galena ore was shipped to Frisco in 1882 but probably not more than 10 tons. In 1883, according to the Montezuma Mill Run, the mine was having development work done, but no mention of shipments was made. According to the same authority it was active in 1884, 1885, and 1886 and shipped some ore in 1886, probably about 30 tons.

Production of Paymaster mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet
assay
(pounds) | Copper,
wet
assay
(pounds) | Zinc
(pounds) |
|-----------|------------------------|--------------------------|----------------------------|-----------------------------------|-------------------------------------|------------------|
| 1882..... | 10 | (?) | (?) | (?) | (?) | (?) |
| 1886..... | 30 | (?) | (?) | (?) | (?) | (?) |
| 1917..... | 12 | 0.54 | 153 | 10,403 | 74 | ----- |
| 1922..... | 23 | 1.40 | 200 | 4,375 | ----- | ----- |

No record available for 1893-1900, 1918-21; no production in 1883-85, 1887-92, 1901-16, 1923-28.

As shown above, the mine is credited with two shipments since 1902. This ore probably came from the Paymaster shaft, where the vein is reported to have had seams of quartz and galena about 10 inches in aggregate thickness in a sheeted zone about 4 feet wide. The ore on the dump near the shaft indicated that the vein was at least 10 inches wide. It consisted largely of coarse-grained vuggy quartz, barite, and galena, but manganosiderite and light-colored sphalerite were common. Pyrite was confined to the wall rocks. The ore milled in the eighties, according to the Colorado Mining Directory, assayed about 34 percent of lead and 30 ounces of silver to the ton. The vein is nearly parallel to the schistosity of the enclosing Idaho Springs formation, which is almost vertical and strikes north-northeast. The country rock is injection gneiss and quartz-biotite-sillimanite schist.

The paragenesis of the ore on the dump shows that silicification and pyritization of the wall rocks occurred early and was followed by the formation of manganosiderite in the vein; barite was deposited later and was followed by galena, sphalerite, and quartz. A large amount of quartz is later than all the other minerals.

PENNSYLVANIA

The Pennsylvania mine is on the northwest slope of Decatur Mountain, about a quarter of a mile south of Peru Creek and 3 miles east-northeast of Montezuma. It has been one of the most productive mines in the quadrangle and has a large mill run by electric power and several smaller buildings for living quarters and offices. The mine is easily accessible by automobile over a good wagon road, which has few steep grades. The mill and the mine buildings are at an altitude of about 10,900 feet and are connected with the two main openings of the mine by short aerial tram lines.

The vein was discovered by J. M. Hall in 1879 and slowly but steadily developed by him and his associates during the next decade. Almost no ore was shipped until about 1887, but from this year until 1893 the production of the mine increased steadily from a few carloads to nearly 7,000 tons a year; from 1894 to 1907 the mine was active, but production gradually fell off, and in 1908 no ore was shipped. The production has been intermittent since 1909 and has fluctuated greatly; thus over 12,000 tons of ore was treated in 1911, less than 50 tons the next year, and about 3,000 tons in 1913. Early in 1892 the mine was leased by the original owners, J. M. Hall, R. S. Morison, B. A. Hopkins, C. N. Foster, and J. H. Husted, to the Decatur Mining Syndicate, Ltd., an English organization, which operated the property during the peak of its production but disposed of it in 1895 to the Pennsylvania Mines Co., which held it for several years. The ore sold prior to 1894 was sorted by hand and shipped directly to the smelters, but in 1895 a mill was completed, and almost all the ore sold since that time has been concentrated in the mill, which has been revamped several times. In 1902 the Ohio Mines Co. bought the property and drove the lowest level on the vein, known as the Ohio or F level. The mine again changed hands in 1905 and was held by the New Pennsylvania Mines Co. until 1918; it was then taken over by the Liberty Mining & Reduction Co. and operated by that company until 1927, when the company was reorganized as the Consolidated Pennsylvania Mining Co.

The mine is opened by six levels, known as A, B, C, D, E, and F. Level A is the highest and is 30 feet above level B but is not connected with it. Both are adits but have long been caved. Level C, 130 feet below level B, is opened by an adit whose portal is at an altitude of 11,290 feet and is connected to the mill by an aerial tram. It was the level through which the mine was operated for many years, and a winze sunk on the vein from this level was used for opening levels D and E, 50 and 130 feet below level C. Level F was opened by another adit and is about 100 feet below level E, its portal having an

altitude of 11,058 feet. The geology and the plan of the accessible workings are shown in plate 33.

The Pennsylvania vein strikes N. 20° – 35° E. and averages about N. 30° E. It dips steeply to the west in most places but locally overturns and dips about 80° E. The vein is chiefly in schistose rocks a few hundred feet east of the Montezuma quartz monzonite stock. (See pl. 3.) The most common rocks on the lowest level of the vein are quartz schist, quartz-biotite schist, injection gneiss, and granite gneiss. Locally thin dikes of Silver Plume granite are present, and a dike of quartz monzonite is cut near the breast of the southwestern split of the vein. (See pl. 33.) On level C the prevailing wall rocks are granite gneiss and injection gneiss, but Silver Plume granite, quartz monzonite porphyry, and quartz-biotite schist are cut by the crosscut on this level. The wall rock of the vein has been markedly silicified and pyritized for a distance of 30 feet west of the vein, but east of the vein the silicification was less intense, although pyrite is abundant 20 feet away.

Only a part of level C was accessible at the time of the writer's visit. The vein has been stoped for over 800 feet on this level, and the stopes are from 6 to 14 feet wide, the largest stopes being at the place where the vein divides into the "east and west splits." As shown in plate 33, these two branches diverge at an angle of about 25° until they are nearly 50 feet apart and then resume the general course of the main vein, continuing parallel as far as they have been explored.

About 180 feet northeast of the "split" and a short distance north of the point where the level C crosscut intersects the vein a pillar of ore has been left. This ore is probably of lower grade than much of that taken from the stope but is instructive as illustrating its general mode of occurrence. The vein here is about 12 feet wide and is a strongly sheeted zone in granite gneiss. Between the walls of the sheeted zone numerous veins of galena, pyrite, chalcopyrite, and quartz seam the altered gneiss. Most of the minor veins are parallel to the walls, but several of them follow an irregular diagonal course across the sheeted zone. Galena is the most abundant mineral in the veins and occurs in seams from 1 to 12 inches wide; about 30 inches of the sheeted zone is galena, 8 inches pyrite, and 2 inches chalcopyrite. The relations of the veinlets clearly show that quartz, pyrite, and chalcopyrite are earlier than galena and that a small amount of dolomite formed later than the galena. According to the miners some of the best ore at the "split" was 14 feet wide, contained less than 2 feet of waste, and carried very little pyrite. Argentiferous gray-copper ore was much more abundant near the surface than in the lower workings, and according to the Georgetown Courier for September 11, 1890, when the vein was first opened large quantities of copper sulphate were found.

Level F follows the vein 1,800 feet south of the level C crosscut, and here, almost vertically below the "split" in level C, the vein branches. The west branch, which has been followed 300 feet farther, is apparently the main vein and shows little change from the course followed by the vein to this point. The east branch has been followed about 200 feet. The walls of the vein and its branches have been intensely silicified and pyritized throughout the level. The vein is smaller on this level than it is on level C, and the ore is commonly lean, pyritic, and thin, but in a few places some good lead ore occurs and stoping has been done. A few feet north of the crosscut a winze was sunk to an unknown depth in 1902, and according to Thomas Sharpe, who worked in the mine in that year, the vein carried only pyrite and quartz as far as the winze was sunk, and no drifts were turned from it. The vein is said to maintain its westerly dip to the bottom of this winze. About 350 feet south of the crosscut the first shoot of lead ore occurred in the vein on level F, although small amounts of galena were sparsely distributed in the pyritic quartz of the vein in many places north of this

place. The ore shoot was about 12 inches wide and 50 feet long and, unlike the others seen, dipped steeply to the east. A short distance farther south the vein resumed its normal dip and again became pyritic. At 70 feet south of this ore body another galena ore shoot was found. The vein here was from 3 to 5 feet wide and had 12 to 30 inches of galena ore for a distance of about 100 feet along the drift. At the south end of the ore shoot a winze was sunk 75 feet. The winze was full of water at the time of the writer's visit, but the vein is said to have galena ore in it as far as the winze was sunk; the maximum width of lead ore in the winze is reported to be about 24 inches, but little stoping was done below the level. Apparently the amount of galena was not large enough to pay the cost of pumping the heavy flow of water found in the winze. At 220 feet south of the winze a short galena ore shoot was found, and a raise has been put up on the vein. At the level of the drift the vein dips 73° W.; 30 feet above it the vein becomes vertical; and 70 feet above the level it overturns and dips 85° E. The galena ore 30 feet above the drift is distributed through about 24 inches of broken sheeted rock, but 70 feet above the drift it pinches to 4 inches in width. Little ore was exposed between this ore body and the place where the vein branches. Here a short crosscut toward the west exposes a sheeted zone about 7 feet wide containing many veins and stringers of galena, which aggregate about 12 inches in width. Very little ore is exposed in the west branch, however, until a point about 140 feet farther south is reached; here an ore shoot containing both lead and copper was found, and some stoping has been done. This shoot is about 80 feet long on level F but is somewhat longer a short distance above it. Although the drift was less than a year old at the time of the writer's visit, the water from the vein carried so much copper that deposits of metallic copper half an inch thick and from 3 to 7 feet long were formed in many places on the iron rails under the stope. The east branch contains very little galena but is heavily seamed with pyrite; this part of the vein is from 12 to 48 inches wide and in places carries as much as 15 inches of pyrite.

Small veins striking parallel to the Pennsylvania vein occur east of it on both levels C and F. The Ouray vein is cut 225 feet east of the Pennsylvania vein on level C. It strikes N. 30° E., dips 80° W., and carries 2 inches of galena ore. On level F a narrow vein locally stained with copper, iron, and manganese is cut about 75 feet east of the Pennsylvania vein. It has been followed about 200 feet north and south of the main crosscut but without encouraging results. About 100 feet farther east another small vein carrying calcite and pyrite was found. No other veins were discovered in this crosscut. The breast is about 400 feet east of the main vein, and there is a heavy flow of water issuing from it.

No conclusive evidence has been found regarding the direction of the premineral movement on the Pennsylvania fissure. Grooves and striations on the wall of the vein dip about 30° SW.; the occurrence of galena in diagonal fractures such as those shown in plate 33 suggests gash veins in a reverse fault; and the marked thinning of the northeastern ore shoot on level F where the vein steepened and overturned toward the east suggests the closing of an irregular open fissure by reverse faulting. The meager evidence available indicates that the west wall moved upward to the northeast relative to the east wall.

As shown on plate 3, the Pennsylvania vein is nearly parallel to the schistosity of the enclosing schist and gneiss. In the Central City and Idaho Springs districts deep exploration has shown that the most productive veins either cut across the schistosity of the country rock or have walls of granite gneiss, porphyry, or pegmatite.²³ In many veins in those districts the

²³ Lovering, T. S., Localization of ore in the schists and gneisses of the mineral belt of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, pp. 234–268, 1930.

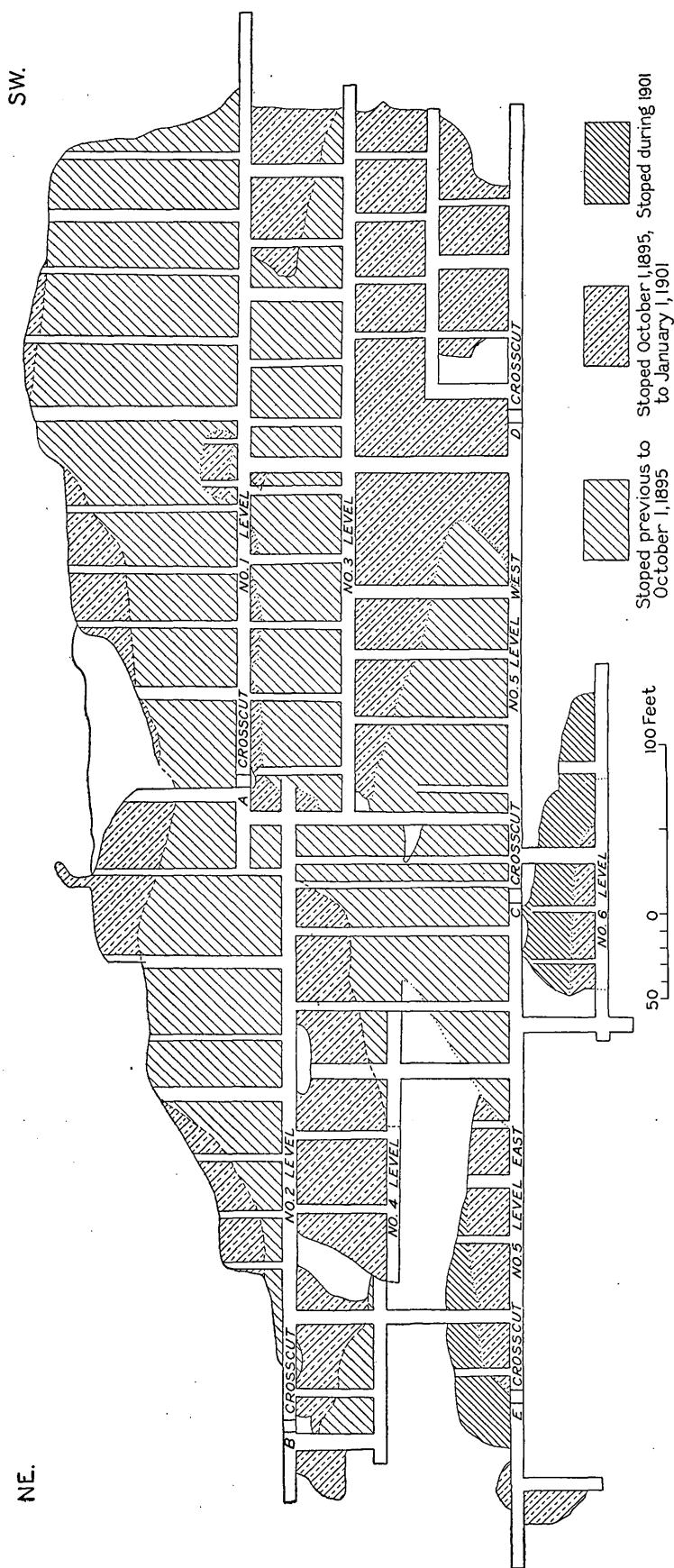
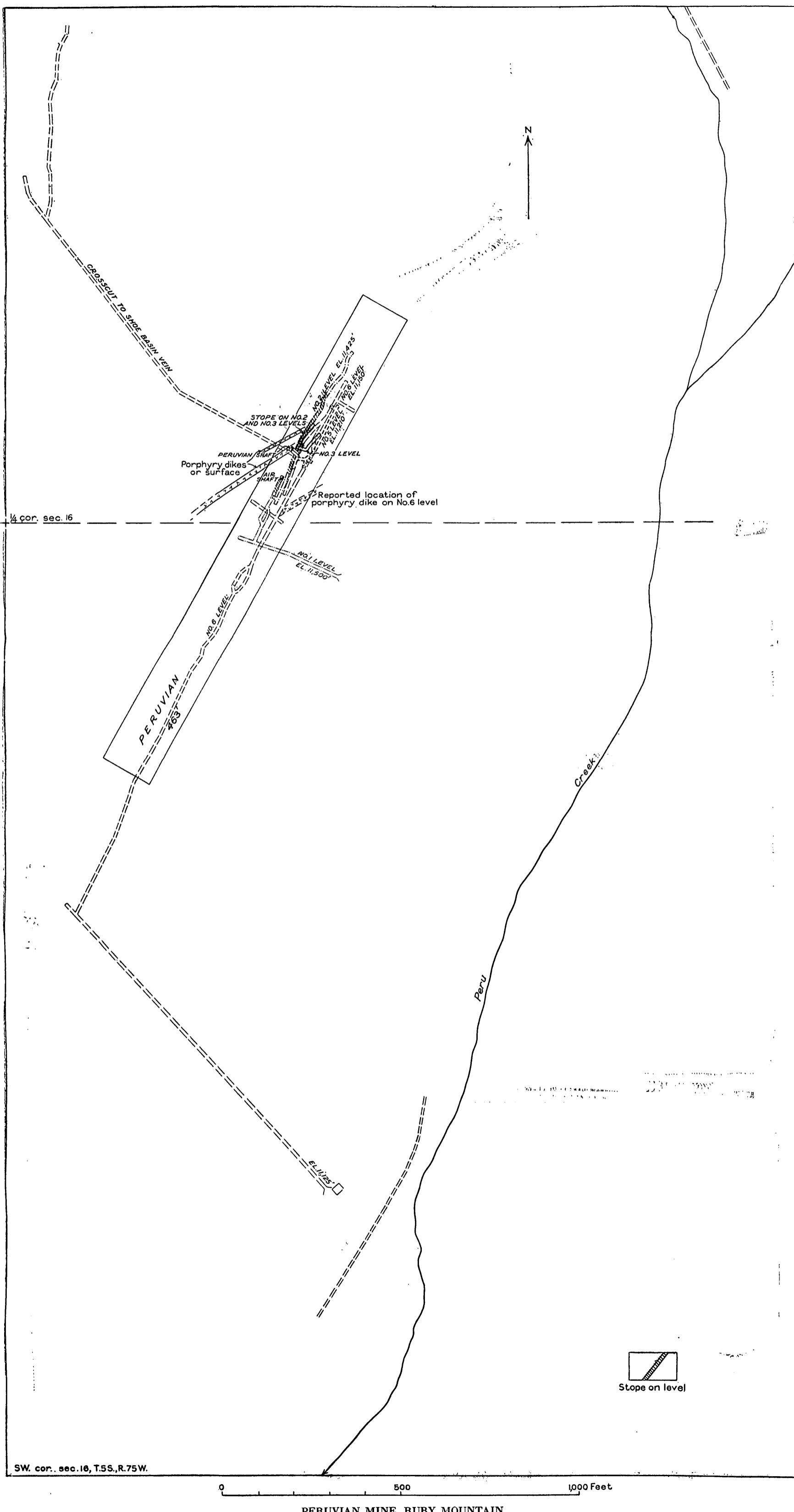


FIGURE 21.—Stope map of north vein of Pennsylvania mine, 1902.



occurrence of ore shoots is definitely related to the occurrence of layers of granite gneiss in the Idaho Springs formation, and an apparently barren vein becomes productive on passing into granite gneiss, or a productive vein becomes barren on passing into schist. In the Montezuma district ore shoots are most commonly found in veins where the schistosity of the enclosing rock makes a decided angle with the vein, or at the intersection of two veins. The large body of ore found in the Pennsylvania vein occurs where it branches and in that part of the vein which has walls of granite gneiss. The split in the vein occurs very close to the south end of the granite gneiss wedge and suggests the weakening of the vein as it passes from the competent gneiss into the incompetent schists. The strain, which was relieved in the granite gneiss by strong fracturing confined to a narrow sheeted zone, may have been distributed over a much wider space in the weaker schists; as a result the vein may weaken and branch as it is followed into the schist. Although there is little likelihood of finding an ore body in the schist comparable to that in the gneiss, it is probable that chimneys or good ore can be found at the "splits" in the vein and in other favorable places. The extension of the Pennsylvania vein to the southwest has been traced in the Delaware, Delaware Extension, and Sunrise claims, but little ore has been produced here except from the Delaware. The workings on the Delaware have long been inaccessible, but their production and history are discussed on page 78.

The known and estimated production of the Pennsylvania group is shown below.

Production of Pennsylvania group

| | Ore (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) | Zinc (pounds) |
|-------------|------------------|--------------------|----------------------|--------------------------|----------------------------|---------------|
| 1885 | 45 | | | | | |
| 1886 | 68 | | | | | |
| 1887 | 30 | | | | | |
| 1889 (Ohio) | (?) | | 9 | 2,086 | | |
| 1890 | 736,149 | 73,61 | 16,681 | 126,447 | | |
| 1891 | 1,646,829 | 164,68 | 74,915 | 567,847 | | |
| 1892 | 4,670,418 | 467,04 | | | | |
| 1893 | 3,299,577 | 329,96 | 138,344 | 1,048,616 | | |
| 1894 | 1,783,596 | 178,36 | 88,538 | 671,140 | | |
| 1895 | 912,794 | 91,28 | 42,428 | 321,599 | | |
| 1896 | 952,726 | 95,27 | 40,114 | 304,071 | | |
| 1897 | 1,672,987 | 160,30 | 63,895 | 484,330 | | |
| 1898 | 1,098,802 | 109,88 | 53,810 | 407,882 | | |
| 1899 | 852,526 | 85,25 | 44,999 | 341,091 | | |
| 1900 | 900,364 | 90,04 | 41,998 | 318,331 | | |
| 1901 | 1,129,515 | 112,95 | 54,104 | 410,098 | | |
| 1902 (Ohio) | 120 | 7,50 | 3,660 | 56,471 | | |
| 1903 | 5,041 | 504,10 | 29,705 | 594,100 | | |
| 1904 | 2,430 | 121,50 | 12,150 | 486,000 | 486,000 | |
| 1905 | 1,284 | 38,70 | 24,504 | 85,106 | | |
| 1906 | 1,000 | 50.02 | 3,000 | 200,000 | 200,000 | |
| 1907 | 35 | | 3,500 | | | |
| 1908 | 58 | 38,98 | 1,088 | 9,796 | | |
| 1912 | 31 | 7,40 | 851 | 6,523 | 485 | |
| 1914 | 45 | 4,70 | 795 | 9,677 | 795 | |
| 1918 | 37 | 4,28 | 1,399 | 17,289 | 264 | |
| 1919 | 117 | 7,84 | 6,024 | 38,496 | 2,275 | |
| 1920 | 33 | 3,64 | 1,630 | 9,390 | | |
| 1921 | 30 | 4,70 | 1,647 | 5,022 | 826 | |
| 1922 | 79 | 7,80 | 3,239 | 32,233 | 755 | 10,789 |
| 1923 | 112 | 7,80 | 7,986 | 36,575 | 2,415 | |

| | Ore to concentrating mills (short tons) | Concentrates produced (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) | Zinc (pounds) |
|------|---|------------------------------------|--------------------|----------------------|--------------------------|----------------------------|---------------|
| 1910 | 9,000 | 1,167 | 160,46 | 28,320 | 193,421 | 17,390 | |
| 1911 | 12,488 | 1,719 | 268,62 | 46,434 | 288,107 | 20,115 | 206,280 |
| 1913 | 3,094 | 476 | 61,08 | 8,089 | 71,556 | 3,489 | |
| 1920 | 1,023 | 134 | 12,60 | 4,351 | 31,653 | 2,795 | |
| 1921 | 8,000 | 920 | 154,62 | 33,728 | 215,860 | 16,088 | |
| 1927 | 1,400 | 171 | 8,80 | 7,003 | 38,281 | 4,644 | |
| 1928 | 1,391 | 100 | 12,00 | 4,200 | 38,000 | 2,000 | 13,000 |

* Content estimated from tonnage, gross value, and average lead, gold, and silver content of ore.

No record available for 1888.

PERUVIAN AND SHOE BASIN

The Peruvian vein and Shoe Basin veins are on the eastern slope of Ruby Mountain, about 4 miles northeast of Montezuma, at altitudes of about 11,800 and 11,500 feet. They were originally opened by shafts on the veins, but in 1911 a long adit was driven that cuts both veins at an altitude of about 11,120 feet. The portal of this adit is on Peru Creek at benchmark 11,099, on the wagon road from Montezuma to Argentine Pass. It is accessible by automobile and marks the eastern limit of such transportation.

The Peruvian vein was discovered in 1874 and was moderately active from that time until 1893. During this period its most productive year was probably 1891; the Georgetown Courier for August 29, 1891, reports that "it has averaged 65 tons a month this year; ore from 49 to 63 ounces of silver per ton and from 7 to 20 percent lead." Little work was done after 1893 until the Shoe Basin tunnel was driven by the Shoe Basin Mines Co. in 1914. As shown below, about 400 tons of ore was shipped in 1914 and 1915. No work has been done on the property since that time, and in 1929 the workings were inaccessible, and the information given below had to be obtained from various reports on the mine, which were kindly made available. Little is known of the history of the Shoe Basin vein; it is said to have been worked in the seventies through a shaft 300 feet deep, but the mine is not mentioned by any of the reports of that time. In 1928 the workings were inaccessible.

Production of Peruvian mine

| | Ore (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) | Zinc (pounds) |
|--------------------------------|------------------|--------------------|----------------------|--------------------------|----------------------------|---------------|
| 1881 | 100 | | | | | |
| 1888 | (?) | | 2,348 | 55,271 | | |
| 1890 | (?) | | 8,445 | 40,895 | | |
| 1914 (Shoe Basin and Peruvian) | 15 | | 471 | 8,609 | | 2,280 |
| 1915 (Shoe Basin and Peruvian) | 40 | 0.98 | 1,257 | 25,997 | 143 | 4,104 |
| | 14 | .14 | 109 | 10,405 | 368 | |

* Concentrates produced from 370 tons of ore.

No record available for 1870-80, 1882-84, 1886-87, 1889, 1892-1900; no production in 1885, 1901-13, 1916-28.

The Shoe Basin adit and the underground workings of the Peruvian mine are shown in plate 34. Prior to 1914 the Peruvian vein was worked by a shaft 450 feet deep from which five levels were turned and by an upper level reached through a crosscut adit 395 feet long. The Shoe Basin adit cuts the Peruvian vein on the sixth level about 1,400 feet southwest of the bottom of the shaft and has been continued 1,100 feet northwest of the shaft as a crosscut to the Shoe Basin vein. The long drift on the vein is said to have been caved in 1920, a short distance north of the main crosscut from the portal and a short distance south of the shaft. The vein followed by this caved drift is known as the "Tunnel vein" and is connected by a crosscut to the Shaft vein, which is 30 feet west of it and about 10 feet east of the shaft. The Shaft vein apparently branches from the Tunnel vein about 150 feet north of the shaft and rejoins it about 180 feet south of the shaft. The southern junction dips about 60° S., and the northern junction dips about 40° S. between the fifth and sixth levels, but its inclination in the shallower workings is not known. The Tunnel vein strikes N. 32° E. and dips 84°-90° W. The Shaft vein trends nearly parallel to the Tunnel vein and dips steeply toward it.

Most of the ore mined was found above the fourth level close to the southern junction of the Shaft and Tunnel veins. There is little stoping north of the shaft except on the first and second levels. The upper level has been caved for a long time, but

according to men who were in the mine about 1915, the second level has several stopes in the first 170 feet north of the shaft. Some stoping has been done on the Shaft vein in the first 70 feet north of the shaft on the third level, but almost no ore has been taken from the veins north of the shaft on the lower levels. The ore shoots in the Shaft vein are separated by low-grade or barren stretches of quartz, but little gouge is present, whereas the Tunnel vein is said to have many wide gouge seams between the ore shoots. The ore close to the surface is said to contain gray copper, galena, zinc blende, pyrite, and from 10 to 50 ounces of silver to the ton. The shipping ore was about 20 inches wide, but the vein averaged nearly 6 feet between walls and widened to about 14 feet at the junctions. Below the fourth level the ore is said to carry more zinc than it does in the higher levels, although galena is still the most abundant sulphide.

The ore on the dump of the Shoe Basin tunnel was of two kinds—a thoroughly silicified gneiss containing disseminated sulphides, and a fissure filling consisting of quartz, barite, dolomite, and sulphides. Galena was abundant and occurred in medium-sized grains disseminated through the vein quartz, barite, and silicified gneiss. The barite was abundant in some specimens and lacking in others. Pyrite and brown sphalerite were common; some gray copper was present and was associated with dolomite, but both were rare. The ore on the dump of the Peruvian shaft was chiefly galena and sphalerite in a quartz-barite gangue, but gray copper was moderately abundant. The earliest mineralization introduced pyrite and quartz and was followed by barite, which in turn was earlier than sphalerite and galena. The ore on the dump of the Shoe Basin workings was very similar in appearance to the Peruvian ore and must have come from a vein at least 10 inches wide.

The Peruvian vein is nearly parallel to the schistosity of the enclosing Idaho Springs formation. A dike of monzonite porphyry exposed on the surface near the shaft strikes about N. 45° E. and is probably the dike found on the sixth level, about 100 feet south of the shaft. The dike is reported to make an angle of about 30° with the vein at its intersection, very close to the reported junction of the Shaft vein and the Tunnel vein. This intersection coincides with the largest stopes found below the fourth level. On the surface the dike of quartz monzonite porphyry west of the vein intersects it at the shaft; this suggests that the Peruvian vein occupies a fault whose east side moved south, but unfortunately the dip of the porphyry dike is unknown, and the displacement of the fault cannot be accurately given.

POTOSI

The Potosi vein is on the west slope of Glacier Mountain at an altitude of about 11,400 feet, about 1 mile southwest of Montezuma and a few hundred yards southeast of the Sts. John mill. It was discovered by Edward Guibor in June 1865, but little work was done on the vein at the surface, although the Sts. John mine developed it at depth by the main crosscut tunnel. Raymond notes that the Potosi was worked and shipped ore in 1875, but no other production is on record. The shipment was probably small, as the Colorado Mining Directory in 1883 states that the total developments consist of three drifts 25, 28, and 16 feet long. The vein was reported to have two pay streaks 4 and 6 inches wide, and the ore was said to be galena and some ruby silver in a quartz gangue, assaying 150 ounces of silver to the ton when sorted.

QUAIL

The Quail mine is on the west slope of Collier Mountain near the head of the south fork of Morgan Gulch, at an altitude of about 12,000 feet, 1 mile due east of Montezuma. A steep

wagon road leads from the town to the mine, but in 1929 it was in such poor repair that it was not passable for automobiles. As shown in figure 22, the chief workings are two adits, each of which follows the vein for about 400 feet. Close to its breast the lower adit is connected with the upper adit by a raise about 210 feet high, and a short intermediate level turns from the raise about 130 feet up. According to James Southerland, of Montezuma, the Quail vein was discovered by Philip Bianchi in the nineties, and some lead ore was shipped by him from the upper tunnel. Most of the work was carried on by Mr. Southerland or under his direction, and after the company's operations stopped in 1916, he leased the mine for several years. He states that 100 to 120 tons of galena ore was shipped each year in 1914, 1915, and 1916, seven 25-ton carloads in 1917 and 1918, and one carload in 1919. The ore sold direct to the smelter is shown below.

Production of Quail mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead, wet
assay
(pounds) | Copper,
wet assay
(pounds) |
|-----------|------------------------|--------------------------|----------------------------|--------------------------------|----------------------------------|
| 1907..... | 37 | | 741 | 60,932 | |
| 1918..... | 70 | 0.30 | 728 | 70,380 | 33 |
| 1919..... | 26 | .30 | 372 | 24,916 | 206 |

No production in 1901-6, 1908-14, 1920-28.

The Quail vein is of especial interest because it goes from the Montezuma quartz monzonite stock southwest into the enclosing Idaho Springs formation. It strikes about N. 40° W. and is nearly vertical. The ore found in the mine since 1914 has come from two ore shoots, one in the quartz monzonite stock and the other in the schist at the contact of the two rocks. The top of the first shoot was cut in the upper level and extended only a few feet above the bottom of the drift, and the vein a short distance away was a tight, barren fissure, containing only a very thin seam of quartz. The shoot had a maximum strike length of about 50 feet on the intermediate level and bottomed about halfway between the lower level and the intermediate level. The best ore in the shoot was nearly pure galena, about 1½ feet wide. The second ore shoot was approximately triangular in shape, and only the lower tip of the triangle entered the upper drift, where it was cut 30 feet southeast of the top of the first shoot. The contact of the quartz monzonite and the schist was the northwestern limit of the ore and is said to pitch steeply south. The general pitch of the ore shoot is northwest, and it had a pitch length of about 35 feet and a maximum strike length of about 30 feet. The ore ranged from 3 to 16 inches in width, and about 100 tons of ore was shipped from this stope. The vein on the lower level was chiefly quartz and contained very little shipping ore, although locally pyrite and sphalerite were abundant. The vein is said to range from 3 inches to 3 feet in width on this level.

The occurrence of the two shoots at the contact of the stock and the schist, one above the other, suggests that other shoots might be found at greater depth similarly related to this contact, but the size of the shoots does not warrant extensive exploration for them.

QUEEN OF THE WEST

The Queen of the West vein is on the steep east side of Horseshoe Basin, 1,200 feet northwest of Argentine Pass and about 5½ miles northeast of Montezuma. The vein was explored at several places by short adits between altitudes of about 12,500 and 13,000 feet, but it was inaccessible in 1928, when the writer visited it. It strikes N. 70° E. and cuts quartz-biotite schists of the Idaho Springs formation. The occurrence of alabandite in the Queen of the West makes it unique, as no other vein in

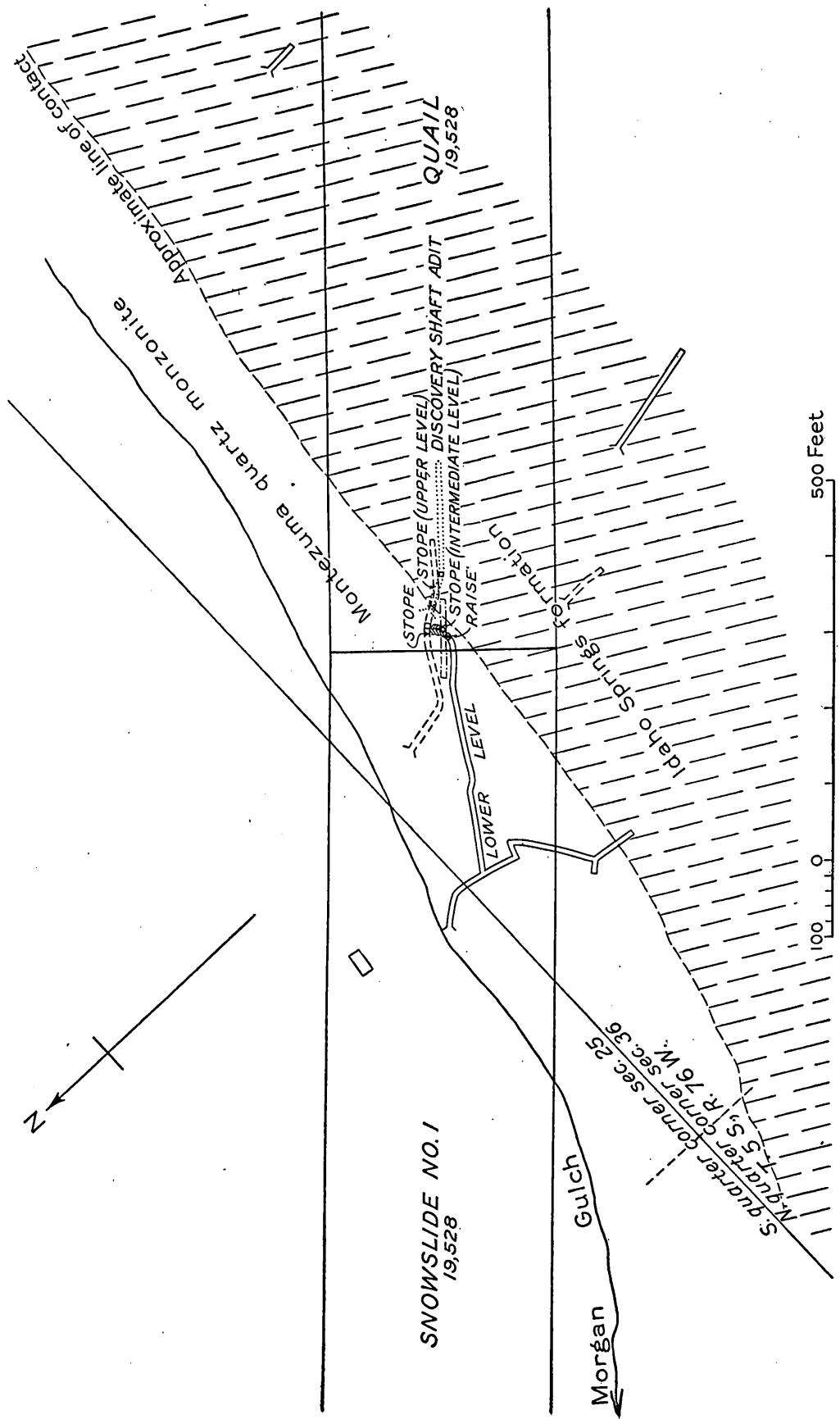


FIGURE 22.—Quail mine, Morgan Gulch.

the region is known to have this mineral. Smith²⁰ describes the occurrence as follows:

"The society is indebted to Mr. J. S. Randall, of Georgetown, for several massive specimens of alabandite, a considerable quantity of which was found last fall in a small vein 1 to 6 inches wide, encountered in sinking a shaft on the Queen of the West mine, near Snake River in Summit County. These specimens have a distinct cubic cleavage and resemble ordinary massive galena except in color, which is nearer a steel-gray on a surface freshly fractured but which soon tarnishes to a dull brown or iron-black. Among specimens recently shown me by Mr. Randall is one containing a single distinct crystal, about 6 millimeters square, embedded in the massive material. The forms exhibited are the cube and the tetragonal trisoctahedron. Unfortunately, but one perfect corner of the crystal is shown, and it is impossible to tell whether there is a tetrahedral development or not. The associated minerals are small crystals of rhodochrosite in cavities of the alabandite—probably resulting from the decomposition of the latter—small dolomite crystals and a few small pyrites. Mr. L. G. Eakins tested the mineral qualitatively and found it to be a manganese sulphide."

RADICAL

The Radical mine is on the western spur from Teller Mountain, known as Radical Hill, about 2½ miles south of Montezuma. The vein was discovered in the seventies, but the exact date is not known; J. B. Briggs, probably the discoverer, sold some ore to the Sts. John smelter in 1875, but no other shipment in the seventies is on record. The mine was idle in 1880, 1881, and 1882 but was worked from 1883 to 1888. As shown below, the production during these years was not large. The mine is reported to have been idle during the nineties and is known to have been nonproductive since 1900. It was inaccessible in 1929. According to miners who have worked in the Radical, the ore streak was about 6 inches wide and consisted of galena in a quartz gangue. Unlike most of the veins nearby, no barite was associated with the quartz and galena. According to the Montezuma Mill Run the ore was from 8 to 16 inches wide in 1883.

Production of Radical mine

| | Ore (short tons) | Silver (fine ounces) | Lead, wet assay (pounds) |
|------|------------------|----------------------|--------------------------|
| 1875 | 2 | 49 | 2,533 |
| 1883 | 10 | — | — |
| 1884 | 10 | — | — |
| 1888 | (?) | 75 | 9,148 |

No record available for 1876-82, 1885-87, 1889-1900; no production in 1901-28.

RAINBOW

The Rainbow mine is on the west slope of Keystone Mountain, 5 miles due west of Montezuma, at an altitude of about 10,250 feet. A good wagon road turns up Keystone Gulch three-quarters of a mile east of Keystone and runs past a trail to the mine, about 1½ miles south. The trail rises 600 feet in the half mile to the mine and is too narrow for automobiles. Little is known of the mine's early history. It shipped about five carloads of ore in 1916 and 1917, but there is no other recorded production. The amount of lead and silver in these shipments is given below.

Production of Rainbow mine

| | Ore (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) |
|------|------------------|--------------------|----------------------|--------------------------|----------------------------|
| 1916 | 31 | 2.39 | 1,141 | 795 | 58 |
| 1917 | 37 | 1.43 | 749 | — | 12 |

No production in 1901-15, 1918-28.

²⁰ Smith, W. B., Alabandite from Summit County, Colo.: Colorado Sci. Soc. Proc., vol. 2, p. 158, 1887.

As shown on plate 32, the chief opening is the lower adit, which has about 1,100 feet of drifts. Two shorter adits, 225 and 300 feet above, expose the vein at higher levels.

The country rock of the mine is hornblende-biotite gneiss of the Swandyke gneiss. It strikes N. 10°-35° W. and dips 40°-55° E. The vein strikes N. 80° E. and dips 55°-65° N. In the uppermost adit the vein is a sheeted zone about 15 feet wide and contains 1 to 3 feet of thoroughly oxidized lead ore, but it was exposed only for a distance of 25 feet in 1928. In the intermediate adit the vein is cut off by a mineralized fault 80 feet east of the portal; a shoot of galena ore 12 inches wide and 40 feet long occurs in the vein just west of the fault, but the vein is barren between the shoot and the portal. The fault strikes N. 30° E., dips 70° E., and is about 24 inches wide. It has been followed north for 60 feet, but the eastern continuation of the vein has not been found. If the fault is normal, as its steep dip suggests, the vein will be south instead of north of the fault; a projection of the vein from the uppermost adit indicates that it should be about 20 feet south of the western segment at the fault. In the lower adit the vein is barren where it is first cut, 350 feet from the portal, and the first ore shoot occurs 320 feet farther east. The vein is from 3 to 15 inches wide in this interval but is sparsely mineralized. No faults were observed cutting it, but the vein jogs over several feet at a place in line with a small fault disclosed in a branch drift 140 feet away. It is probable that this sharp bend reflects the movement that caused the fault. The vein branches in a few places, as shown on plate 32, but these divisions do not correspond to the location of the ore shoots. The first ore shoot is about N. 30° E. of the ore shoot on the intermediate level and is close to the place where the mineralized fault noted there should appear on the lower level. It was not observed, however, and if present is much less prominent than on the intermediate level. At 60 feet northeast of the ore shoot a strong vein was found striking N. 85° E. and dipping 60° N. As shown in plate 32, it is probably a branch of the vein followed by the drift west of this place and should intersect the main vein a few feet beyond the breast of the drift. An ore shoot occurs at the breast, and a small stope has been made. This ore shoot is directly down the dip of the vein from the oxidized ore in the uppermost adit and may be part of the same shoot.

As shown in cross section C-C', plate 4, the hornblende gneiss country rock of the mine is underlain by Upper Cretaceous shale, over which it has been carried by the Williams Range thrust fault. In the Ida Belle mine, described on pages 82-83, the best ore occurred where the vein cut the thrust-fault breccia at the contact of the shale and the gneiss. A similar relation might be found where the Rainbow lode cuts the underlying shale, but the depth to the contact may make it impracticable to mine such ore economically. If the thrust fault maintained its normal dip of about 30° from its outcrop on the east slope of Soda Creek, it would be about 4,500 feet below the lower level of the Rainbow mine. There is a strong fault in the valley of Jones Gulch, half a mile west of the Ida Belle mine, striking N. 10°-25° W., having a displacement known to be more than 2,500 feet, and the east side of the fault has risen relative to the west side. Keystone Gulch is parallel to Jones Gulch, and the Rainbow mine is on the east slope of the valley. It is a structural valley and is thought to follow a fault similar to the one that produced Jones Gulch, but there is no way of determining the displacement on this fault except by geophysical methods or by diamond drilling. Resistivity measurements, made by J. H. Wilson during the writer's study of the geology of the proposed Blue River water-diversion tunnel, verified the presence of a strong fault zone along the valley but indicated that the Cretaceous shales were probably at a depth of more than 1,000 feet below the valley bottom, half a mile south of the Rainbow mine. The depth to the shale makes it unprofitable to explore

for a body of ore at the place where the Rainbow lode intersects the thrust fault.

RED JACKET

The Red Jacket claim is on the northeast slope of Teller Mountain, about 1½ miles southeast of Montezuma. The deposit was discovered about 1885 and yielded 10 tons of ore the next year. No other recorded production has been found for the mine, but according to John Sundragger, who has owned and worked the nearby Mohawk mine for 45 years, about three carloads of ore were shipped in 1894 and 1895. The ore was chiefly galena and carried a little silver.

ROBERTA (MARLIN)

The Roberta tunnel is on the west side of St. Johns Creek, about half a mile west of Montezuma. The tunnel runs N. 80° W. into the Swandyke gneiss of Bear Mountain and was about 600 feet long in 1927. A 6-inch vein of galena, quartz, and oxidized pyrite was found about 60 feet from the portal. It strikes northeast and dips 35° NW. At 300 feet from the portal a normal fault is exposed that strikes N. 55° W. and dips 75° SW. The zone of gougy crushed rock is about 5 inches wide. A vein of ankerite about 4 inches wide was found 500 feet from the portal; it strikes northeast and dips 65° SE. The property has not shipped any ore, so far as known.

ROCHESTER QUEEN (ARRASTRE QUEEN)

The Rochester Queen or Arrastre Queen, as it was later known, is on the North Fork of the Swan River 3 miles from its mouth and about 3½ miles southwest of Montezuma. It was discovered by Daniel Patrick about 1880, and in 1883 it was developed by a 75-foot shaft, 325 feet of drifts, a tunnel 100 feet long, and a 75-foot winze. The town of Rexford sprang up a few hundred yards below the mine chiefly because of the extensive work carried on at the Rochester Queen. A mill was built and connected with the portal of the mine by a wooden tram line, and ore was milled for many years. According to Burchard the mine produced \$5,000 worth of ore a month for 3 months in 1881, and shipments were sent to the Argo smelter in 1881 and 1882, but no work was done in 1883. The ore contained iron, copper, galena, and some honeycombed gold-bearing quartz. According to the Colorado Mining Directory for 1883, the Rochester Queen had produced 500 tons of gold-silver ore prior to that year. The veins were said to be fissures from 6 to 10 inches wide containing decomposed iron-stained porphyry and quartz and had a fair tenor in both silver and gold, assaying when sorted about \$50 a ton in these two metals. The mine was inaccessible in 1929, and the town of Rexford had long been abandoned. According to C. M. Snyder, of Hall Valley, the tunnel at Rexford was visited by him in 1918 and was in very poor repair at that time. The workings did not follow any well-defined vein but explored several narrow fissures in the strongly fractured gneiss and porphyry. The soft decomposed rock in the fissures carried only half an ounce of gold to the ton, according to Mr. Snyder, but samples of the hard wall rock next to these fissures assayed from \$20 to \$40 a ton, chiefly in gold. The gold content was erratic, however, and could be discovered only by assaying. As shown on plate 3, the country rock of the mine comprises biotite diorite porphyry and hornblende gneiss that have broken away from the cliffs above and slid to their present place since the last retreat of the glacier which formerly occupied the valley. It is probable that the channel was oversteepened by the action of the ice and that large landslides resulted when the glacier melted. The gold ore found near Rexford was probably formed by the enrichment of low-grade pyritic ore similar to that found in the Carrie mine nearby. Its occurrence in the valley bottom is accidental, as it is a rock mass which was at a much higher level during the progress of gold and silver enrichment.

ROTHSCHILD (MINEROU)

The Rothschild tunnel has been driven 4,600 feet northwest under Cooper Mountain and has its portal 200 feet above Peru Creek, about half a mile northwest of the mouth of Cinnamon Gulch. It is 3 miles east-northeast of Montezuma and is easily accessible by automobile over a good wagon road. The tunnel was driven with the object of exploring the veins of Cooper Mountain at depth and providing a transportation tunnel for them. Since the work of driving the tunnel stopped little has been done except for a small amount of stoping on some of the veins opened during the main work on the tunnel. The known production of the property has been small, although some ore was produced from the shallow upper adits and would increase the figures given below if the amount were known.

Probably the most productive veins on Cooper Mountain are the Tariff and the Rothschild. They were discovered in 1873 by W. T. Lewis, and after a moderate amount of development work and the shipment of some rich silver ore, the claims were sold in 1878. Exploration of the veins was continued by the new owners during 1879 and 1880. In 1883 the property was still idle and according to the Colorado Mining Directory was owned by W. T. Lewis. It is credited with a total production of \$20,000 in 1883, and the ore is reported to have assayed from 20 to 35 percent of lead and 100 to 500 ounces of silver to the ton when sorted. The ore was from 3 to 36 inches wide and consisted of galena, gray and yellow copper, and some ruby silver, in a quartz gangue. The production came from the Tariff East and Rothschild claims.

The property was idle during the eighties and most of the nineties but became active again about 1899. In May 1900 the main crosscut tunnel was started, and by 1906 it had been driven its present length. It has been operated intermittently since 1907, and some good silver ore has been shipped by various lessees. As shown in figure 23, the tunnel is entirely in the Montezuma quartz monzonite. The veins are thin, but lenticular swellings in them occur in places and carry workable bodies of ore, consisting of galena, sphalerite, pyrite, and some ruby silver in a quartz gangue. The known production of the property is shown below.

Production from Rothschild tunnel

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet
assay
(pounds) | Copper,
wet
assay
(pounds) | Zinc
(pounds) |
|---------------|------------------------|--------------------------|----------------------------|-----------------------------------|-------------------------------------|------------------|
| Prior to 1879 | 2,500-5,000 | | 1,875 | | | |
| 1901 | 10 | | | | | |
| 1906 | 300 | 12.50 | 7,500 | 58,824 | 7,143 | 47,000 |
| 1907 | 20 | | 4,000 | 4,240 | | |
| 1922 | 78 | 1.80 | 3,544 | 9,565 | 13 | |
| 1923 | 24 | .50 | 1,190 | 4,630 | | |

No record available for 1879-80, 1883-86, 1889-1900; no production in 1881-82, 1887-88, 1902-5, 1908-21, 1924-28.

ROYAL TIGER

The Royal Tiger Mines Co. controls a large amount of property in the southwestern part of the quadrangle and in the Breckenridge district, south and southwest of the quadrangle. Up to 1930 little ore had been produced, although several properties were explored for many years and considerable sums of money had been spent on the mill at Tiger. John Traylor, the general manager, stated that he expected to solve the difficulties of successfully milling the low-grade ores of the stockworks west of Tiger and hoped ultimately to raise enough money to build a 5,000-ton mill for exploitation on a large scale. As the writer was denied the opportunity of studying any of the mines controlled by the Royal Tiger Mines Co., he was unable to learn what the developments since Ransome's visit in 1909

had disclosed. Many of the properties of the company, particularly the Cashier and I. X. L., were studied by Ransome, and the reader is referred to his report for details concerning their geology and history.³⁰ The geologic setting of the deposits and the general character of their ore has been summarized on pages 59-60.

STS. JOHN

The Sts. John mine is the oldest producing mine in the Montezuma district and is one of the oldest silver mines in Colorado. It is on the west slope of Glacier Mountain about a mile southwest of Montezuma. The mill and the chief mine buildings are at an altitude of about 10,800 feet and are at the end of a wagon road that leads from Montezuma to the mine. The road is passable for automobiles but has some very steep grades a short distance southwest of the town.

The Comstock lode of the Sts. John mine was discovered in 1865, and work was started on the vein at once. The Boston Silver Mining Association was organized in 1866 and opened the vein by two adits close to the outcrop of the vein. According to

in the mill, and, according to a mining paper, in July 1875 the ore treated by the company from the upper levels had averaged 40 ounces of silver to the ton.

In 1875 the mine was worked by the Boston Silver Co. but with the same officers as before. The mill was thrown open for custom ore and consumed nearly all the ore produced in the Montezuma district that year. The ore receipts of the Boston Silver Co. for 1875-78 are extant and indicate that less than 50 tons of ore was purchased in a year. By the later part of 1875 the lowest adit had reached a length of 1,075 feet and had cut nine veins, but the Comstock lode was not recognized. Good ore was found on vein 5, and a drift was driven north to prepare for stoping. At the end of the year the company had about 800 tons of ore on hand, three-quarters of which was dressing ore and was to be concentrated in its mill and smelted into pig lead. The mine was active during 1876, 1877, and 1878 and bought ore from the surrounding mines and treated its own ore, most of which came from vein 5 north of the main adit. The mine was taken over by the Boston Mining Co. in 1878 and operated intermittently by it for many years. There is no record of the

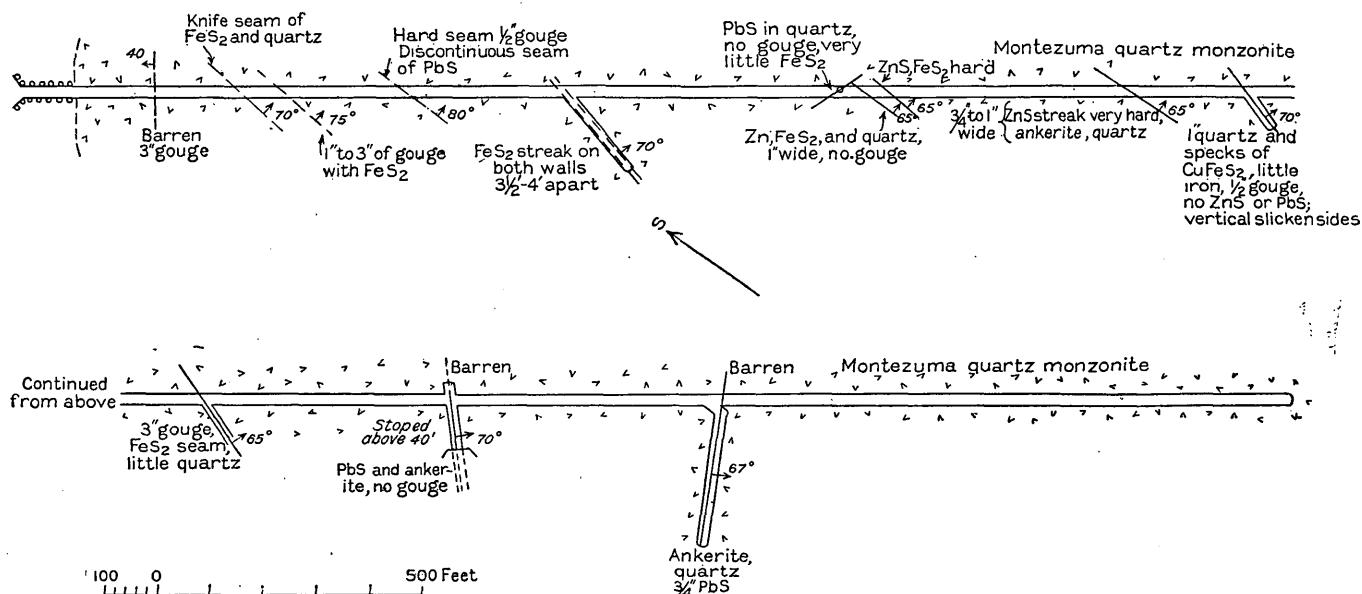


FIGURE 23.—Rothschild tunnel, Cooper Mountain, 1929.

King,³¹ who visited the mine in 1869, the upper adit was from 60 to 100 feet below the surface, and the second adit was 70 feet lower. Some Scotch hearths had been built, and base bullion carrying from 100 to 170 ounces of silver to the ton and valued at \$3,500 had been produced. At this time complex ore carrying zinc and copper assaying from \$100 to \$200 a ton was not worked. In 1870, according to Raymond, the lower adit was 150 feet long and connected with a drift on the vein 425 feet long. A winze 75 feet deep connected this level with a sublevel about 200 feet long, and a raise 70 feet high joined it to the upper adit level. About 3,000 tons of ore worth from \$40 to \$400 a ton was piled at the mouth of the tunnel ready for the reduction works. This ore was not satisfactorily smelted by the furnaces, and the mine had much the same difficulty with barite as the Hall Valley smelter had a few years later. Mining was almost suspended in 1871, and a 50-ton concentration mill was started. It was not finished until late in 1872, and only a few tons of ore was treated. The long adit cutting the vein about 700 feet below the outcrop was started in this year and was driven steadily ahead until about 1878. During the next 2 years no ore was stoped, but the ore on the dump was probably dressed

production for the years from 1871 to 1880, but the mine had been inactive for several years in 1882, when the Montezuma Mill Run commenced publication. Some ore, probably less than 50 tons, was shipped to the Sissapo sampler at Montezuma during 1882, but 1,000 tons was said to be stored at the mine. The mine was idle in 1883. In 1884 operations were resumed, and ore was shipped during the later part of that year as well as in 1885, 1886, and 1887. Only a small force worked at the mine in 1887, and operations were suspended during the winter of 1887-88. Work was resumed with a small force in 1888, but there was no production in that year or the next. In 1889 shipments were again resumed, and the mine was operated steadily for several years. In 1890 the mine was worked by the Boston Mining Co. under the management of T. E. Schwartz, and a moderate and steady production was maintained until the panic of 1893, when the company suspended operations. Ore was mined intermittently until 1899 by lessees, however, and according to a report by Mr. Schwartz about 3,000 tons of ore was shipped in 1890-99 and commonly assayed from 30 to 35 percent of lead and 40 to 45 ounces of silver to the ton. No mining was done between 1900 and 1913, though several small shipments of ore sorted from the dump were made by various lessees. In 1910 the mine was bought by the St. John Mines Co., Ltd., which operated it from 1913 to 1916. It was bought

³⁰ Ransome, F. L., The geology and ore deposits of the Breckenridge district, Colo.: U.S. Geol. Survey Prof. Paper 75, pp. 148-150, 1911.

³¹ King, Clarence, U.S. Geol. Expl. 40th Par. Rept., vol. 3, pp. 617-624, 1870.

by the Montezuma Silver-Lead Mines Co., Ltd., in 1917 and operated by that company in 1917-18. A small production was maintained in 1919, 1920, and 1921 by lessees of this company, but in 1923 the property reverted to the St. John Mines Co., Ltd., which still owned it in 1929.

Most of the ore above the main tunnel level had been removed before the writer's visit to the mine, but some early accounts of the property describe the ore found in the upper levels. The country rock is hornblende gneiss and pegmatite of the Swandyke gneiss. The gneiss strikes from northeast to north and dips 50°-90° E.; the prevailing strike is slightly east of north, and the prevailing dip is about 75° E. Most of the ore has been obtained from the Comstock vein, which is more commonly known as vein 5. It strikes northeast, dips steeply northwest, and crosses vein 7, which strikes north of east and dips about 55° N. Vein 7 contains much more barite than the Comstock vein and has been exploited to only a moderate degree because of failure to mill the ore satisfactorily.

According to Clarence King, the ore exposed in the Comstock vein in 1869, less than 160 feet below the surface, was argentiferous galena, two or three kinds of zinc blende, a little argentiferous gray copper, and ruby silver, in a gangue of barite, quartz and siderite. The vein filling was from 1 to 8 feet wide and averaged about 3 feet; it was separated from the walls by a thin seam of gouge. The pay streak was from 6 to 12 inches wide and occurred on either the hanging-wall or footwall side of the vein. "The continuity of the pay seam * * * is one of the notable features of this lode." In his report for 1870 Raymond says:

"The vein of the Comstock stands nearly perpendicular and varies in size. At one point it spread out to 8 feet, and at another it contracted to a few feet, but it preserved a general width of 4 or 5 feet. At the point of greatest width there was a stratum of compact ore 2 feet thick upon the hanging wall; the same upon the footwall; while ore was disseminated through the intervening mass of feldspathic gangue. In the different works disclosing the vein the solid ore ranged from 4 inches to 2 feet thick, and I should judge it fairly averaged 18 inches. The galena was massive and formed perhaps one-third of the ore. Zinc blende and iron and copper pyrites occur also abundantly, and in the deepest works silver glance and brittle silver are not uncommon. Handsome crystals of heavy spar are of frequent occurrence."

In 1875 the main crosscut tunnel 700 feet below the outcrop of the vein had been driven 1,100 feet and had cut nine veins. Nos. 1, 2, 3, 4, 6, and 9 contained iron pyrites in a quartz gangue; nos. 5 and 8 had zinc blende and galena in a quartz gangue; no. 7 had barite, zinc blende, galena, and a little pyrite. Raymond says:

"While at the intersection of the tunnel with no. 5 only galena, blende, and a little iron pyrites were found, containing, when solid, 60 to 70 ounces of silver per ton, the vein carried beyond a point 75 feet from the entrance northward, besides the minerals named, rich silver ores such as ruby silver, stephanite, polybasite, and tetrahedrite in considerable quantity, so that the average value of the ore was more than doubled. The south drift on no. 5 * * * has since been driven to the intersection with no. 7, 140 feet from the tunnel. In this drift only one pocket of ruby silver, stephanite, and fahlore [gray copper] was found. The drift on no. 7 north of the tunnel was in soft ground * * * carrying no ore. The south drift was in about 200 feet and showed ore (zinc blende and galena in barite) for almost the whole distance, the vein being on the average from 4 to 5 feet wide, and the ore streak varying from 1 to 3 feet. * * * About 130 feet from the entrance the drift encountered a horizontal fault of about 8 feet (the vein being thrown to the east), and 12 feet farther a second fault of 6 feet in the same direction. Between the two the vein carried very good galena. About 6 feet beyond the second fault

the galena became very solid and contained much native silver, which continued for a distance of 30 feet. The ore in no. 7 at the intersection with the tunnel contained in solid galena from 48 to 50 ounces of silver; at the farther end of the drift, where the native silver was visible, it contained from 100 to 500 ounces, and in ordinary galena from 70 to 80 ounces. * * * [From the north no. 5] extraordinarily rich silver ores are now being extracted, carrying, however, very little galena. * * * On no. 7 one raise now 120 feet high has been made. * * * There are three stopes opened on no. 7, two of which produce ore."

The Comstock vein has been followed over 800 feet northeast of the main crosscut tunnel and 1,100 feet southwest of it and has been stoped for much of its length. The northern ore shoot was almost continuous from the main tunnel to a place about 750 feet northeast, where the vein is cut by a strong northward-trending fault. The drift is caved a short distance beyond and could not be examined in 1927, but it is reported that no ore was found farther north. The rich silver ore was

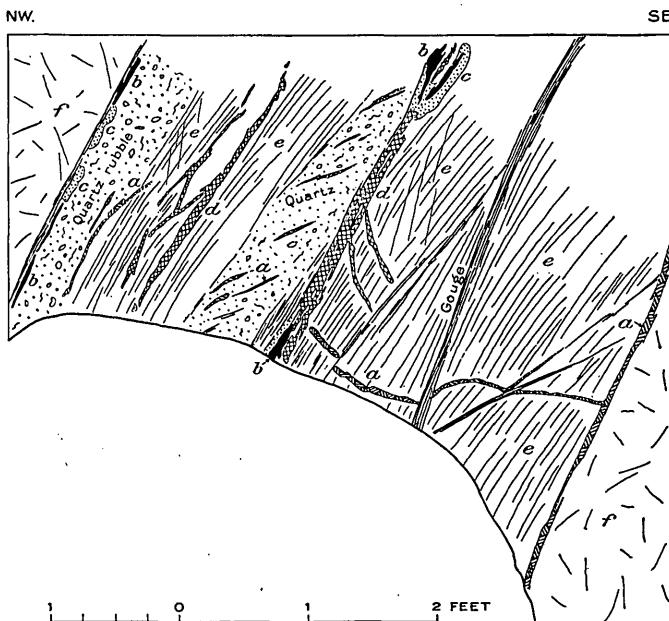


FIGURE 24.—Looking north at vein 5, 750 feet north of main crosscut, Sts. John mine. Vein in wide premineral fault but affected by later movement along the fissure. *a*, Pyrite; *b*, galena; *c*, sphalerite; *d*, ankerite; *e*, strongly sheeted altered granite; *f*, slightly fractured gneiss.

mined out in the seventies, but some of the leaner ore near the fault was seen, and its mode of occurrence is illustrated in figures 6 and 24. The vein becomes poorer and poorer as it turns into the fault zone and is nearly barren for the last 50 feet in which it is exposed. The decrease in mineralization coincides with an increase in the amount of gouge. Quartz, pyrite, and barite predominate as the fault zone is approached, and galena and sphalerite gradually increase as the vein is followed away from it. At 50 feet from the fault the vein contains about 10 inches of gangue and 8 inches of ore, and 50 feet farther away the vein carries 10 inches of gangue and 18 inches of ore. Here the gangue is chiefly barite but contains moderate amounts of rhodochrosite and a small amount of quartz. The ore consists of galena and sphalerite in nearly equal amounts. No gray copper was seen, and the silver-bearing minerals were probably found in the southwestern part of this ore shoot.

The Comstock vein splits a short distance southwest of the main tunnel, where two overlapping parallel northeasterly fissures about 80 feet apart are connected by a northerly bedding-plane fracture. The vein, which had been following the western fissure, continues southwest on the eastern fissure. It is barren on the lower level near the junction of the northerly

and northeasterly fissures, and no ore was observed for 120 feet south of the junction. Southwest of this place the vein has been stoped almost continuously for 850 feet. At some places, however, pillars of lean ore have been left, and in them the vein filling is about 6 inches wide and is chiefly quartz with a moderate amount of barite and galena. In the productive part the vein dips 55°-60° NW., but steeper dips were observed in the leaner pillars that came down to the level of the drift. In a stope 150 feet northeast of the breast the vein has a dip of 65° in the first 60 feet but flattens to 51° for the next 50 feet. The ore is from 4 to 6 inches wide in the first 60 feet and from 6 to 12 inches wide in the next 50 feet. The ore in this stope is chiefly galena, but a thin seam of rhodochrosite, quartz, and barite is commonly present; moderate amounts of sphalerite are associated with the galena, and locally small amounts of argentiferous gray copper occur. Where the vein flattens in the stope a strong gougy fissure goes into the hanging wall, continuing the steep dip of the vein up to this point. A small normal fault dipping steeply eastward displaces the vein about 24 inches 105 feet above the drift; as shown in the cross section in plate 35, it is undoubtedly the same fault that was followed south from its intersection with the vein on the lower level, 270 feet northeast of the breast. The presence of gouge and steel galena in the Comstock vein indicates postmineral movement along the vein, and the bedding-plane fault just described probably carried some of the movement, which was in places taken up by the vein fissure.

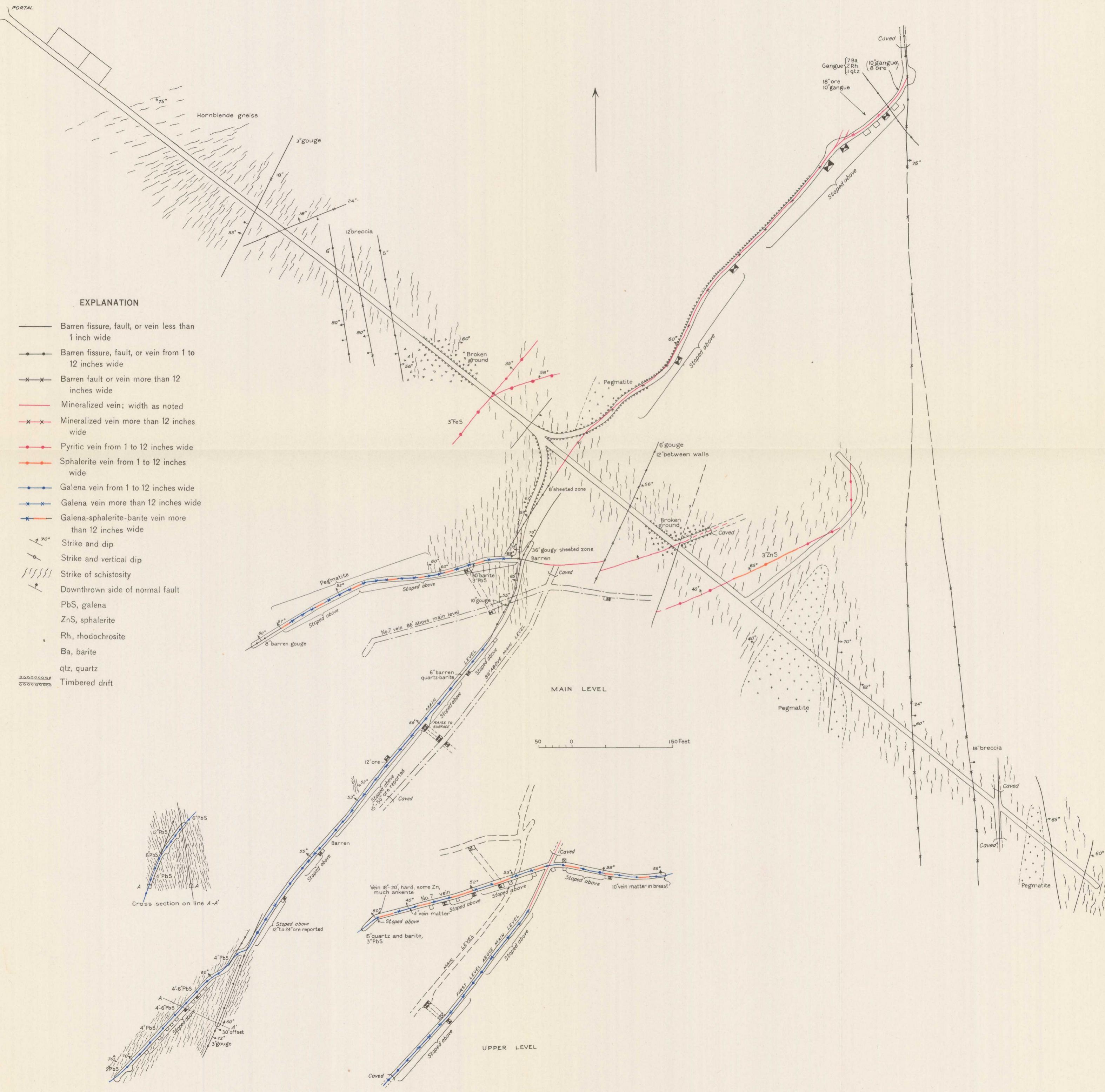
The Comstock vein has a general dip of 55°-60° for almost its entire length on the main tunnel level, and this dip if maintained would cause it to crop out where the Tiger vein is exposed on the surface. About 70 feet above the second level, 150 feet above the main tunnel level, the vein steepens and becomes nearly vertical, dipping 75°-80° NW. This dip is maintained for at least 50 feet more, but the workings of the mine were inaccessible above this place in 1929. However, according to a report quoted earlier, the vein is nearly vertical in the upper levels, and it is probable that the average dip from the outcrop of the Comstock vein to a line about 150 feet above the main tunnel level is between 75° and 80°. The Tiger vein at its outcrop dips 60° NW., and it should join the Comstock vein near the main tunnel level or be cut by the main crosscut a short distance east of the Comstock vein if its dip steepened. The Tiger vein has not been recognized in the Sts. John workings by anyone who has studied the mine. Although the change in dip of the Comstock vein 150 feet above the main tunnel level suggests that the Tiger vein may come in from the footwall side and join the Comstock vein at this place, it is unlikely that such a junction would be unrecognized along 1,300 feet of stopes. However, the dip and strike of the two veins are almost parallel, the character of the ore and gangue is very similar, the Tiger at its outcrop is as wide as the Comstock, it can be traced on the surface as great a distance as the Comstock, and probably it persists to as great a depth as the Comstock. The strong northerly fault that terminates the Comstock on the main tunnel level dips 75° E. in the caved part of the drift, according to miners who worked in that part of the mine. It is strong and readily recognized where it is cut by the main crosscut tunnel, 1,000 feet to the south, and there it dips 65° E. S-shaped fractures in the fault indicate that its hanging wall moved downward. Nearly all the other northerly faults in the mine dip east, and on all those in which the direction of movement was ascertained the displacement is normal; it is very probable, therefore, that this fault, which is the strongest of the northerly faults observed in the mine, is also a normal fault. As it definitely limits the Comstock vein, it probably terminates the Tiger vein also, and the writer believes that the Tiger vein is the downthrown continuation of the Comstock vein. The intersection of the vein with the fault would pitch about 50° N., and the dip slip would be about 350 feet. It is noteworthy

that the stope map of the Comstock vein indicates that the northwest termination of the ore pitched less than 50° N. If the Tiger vein is broken by this fault it should end against it about 750 feet above the main tunnel level at a point vertically above the crosscut tunnel, and the intersection of the vein and the fault should be found on the tunnel level about 700 feet north of the main crosscut.

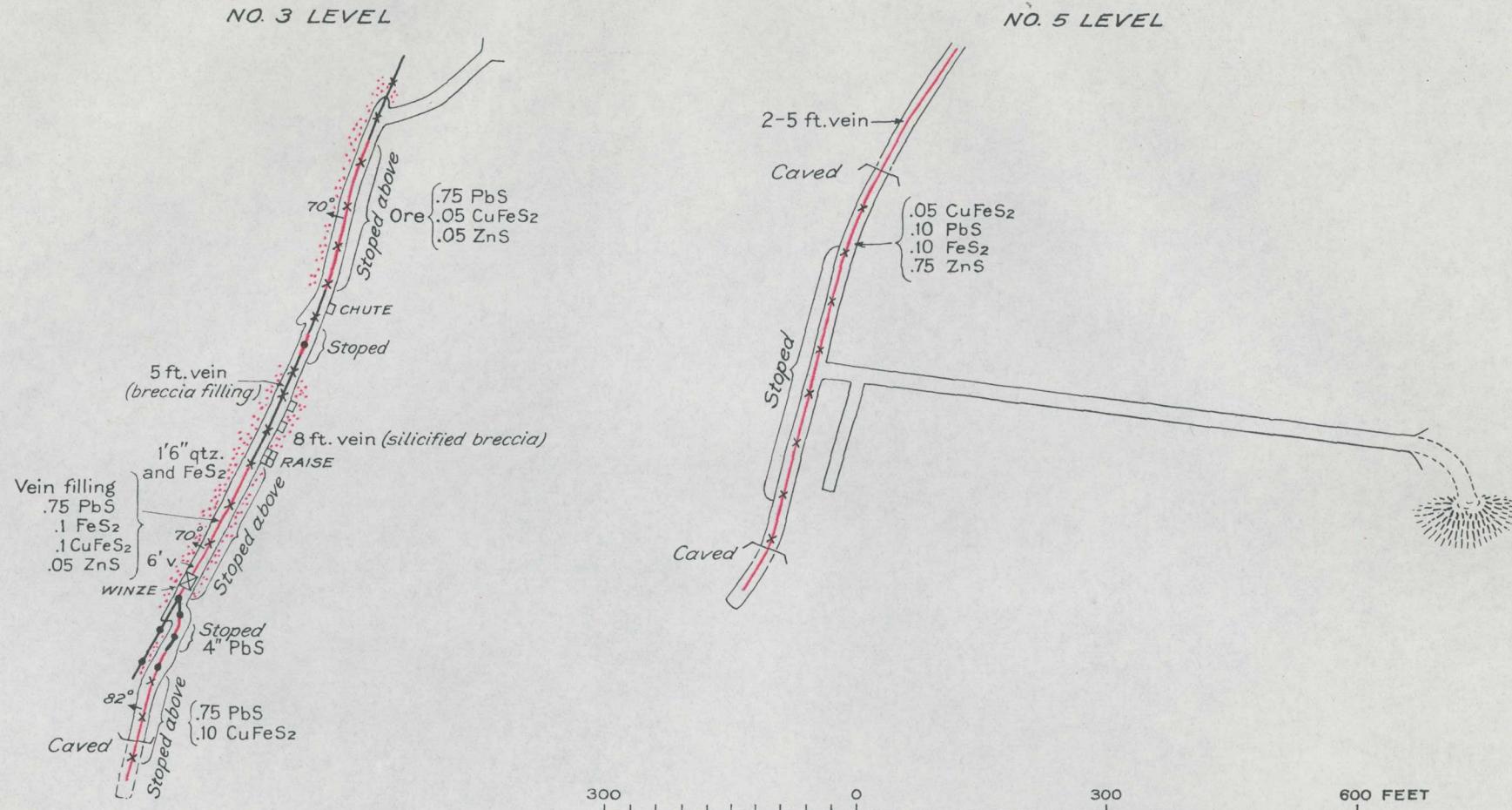
About 170 feet south of the main tunnel on the lower level the Comstock vein crosses vein no. 7. The Comstock fissure is barren at this place but is clearly later than vein no. 7. The intersection of the two veins is not exposed on the next level, but on level 3, about 175 feet above the lower level, the junction is easily studied. Here the Comstock vein consists of about 3 inches of barite, quartz, and galena and cuts across vein no. 7 without a break, although there is a small vertical fault almost at the junction which displaces the veins about 5 inches. Vein no. 7 is from 12 to 36 inches wide for most of its length and consists chiefly of barite containing moderate amounts of quartz, sphalerite, and galena. It strikes a little north of east and dips 48°-60° N., averaging about 55°. The drift following vein no. 7 on the main tunnel level east of the Comstock vein has long been caved, and no map of it was available, but according to a report quoted earlier some very good lead-silver ore was found a short distance east of the junction. Much of the ore has been stoped east of the junction above the second level, but little work has been done above the third level. At the top of the stopes, west of the junction of the two veins, about 70 feet above the second level, the vein is about 12 inches wide and contains comparatively little barite. It is largely rhodochrosite, with moderate amounts of galena, sphalerite, and quartz. The vein is barren and tight at the west end of the drift on the main tunnel level and is barren a short distance east of the place where it is cut by the main crosscut tunnel. The length of the ore shoot, including the short barren interval at the junction of the veins on this level, is about 650 feet. The upper limit of the ore shoot is not exposed on the upper levels, but the vein is much poorer at the west end of the drift on the second level than it is directly below, in the drift on the main tunnel level. The vein has not been exploited close to the surface, and nothing is known of the character of the ore above the third level.

The drag in the gneiss next to the Comstock vein, shown on the first level about 70 feet south of the junction of the two veins, indicates that the vein follows a premineral reverse fault. The direction of movement on vein no. 5 is unknown. The widening of the ore where the Comstock vein flattens is in harmony with the supposition that the vein occupies a reverse fault. Some of the ore on the lower level in the Comstock vein is reported to have been 4 feet wide, and the width of some stopes suggests that the report is correct. Above the second level, however, all the accessible stopes indicate that the ore was less than 2 feet wide in most places, but the report of Clarence King indicates that it was much wider in some places near the surface. The stope maps (see fig. 25) indicate that the vein was poorer above the third level than below this level, and it is possible that the ore body found near the surface was localized by the northerly fault that terminates the vein.

An interesting feature of the mine is the presence of richer silver ore on the lowest level than was found on the upper levels. According to the available records, the ore less than 150 feet from the surface was chiefly galena with moderate amounts of sphalerite, a little tetrahedrite, and rarely some polybasite. The ore coming from the mine, when the workings had been deepened 75 feet more, is reported as chiefly galena, but sphalerite, pyrite, and chalcopyrite were also abundant, and argente and brittle silver were not uncommon. There is no record of the kind of ore found between the upper levels and the rich silver ore found at the main tunnel level, but here proustite, polybasite, stephanite, and argentiferous tetrahedrite were



PLAN OF LOWER LEVEL OF STS. JOHN MINE, GLACIER MOUNTAIN



EXPLANATION

—●— Barren fissure, fault, or vein from 1 to 12 inches wide

—*— Barren fault or vein more than 12 inches wide

—●— Mineralized vein from 1 to 12 inches wide

—x— Mineralized vein more than 12 inches wide

●●● Pyritized and silicified wall rock

— 1^{70°} — Strike and dip

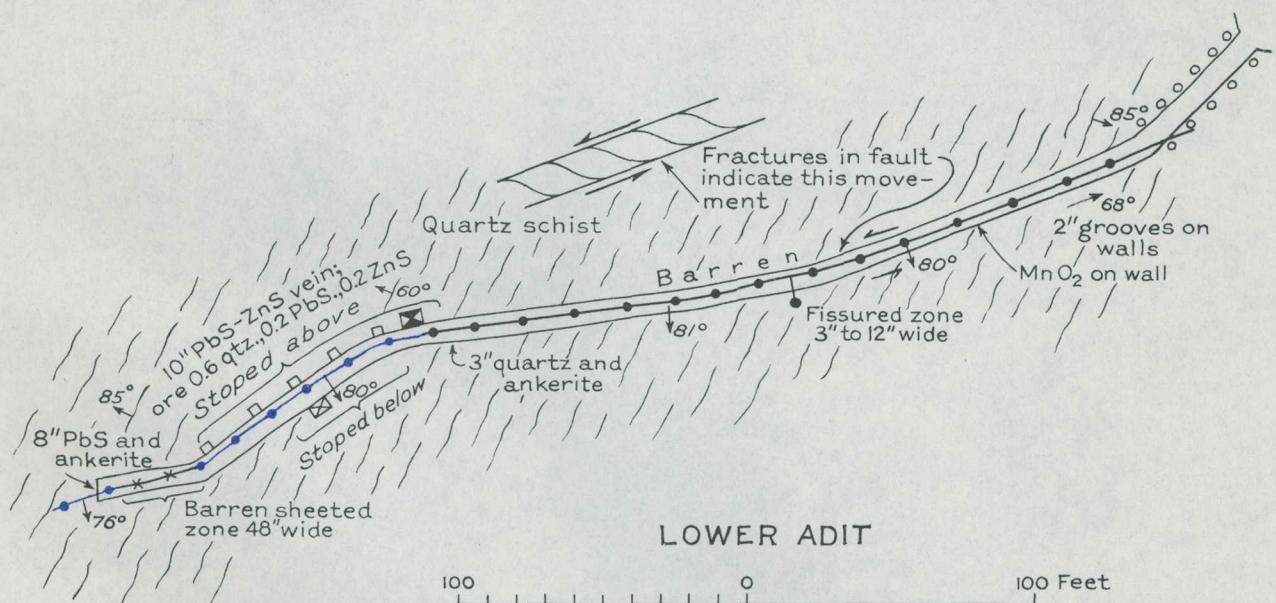
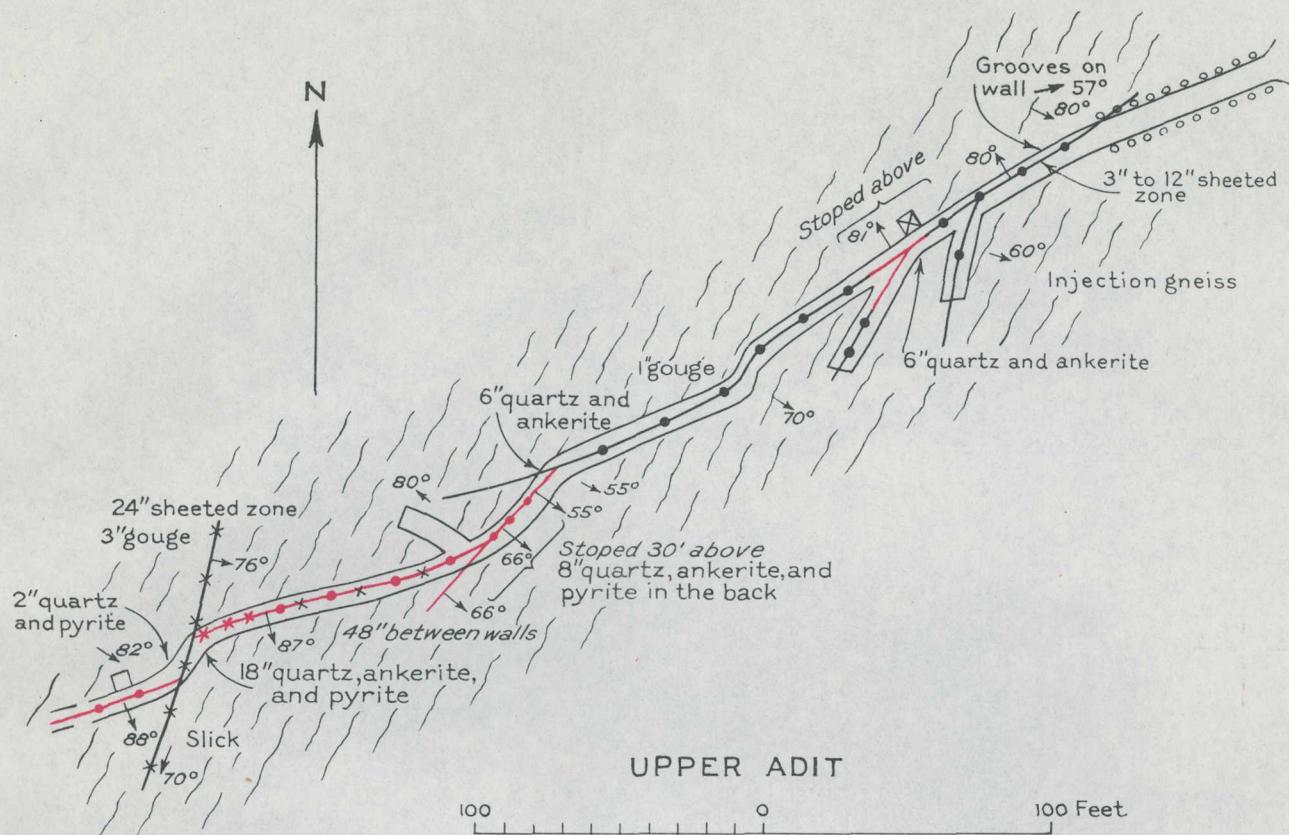
PbS, galena

ZnS, sphalerite

CuFeS₂, chalcopyrite

FeS₂, pyrite

PLANS OF LEVELS 3 AND 5 OF THE SANTIAGO MINE, McCLELLAN MOUNTAIN



EXPLANATION

| | | | |
|---------|--|------------------------------------|---|
| — | Barren fissure, fault, or vein less than 1 inch wide | ●—● | Galena vein from 1 to 12 inches wide |
| —●—●— | Barren fissure, fault, or vein from 1 to 12 inches wide | ↑ 70° | Strike and dip |
| —*—* | Barren fault or vein more than 12 inches wide | /// / // | Strike of schistosity |
| — | Pyrite vein less than 1 inch wide | ↙ | Downthrown side of normal fault |
| —●—●— | Pyrite vein from 1 to 12 inches wide | ↔ | Relative movement of walls (horizontal component) |
| —*—* | Pyrite vein more than 12 inches wide | PbS, galena | PbS, galena |
| —●—x—●— | Fissure zone more than 12 inches wide carrying from 1 to 12 inches of pyrite | ZnS, sphalerite | ZnS, sphalerite |
| | | MnO ₂ , manganese oxide | MnO ₂ , manganese oxide |
| | | qtz, quartz | qtz, quartz |
| | | oooooo | Timbered drift |
| | | ooooooo | Slick slickensides |

PLANS OF UPPER AND LOWER ADITS, SILVER KING MINE, GLACIER MOUNTAIN

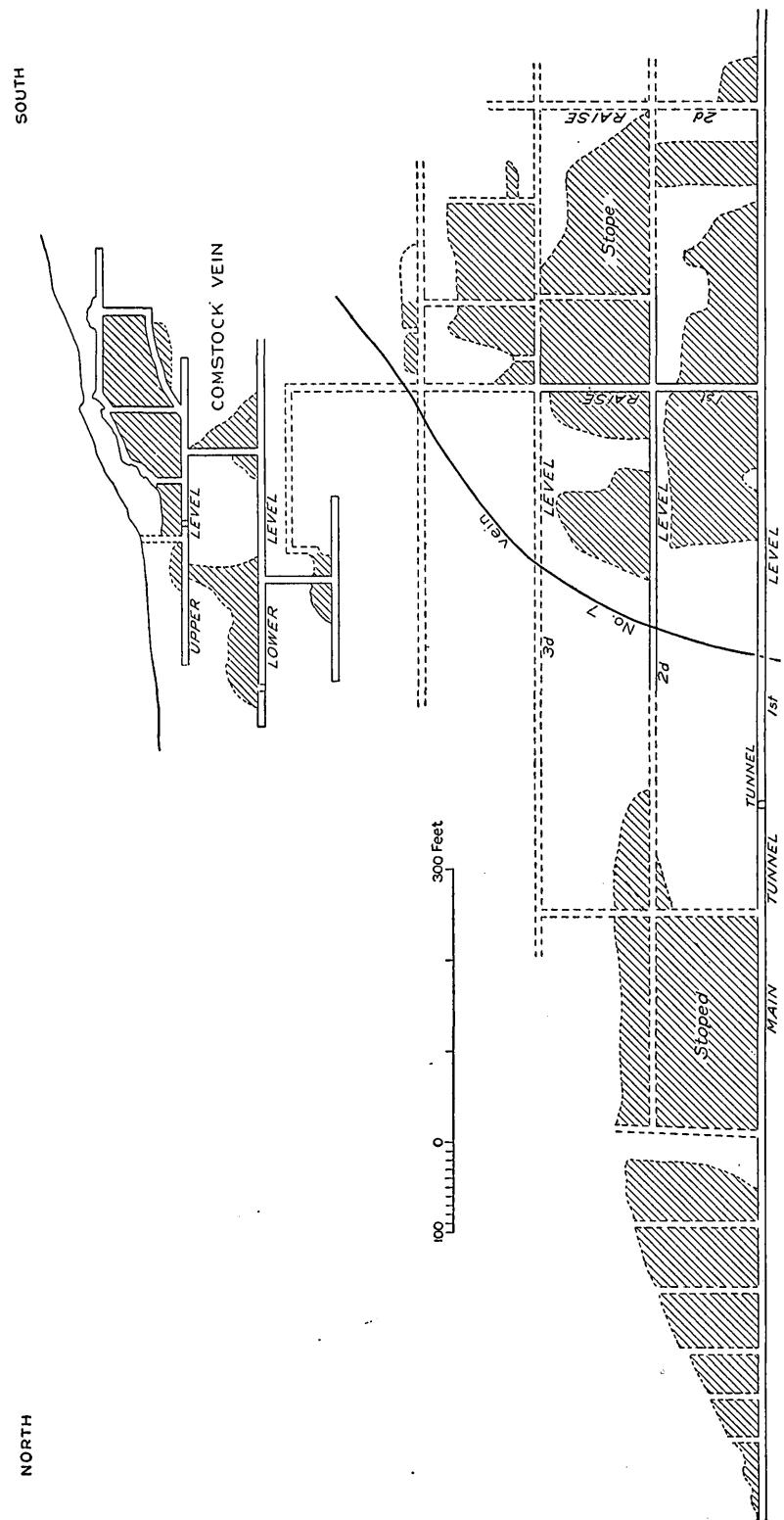


FIGURE 25.—Stope map of vein 5, Sts. John mine.

abundant in ore that carried only a small amount of galena. The ore south of this shoot was chiefly galena with little sphalerite and a small amount of tetrahedrite. In vein no. 7 northeast of the junction of the main tunnel level, native silver was found in ore that was chiefly galena. This rich silver ore did not continue above the next level, however, and probably changed into a mixed sphalerite-galena ore in a quartz-barite gangue. The ores on the main tunnel level show no oxidation or evidence of enrichment, and few veins in this region are appreciably oxidized more than 50 feet below the surface. It is very unlikely that the silver ore shoots in the Sts. John mine are related in any way to the action of surface waters.

The available production figures of the Sts. John mine are shown below.

Production of Sts. John mine

| | Ore (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) | Zinc (pounds) |
|-----------------------------------|------------------|--------------------|----------------------|--------------------------|----------------------------|---------------|
| 1870, August to December | | | | 29,720 | | |
| 1882 | 50 | | | | | |
| 1884 | 25 | | | | | |
| 1885 | 200 | | | | | |
| 1886 | 35 | | | | | |
| 1887 | 94 | 3,354 | 23,174 | | | |
| 1890 | 44 | 1,650 | 39,785 | | | |
| 1891 | 805 | 32,274 | 1,293,307 | | | |
| 1892 | 628 | 24,773 | 607,518 | | | |
| 1893-99 | 1,523 | | | | | |
| 1900 | 80 | 2,936 | 79,200 | | | 9,600 |
| 1901 | 1 | 138 | | | | |
| 1904 | 5 | 125 | 4,000 | | | |
| 1914 | 181 | 0.99 | 6,842 | 110,234 | 327 | |
| 1915 | 23 | 1,088 | 13,138 | 78 | | |
| 1916 (Tiger extension) | 3 | | 683 | 629 | 47 | |
| 1917 | 17 | | 720 | 12,528 | 70 | |
| 1918 (old Comstock dump) | 27 | 10 | 1,045 | 4,814 | 251 | |
| 1919 | 67 | 2.11 | 2,952 | 34,914 | 175 | |
| 1920 | 29 | 20 | 857 | 23,852 | 22 | |
| 1922 (old Comstock mine and dump) | 21 | 20 | 407 | 13,273 | 22 | |
| 1923 | 93 | 40 | 1,615 | 97,462 | | |
| 1924 | 94 | 2,174 | 101,874 | | | |
| 1928 | 13 | 30 | 411 | 11,694 | | |

| | Ore to concentrating mills (short tons) | Concen- trates pro- duced (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) | Zinc (pounds) |
|-----------------------------------|---|--|--------------------|----------------------|--------------------------|----------------------------|---------------|
| 1910 | 330 | 33 | | 482 | 21,455 | | 17,000 |
| 1911 | 2,730 | 273 | 1.13 | 8,086 | 241,621 | | |
| 1913 | 7,400 | 74 | .36 | 2,754 | 79,176 | | |
| 1914 | 50 | 12 | | | | | 7,200 |
| 1916 (Tiger extension and others) | 530 | 53 | 1.09 | 1,586 | 32,279 | 174 | |
| 1917 | 1,200 | 137 | 1.42 | 3,259 | 53,176 | 493 | |
| 1918 (Old Comstock dump) | 1,120 | 112 | .55 | 3,405 | 83,092 | 108 | |
| 1926 | 3,000 | 200 | 1.20 | 4,987 | 76,424 | 114 | 122,378 |
| 1927 | 4,000 | 340 | .30 | 2,239 | 58,015 | 23 | 226,632 |

• Base bullion.

No record available for 1871-75, 1877-80; no production in 1876, 1881, 1883, 1888-89, 1902-3, 1905-9, 1912, 1921, 1925.

SANTIAGO-COMMONWEALTH-CENTENNIAL

The Santiago mine is on the southeast slope of McClellan Mountain, at an altitude of about 12,000 feet. It is about half a mile northwest of the Waldorf tunnel and 6½ miles northeast of Montezuma. The vein is opened by five tunnels and an underground shaft 300 feet deep on level 5. At the time of the writer's visit tunnels 3 and 5 were partly accessible, and they are shown on plate 36. The mine can be reached by automobile from Georgetown, although the road was in poor condition in 1927 and had many steep grades. The lower tunnel is connected by an aerial tram with the Waldorf mill, 450 feet below and half a mile southeast.

The Santiago mine is on the southern part of a vein that has been productive for nearly a mile in length and 800 feet in depth. The Santiago ore shoot is about 1,100 feet long and

has been explored to a depth of about 700 feet below its top. As shown in figure 26, the top of the ore shoot is well below the surface, and, though some ore along the north side cropped out in the steep-walled glacial cirque where the mine is situated, the ore is virtually in a "blind" shoot.

Little is known of the history of the mine, but unlike most of the veins nearby, the Santiago has yielded the bulk of its production since 1900, and the figures given below probably give a fair approximation of the entire output.

Production of Santiago mine

| | Ore (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) | Zinc (pounds) |
|------------------|------------------|--------------------|----------------------|--------------------------|----------------------------|---------------|
| 1901 | 300 | 292.62 | 9,627 | 61,924 | | |
| 1903 | 40 | 20.00 | 1,200 | 5,176 | | |
| 1905 | 1,037 | 528.74 | 22,086 | 202,028 | 16,044 | |
| 1906 | 715 | 202.30 | 11,785 | 120,826 | | |
| 1908 | 1,253 | 645.18 | 25,419 | 162,372 | 44,361 | 26,644 |
| 1909 | 1,200 | 799.08 | 32,000 | 356,322 | 81,067 | 56,020 |
| 1913 | 944 | 561.24 | 10,833 | 223,455 | 41,988 | |
| 1916 | 60 | 15.89 | 707 | 24,976 | | |
| 1917 | 68 | 81.07 | 1,084 | 30,585 | 4,405 | |
| 1918 | 67 | 10.60 | 506 | 33,124 | 434 | |
| 1927 | 23 | 11.28 | 383 | 10,675 | 896 | 1,893 |
| Dry ore: | | | | | | |
| 1902 | 175 | 90.00 | 7,189 | | | |
| 1904 | 494 | 230.87 | 7,660 | | 2,831 | |
| 1917 | 17 | 8.18 | 155 | 717 | 784 | |
| 1919 | 2 | .03 | 135 | 157 | | |
| Copper ore: | | | | | | |
| 1910 | 1,871 | 2,288.32 | 40,801 | 12,395 | 205,821 | |
| 1911 | 2,713 | 1,961.15 | 36,452 | 9,832 | 187,920 | |
| 1914 | 731 | 896.93 | 12,504 | 18,657 | 73,185 | |
| 1915 | 20 | 42.80 | 717 | | 3,864 | |
| 1916 | 825 | 950.76 | 23,323 | 66,199 | 116,671 | |
| 1917 | 30 | 9.35 | 221 | 1,037 | 2,143 | |
| 1918 | 54 | 30.30 | 954 | 4,447 | 5,278 | |
| 1919 | 213 | 206.63 | 4,209 | 13,427 | 39,025 | |
| 1920 | 85 | 97.20 | 2,746 | 8,266 | 19,796 | |
| 1923 | 42 | 30.15 | 837 | 4,002 | 5,668 | 2,136 |
| 1924 | 17 | 16.00 | 328 | 1,633 | 2,024 | |
| Lead-copper ore: | | | | | | |
| 1912 | 1,577 | 802.41 | 26,507 | 578,650 | 105,153 | |
| 1915 | 1,070 | 1,226.65 | 15,266 | 53,668 | 96,157 | |
| 1916 | 113 | 100.80 | 2,944 | 27,596 | 16,233 | |
| 1917 | 439 | 439.02 | 9,529 | 52,826 | 57,801 | |
| 1918 | 21 | 9.90 | 405 | 5,102 | 1,358 | |
| Commonwealth: | | | | | | |
| 1888 | (?) | .73 | 527 | 15,247 | | |
| 1889 | (?) | 2.33 | 1,873 | 51,215 | | |
| 1890 | (?) | 44.00 | 9,765 | 241,549 | | |

| | Ore to concentrating mills (short tons) | Concen- trates pro- duced (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) | Zinc (pounds) |
|------|---|--|--------------------|----------------------|--------------------------|----------------------------|---------------|
| 1907 | 1,050 | 279 | 209.66 | 5,668 | 4,728 | 15,421 | |
| 1918 | 5 | 2 | 1.77 | 34 | 2,917 | | |

No record available for 1891-1900; no production in 1928.

The vein is a fissured zone that strikes N. 15°-35° E. and dips 70°-85° W. It is from 3 to 8 feet wide on the third level and from 2 to 5 feet wide on the fifth level, where the writer saw it, but neither level was open to the breast. In the widest parts of the vein on the third level the filling is coarsely brecciated granite which has been strongly silicified and pyritized. This silicification and pyritization was earlier than the lead-zinc-copper metallization and does not indicate the presence of pay ore; the lead-silver-gold tenor was so low in a place where the pyritic silicified breccia was 8 feet wide that no stoping was done. The ore on the third level and above it is chiefly galena containing moderate amounts of chalcopyrite; but pyrite is usually present in small quantities, and sphalerite is common, though it rarely makes up more than 5 percent of the ore. On the fifth level sphalerite is the most abundant sulphide in those parts of the vein that remain unstopped; galena and pyrite are present in nearly equal amounts but are much less abundant than the sphalerite; chalcopyrite is common but is less abundant than on the third level. Although some of the gangue on the

third level is manganeseiferous ankerite, quartz greatly predominates over the carbonate, but on the fifth level the relative proportions of the two gangue minerals are reversed, and the ankerite is much more abundant than the quartz. In most places where the ankerite is wide the ore is thin. The sixth and seventh levels were not accessible at the time of the writer's visit, but according to a miner who had worked in the lowest level the mineralization was not as strong there as it was on the upper levels, and sphalerite and pyrite were the predominant sulphides, although galena and chalcopyrite were locally abundant. The gold content on the lower levels was reported to be

the vein is also opened at about 11,650 feet by the Waldorf or Wilcox tunnel. The relation of the tunnels and the general geology are shown in figure 16. Where the Commonwealth vein is cut by the Waldorf tunnel it strikes N. 25° E., dips about 70° SE., and carries small amounts of lead, zinc, and iron sulphides. About 300 feet northeast of the crosscut tunnel the vein swings north and strikes N. 12° E. and dips steeply to the northwest. Here the ore is of much better grade and was stoped, although the extent of the stoping is not known. The ore in this part of the vein is chiefly galena carrying moderate amounts of sphalerite and some pyrite. Some of the ore left

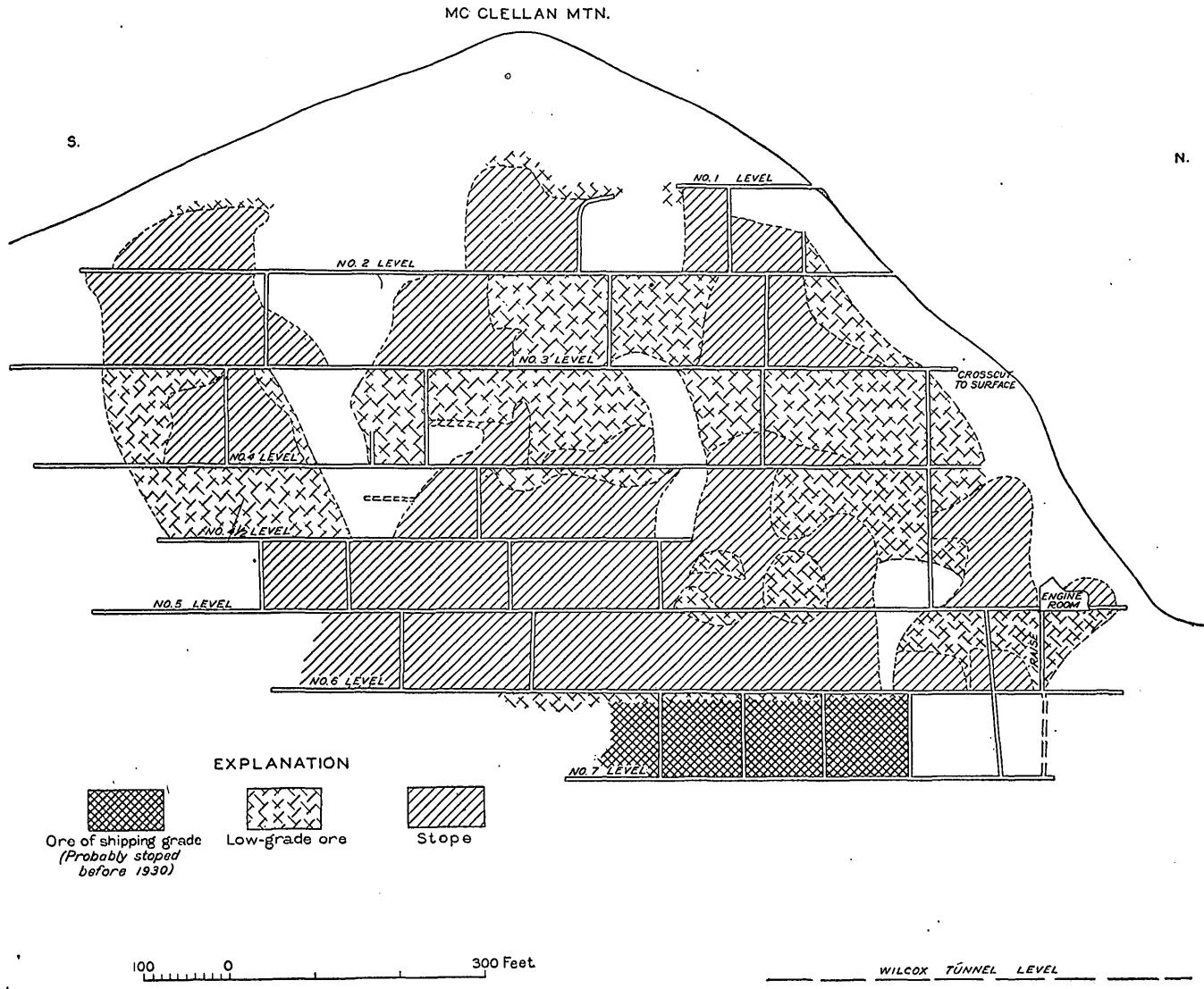


FIGURE 26.—Stop map of Santiago mine, looking west. (From map by F. Ricci.)

directly related to the presence of light-colored sphalerite, or "rosin jack."

About a quarter of a mile north of the Santiago mine a few dilapidated buildings cluster about the caved entrance to the Commonwealth tunnel. This part of the Santiago-Commonwealth-Centennial vein was worked in the seventies and eighties, but little is known about the production or the developments prior to 1900. The Georgetown Courier for December 6, 1888, reports a shipment of 4 to 5 tons of ore, which ran 68 ounces of silver to the ton and 61 percent of lead, and the same paper mentions the mine again in 1889 and 1890. The altitude of the Commonwealth tunnel is about 12,000 feet, but

is from 3 to 5 inches wide and contains very little gangue. The vein becomes barren about 1,000 feet north of the crosscut tunnel, and when the writer visited it in 1926 the drift was caved a short distance beyond. According to A. A. Atkins, who had charge of the Waldorf tunnel when the last work was done prior to 1926, the Commonwealth vein was followed about 800 feet farther, but no ore shoots were found. This barren segment of the vein is on the Centennial claim, but little work has been done at the surface in this ground, and some ore may be present. The wall rock of the vein is Silver Plume granite, Idaho Springs schist, and granite gneiss, and, as shown on plate 3, the schist becomes increasingly abundant to the north.

SARSEFIELD

The Sarsefield mine is on the west slope of Collier Mountain, about $1\frac{1}{2}$ miles east-southeast of Montezuma. It is opened by three adits at altitudes of 12,270, 12,390, and 12,445 feet, and the upper adit is connected to the surface by an air shaft. The mine was originally located in the seventies as the Waterman and was relocated about 1881 as the Sarsefield. It was owned and worked by Cunningham & Taylor from 1883 to 1888, and several carloads of ore were shipped during those years. Only a small amount of ore is known to have come from the first adit, which was driven before 1883; the second adit was driven in 1885, and most of the production made in the eighties came after its completion. The mine was idle during most of the nineties, but in 1898 the lower adit was driven 120 feet below the second adit. All the workings of the Sarsefield were inaccessible at the time of the writer's visit, and most of the information regarding the mine has been obtained from James Southerland, who had charge of driving the lower adit.

The ore obtained from the upper workings occurred in a single vertical ore shoot, which cropped out on the shoulder of the mountain. The richest part of this shoot was nearly pure galena ore 3 feet wide. The lower adit was driven east 200 feet to the vein, which was followed to the northeast for about 400 feet. The vein dips 80° SE., and its course in the upper levels is N. 43° E., but in the lower adit the vein strikes N. 32° E. where it was first tapped by the crosscut. About 100 feet northeast of the crosscut the vein swings northeast and follows the same course that it maintained in the upper levels. The vein is about 6 feet wide, but the ore streak is commonly less than 15 inches thick. The best ore shoot found on this level occurred about 70 feet from the crosscut and continued 80 feet along the drift. At the northeast edge of the shoot a winze was sunk 82 feet and is reported to have passed through the ore shoot at 50 feet. A short drift was driven northeast from the bottom of the winze, and the ore shoot was stoped to the surface. It maintained its pitch of about 40° toward the northeast throughout this distance. The ore was nearly free from gangue and was from 24 to 36 inches wide. It was chiefly galena and light-colored sphalerite but contained small amounts of pyrite, gray copper, barite, and quartz. Most of the ore shipped assayed about 45 percent of lead and 72 ounces of silver to the ton. The ore above the lower adit level contained about 14 percent of zinc, but the ore from the bottom of the winze carried a little more than 20 percent of zinc. The silver content is said to have been much higher close to the surface than at the adit level.

A vertical ore shoot was found about 100 feet northeast of the shoot just described. This second shoot was about 40 feet long, and the ore in the drift was only 4 inches wide. A short distance above the drift, however, it widened to 12 inches, and ore of this width was stoped upward for about 50 feet, to a point where it pinched to a seam only an inch in width. The shoot was not followed farther, but from its position in the mine it seems probable that this ore is in the lower part of the chimney exploited in the upper level. The ore was of better grade than that in the first shoot and is said to have been almost pure galena.

The country rock of the mine is the Idaho Springs formation, which strikes about N. 30° E. and dips 80° – 90° W. Several small masses of fine-grained sodic rhyolite porphyry crop out near the mine, and it is probable that some porphyry was cut by the mine workings. The southwest ore shoot occurred where the vein changed its course, and the vertical shoot was found where the vein was cutting across the schistosity of the enclosing quartz-biotite-sillimanite schist.

The production of the mine is given below.

Production of Sarsefield mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet
assay
(pounds) | Zinc
(pounds) |
|------|------------------------|--------------------------|----------------------------|-----------------------------------|------------------|
| 1884 | 13 | | | | |
| 1885 | 35 | | | | |
| 1886 | 26 | | | | |
| 1888 | (?) | | 1,824 | 11,425 | |
| 1899 | 198 | 5.36 | 16,121 | 185,856 | 65,125 |
| 1900 | 75 | .77 | 4,008 | 64,602 | 17,012 |
| 1905 | 10 | | 396 | 10,107 | 3,334 |
| 1906 | 35 | | 1,362 | 28,790 | 12,844 |
| 1907 | 9 | | 466 | 6,333 | 4,018 |

No record available for 1889-98; no production in 1887, 1901-4, 1908-29.

SILL

The Sill vein is at the head of West Geneva Creek, on the east slope of Collier Mountain, 2 miles east of Montezuma, at an altitude of about 11,700 feet. It is at the end of a wagon road leading up West Geneva Creek from Grant, about 12 miles to the southeast, but the last 3 miles of the road was in poor condition in 1928. The mine is said to have shipped about 10 tons of gold ore in the nineties and about the same amount of lead ore in 1909, but no record of the shipments has been found. The vein is from 12 to 24 inches wide and strikes N. 38° E., parallel to the schistosity of the quartz-biotite-sillimanite schist, which is the country rock of the region. The ore consists chiefly of well-crystallized pyrite and quartz, but both light and dark sphalerite are present in the ore left on the dump. The pyrite is earlier than the sphalerite, and the sphalerite is earlier than the coarse-grained quartz. The shipping ore is said to occur in pockets which contained appreciable amounts of gold.

SILVER CORD (RAINBOW)

The Silver Cord claim is 150 feet wide and 1,500 feet long and is an early patent on the Silver Wave vein northeast of the Silver Wave claim. The Rainbow claim, covering the same portion of the vein, was patented later and is 300 feet wide and 1,500 feet long. It lies on the east slope of the Continental Divide, on the west side of West Geneva Creek, and has been opened by three adits. The portals of these adits were locked at the time of the writer's visit in 1928, and he did not examine them. The upper adit is at an altitude of about 12,950 feet, the intermediate adit at 12,850 feet, and the lower adit at about 12,500 feet. According to the owner, James Southerland, an ore shoot was found in the upper adit 100 feet from the portal and a second one 15 feet from the breast, which at that time was at the end line between the Silver Cord and Silver Wave claims. The first shoot was about 30 feet long and 12 inches wide and consisted chiefly of galena assaying about 20 ounces of silver to the ton. This shoot was also found on the second level and has about the same dimensions and character as on the first level; it is said to pinch at the bottom of the drift, and no effort was made to explore it below the level. The second ore shoot was largely mined through the Silver Wave workings and was part of the shoot shown at the northeast end of adit 1 in figure 28. The first ore shoot is almost over the long stope on level 5 of the Silver Wave and is probably part of the same ore channel. The vein has the same strike in the Silver Cord claim as it does on the Silver Wave claim and dips 74° NW. near the upper adit. No information was obtained on the lower adit. The known production of the Silver Cord consists of 70 ounces

of silver and 953 pounds of copper in 1888 and 700 ounces of silver and 23,082 pounds of copper from 20 tons of ore in 1902.

SILVER KING

The Silver King mine is on the east slope of Glacier Mountain, about 200 yards northwest of the Bolivar mill and half a mile south of Montezuma. The lode was discovered by J. T. Lynch in 1866 and was called the Sukey until 1880, when it was relocated as the Silver King. According to Raymond's report for 1870 the Sukey was developed by two adits and a 40-foot discovery shaft. The shaft was 180 feet above the upper adit, which was 96 feet long, and 330 feet above the lower adit, which was 260 feet long. The vein was reported to be from 4 to 6 feet wide and to have an ore seam from 20 to 36 inches wide. Most of the ore was worth between \$35 and \$40 a ton. At this time the mining company owned a 5-stamp mill, a roasting furnace, and two amalgamating pans. In 1873 this plant treated 70 tons of

ore that averaged 60 ounces of silver to the ton; the cost of reduction was \$23 a ton. The mine was not operated again until 1875, when the mill made a short but unsuccessful run on some of the lower-grade ore of the mine. Some high-grade ore was shipped that summer, but the amount is not known. The mine was operated more successfully in the next 5 years, however, and a dividend of \$50,000 was paid in 1881. In 1882 the mine was developed by three drifts, 155, 460, and 600 feet long, with connecting winzes aggregating 170 feet, according to the Colorado Mining Directory. The ore was from 8 to 80 inches wide and consisted of galena, gray copper, ruby silver, and native silver in a quartz gangue, and sorted ore assayed 55 percent of lead and from 50 to 100 ounces of silver to the ton. The mine produced about 5 tons of ore a day for some time and treated it in a 10-stamp mill before shipping. In the summer of 1883 the old Sukey

mill was remodeled by the Silver King Mining Co., and in November the mill started operating on ore bought from the Radical and Chatauque mines. The mill did not run all winter, however, and it burned down early in the summer of 1884 and has never been rebuilt. A small amount of ore from the Silver King was concentrated in the mill before it burned, but no more ore was shipped until 1886. The mine was steadily operated, however, and the drifts were extended in the search for new ore bodies. In 1886 a carload of ore was shipped which netted the company \$90 a ton. As shown in the table below, a small amount of ore was shipped the following year, but the mine was not worked in 1888-91. In 1892 it shipped 15 carloads of ore, but it was again closed in 1893 and was not reopened until about 1899. In this year and in 1901 a small amount of ore was shipped. The Silver King was again operated in 1909 by the Silver Princess Mining Co., and during the next 3 years a few carloads of ore were treated at this company's mill in Montezuma. The exact amount of ore milled is unknown, as the mill was using ore from the Chatauque, Silver Wave, and Silver King mines, but the best estimates available have been used in prorating the ore treated at the mill in 1909-12, and the production figures given are probably fairly close to the actual output of the various

mines. No work has been done on the Silver King since 1912.

As shown on plate 37, the vein strikes N. 35° - 60° E. and dips 65° - 88° SE. On the upper level the vein everywhere cuts across the schistosity, which strikes about N. 25° E. and dips steeply to both east and west. On the lower level the vein in some places turns and runs parallel to the schistosity for short distances before resuming its general trend of N. 60° E., and on this level there are many branching veins parallel to the bedding planes of the enclosing gneiss. In short, the vein is much less definite on the lowest level than it is in the upper level and has the appearance of a vein that is splitting or "horsetailing" and will disappear at no great depth. Little ore was found in that part of the lowest level which was accessible at the time of the writer's visit, but, as shown on figure 27, the lower part of the ore shoot opened by the upper level was found and stoped.

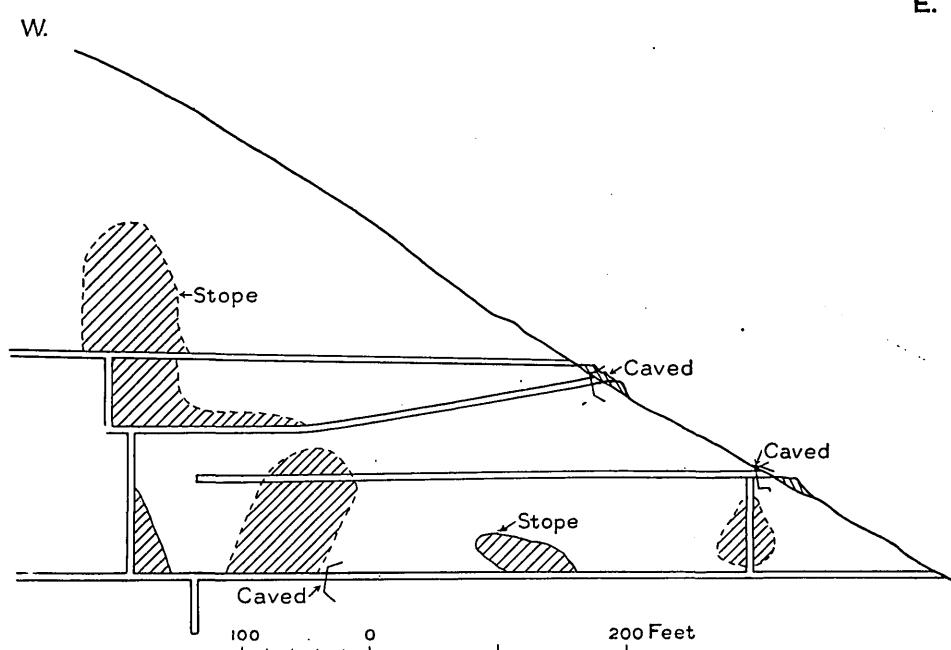


FIGURE 27.—Sketch map of stopes in Silver King mine, August 1929, looking north.

The direction of movement of the premineral fault occupied by the Silver King vein can be given with some confidence. The walls are deeply grooved on both the upper and lower levels, and the grooves pitch 57° - 68° NE.; S-shaped fractures in the barren fissured zone east of the ore shoot indicate that the hanging wall moved downward and eastward, and thus it may be assumed that the Silver King vein occupies a normal fault in which there was a small horizontal component of movement, the hanging wall moving downward and northeastward at an angle of about 63° . Movement in this direction would tend to create open spaces wherever the vein swung from a N. 60° E. course to one which was more northeasterly. The ore shoots on the upper level and those in the accessible part of the lower level occur where the vein swings to a northeasterly course. On the lower level mineralization followed the intersection of the vein and a premineral fault striking parallel to the gneiss, but the quartz, pyrite, and ankerite vein filling was of too low grade to stop. A small ore shoot was also formed at the junction of the vein and a branching fissure and is said to have contained some ruby silver a short distance above the level.

The ore in the accessible part of the lower level consisted chiefly of quartz, pyrite, and ankerite, with a small amount of galena and sphalerite sparsely distributed through the other

minerals. On the upper level galena was slightly more abundant than sphalerite, and the two sulphides were about equal to the quartz gangue; small amounts of pyrite and chalcopyrite were present also, and near the end of the ore shoots manganiferous ankerite was abundant and is said to have been associated with some ruby silver.

The following are the available figures of production:

Production of Silver King mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet
assay
(pounds) | Copper,
wet
assay
(pounds) | Zinc
(pounds) |
|------|------------------------|--------------------------|----------------------------|-----------------------------------|-------------------------------------|------------------|
| 1883 | 25 | | | | | |
| 1886 | 10 | | | | | |
| 1887 | 7 | | 379 | | | |
| 1892 | 203 | 72.94 | 7,923 | 144,009 | | 40,122 |
| 1904 | 5 | 11.00 | 103 | | | |
| 1909 | 80 | 1.60 | 460 | 15,500 | 83 | |
| 1910 | 10 | .08 | 210 | 12,222 | 58 | |
| 1912 | 39 | 1.57 | 602 | 16,138 | 315 | |
| 1928 | 1 | | 181 | 487 | | |

No record available for 1871-74, 1876-80, 1882, 1884-85, 1889-91, 1893-1900; no production in 1870, 1875, 1881, 1888, 1901-3, 1905-8, 1911, 1913-27.

The Silver Wave vein was discovered about 1882 and was actively developed in the next few years. The mine commenced production in 1885 and continued to 1890; it was probably idle most of the time from 1890 to 1905, when the Silver Wave Mining Co. began to develop it. The mine has been an intermittent producer since that time, and for a while, about 1909, was operated by the Silver Princess Mining Co. The upper adits have long been inaccessible, but no. 5 and part of no. 6 were open in 1929. According to the Montezuma Mill Run, in 1885 the upper adit reached ore after following the vein 60 feet through a barren stretch. Adit 2 started in ore running 160 ounces of silver to the ton, and good ore, averaging 12 inches in width and reaching a maximum of 36 inches, continued for about 60 feet, when a barren space was found. Adit 3 found no ore until it came under the shoot discovered at the portal of adit 2, and 78 feet of this adit out of a total of 300 feet was in ore. Most of adit 4 was in ore, although much of it showed only in the bottom of the drift; 200 feet of the 225 feet driven was called ore, and at that time (1885) a stope 165 feet long was well started on ore that averaged about 9 inches in width. Level 5 was 116 feet on the lode, which carried quartz

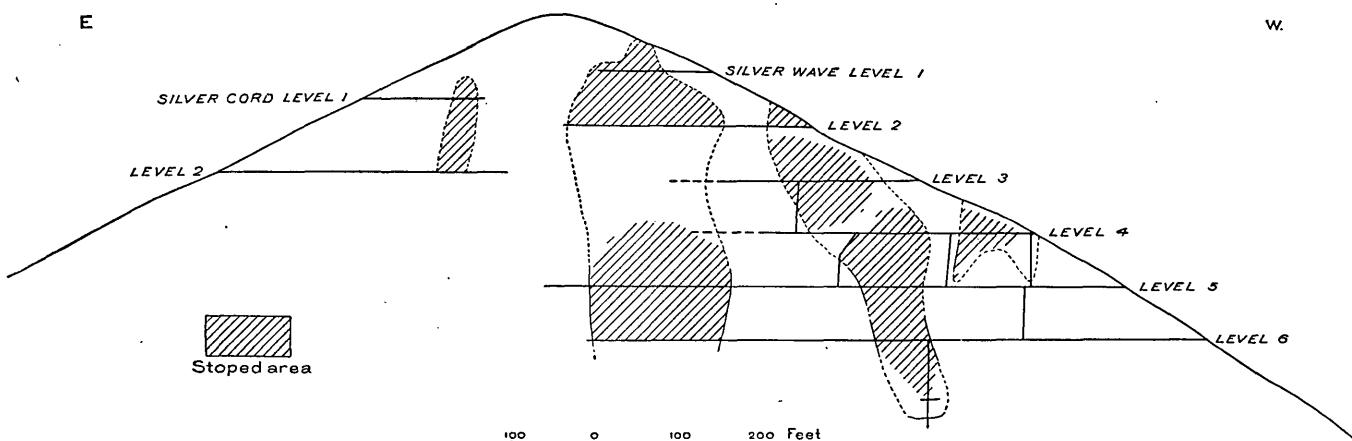


FIGURE 28.—Approximate shape of ore shoots on Silver Wave vein, looking southeast.

SILVER PRINCE

The Silver Prince mine is on the west slope of Glacier Mountain at an altitude of about 11,300 feet, about 2 miles south of Montezuma. It is probably the western continuation of the Wild Irishman vein, but the development work on the two claims is not enough to establish the continuity. The vein was located in 1881 by E. L. Doyle and yielded some ore in the next few years. According to the Colorado Mining Directory the ore was from 6 to 20 inches wide and consisted of gray copper and galena in a quartz gangue. The known production has consisted of 3 tons of ore in 1882, 45 tons in 1884, and 37 tons in 1885.

SILVER WAVE

The Silver Wave vein is in the small gulch between Santa Fe Peak and Sullivan Mountain, on the west slope of the Continental Divide, about 2 miles southeast of Montezuma. The vein has many workings on it, but the chief production has come from the Silver Wave mine, developed by six adits spaced about 65 feet apart vertically, at altitudes of 12,987, 12,920, 12,855, 12,790, 12,725 and 12,657 feet. The lowest adit, no. 6, is at the terminal of a long aerial tramway, which connects the mine with the wagon road 1,650 feet below in the valley of the Snake River, about a mile south of Montezuma. There are several buildings near the portal of adit 6, but both they and the tramway were in poor repair when the writer visited the mine in 1929.

streaked with "mineral." In 1886 adit 2 was 300 feet long, and 260 feet of the drift was reported to expose shipping ore. According to James Southerland, the best ore was found on level 4 in two strong shoots which were about 50 feet apart and not far from the portal of the adit. The ore in the first shoot did not continue down to level 5 but was stoped to the surface about level 4. The second shoot was also stoped to the surface and is reported to have been in some places largely fine-grained galena 34 inches wide. Little information was found concerning the other ore shoots above level 5. The data gathered from many sources, including an early stope map, have been graphically summarized in figure 28.

As shown on plate 16, the country rock of the mine is largely quartz schist of the Idaho Springs formation, which strikes N. 25° W. to N. 55° E. but is nearly north and south in most of the workings. The schist dips west or northwest at 45° to 75° and in some places is parallel to the vein, which strikes N. 27°-50° E. and dips steeply northwest throughout most of its length. A small mass of Silver Plume granite is cut 130 feet from the portal of adit 5 and is also present on adit 6 vertically below. Some small masses of monzonite porphyry were found near the vein on the surface, but none was observed underground. Although small amounts of ore occur in the vein under the first shoot of level 4, and the walls of the drift are in places incrusted with copper sulphate 1 inch thick, the first ore body of commercial size was found about 310 feet from the portal. As the drift was driven in the footwall of the vein for about 80 feet

before the ore was cut, the ore shoot was entered near its northeast end and a drift was driven back southwest for 50 feet, to a point where the ore abruptly pinched to a thin, unprofitable quartz seam. This ore shoot is about 70 feet long on level 5 and is reported to have about the same length on level 6, but the drift was caved 10 feet beyond the southwestern limit of the shoot on the lower level, and the distance could not be measured. According to Jack Ryan, who was a lessee in 1917, the ore shoot was followed below level 6 by a winze 104 feet deep, but the ore pinched suddenly about 5 feet from the bottom. The writer was able to descend this winze only about 15 feet because of the thick coating of ice on the ladders; at this place the vein was well exposed, however, and contained 22 inches of sulphide ore. Over half of the ore was zinc blende, but chalcopyrite and pyrite were abundant, some galena was present, and in the siliceous walls of the main sulphide seam arsenopyrite was common. Here the vein strikes N. 35° E. and dips 85° NW. For about 150 feet northeast of this ore shoot on level 5 the vein is chiefly fine-grained quartz 6 to 8 inches wide and contains many ramifying veinlets of arsenopyrite. It is open and vuggy in many places, and late barite is common in the vugs, but little galena, sphalerite, or other sulphides were seen. At the end of this barren stretch an ore shoot 190 feet long was found and is stope both above and below the level and was undoubtedly reached by level 6. The breast of the drift is 50 feet beyond the stope, and here the vein is 12 inches wide and consists of nearly equal parts of light-colored sphalerite and fine-grained quartz, but a moderate amount of barite occurs disseminated through the other minerals.

The Silver Wave vein is a mineralized sheeted zone whose individual fissures branch and intertwine or gather together in a single strong fissure. In many parts of the barren stretches the vein is followed with great difficulty because of the common occurrence of diverging fracture planes. The ore shoots studied all widen abruptly from narrow seams of ore to commercial bodies 12 to 24 inches wide within a distance of 5 or 10 feet and, of course, pinch as abruptly into lean unprofitable streaks. According to Mr. Ryan, the lower termination of the second ore shoot was as abrupt as its lateral termination. There was little evidence on level 5 of the presence overhead of the first ore shoot of level 4. The schistosity of the wall rock is in some places parallel to the vein and in other places makes a decided angle to it; the vein is nearly barren on level 5 wherever it is parallel to the schist, and ore occurs wherever the vein is decidedly cross-breaking. The termination of an ore shoot sketched in plate 16 illustrates the character of the fissuring in the vein as well as the rapid change in width of the sulphide ore. It is difficult to estimate the depth to which a given ore shoot will extend, but the chimneylike longitudinal section suggests that the vertical extent is generally greater than the horizontal extent. The ore in the upper levels was largely galena and contained moderate amounts of gray copper, and the ore on the lower levels was chiefly sphalerite and chalcopyrite. The known production is given below.

Production of Silver Wave mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet assay
(pounds) | Copper,
wet assay
(pounds) |
|-----------------------------|------------------------|--------------------------|----------------------------|--------------------------------|----------------------------------|
| 1885 | 70 | | | | |
| 1886 | 908 | | | | |
| 1887 | 75 | 23.18 | 5,715 | 153,253 | |
| 1888 | (?) | | 2,497 | 9,796 | |
| 1889 | (?) | | 447 | 24,101 | |
| 1890 | (?) | 32.20 | 3,857 | | |
| 1910 | 22 | 2.67 | 746 | 11,319 | 4,011 |
| 1911 | 30 | 4.35 | 983 | 13,309 | 1,962 |
| 1912 | 291 | 19.66 | 8,714 | 91,672 | 10,074 |
| 1913 (see also milling ore) | 310 | 26.67 | 7,367 | 93,155 | 7,323 |
| 1914 (see also milling ore) | 143 | 5.47 | 4,041 | 100,580 | 3,491 |
| 1916 (see also milling ore) | 18 | 1.66 | 588 | 18,580 | 308 |
| 1917 (see also milling ore) | 28 | 1.38 | 520 | 21,945 | |

Production of Silver Wave mine—Continued

| | Ore to
concentr-
ating
mills
(short
tons) | Con-
cen-
trates
pro-
duced
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet
assay
(pounds) | Copper,
wet
assay
(pounds) | Zinc
(pounds) |
|---------------------------|--|--|--------------------------|----------------------------|-----------------------------------|-------------------------------------|------------------|
| Lead concentrates: | | | | | | | |
| 1913 | 171 | 24 | 2.15 | 1,243 | 37,825 | | |
| 1914 | 75 | 32 | | 915 | 29,876 | | |
| 1915 | 1,560 | 72 | 9.16 | 2,875 | 79,464 | 1,147 | |
| 1916 | 3,231 | 305 | 15.47 | 10,769 | 304,252 | 5,581 | |
| 1917 | (?) | 4 | .25 | 130 | 3,511 | 74 | |
| 1922 | (?) | 20 | .50 | 549 | 3,704 | 421 | |
| Zinc concentrates: | | | | | | | |
| 1913 | | 49 | | 1,330 | | | 43,040 |
| 1914 | | 40 | | | | | 30,923 |
| 1915 | | 100 | 7.00 | 3,320 | | | 74,000 |
| 1916 | | 54 | | 2,081 | 9,214 | | 36,856 |
| 1917 | | 5 | .06 | 148 | 479 | 212 | 3,734 |

No record available for 1891-1900; no production in 1901-8, 1918-21, 1923-28; production in 1909 probably included with that of Silver King mine, as both that mine and the Silver Wave were then being operated by the Silver Princess Mining Co. (See pp. 107-108.)

STAR OF THE WEST

The Star of the West mine is on the west slope of Teller Mountain, about 2½ miles south of Montezuma, at an altitude of about 11,800 feet. The vein was discovered in 1874, and according to the Montezuma Mill Run, the lower level in 1882 comprised a crosscut 218 feet long and a drift on the vein 200 feet long. The vein was reported to be "a soft light-colored gangue matter" 30 feet wide. The middle level was driven 225 feet on the lode, which carried from 1 to 6 feet of paying ore. The upper level was 60 feet long on the vein, and the ore seam was about 1 foot wide and contained high-grade gold and silver ore. Free gold, gray copper, chalcopyrite, bismuth, and galena were found, and high assays were reported. There is little recorded production for the mine prior to 1886, but some ore is known to have been shipped in 1875 and 1882, and ore is said to have been shipped about 1898. The tonnage was never large, and the total production was probably less than 50 tons. The ore shipped in 1887 averaged 5 ounces of gold and 40 ounces of silver to the ton. The mine was inaccessible in 1929.

STAR OF THE WEST NO. 2

The Star of the West no. 2 is about a quarter of a mile west of the Star of the West and a few hundred feet below it. The lode was located in 1880 by Oliver Milner and was developed by two adits. No production is recorded for the property. The vein in places is said to have carried from 10 to 15 inches of quartz, galena, and gray copper and assayed from half an ounce to 1 ounce of gold and 75 to 125 ounces of silver to the ton and 40 percent of lead. The geology of the lower adit of this prospect is shown in plate 23.

STEVENS

The Stevens mine is in Stevens Gulch, about 6½ miles northeast of Montezuma, at an altitude of about 11,400 feet. It can be reached by automobile from Silver Plume, 7 miles distant by road. In 1927 the roads were in poor condition and had so many steep grades that supplies were hauled to the mine by wagons.

The Stevens mine has been one of the most productive in the Montezuma quadrangle, although its output has been small since 1910. The lode was discovered in the late sixties, but the exact date is unknown. The mine is mentioned by the Georgetown papers much more frequently than any other in the quadrangle and apparently was a steady producer from 1870 until 1893 and has been intermittently productive since that time. The total production is not accurately known, but the figures given below indicate the tenor of the ore and suggest the general order of magnitude of the tonnage that has been produced.

The record of the mine's early shipments suggests that the surface ore was not exceptionally rich but carried considerable lead and silver. The Georgetown Miner for October 13, 1870, reports that the Crescent Silver Mining Co., operating the Stevens mine, had produced 40 tons of ore which yielded \$200 a ton simply in drifting on the vein. Raymond's report for 1872 says:

"The Stevens lode has been constantly and profitably worked during the year, yielding an average of 30 tons per month of good ore, averaging 150 ounces of silver per ton, with a high percentage of lead. This lode is owned by a company who are conducting their operations with economy and ability."

The Georgetown Miner for February 12, 1876, reports that 20 men were working at the Stevens and that the mine was producing ore assaying from 80 to 100 ounces of silver to the

for almost 400 feet, although on the level 100 feet higher, ore was stoped continuously for 350 feet of this distance. Where the ore comes down to the main tunnel level at the south end of the shoot, it continues about 120 feet along the drift. A few small pockets of ore have been found south of this shoot, but the mineralization spread along branching fractures, and the ore bodies are small. Plate 38 shows the mineralization of the branching and intersecting fissures in the southern part of the mine. On the level 100 feet above the main tunnel level, where extensive stopes overlie barren vein matter in the lower level, the ore left on the walls of the stopes, in the pillars, and in the gob is invariably much higher in lead than the ore found on the main tunnel level. Much of the ore seen in the upper level was essentially clean galena, although some sphalerite and chalcopyrite were found in the bottom of the drift near the north end of the shoot. In the main level directly beneath the stopes the vein consisted of a narrow vein of quartz and pyrite or a wide seam of manganiferous ankerite. Beneath the stopes the walls of the drift on the main tunnel level were covered with a white coating of limy carbonate, which was stained brilliant green in some places and partly covered with jet-black deposits in other places, no doubt reflecting the leaching of lime, copper, and manganese by water descending over the broken ore in the stopes above. Where this ore shoot is exposed on the main tunnel level the southern part of it contains more galena than the northern part, and the galena seems to material pitching southward at a low angle. This is shown in figure 29.

Available production figures for the Stevens mine are given below.

Production of Stevens mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet
assay
(pounds) | Copper,
wet
assay
(pounds) | Zinc
(pounds) |
|-----------|------------------------|--------------------------|----------------------------|-----------------------------------|-------------------------------------|------------------|
| 1870..... | 40 | — | — | — | — | — |
| 1872..... | 200 | — | 25,000 | 200,000 | — | — |
| 1887..... | (?) | 54.12 | 12,947 | 390,698 | — | — |
| 1888..... | — | 91.91 | 21,135 | 857,653 | — | — |
| 1889..... | — | 103.34 | 17,890 | 811,106 | — | — |
| 1892..... | (?) | — | 42,666 | 2,601,203 | — | — |

No record available for 1872, 1877-80, 1884, 1893-98; unknown production in 1871, 1874-76, 1883, 1885-86, 1890-91, 1899-1900; no production in 1881-82, 1901, 1921-28; for 1902-20 see Waldorf group, p. 112.

TIGER, TIGER EXTENSION, ST. CLOUD, AND WINDSOR

The Tiger and Tiger Extension claims are on the crest of Glacier Mountain, about a mile southwest of Montezuma, and are developed by several shafts. The deepest shaft is about 100 feet deep, and its collar is at an altitude of 11,775 feet. The property can be reached by a steep trail that leads up the west slope of the mountain from the Sts. John mine. It was discovered before 1870, and ore was sold to the Sts. John smelter prior to 1880. The mine is not mentioned as an active property by the Montezuma Mill Run until 1885. The shipments are shown in the table below. The mine has been inactive since 1890.

ton and averaging about 65 percent of lead. Ten years later the tenor of the ore being shipped was somewhat poorer, a 10-ton mill run on September 16, 1886, assaying 1.1 ounces of gold and 44 ounces of silver to the ton and 47 percent of lead. During 1888 several hundred tons of ore was shipped, averaging about 1.1 ounces of gold and 26 ounces of silver to the ton and 50 percent of lead. In 1891 seven carloads of ore averaged 0.1 ounce of gold and 24 ounces of silver to the ton and 66 percent of lead. A gradual decrease of silver with depth is indicated.

The mine was opened by several adits and by winzes sunk from some of the levels. Most of the portals of the upper levels have been obliterated by snowslides or caving, and it is impossible to tell how many tunnels were driven. The main tunnel level is known as the fourteenth level, and the next tunnel level above was called the ninth level and is supposed to be about 300 feet above the main level, suggesting that the levels were numbered every 10 fathoms in depth. At the time of the writer's visit the main tunnel level and part of the next level above it were accessible. Two winzes have been sunk from the main tunnel level and are reported to be 80 feet deep and to be connected by a drift. They were filled with water in 1927, however, and this information could not be verified by observation.

As shown on plate 38, the ore occurs in branching fissures whose general trend is slightly west of north and whose general dip is 60° - 75° E. Most of the ore found on the main tunnel level contains more sphalerite than galena and has a moderate amount of pyrite and manganiferous ankerite. Ore of this character, 4 to 10 inches wide, occurs in a shoot about 200 feet long just south of the main tunnel where it cuts the vein. As shown in figure 29, no more ore is found in the vein on this level

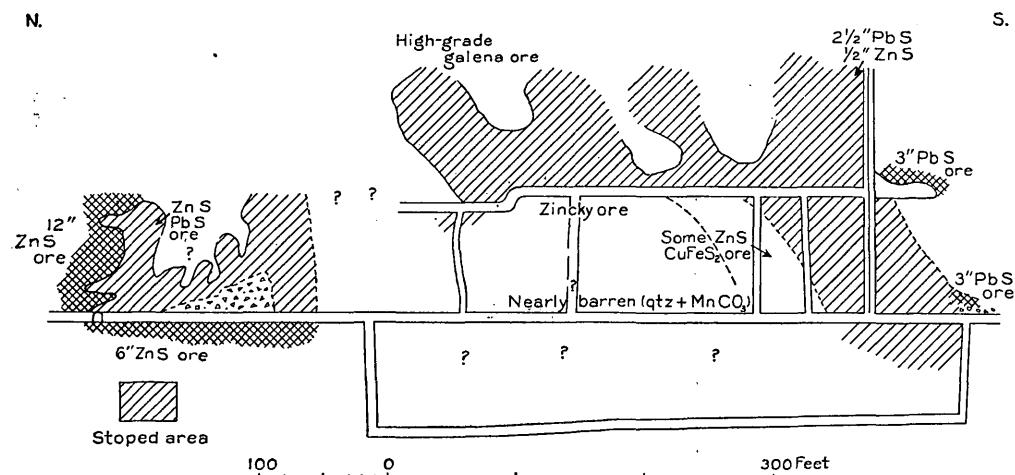
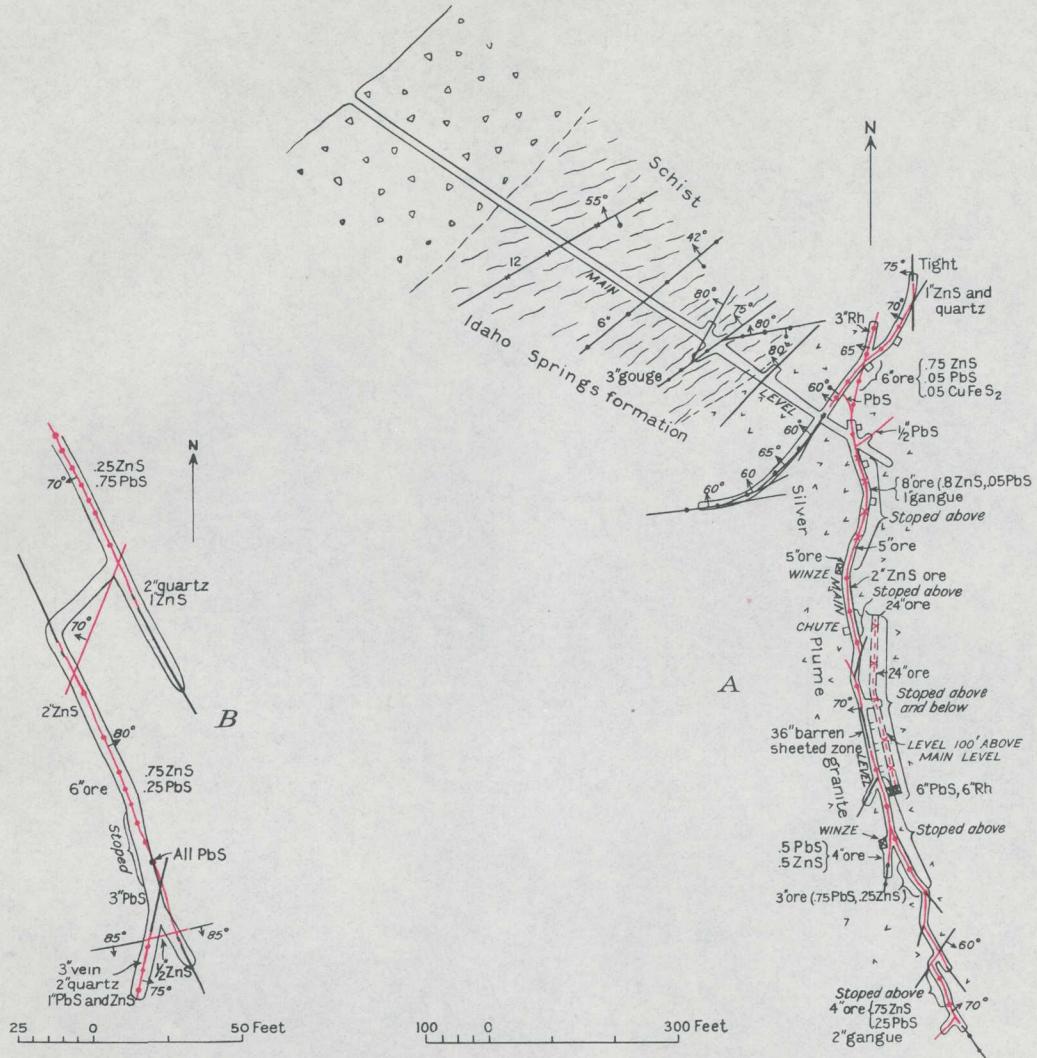


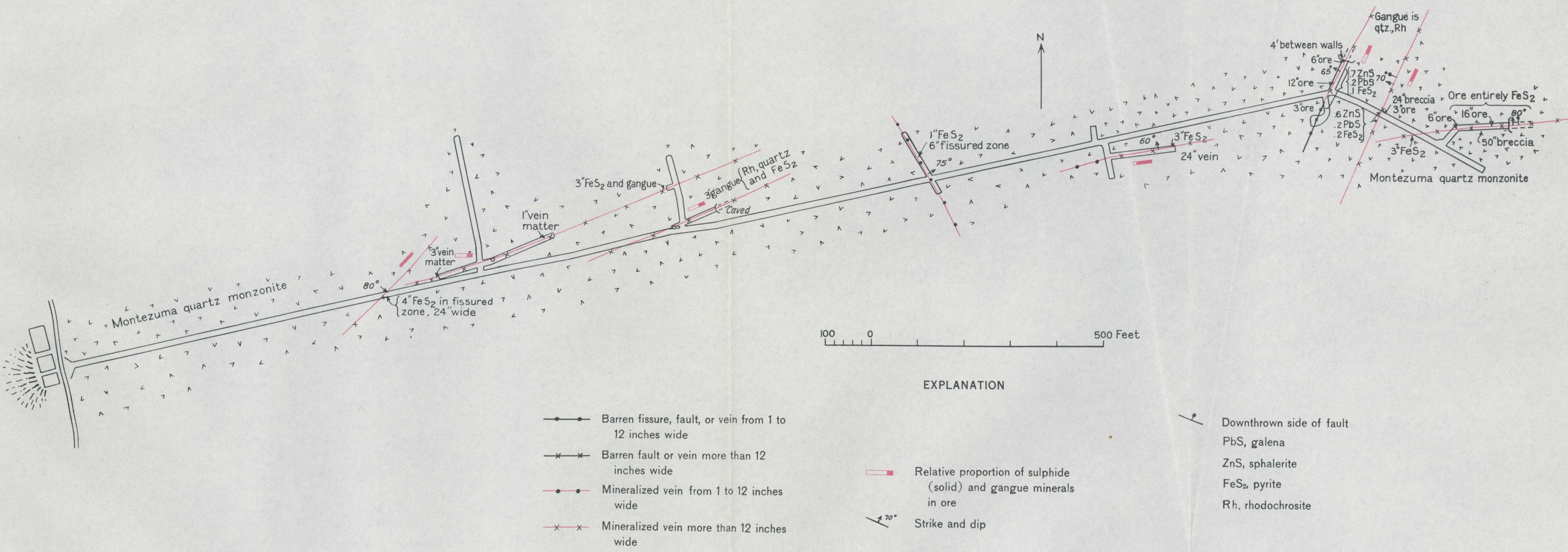
FIGURE 29.—Approximate relations of stopes along main tunnel level, Stevens mine. Sketched by T. S. Lovering.

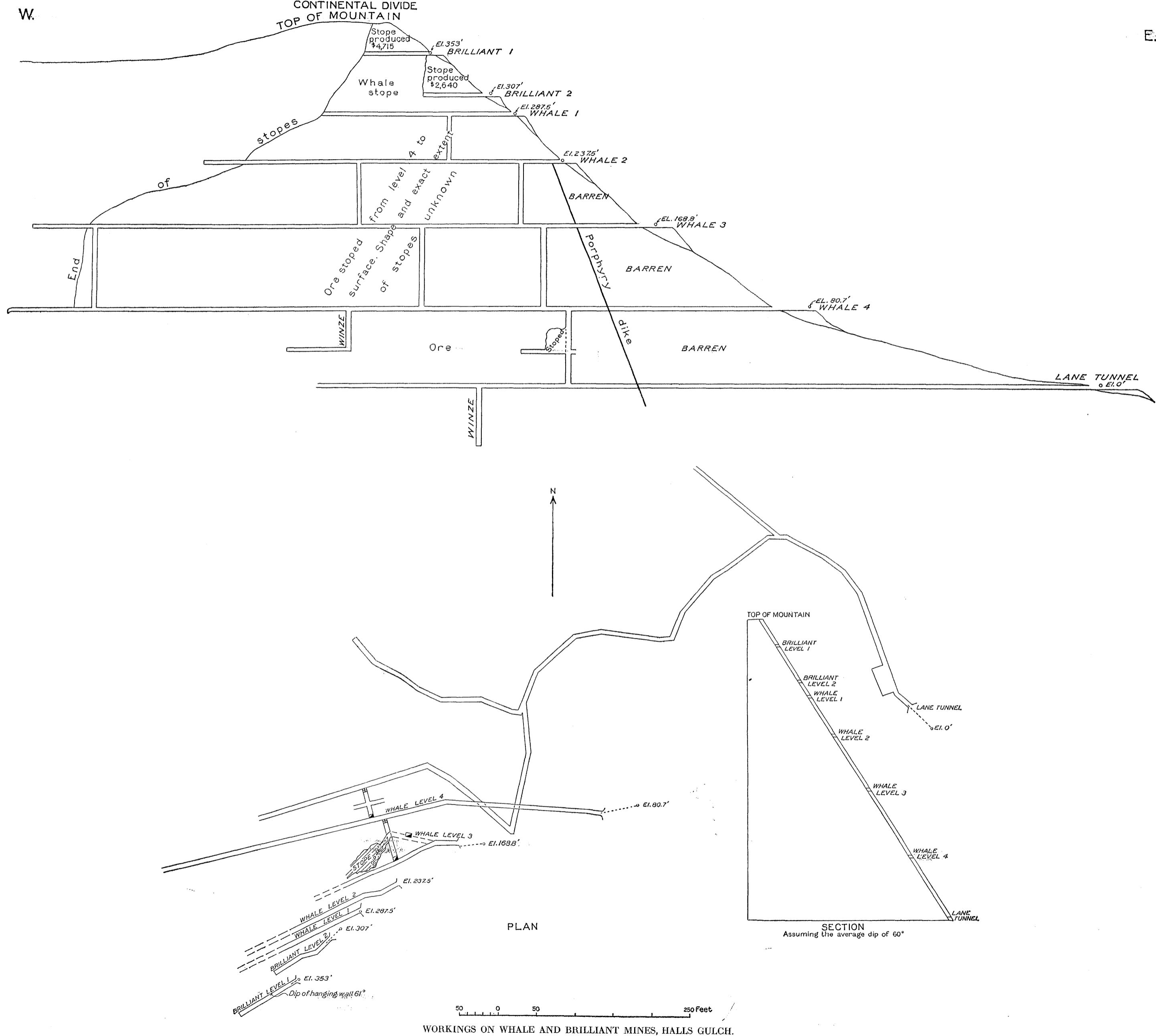


EXPLANATION

- Barren fissure, fault, or vein less than 1 inch wide
- Barren fissure, fault, or vein from 1 to 12 inches wide
- ×— Barren fault or vein more than 12 inches wide
- Vein with sulphides from 1 to 12 inches wide
- ×— Vein with sulphides more than 12 inches wide
- x—x— Vein with sulphides more than 12 inches wide on upper level
- 70° — Strike and dip
- /— Strike of schistosity
- /— Downthrown side of fault
- PbS, galena
- ZnS, sphalerite
- CuFeS₂, chalcopyrite
- Rh, rhodochrosite

PLAN OF LEVEL 14, STEVENS MINE, STEVENS GULCH (A),
AND DETAIL OF SOUTH END OF MAIN DRIFT (B)





Production from Tiger and Tiger Extension claims

| | Ore (short tons) | Silver (fine ounces) | Lead, wet assay (pounds) |
|------------------|------------------|----------------------|--------------------------|
| Tiger: | | | |
| 1885..... | (?) | 6 | |
| 1887..... | (?) | 304 | |
| Tiger Extension: | | | |
| 1889..... | (?) | 537 | 13,252 |
| 1890..... | (?) | 1,602 | 28,418 |

Tiger: No record available for 1886, 1889-1901; no production in 1888. Tiger Extension: No record available for 1891-1900; no production in 1901-9; for 1910-28 see Sts. John.

In 1870 Raymond reported that the Tiger had a shaft 20 feet deep on a vein that was 6 feet wide and contained two pay streaks. The ore next to the north wall was chiefly galena assaying about 100 ounces of silver to the ton and was 10 inches wide. The ore next to the south wall was 6 inches wide and assayed from 1,000 to 2,500 ounces of silver to the ton. The vein matter between the two ore streaks assayed from 16 to 30 ounces of silver to the ton. In 1883, however, according to the Colorado Mining Directory, the ore assayed about 55 percent of lead and 100 to 150 ounces of silver to the ton and contained galena, gray copper, and "chlorides" in a quartz gangue. The ore on the dump of the mine in 1929 contained both galena and sphalerite in a quartz-barite gangue, and the vein from which the ore was broken must have been at least 9 inches wide.

The vein strikes N. 40° E. and dips 60°-80° NW. The Sts. John tunnel, 700 feet below, was driven 1,000 feet east of its vein in search of the Tiger vein but without success. The dip of the Tiger vein would carry it through the Sts. John tunnel very close to the place where vein 5 of that mine was found. It is probable either that vein 5 is an upfaulted part of the Tiger vein, or that the Tiger vein runs into vein 5 above the lower Sts. John tunnel.

TOLEDO

The Toledo tunnel and the Toledo mill are on the east side of the Snake River Valley, about a quarter of a mile north of Montezuma, at an altitude of about 10,300 feet. The wagon road from Montezuma to Chihuahua and Decatur runs past the portal of the tunnel, which is just across the road from the mill. Neither the mine nor the mill has been operated since 1915. Most of the ore treated by the Toledo mill came from the Jumbo mine (see p. 85), but some of the ore was taken from the Toledo tunnel and other properties. As shown on plate 39, the tunnel is about 3,150 feet long and runs east-northeast into the lower part of Tiptop Peak. It is entirely in the Montezuma quartz monzonite, most of which is very fresh and unaltered. A few small pyritic veins were cut that trend a little more northeasterly than the tunnel, but the drifts that follow these veins have no stopes, and the ore was probably of low grade. Near the breast of the tunnel, 2,800 and 2,900 feet from the portal, two veins striking north-northeast were cut, and both contain lead-silver ore. The veins are 3 to 13 inches wide and contain pyrite, galena, sphalerite, and some freibergite. At 3,000 feet from the mouth of the tunnel a strong eastward-trending brecciated fault zone was found. Like the other eastward-striking fractures, it is pyritic but does not contain appreciable amounts of the lead, zinc, or silver sulphides.

VIDLER

The Vidler tunnel is in Mount Edwards, a short distance north of Argentine Pass and about 5 miles east-northeast of Montezuma. It was originally intended to be a railroad tunnel and to serve a proposed narrow-gage railroad extending from Silver Plume to Dillon. Work was started on the tunnel in 1901, and for a time headings were driven from both the east and the west portals. The west portal was abandoned after the face had been carried about 700 feet, but in spite of repeated changes in ownership and reorganizations, the eastern section of the tunnel was gradually advanced until in 1911 it had a length of 5,118 feet. No work is known to have been done since that time, however, and the breasts of the east and west sections are reported to be separated by about 1,700 feet. The altitude of both portals is about 11,650 feet. The east half of the tunnel trends S. 70°47' W., and the west half N. 58°17' E. The tunnel was not accessible at any time during the writer's visits, but some information was found in reports by G. W. Schneider, J. W. Astley, and Herbert Strickland, quoted in a prospectus of the Argentine Tunnel Railway Co. The eastern section of the tunnel is reported to cut veins at distances of 227, 248, 265, 330, 380, 500, 885, 1,956, and 2,175 feet from the portal. Most of the veins were small and contained only quartz and pyrite, but three carried lead-zinc ore. Galena and sphalerite containing 12 ounces or less of silver to the ton and very little gold were found in the veins cut at 227, 265, and 885 feet, but only the last vein, known as the Flossie or Red Light, was strong enough to encourage much development. This vein strikes about N. 33° E. and dips about 85° NW. It carried galena and sphalerite in a quartz gangue, and the ore-bearing part of the vein ranged from 1 to 18 inches in width, averaging about 6 inches. Some ore was stoped in this vein both north and south of the main crosscut tunnel. No production figures have been found, but the property has never been an important producer.

WALDORF, PAYMASTER, AND COMMONWEALTH

The Waldorf mine is near the head of Leavenworth Creek, 6½ miles east-northeast of Montezuma, at an altitude of about 11,600 feet. It can be reached by automobile from Georgetown, 6 miles northeast of the mine, but the wagon road has many steep grades and was in poor condition in the summers of 1926-29. There were several buildings at the mine in a fair state of repair, including boarding houses and a 59-ton mill. The Wilcox tunnel, whose portal is close to the mill, goes northwest into McClellan Mountain about 4,000 feet. It was driven primarily to cut the Commonwealth vein, which is described on page 105. As shown in figure 16, the tunnel cuts many veins, but as most of them are pyritic and carry little gold or silver, few of them have been explored. Most of the tunnel is in schist or injection gneiss, which strikes north or east-northeast and is nearly vertical. Silver Plume granite is found near the portal and in the last 1,000 feet of the tunnel. About 1,600 feet from the portal a dike of rhyolite porphyry was found that strikes northeast and dips about 40° NW. No ore was associated with the dike where it is cut by the tunnel.

Near the breast of the tunnel the vein locally known as the Paymaster was cut about 350 feet below the upper Paymaster or Commonwealth tunnel. This vein strikes northwest and dips steeply southwest. It was nearly barren on the Wilcox tunnel level but contained some gold-bearing chalcopyrite ore a short distance above the tunnel. The walls of the drift were heavily coated with copper-stained deposits of lime at the time of the writer's visit, but no good exposures of the vein were seen.

Incomplete production figures for the Waldorf, Paymaster, and Commonwealth group are given below.

Production of Waldorf, Paymaster, and Commonwealth group

| | Ore (short tons) | Gold (fine ounces) | Silver (fine ounces) | Lead, wet assay (pounds) | Copper, wet assay (pounds) | Zinc (pounds) |
|---|------------------|--------------------|----------------------|--------------------------|----------------------------|---------------|
| Paymaster: | | | | | | |
| 1882 | 5 | | | | | |
| 1887 | (?) | | 1,555 | 68,691 | | |
| 1888 | | 18.09 | 3,992 | 177,248 | | |
| 1889 | (?) | 57.97 | 13,679 | 595,584 | | |
| 1890 | (?) | 19.00 | 3,197 | 133,562 | | |
| 1891 | (?) | 28.14 | 4,496 | | | |
| 1892 | (?) | | 36,882 | 481,686 | | |
| <i>Dry ore</i> | | | | | | |
| Waldorf group: | | | | | | |
| 1907 (Tobin, Stevens, and Argentine) | 896 | 277.76 | 25,240 | 6,292 | | |
| 1908 | 200 | 23.19 | 6,124 | 1,880 | | |
| 1910 | 231 | 66.01 | 3,531 | | 1,560 | |
| 1913 (Tobin) | 582 | 224.66 | 13,360 | 16,183 | 30,757 | |
| 1913 (Commonwealth) | 17 | 18.78 | 278 | | | |
| 1914 (Waldorf) | 7 | .42 | 58 | | | |
| 1915 (probably Waldorf and Tobin) | 70 | 34.72 | 1,834 | 672 | 699 | |
| <i>Copper ore</i> | | | | | | |
| 1913 | 41 | 19.32 | 551 | 580 | 2,859 | |
| 1914 | 132 | 150.31 | 2,571 | 8,880 | 12,288 | |
| 1915 (probably Waldorf and Tobin) | 30 | 29.94 | 1,406 | | 8,719 | |
| 1917 | 43 | 29.90 | 1,268 | 4,968 | 7,149 | |
| <i>Lead ore</i> | | | | | | |
| Waldorf group: | | | | | | |
| 1902 | 200 | 30.00 | 12,000 | 97,087 | | |
| 1903 | 100 | 21.77 | 6,553 | 28,821 | | |
| 1909 | 68 | 15.36 | 625 | 40,802 | 1,874 | |
| 1910 | 123 | 27.01 | 4,805 | 16,446 | 692 | |
| 1911 (Stevens) | 4 | 1.61 | 63 | 6,038 | | 241 |
| 1911 (Commonwealth) | 19 | 2.79 | 343 | 12,422 | | 505 |
| 1911 (Paymaster) | 20 | 2.99 | 452 | 14,016 | | 1,170 |
| 1911 (Tobin) | 101 | 20.09 | 1,815 | 55,837 | 565 | 3,390 |
| 1912 (Commonwealth) | 31 | 6.06 | 588 | 19,793 | | |
| 1913 (M U) | 10 | 1.96 | 125 | 1,274 | | |
| 1914 (Paymaster) | 4 | .60 | 103 | 4,255 | | |
| 1915 (probably Waldorf and Tobin) | 185 | 52.66 | 3,285 | 150,387 | 2,699 | 2,413 |
| 1917 | 58 | 28.33 | 1,249 | 24,233 | 4,799 | |
| 1918 | 16 | 4.40 | 320 | 16,206 | 407 | |
| 1919 (Centennial and Stevens) | 18 | 4.10 | 384 | 11,792 | 328 | |
| 1921 (Waldorf) | 10 | 1.35 | 566 | 2,120 | | |
| <i>Gold-silver-copper ore</i> | | | | | | |
| 1915 (probably Waldorf and Tobin) | 219 | 340.03 | 9,765 | 89,158 | 48,795 | 2,180 |
| 1916 | 336 | 331.77 | 12,126 | 58,271 | 63,549 | |
| 1917 | 46 | 56.91 | 2,684 | 7,542 | 11,209 | |
| 1920 (Centennial, Stevens, and Waldorf) | 97 | 29.56 | 1,964 | 70,198 | 5,597 | |
| <i>Dry gold-silver ore</i> | | | | | | |
| 1915 (probably Waldorf and Tobin) | 78 | 50.67 | 1,633 | 2,127 | 1,463 | 245 |

Production of Waldorf, Paymaster, and Commonwealth group—Continued

| | Concen-
trates
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet as-
say
(pounds) | Copper,
wet as-
say
(pounds) | Zinc
(pounds) |
|-----------------------------------|--------------------------------------|--------------------------|----------------------------|-------------------------------------|---------------------------------------|------------------|
| <i>Copper concentrates</i> | | | | | | |
| Waldorf group, 1910 | 537 | | 455.69 | 6,365 | | 27,620 |
| <i>Lead-copper concentrates</i> | | | | | | |
| 1915 (probably Waldorf and Tobin) | 123 | 95.12 | 2,708 | 31,650 | 11,677 | 5,600 |
| 1919 (Waldorf) | 52 | 29.47 | 708 | 6,566 | 3,164 | |

| | Ore to
concen-
trating
mills
(short
tons) | | Ore to
concen-
trating
mills
(short
tons) |
|--------------------------------------|--|--|--|
| Waldorf group: | | | |
| 1904 | 1,180 | | |
| 1905 (Stevens) | 800 | | 180 |
| 1906 | 1,348 | | |
| 1907 (Argentine, Tobin, and Stevens) | 595 | | 3,184 |
| 1908 | 900 | | 1,435 |
| 1909 | 1,071 | | 2,690 |
| 1910 | 2,100 | | 520 |
| Waldorf group—Continued. | | | |
| 1913 (M U and Stevens) | | | 36 |
| 1914 (Waldorf) | | | |
| 1915 (Waldorf and Tobin) | | | |
| 1916 | | | |
| 1917 | | | |
| 1919 (Waldorf) | | | |
| 1920 (Waldorf, Centennial, Stevens) | | | 100 |

No record available for 1883-86.

WASHINGTON

The Washington vein is on the northeast slope of Collier Mountain at the head of the south fork of Morgan Gulch, at an altitude of about 12,500 feet. It is about 1 1/4 miles due east of Montezuma and can be reached by way of the trail from the town to Warden Gulch. The vein was discovered by Isaac Ware in 1873 and was worked intermittently during the seventies and eighties. As shown below, it produced a few carloads of lead ore in 1886 and 1887. No work is known to have been done on the property, and the workings had long been inaccessible in 1929. According to the Colorado Mining Directory for 1883, the ore was from 10 to 18 inches wide and consisted of "yellow and gray copper and sulphides in quartz" and assayed 20 percent of copper and 100 to 200 ounces of silver to the ton. At that time it was developed by a drift 175 feet long and was credited with a total production of 50 tons.

The vein strikes N. 20° W. and cuts across the schistosity of the Idaho Springs formation, which is the country rock of the vein and strikes about N. 20° E. and dips 60°-70° E.

The only available record of production is given below.

Production of Washington mine

| | Ore (short tons) | Silver (fine ounces) | Lead, wet assay (pounds) |
|------|------------------|----------------------|--------------------------|
| 1876 | 1 | 64 | |
| 1878 | 1 | 86 | |
| 1886 | 18 | | |
| 1887 | 15 | | |

No record available for 1877, 1879-85.

WAUKEEGAN

The Waukeegan vein is on the west slope of Collier Mountain about 1 1/2 miles southeast of Montezuma and is developed by three adits at altitudes of 12,350, 12,380, and 12,470 feet. It is about 1,500 feet above the valley of the Snake River and is accessible only by a steep trail, which leads past the Bullion mine. The vein was discovered about 1880, and a small amount of lead ore was shipped in 1885 and 1889. No work is known

| | Concen-
trates
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet assay
(pounds) | Copper,
wet assay
(pounds) | Zinc
(pounds) |
|--------------------------------------|--------------------------------------|--------------------------|----------------------------|--------------------------------|----------------------------------|------------------|
| <i>Lead-zinc concentrates</i> | | | | | | |
| Waldorf group: | | | | | | |
| 1904 | 197 | 36.00 | 3,180 | 156,949 | 63,709 | |
| 1905 (Stevens) | 133 | 169.31 | 9,934 | 200,251 | 50,966 | |
| 1906 | 225 | 278.45 | 30,988 | 459,527 | 14,456 | 302,000 |
| 1910 | 15 | 4.95 | 553 | 2,133 | 305 | 10,118 |
| 1913 (Stevens) | 9 | 2.50 | 108 | 4,128 | | 3,682 |
| <i>Lead concentrates</i> | | | | | | |
| 1907 (Tobin, Argentine, and Stevens) | 99 | 143.05 | 6,536 | 259,190 | | |
| 1908 | 150 | 58.52 | 1,586 | 77,491 | 1,206 | |
| 1909 | 236 | 98.47 | 3,525 | 81,412 | 6,866 | |
| 1910 | 84 | 41.22 | 1,307 | 55,369 | 1,846 | |
| 1913 (M U) | 3 | 1.11 | 68 | 3,164 | | |
| 1914 (Waldorf) | 19 | 7.16 | 136 | 2,406 | 577 | |
| 1915 (Waldorf and Tobin) | 228 | 91.00 | 4,757 | 81,701 | 9,000 | |
| 1916 | 205 | 116.22 | 4,255 | 60,695 | 11,378 | |
| 1917 | 489 | 211.43 | 9,421 | 210,566 | 19,466 | |
| 1920 (Centennial, Stevens, Waldorf) | 14 | 6.62 | 222 | 2,994 | 332 | |

to have been done on the vein since 1890. The country rock is the Idaho Springs formation, which strikes northeast and is essentially parallel to the vein.

WHALE

The Whale mine is at the head of Hall Valley, about 3½ miles south of Montezuma, and is opened by seven adits between altitudes of 12,100 and 12,530 feet. As shown in plate 40, the levels are from 25 to 110 feet apart vertically. The mine is at the end of the wagon road leading from Webster up Hall Valley, but in 1929 the road was not passable to automobiles a mile south of the mine.

The Whale vein was discovered in 1869, and the mine was the chief one of the Hall Valley Silver-Lead Mining & Smelting Co., Ltd., at the time that company made an unsuccessful attempt to mine and smelt the silver-bearing barite ore of this region. In 1873 the development of the Whale was pushed by this company while it was erecting several blast furnaces 3 miles down the valley and laying a wooden tramway from the mine to the smelter. According to Raymond's report for 1873,

"The Whale lode is opened by three tunnels run in along the vein and by a fourth adit, which runs across the country rock from the foot of the mountain and will strike the vein at a distance of 800 feet. The latter is intended as the principal working tunnel. It was in 125 feet at the end of the year; 225 feet vertically above it is level no. 1, which was 166 feet long; 60 feet higher up is level no. 2, 85 feet long at the end of the year; and 70 feet still higher is level no. 3, which had reached a length of 122 feet. The faces of all the levels stand in ore. A sample of 20 tons of average ore from the mine assayed 120 ounces of silver per ton."

After the unsuccessful attempt to smelt the refractory barite ore in 1876, the English company failed, and the Whale was idle until 1883. At this time the Comet Consolidated Mining Co. obtained the mine and operated it for several years. Burchard's report for 1882 says:

"The Whale has about 2,000 feet of development on the vein in the four levels, with a pay streak from 8 inches to 2 feet in thickness and continuous. The ore is gray copper and galena, the first-class milling 250 ounces in silver, and second-class 100 ounces, with an average of over 30 percent lead. At least 5,000 tons of concentrating ore are dumped at the mouths of the different levels."

In 1883 Burchard reported:

"The Whale mine has four levels on the vein, aggregate development about 3,300 feet; * * * only a small force of men employed, averaging nine, partly in development and partly in extraction of ore; ore, argentiferous galena, with gray and yellow copper; average assay, 375 ounces of silver per ton and 20 percent lead; average width of pay ore, 10 inches; * * * total weight shipped, 232½ tons; gross value of production, \$24,515.85."

The mine was acquired by C. C. Welch, of Golden, about 1888 but was involved in litigation for several years afterward. The title to the property was finally cleared about 1894, and Mr. Welch still retains the chief interest in the mine. Except for a little work in 1890 the property was idle from 1888 to 1898, when the mine was reopened by C. E. Street. As shown in the table below, the mine has been intermittently active since that time, but it was inaccessible in 1929 and had been idle for many years. A mill was built for gravity concentration of the ores in 1874 and was unsuccessful in separating the sulphides from the barite gangue; another gravity concentration mill was installed later but is said to have been unsatisfactory also. A flotation mill was erected about 1917 and made a good concentrate, separating the ore cleanly from the barite gangue.

The country rock of the mine is hornblende gneiss of the Swandyke gneiss and strikes about N. 15° W. and dips about 80° W. Some dacite porphyry dikes were found on the surface near the trace of a strong north-northwest fault; similar porphyry is said to cut and fault the vein underground, but the vein is not certainly recognized east of the porphyry. The vein strikes N. 75° E. and dips 45°-60° N., averaging about 57°. A good description of the vein as it appeared in 1873 was given by Jernegen³² and is summarized below. On the surface of the mountain the vein crops out in a depression and is evidently less resistant to weathering than the surrounding gneiss. The walls of the vein were from 5 to 10 feet apart, but the pay ore ranged from less than an inch to 36 inches in thickness. Between the ore and the walls of the vein the rock was light-colored, altered, and impregnated with pyrite; in many places the ore seam was separated from the altered rock by a thin seam of gouge. The ore seam swells and pinches markedly and has a banded appearance in the thinner parts and a "porphyritic" appearance in the wider parts, where the abundant white barite encloses irregular lumps of galena and gray copper. The ore also contains quartz, brown dolomite, and chalcopyrite, but pyrite is almost wholly confined to the altered rocks on each side of the central ore seam. Near the surface malachite, azurite, and copper sulphate occurred. Barite was almost the only gangue mineral where the ore vein was wide, but where it became narrow quartz and dolomite appeared, barite becoming much less abundant or disappearing entirely, especially if the vein carried no ore. In some places the vein splits and encloses a horse of country rock, and short spur veins are not uncommon. The spurs are parallel to the schistosity of the gneiss and are not persistent.

"As regards the distribution of the metalliferous minerals within the vein, it seems to be more or less influenced by the nature of the country rock, gangue, and width of the crevice. Where the crevice is wide the gangue is soft and decomposed and at the same time strongly impregnated with iron pyrites, and the metalliferous minerals seem to be present in much greater proportion. Where the vein is pinched the wall rocks are unconformable, hard, and of a less decomposed nature, light-greenish or black mica forming one of the vein's principal constituents; it is deficient in iron pyrites and at the same time contains numerous little stringers of grayish quartz. The gray copper oftentimes seems to be present in proportionately larger quantities in the narrower parts of the vein; or, more strictly speaking, the relative proportion of gray copper to galena is greater than in the wider portions of the vein. Where barite occurs in large crystals, the metalliferous minerals are much more scattered and less frequent. Where the vein throws off spurs or divides in making a horse, it is almost always poorer. It is probable that in further exploitation the ore will be found chiefly confined to zones, or chimneys, as already the first, second, and third levels have been drifted through considerable ground on the vein that has proved quite barren of ore, though the crevice has always remained well defined."

According to miners who have worked in the Whale, the ore seam in the lowest workings was of about the same width as in the upper workings. Chalcopyrite is said to be a little more abundant in the lowest workings than it is in the upper tunnels.

As shown in plate 40, the stope length of the ore is much shorter near the surface than on the lower levels, but no exploration was made beyond the place where the vein pinched and became barren on the upper levels. Two or three persistent ore shoots from 50 to 150 feet long, separated by lean narrow stretches of the vein, were found northeast of the main ore shoot on the fourth and fifth levels. Very little work was done

³²Jernegen, J. L., Jr., The Whale lode of Park County, Colo.: Am. Inst. Min. Eng. Trans., vol. 3, pp. 352-356, 1875.

at the southwest end of the main shoot on any of the levels, according to miners, and plate 40 corroborates this information. The occurrence of the ore close to the strong northwesterly fault shown on plate 3 is very similar to the occurrence of ore in the Leftwick and Missouri veins, a short distance south. The same northwesterly fault is associated with the localization of ore shoots in the three veins and probably traces the course of a deep-lying channel of mineralization.

Incomplete production figures for the Whale are given below.

Production of Whale mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet assay
(pounds) | Copper,
wet assay
(pounds) | |
|---|--|---|----------------------------|--------------------------------|-------------------------------------|---------------------------------------|
| 1877 | 99½ | | 1,324 | 3,665 | 154 | |
| 1878 | 2½ | | 252 | 1,548 | | |
| 1879 | 16 | | 1,842 | 2,108 | | |
| 1880 | 3 | | 210 | 1,631 | | |
| 1881 | 2 | | 199 | 1,919 | | |
| 1882 | 10 | | 842 | 4,482 | 25 | |
| 1883 | 232½ | | 13,000 | 74,500 | 6,550 | |
| 1884 | 61½ | | 3,001 | 14,012 | | |
| 1885 | 26 | | 1,050 | 6,410 | 456 | |
| 1887 | 54 | | 3,087 | 22,755 | 500 | |
| 1888 | 41 | | 2,271 | 23,100 | 756 | |
| 1890 | 15½ | | 758 | 5,428 | 324 | |
| 1900 | 10½ | | 430 | 3,305 | 127 | |
| 1916 | 28 | 9.09 | 1,040 | 2,988 | 1,021 | |
| 1917 | 12 | | 363 | 2,820 | 188 | |
| 1922 (Whale, Lane, and Leftwick) | 20 | .20 | 666 | 6,024 | 590 | |
| 1928 | 5 | .10 | 234 | 1,184 | 99 | |
| Brilliant claim (upper adits on
Whale vein): | | | | | | |
| 1899 | 83 | | 7,318 | 28,463 | | |
| 1900 | 60½ | | 3,888 | 29,035 | | |
| 1903 | 7 | | 282 | 4,835 | | |
| 1904 | 56½ | | 2,161 | 25,192 | | |
| | Ore to
concen-
trating
mills
(short
tons) | Concen-
trates
produc-
ed
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet as-
say
(pounds) | Copper,
wet as-
say
(pounds) |
| 1918 | 910 | 91 | | 4,310 | 47,506 | 1,915 |
| 1919 | 2,290 | 229 | 0.19 | 12,608 | 82,762 | 6,383 |
| 1920 (Whale, Lane and
Leftwick) | 800 | 71 | | 4,466 | 48,254 | 1,917 |
| 1921 (Whale, Lane and
Leftwick) | 2,655 | 164 | | 11,646 | 94,827 | 1,941 |

No record available for 1886, 1889, 1891-98; no production in 1901-2, 1905-15, 1923-27.

WHITE SWAN

The White Swan vein is in the valley of the Middle Fork of the Swan River about three-quarters of a mile east of Swandyke and about 5 miles south of Montezuma. The workings are at an altitude of about 11,250 feet and are at the end of a secondary road that follows the stream down to the Swan River, where it joins another wagon road that leads to Tiger. The vein strikes N. 85° E. and dips 85° N. The principal opening is an adit, which follows the vein east for a few hundred feet. As the portal is only a short distance from the stream and the adit is almost parallel to the course of the valley, depth is gained very slowly, and the breast is only a short distance below the surface. A sheeted zone about 12 inches wide contains galena, pyrite, sphalerite, and ankerite veins whose aggregate width is commonly about 4 inches. Striations on the walls of the vein dip about 10° W., and the south wall moved west. The country rock of the vein is hornblende gneiss of the Swandyke gneiss, and it strikes about N. 20° W. and dips steeply west.

No ore is known to have been shipped from the White Swan.

WILD IRISHMAN

The Wild Irishman mine is on the west slope of Glacier Mountain near the head of St. Johns Creek, about 1½ miles southwest of Montezuma. The vein was discovered about 1880 and was rapidly developed in the next few years. The mine was a steady shipper from 1883 to 1886 but has no recorded production from that year until 1901, when it shipped several carloads of ore; some ore was shipped the following year, but little has been produced since that time. A small concentrating mill was built at the mine in 1884 but was unsuccessful in separating the barite from the sulphides and was soon abandoned.

The mine was inaccessible in 1929, but the underground workings are shown in figure 30, and the vein was studied on the surface by the writer. The lower adit has an altitude of about 11,400 feet, and the ore on its dump indicates that here the vein consists largely of manganosiderite carrying moderate amounts of galena. At 350 feet above the lower adit manganosiderite is rare, and the gangue is chiefly fine-grained quartz and small amounts of coarse-grained barite. Galena is moderately abundant, and pyrite and sphalerite are rare. Much of the galena is disseminated through the quartz in scattered individual grains and in thin veinlets, but some seams occur that are as much as 3 inches wide. Most of the vein material is very vuggy and open-textured, and in places the vein is apparently a mineralized fault breccia at least 8 inches wide. The country rock of the region is hornblende gneiss of the Swandyke gneiss and strikes about N. 30° E. and dips about 75° E. The vein strikes N. 75° E. and dips steeply to the north. The early accounts of the mine in the Montezuma Mill Run, as well as the stope map shown in figure 30, indicate that the ore occurred in nearly vertical shoots or chimneys from 40 to 100 feet long separated by barren stretches along the vein. The presence of barite in the ore made it difficult to use before the days of the flotation mill but should present little difficulty to the modern ore-dressing plant.

The following are incomplete production records:

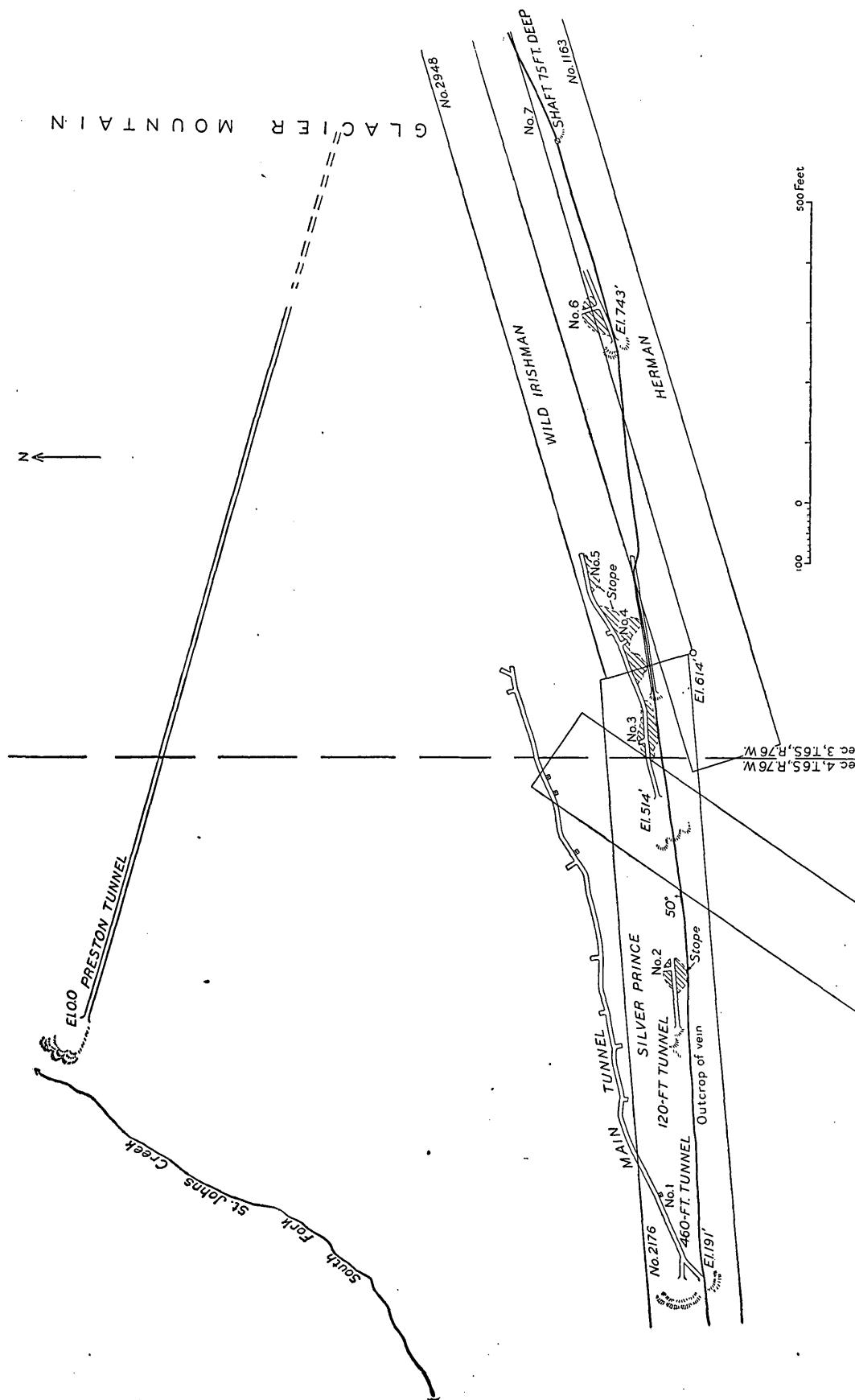
Production of Wild Irishman mine

| | Ore
(short
tons) | Gold
(fine
ounces) | Silver
(fine
ounces) | Lead,
wet assay
(pounds) | Copper,
wet assay
(pounds) | Zinc
(pounds) |
|------|------------------------|--------------------------|----------------------------|--------------------------------|----------------------------------|------------------|
| 1883 | 30 | | | | | |
| 1884 | 35 | | | | | |
| 1885 | 30 | | | | | |
| 1886 | 48 | | | | | |
| 1901 | 56 | Trace | 5,726 | | | |
| 1902 | 28 | | 1,960 | 26,353 | | |
| 1907 | 35 | | 1,260 | 29,652 | | |
| 1913 | 113 | | 1,392 | 115,736 | 45 | |

No record available for 1887-1900; no production in 1903-6, 1908-12, 1914-28.

WINNING CARD

The Winning Card mine is on the south slope of Lenawee Mountain at an altitude of about 12,500 feet, at the head of the valley of the small stream that empties into the Snake River at U.S.L.M. Adrian. It is about 2½ miles north of Montezuma and is reached by a Forest Service trail, which passes over the crest of Lenawee Mountain a short distance west of the mine. The vein was discovered in 1882 by Isaac Filger, and in 1885 rich silver ore containing stromeyerite was found in it. As shown in the table below, several tons of high-grade ore was



shipped in the next few years. According to the Montezuma Mill Run, a 50-foot shaft was sunk in 1885 where the original crosscut adit cut the vein, 30 feet from the portal. No ore was found east of the shaft at its top or bottom. In the main drift the ore was said to range from 2 to 6 inches in thickness and to average about 5 inches. This ore seam was nearly continuous for 130 feet. In 1886 the main drift had been extended to a length of 170 feet east of the winze and the vein was reported as being from 1 to 3 inches wide. At the bottom of the winze the vein was followed 90 feet east, but very little ore was found. The drift west from the bottom of the winze followed a thin seam of quartz and stromeyerite for 60 feet. The ore in this drift was from 1 to 3 inches thick but increased slightly in thickness as it was stoped upward toward the main level. An analysis of the ore from the lower drift, by Robert Newman, of Georgetown, indicated that the sulphide contained 36 percent of copper and 40 percent of silver.

According to James Southerland, who leased the Winning Card in 1886, the vein strikes northwest and is vertical. The main ore body was about 30 feet long and about 100 feet from top to bottom. It was from 2 to 6 inches wide in most places

and consisted of nearly pure stromeyerite but had a small amount of quartz gangue. The ore shoot was vertical and nearly in the center of the Montezuma quartz monzonite stock. Partial production records are given below.

Production of Winning Card mine

| | Ore (short tons) | Silver (fine ounces) | Copper, wet assay (pounds) |
|-----------|------------------|----------------------|----------------------------|
| 1885..... | 25 | ----- | ----- |
| 1886..... | 7 | ----- | ----- |
| 1887..... | 1 | 1,915 | 761 |
| 1889..... | (?) | 201 | ----- |

^a Value, \$25,090.

No production in 1884, 1888.

YORKSHIRE

The Yorkshire mine is on the north slope of Glacier Mountain about a quarter of a mile west of Montezuma. The vein was discovered about 1880 and yielded 20 tons of ore in 1885 and 1886. No other work has been done on the property, so far as known, and it was inaccessible in 1929.

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