Geology and Ore Deposits of the Upper Blue River Area Summit County Colorado

GEOLOGICAL SURVEY BULLETIN 970

Prepared in cooperation with the Colorado Geological Survey Board and the Colorado Metal Mining Fund

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By QUENTIN D. SINGEWALD

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GEOLOGY AND ORE DEPOSITS OF THE UPPER BLUE RIVER AREA, SUMMIT COUNTY, COLORADO

By Quentin D. Singewald

ABSTRACT

The upper Blue River area includes 85 square miles in Summit County. It is partly surrounded by the Breckenridge, Kokomo, Climax, Alma, and Beaver-Tarryall mining districts of central Colorado. It has yielded more than a million dollars' worth of metals, chiefly gold and silver. This area was studied during 5 months of 1940 and 1941 as one of the cooperative projects of the United States Geological Survey, the Colorado Geological Survey Board, and the Colorado Metal Mining Fund.

Unconsolidated deposits are widespread. Though locally rich in placer gold, they conceal many stratigraphic and structural features of the bedrock that might lead to discovery of ore bodies. Terrace gravel, moraine, and alluvium have been mapped, but talus and slide rock have not been mapped.

The bedrock comprises five main groups of rocks—pre-Cambrian, pre-Pennsylvanian sedimentary, Pennsylvanian and Permian sedimentary, Mesozoic sedimentary, and late Cretaceous or early Tertiary igneous rocks. Each group is separated into two or more mappable units. Pre-Cambrian rocks include complex gneisses of the Idaho Springs formation, granite, and pegmatite, which is unmapped. Pre-Pennsylvanian sedimentary rocks along the eastern slope of the Tenmile Range include the Sawatch quartzite (Cambrian), shale and limestone of the Peerless formation (Cambrian), the Manitou limestone (Ordovician), and the Parting quartzite and Dyer dolomite members of the Chaffee formation (Devonian). These rocks are missing at many places north of Spruce Creek because of Pennsylvanian overlap. Pennsylvanian and Permian clastic strata and intercalated thin calcareous beds are more than 9,000 feet thick southwest of the Boreas Pass fault but less than 1,500 feet thick northeast of the fault. The section southwest of the fault is separated into three divisions; that northeast of the fault is mapped as a single unit. The upper part of the middle division and the entire upper division consist of redbeds. The Mesozoic rocks mapped include the Entrada (?) sandstone (Jurassic), the variegated shale and limestone of the Morrison formation (Jurassic), the Dakota quartzite (Upper Cretaceous), and the Benton shale (Upper Cretaceous). The two Jurassic formations have been mapped together at most places. Igneous rocks called porphyries, of late Cretaceous or early Tertiary age, form many dikes in pre-Cambrian rock and sills, sill zones containing intercalated sedimentary strata, laccolithic sills, and irregular crosscutting masses in sedimentary strata. The porphyries comprise four mappable units. From youngest to oldest, they are White porphyry, Lincoln porphyry, quartz monzonite porphyry, and monzonite porphyry. Closely related to the Lincoln porphyry is the granodiorite of a stock at the head of Lehman Gulch.

Deformation during pre-Cambrian time produced local effects that were influential in localizing deformation and mineralization during Laramide time. The Laramide deformation, which followed the Mesozoic era, is responsible for the regional easterly dip of all sedimentary strata; the five major longitudinal faults associated with major folds; a belt of major transverse and oblique faults that trends southwestward from Breckenridge toward Kokomo; and a host of minor faults. Faults originated while compression was intense, but movements along most of them continued after compressive stress relaxed. Igneous intrusion during late Cretaceous or early Tertiary time and subsequent ore deposition were closely associated with the Laramide orogeny.

Ore deposits are restricted to two general areas, the western and the eastern. The western mineralized area surrounds the intersection of two pre-Cambrian belts of pronounced deformation on the eastern slope of the Tenmile Range. Metals and minerals in this area exhibit zonal arrangement outward from a high-temperature center toward a relatively cool border. The higher-temperature deposits contain gold, subordinate amounts of tungsten and iron, minor amounts of lead and zinc, and widespread though noncommercial amounts of molybdenum, whereas the lower-temperature deposits contain silver, subordinate amounts of lead and zinc, and little or no gold. Weathering at many places oxidized and enriched the original ore. Mineral deposits in the pre-Cambrian rocks occur as simple and composite veins, those in the Cambrian quartzites mainly as veins and replacement veins, and those in the post-Cambrian strata as bedded replacement bodies and replacement veins in favorable dolomites and limestones.

The eastern mineralized area includes the western and southwestern outskirts of the Breckenridge district and a zone that extends southeastward along the Boreas Pass fault. Oxidation obliterated the original minerals and enriched the ore at many localities in this area. In general, the original deposits consist largely of galena, sphalerite, and pyrite associated with ankerite, calcite, quartz, and sericite gangue. Mineralogic evidence that is not particularly conspicuous suggests decreasing temperature of deposition away from major longitudinal faults and also southward from Breckenridge. The ore deposits comprise veins in pre-Cambrian rocks, in sandy beds near the top of the Pennsylvanian and Permian strata, in contact-metamorphosed Morrison strata, and in igneous rocks of late Cretaceous or early Tertiary age and "blanket" lodes, or sheets of ore as much as 2 feet thick that have replaced beds in the upper part of the Pennsylvanian and Permian strata. Ore bodies consisting of innumerable irregularly distributed stringers are restricted to the Dakota quartzite.

On the basis of stratigraphic, structural, and economic evidence, it is suggested that new ore bodies in the western mineralized area are most likely to be found along known veins, but, in addition, concealed deposits may be discovered in pre-Pennsylvanian rocks where covered by Pennsylvanian strata and in a dolomite zone at the base of the middle division of Pennsylvanian and Permian strata. Because moraine also covers the ground in most tracts favorable for concealed ore bodies, exploration will be relatively expensive. Most of the favorable ground within the eastern mineralized area is likewise covered by unconsolidated deposits.

About a third of the report comprises descriptions of individual mines for which data could be obtained.

INTRODUCTION

Numerous mines and prospects reveal widespread mineralization and account for the production of more than a million dollars' worth of ore within a hitherto unmapped area (fig. 1) of about 85 square miles that is partly surrounded by the Breckenridge, Kokomo, Climax, Alma, and Beaver-Tarryall mining districts of central Colorado. In order to fill so large a gap in regional geologic data and to study local mineral resources, the writer mapped this area during 5 months of the summers of 1940 and 1941. As a result, new information on regional stratigraphy has been obtained, several major structural features have been discovered, and areas favorable for prospecting have been delineated.

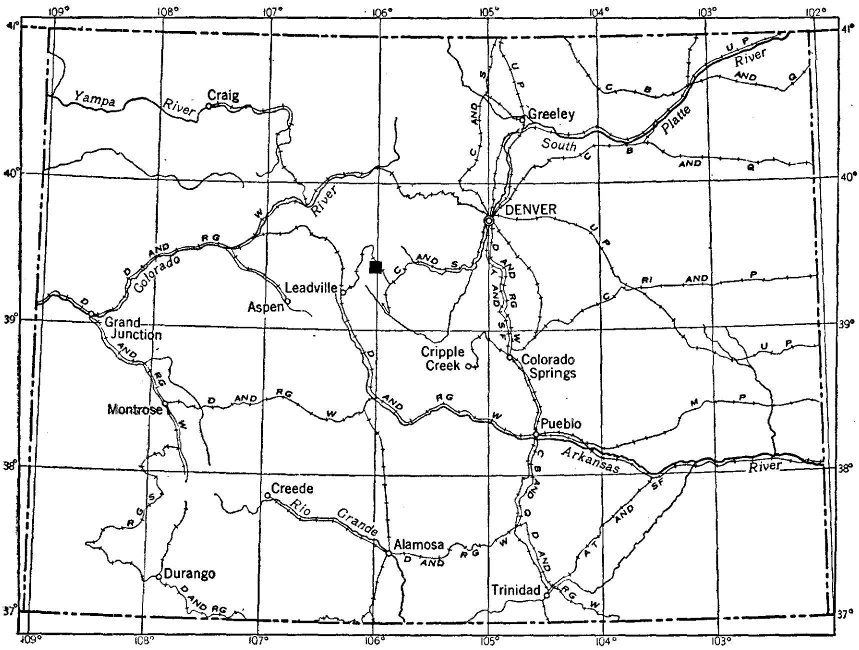


FIGURE 1.—Index map, showing position of the upper Blue River area.

The work constituted one project in the cooperative program of the United States Geological Survey, the Colorado Geological Survey Board, and the Colorado Metal Mining Fund. The local public at Breckenridge gave aid in many ways and furnished valuable information. Particularly helpful have been Messrs. Harry Dunn, J. D. Galloway (United States mineral surveyor), Joseph Mars, D. F. Miner, and George Robinson. As field assistants, Messrs. Richard E. Stoiber and Robert E. Fellows during 1940 and Mr. John G. Broughton during 1941 rendered able service. In addition Messrs. S. R. Capps and W. S. Burbank of the United States Geological Survey and Mr. Charles W. Henderson of the United States Bureau of Mines have made valuable suggestions and comments.

This report makes free and frequent use of data obtained by the Geological Survey in surrounding districts, and several publications can be consulted to advantage by the reader. Most closely related to this report are those by Ransome (1911), Butler and Vanderwilt (1933), Lovering (1934), Singewald and Butler (1941), and Singewald (1942b).

The area described extends northward from the Continental Divide between Boreas Pass and the crest of the Tenmile Range, in the southern part of Summit County. Breckenridge with a population of about 350 is within the area mapped, and Kokomo with a population of nearly 200 lies less than 2 miles to the west. Ten miles north of Breckenridge is the smaller town of Dillon, located at the intersection of the Denver-Glenwood Springs and the Breckenridge-Kremmling highways. A State highway extends southward from Breckenridge through Hoosier Pass and Alma to Fairplay, where it connects with highways to Denver, Colorado Springs, and Salida.

The drainage pattern is shown on the areal geologic map, plate 1. The main divides are the eastward-trending Continental Divide and the north-northeastward-trending Tenmile Range; lesser divides separate the principal tributaries of the Blue River, as indicated on plate 1.

Great relief and rugged topography cause much of the area to be difficult of access and hamper mining operations. West of the Blue River many mine workings are perched on cliffs that can be ascended only by aerial tramway or on foot, but east of the Blue River nearly all the workings could be made accessible by building roads. During 1940 and 1941 only a few roads were passable, even by truck with extra-low gear. At that time passable roads extended all the way up Indiana Creek; part way up Monte Cristo and Spruce Creeks and McCullough Gulch; to the Magnolia mine on North Star Mountain and the Fredonia mine on the face of Red Mountain; and as far as an altitude of 12,000 feet toward the Briar Rose mine. (See pls. 1 and 2.)

The climate, comparable to that of other regions in the high mountains of Colorado, is unfavorable to mining. The highest workings are practically snowbound during winter months, and at most other places mining can be maintained the year round only by expending much effort on snow removal. Timber line is at an altitude of about 11,500 feet, so timber must be hauled to mines above that altitude. Below timber line, pine and aspen are abundant except on sheer cliffs and steep talus slopes.

UNCONSOLIDATED DEPOSITS

Three types of unconsolidated deposits have been mapped—terrace gravels, moraine, and alluvium. The alluvium comprises undifferentiated recent stream alluvium; outwash gravels from glaciers of the Wisconsin stage; and sediments deposited on the floor of a temporary lake in the vicinity of Goose Pasture, behind the terminal moraine deposited by the Blue River Glacier during the Wisconsin stage. All moraine boundaries on plate 1 have been mapped by the writer, but boundaries for the other two types of unconsolidated deposits where not bordered by moraine have been taken from Ransome's map (1911, pl. 1). The distribution, thickness, and character of the unconsolidated deposits are set forth in detail by Ransome (1911, pp. 72–80) and summarized by Lovering (1934, pp. 13–14), so will not be repeated in this report.

Unconsolidated deposits not shown on plate 1 include talus or "float rock," derived more or less in place, and slide rock.

Terrace gravels, moraine, and alluvium contain placer gold in places. The most favorable placer ground within the area shown on plate 1 is in the Blue River Valley, from the outer part of the terminal moraine northward, and in French Gulch. Most of this ground has been worked already. Several small placers are located along the bed and banks of the Blue River south of the Governor mine. The largest is at the Bemrose property, where detrital gold occurs in the margin of moraine and in outwash material immediately beyond; both placers are derived from the Platte Glacier by overflow through Hoosier Pass.

Except for their placer gold, unconsolidated deposits are unfavorable to mining activity. They conceal any lode deposits that exist beneath them, and they also conceal stratigraphic and structural features of the bedrock that might lead to the discovery of ore bodies. Further, adits or shafts driven through them are subject to caving.

BEDROCK

PRE-CAMBRIAN ROCKS

IDAHO SPRINGS FORMATION

Pre-Cambrian rocks crop out over a vast area along the crest and both slopes of the Tenmile Range and in a much smaller area northeast of Breckenridge. There is also a small outcrop, shown on Ransome's map (1911, pl. 1), in Illinois Gulch half a mile northeast of the area shown on plate 1. In all these areas the prevailing rocks are gneisses, with which relatively insignificant amounts of nearly pure schist are associated. These gneisses throughout central Colorado have been correlated by Lovering (1929, pp. 64–65) with the Idaho Springs formation of the Front Range. They are derived from former sedimentary rocks by dynamic metamorphism and magmatic injection.

The Idaho Springs formation comprises a great diversity of rock types, differing in mineral composition and texture. The different facies are complexly intermingled, grade into one another, and commonly are indistinguishable megascopically; they do not serve as mappable units. The following classification is slightly modified from one prepared for descriptive purposes by Fellows (1941):

1. Quartz-plagioclase-mica gneiss.
   a. Intermediate and coarse-grained andesine-bearing facies.
   b. Fine-grained andesine-bearing facies.
   c. Intermediate and fine-grained albite-oligoclase facies.
2. Quartz-plagioclase-mica gneiss containing andalusite, garnet, and/or sillimanite.
3. Microcline-bearing gneiss.
   a. Microcline-bearing quartz-plagioclase-mica gneiss.
   b. Microcline-bearing quartz-plagioclase-mica gneiss containing andalusite, garnet, and/or sillimanite.
4. Amphibolite.

Gneisses containing only quartz, plagioclase, biotite, and muscovite as essential minerals are much more widespread than those containing andalusite, garnet, and sillimanite in addition. The latter form lenses having no apparent regularity in distribution. Microcline-bearing gneisses represent mixtures of metamorphic rock and pegmatite, called injection gneiss; rocks of this type are abundantly intermingled with noninjected gneiss free of microcline. Amphibolites are quantitatively insignificant, yet they may be found at many places as roughly tabular-shaped bodies a few feet wide and as lenses as much as a thousand feet in length. The lenses could be derived either from impure limy members in the original sedimentary rock or from basic intrusive rocks, but the tabular bodies almost certainly represent basic dikes.

The rocks of the Idaho Springs formation range in texture from coarse-grained to fine-grained, but an intermediate grain size prevails. General parallelism of the rock structure as a whole is due mainly to orientation of micas. Light-colored constituents are segregated into bands ranging from mere films to layers more than an inch thick, lenses, and irregular-shaped blotchey masses. The over-all color, when seen at a distance, is medium gray to fairly dark gray, except where hydrothermal alteration has imparted a greenish tone or weathering a rusty-brown coloration. Detailed descriptions of microsopic aspects of each facies are given by Fellows (1941).

No specimen collected from the Idaho Springs formation is entirely free of hydrothermal products, yet the intensity of alteration varies greatly from place to place. Persistent hydrothermal products seen under the microscope are sericite, chlorite, rutile, leucoxene, pyrite, and dusty magnetite; less common are hydromica and epidote. As these minerals are characteristic of intermediate temperatures and pressures, they probably developed mainly during the Cretaceous or Tertiary cycle of igneous intrusion and are deposition rather than during the pre-Cambrian magmatic cycle.

Areas of silicified pre-Cambrian rock occur locally between Spruce Creek and Sawmill Gulch, particularly between Spruce and Crystal Creeks. Some have no definite shape; others are long and narrow as though following fault zones and are mapped as faults on plate 1. The White porphyry is abundant in several of the most intensively silicified areas. Whatever the structural and petrographic significance may be, silicification is one feature of the magmatic cycle of intrusion, alteration, and ore deposition of Cretaceous or Tertiary time.

GRANITE

Three masses of pre-Cambrian granite, all in Monte Cristo Gulch, are shown on plate 1. In addition, granite is widely distributed in films, bands, lenses, and irregular layers too numerous and too small to be mapped. The granite bodies shown on plate 1 may be regarded as outliers of much larger bodies in the Mosquito Range, which have been correlated with the Silver Plume granite (Butler and Vanderwilt, 1933, p. 209) of the Front Range.

The prevailing type of granite ranges from gray to pink, from medium-grained to coarse-grained, and from granular to trachytoid. Trachytoid varieties exhibit conspicuous subparallel arrangement of tabular feldspars. In general the tendency toward trachytoid texture increases with grain size. Visible minerals are feldspar, quartz, biotite, and muscovite. Minerals identified microscopically (Fellows, 1941, p. 48), in their usual order of abundance, are quartz, potash-bearing feldspar (microcline and subordinate amounts of orthoclase), albite, muscovite, biotite, magnetite, zircon, apatite, sphene, and scant but variable amounts of hydrothermal sericite, chlorite, and rutile.

The granite cropping out in the eastern part of Monte Cristo Gulch has slightly smaller grain size, slightly less muscovite, and decidedly less tendency toward trachytoid texture than the prevailing type. As seen under the microscope, this rock is composed (Fellows, 1941, p. 46) mainly of potash-bearing feldspar (microcline and subordinate amounts of orthoclase), quartz, and oligoclase in nearly equal proportions, with minor amounts of biotite and muscovite, accessory magnetite, zircon, and apatite, and small amounts of hydrothermal sericite, chlorite, clinozoisite, and rutile.

PEGMATITE

Pegmatites are widespread in the Idaho Springs formation and in the granite. Pegmatites in gneiss occur both as conformable and crosscutting bodies ranging from paper thin to many feet in width. Grain size in different pegmatites ranges from small to very large. Those pegmatites with smaller grain size are transitional to granite and aplite. Pure pegmatite consists of feldspar, quartz, and muscovite, yet few specimens are entirely free of admixed gneiss. The very abundance and diversity in size of pegmatite bodies preclude their representation on plate 1.

PRE-PENNSYLVANIAN SEDIMENTARY ROCKS

Pre-Pennsylvanian sedimentary rocks are the principal ore-bearing formations of central Colorado and so command particular interest. These rocks, within the area shown on plate 1, crop out continuously from North Star Mountain to the north side of McCullough Gulch, along the south side of Spruce Creek, and at several isolated localities between the north bank of Spruce Creek and the head of Sawmill Gulch. From their outcrops between North Star Mountain and Spruce Creek, pre-Pennsylvanian strata slope beneath the surface at increasing depth eastward as far as a zone of westerly dips in the Blue River Valley. Perhaps they continue still farther eastward at depths too excessive for prospecting.

The following table gives the age, name, lithologic character, and measured thicknesses of pre-Pennsylvanian strata found along the eastern slope of the Tenmile Range. More detailed descriptions would merely duplicate data published for the Alma district (Singewald and Butler, 1941, pp. 7–14). To be particularly noted is the absence here of the Leadville limestone in the upper part of Emmons' Blue limestone (Emmons, 1886, pp. 63–66) of the Mosquito Range. Bedded replacement deposits that may be localized beneath relatively impervious basal Pennsylvanian strata, therefore, would be in the Dyer dolomite member of the Chaffee formation, a rock somewhat less favorable to replacement than the Leadville.

Pre-Pennsylvanian strata along eastern slope of Tenmile Range, Summit County, Colo.

Age	Formation and member		Character	Thickness (feet)		
				North Star Mountain (composite)	North side of Monte Cristo Creek	South side of Spruce Creek
Pennsylvanian.						
	— Disconformity —					
Upper Devonian.	Chaffee formation.	Dyer dolomite member.	Dolomite that is fairly thin and moderately well bedded, mainly dense-textured, and white or (less commonly) light blue. Shale partings or siliceous ribs rare. Exposed surfaces generally smooth. White beds weather buff.	50±	(?)	Upper part not exposed. 25+
		Parting quartzite member.	Cross-bedded and conglomeratic sandy limestone and quartzite containing subangular quartz pebbles as much as 1 inch in diameter. Weathers gray to brownish gray.	10±	16±	30
	— Disconformity —					
Lower Ordovician.	Manitou limestone.		Thin-bedded white to medium-blue mostly "crystalline" dolomite. Exposed surfaces are light-gray and show conspicuous siliceous ribbing conformable with bedding and also transverse to it. Thickness of siliceous ribs increases upward in section to maximum of half an inch near top.	70±	75±	0
Upper Cambrian.	Peerless formation.		Lower part equivalent to "Transition shale" at Leadville. Basal quartzite is purple to nearly black, faintly cross-bedded, and 2 to 12 feet thick; contains tiny angular quartz pebbles; and is a readily discerned marker bed. Middle part, 10 to 20 feet thick, is brownish-weathering dolomite in beds 3 inches to 3 feet thick. Upper 10 to 20 feet is green platy shale with intercalated thin dolomites, highest of which contain "red casts." Upper part equivalent to basal "White limestone" at Leadville. Thin-bedded drab-weathering to brownish-weathering dolomite. Uppermost beds are slightly shaly and locally contain partings or thin layers of green shale. Upper boundary indefinite.	60±		85
	— Hiatus —					
	Sawatch quartzite.		Predominantly fine-grained white quartzite in beds 6 inches to 3 feet thick; rare sericitic partings. At base is micaceous dark shaly conglomerate 6 inches to 2 feet thick; overlain by white conglomerate 6 inches to 2 feet thick. Pebbles less than 1 inch in diameter. Upper half of member includes some greenish quartzites and also some beds having calcareous cement that weather brown and "sandy-looking."	100	125	140
	— Nonconformity —					
Pre-Cambrian.						

One regional objective of the present work was to obtain data regarding the disappearance, noted by Ransome (1911, pp. 66–67), of pre-Pennsylvanian strata between the Continental Divide and Breckenridge. They do not simply thin to nothing northward, as assumed by Ransome and other authors lacking stratigraphic data for the area between the two localities. On the contrary the Sawatch quartzite, the Peerless formation, and the Parting quartzite and Dyer dolomite members of the Chaffee formation all maintain essentially uniform thickness from the Continental Divide northward as far as Spruce Creek, except possibly across a moraine-covered horst (uplifted fault block) north of McCullough Gulch. The Manitou limestone, however, thins to nothing north of Monte Cristo Creek, presumably because of local pre-Devonian erosion. Between Spruce Creek and Carter Gulch basal Pennsylvanian strata seem to rest at different places on pre-Cambrian rocks, Sawatch quartzite, and the Peerless formation, thereby indicating that all pre-Pennsylvanian strata except local patches of Cambrian beds are missing. North of Carter Gulch pre-Pennsylvanian rocks are absent everywhere except at the crest of the Tenmile Range, where a small infolded and faulted island forms the wall of a Tertiary igneous stock. The abrupt stratigraphic change across Spruce Gulch suggests that there the north wall of a postulated fault moved relatively west, bringing an area originally nearer the Paleozoic shore lines, where Pennsylvanian overlap was pronounced, into juxtaposition with an area originally farther from the shore lines. Additional evidence of this fault is given in the discussion of structure. Similar lateral movement along either a large fault in Carter Gulch (see pl. 1) or a concealed fault in pre-Cambrian rocks not far to the north may account for the absence not only of all pre-Pennsylvanian rocks but of most of the Pennsylvanian and Permian strata in the northern part of the area mapped.

PENNSYLVANIAN AND PERMIAN SEDIMENTARY ROCKS

SOUTHWEST OF BOREAS PASS FAULT

The total thickness of Pennsylvanian and Permian sedimentary rocks differs radically on opposite sides of the Boreas Pass fault (see pl. 1), being more than 9,000 feet on the southwest side and less than 1,500 feet on the northeast side. The sequences of beds in the two areas, therefore, must be discussed separately.

The thick section crops out along the Continental Divide between North Star Mountain and Boreas Pass, whence it extends northward at least to Carter Gulch and perhaps to Sawmill Gulch. The northward termination is concealed by moraine and terrace gravels but must lie against a strong transverse fault the north wall of which is upthrown. Strata southwest of the Boreas Pass fault continue without interruption into the Beaver-Tarryall district, where recently they have been studied, mapped, and described in some detail (Singewald, 1942b). A threefold local division proposed for the series south of the Continental Divide may, therefore, conveniently be extended into the area shown on plate 1, as given below.

Pennsylvanian and Permian strata southwest of Boreas Pass fault, Summit County, Colorado

	Thickness (feet)
Upper division: Redbeds. Prevailing strata clastic; include boulder conglomerates, pebble conglomerates, sandstones, siltstones, and shales; all contain visible mica, and all except shales contain visible feldspar. Intercalated limestones rare except near base. Individual beds lenticular; abrupt vertical changes frequent	5,000
Middle division: Strata predominantly clastic, but intercalated dolomites common in prevailingly nonred lower third and limestones common in prevailingly red upper two-thirds. Clastic types include boulder conglomerates, pebble conglomerates, sandstones, siltstones, and shale; all are micaceous, and all except shales have visible feldspar. Beds lenticular; abrupt vertical changes repeated. Principal dolomite zone taken as base; upper of two principal limestone zones taken as top	2,800
Lower division: Chiefly gray micaceous strata ranging from coarse arkosic conglomerate to shale. Numerous layers of dark nonmicaceous shale, especially in lower part. Dolomites rare except in a zone a few hundred feet above the base	2,000

The base of the middle division is a dolomite zone comprising one thick bed or several thin beds intercalated with dark shale. It may be traced continuously from Hoosier Pass to the Bemrose shaft, but its correlation with dolomites in scattered outcrops farther north becomes uncertain. From Hoosier Pass the basal dolomite has been traced south, with fair assurance, for 5 miles to a typical exposure in Beaver Creek. The top of the middle division is the uppermost thick limestone found along the Continental Divide. This limestone is traceable northward with assurance for only 1½ miles, as shown on plate 1. As oolites were found sparingly in limestones at or very near the top of the middle division, this bed may be equivalent to the Jacque Mountain limestone member of the Maroon formation of the Tenmile district (Emmons, 1898, p. 2).

Approximate thicknesses, exclusive of interbedded porphyry sills, are given in the table above. The thickness of the lower division cannot be determined definitely, because its base and top everywhere are separated by a major longitudinal fault. Not less than 1,100 feet, as shown by section *D–D′*, plate 1, and perhaps as much as 1,700 feet (if dips are steeper than shown on the geologic cross section) are represented west of Hoosier Pass, but this amount does not include the upper part of the division. The thickness given in the table on page 11 is therefore approximate. The prevailingly nonred lower part of the middle division is about 900 feet thick in the Beaver-Tarryall area but cannot be measured in the upper Blue River area; redbeds of the division include some 600 feet below the main limestone bed of the Fredonia mine and 1,300 feet above. Thus, the middle division is about 2,800 feet thick. The upper division, as shown on plate 1, is about 5,000 feet thick.

Rocks throughout the series are mainly clastic types, but limestones and dolomites are intercalated. The clastic types include almost all possible varieties—coarse conglomerates with cobbles as much as 6 inches in diameter, intermediate and finer-grained conglomerates, sandstones with grain sizes ranging from fine to coarse, siltstones, and shales. All clastic rocks except a few of the black and green shales are conspicuously micaceous, and nearly all sandstones and conglomerates except a few near the base contain visible feldspar. Individual beds range from paper thin to about a hundred feet in thickness, but most are not more than a few feet thick. Each bed lenses laterally, and vertical changes from one type to another are abrupt and frequent. The lower part of the series is prevailingly gray, with only minor quantities of dull-red shale, whereas the upper part is a series of redbeds having locally a few layers, masses, or splotches of greenish-gray rock. No clastic bed within the series serves as a horizon marker.

Limestone and dolomite beds range from paper thin to about 50 feet in thickness. Those more than 4 inches thick were mapped wherever found, partly because they serve as horizon markers over short distances and partly because they have greater economic interest than clastic strata. Limestones and dolomites both can be found within a narrow zone 200 feet thick immediately below the base of the redbeds. Above this zone all calcareous beds are nonmagnesian limestones, and below it all are dolomites. Cliff exposures reveal lateral transitions from limestone to green shale within a few hundred feet, and vice versa, so the calcareous beds indicated by each of the longer lines on plate 1 should be regarded as a series of lenses at about the same stratigraphic position. The thicker and more persistent units are zones in which individual beds pinch and swell, locally coalescing into a single bed.

NORTHEAST OF BOREAS PASS FAULT

Pennsylvanian and Permian sedimentary rocks northeast of the Boreas Pass fault crop out continuously along the lower slope of Bald Mountain and at several isolated localities north of Breckenridge, as shown on plate 1, and also within the Breckenridge district as shown on Lovering's map (1934, pl. 2). Their thickness in a partly concealed section measured by the writer along the west bank of the Blue River, 3 miles north of Breckenridge, is about 600 feet. According to Lovering (1934, p. 5), their thickness in the Breckenridge district ranges from 600 to 900 feet, and at the Twin Sisters mine, as indicated by section *A–A′*, plate 1, it is not less than 1,200 feet; they seem to thicken gradually southeastward.

The strata of this relatively thin section have been mapped as an undivided unit. According to Lovering "the beds show all the variations of lithology that the thickest sections show elsewhere." In the section measured 3 miles north of Breckenridge dolomites are absent. One fossil in limestone located stratigraphically about 30 feet above the basal contact with pre-Cambrian rocks was identified by L. G. Henbest as *Wedekindellina euthysepta* (Henbest), which is restricted to the lower half of the rocks of Des Moines age (Pennsylvanian).

MESOZOIC SEDIMENTARY ROCKS

Mesozoic sedimentary rocks crop out northwest of Breckenridge and also along the western slope of Bald Mountain, southeast of Breckenridge. Along the slope of Bald Mountain they form two nearly parallel belts that are separated by the Boreas Pass fault. (See pl. 1.) They also crop out along the Blue River north of the area represented on plate 1 and within the area shown on Lovering's Breckenridge special map (1934, pl. 2). Their ages, names, lithologic character, and thicknesses are given in the following table. More detailed data may be obtained from either the Breckenridge (Lovering, 1934, pp. 6–13) or the Beaver-Tarryall (Singewald, 1942b) reports.

Nonmicaceous strata, here classified as possibly Triassic, crop out at the Continental Divide but because of lack of outcrops cannot be traced northward. They have not been mapped separately. Wherever present they may be regarded as included with the top of the upper division of the Pennsylvanian and Permian strata.

The Entrada (?) sandstone and the Morrison formation have been separately mapped in the northern part of the area, where their differentiation aids the elusive interpretation of structure. Elsewhere they are undifferentiated to avoid useless cluttering of the map.

Mesozoic formations of the upper Blue River area, Summit County, Colo.

Age	Formation	Description	Thickness (feet)
Upper Cretaceous.	Benton shale.	Mainly dark-gray shale, fissile where weathered. Intercalated limestone beds several hundred feet above base may represent Niobrara formation of Breckenridge.	1,000
	Dakota quartzite.	White to medium-gray quartzitic sandstone with intercalated black shale, especially in middle member. Fairly thin and well-bedded.	140-175
Jurassic.	Morrison formation.	Interbedded limestone and shale in lower part, variegated shales in upper part. All shale nonmicaceous.	230-360
	Entrada (?) sandstone.	Medium-grained white to light-gray sandstone, somewhat quartzitic. Locally cross-bedded. Grains under hand lens are of two distinct sizes. Bedding planes range from well-defined to obscure.	Maximum, 100
Triassic (?).	(?)	Variegated nonmicaceous shales, chiefly red, with several intercalated beds of conglomerate and limestone breccia. Exposed only at Boreas Pass. Included with the upper division of the Pennsylvanian and Permian strata on areal geologic map.	200

The Dakota quartzite requires no special comment. Beds above the Dakota quartzite have all been mapped as Benton shale, though within a mile of the Continental Divide, east of Boreas Pass, they may possibly include strata as young as the Niobrara formation or even the Pierre shale of the Breckenridge special area (Lovering, 1934, pp. 11–13).

LATE CRETACEOUS OR EARLY TERTIARY IGNEOUS ROCKS

FORM AND CLASSIFICATION

Igneous rocks of late Cretaceous or early Tertiary age, commonly designated "porphyries," are widely distributed in a variety of forms. Sills, sill zones composed of sills separated by layers of sedimentary strata, laccolithic sills, and crosscutting bodies predominate in the sedimentary strata, whereas dikes abound in pre-Cambrian rocks. In addition, one typical stock, characterized by granular instead of porphyritic texture, occurs at the head of Lehman Gulch.

The rocks are classified in five mappable units. From youngest to oldest they are White porphyry, granodiorite, Lincoln porphyry, quartz monzonite porphyry, and monzonite porphyry. Although nearly all outcrops can be referred readily to one or another of these types, a few that are intermediate between monzonite and quartz monzonite porphyry must be arbitrarily classified. Moreover, several of the larger crosscutting bodies consist of mixed Lincoln porphyry and quartz monzonite porphyry, gradational into each other. The petrographic features of the different types have been described in detail for adjacent areas, so only megascopic features will be discussed here.

(See particularly Ransome, 1911, pp. 43–62, and Singewald and Butler, 1941, pp. 17–22.)

MONZONITE PORPHYRY

Monzonite porphyry is characterized by a medium-gray color, commonly with a greenish tone due to hydrothermal alteration, and by the absence or extreme scarcity of visible quartz. Dull-white feldspar and dark-green chloritized hornblende and biotite occur profusely as phenocrysts, which range in size in different occurrences from minute to moderately large. The groundmass appears homogeneous. Monzonite porphyry is abundant in the eastern part of the area but very scarce elsewhere. The largest mass is a huge laccolithic sill on Bald Mountain, but many sills, sill zones, and thick lenses are found in the middle and upper divisions of the Pennsylvanian and Permian strata. Only the larger and the more continuous bodies are shown on plate 1.

QUARTZ MONZONITE PORPHYRY

Quartz monzonite porphyry, as implied by the name, contains visible quartz in small to large quantities. In all other respects it closely resembles the monzonite porphyry. The term as used in this report corresponds with "quartz monzonite porphyry (intermediate type)" as used by Ransome (1911, pp. 57–59) and with "intermediate type" as used by Lovering (1934, p. 15) for the Breckenridge district.

This rock is abundant in the central and western parts of the area, where it forms many narrow, mostly unmapped, dikes in pre-Cambrian rocks; sills in pre-Pennsylvanian rocks; and sills, sill zones, laccoliths, and irregular crosscutting bodies in Pennsylvanian and Permian strata, mainly in the middle division. A transition zone between the main belt of monzonite porphyry on the east and the main belt of quartz monzonite on the west locally contains both types and also most of the occurrences that cannot readily be classified as one or the other.

LINCOLN PORPHYRY

The Lincoln porphyry differs from the other porphyries of the area in containing large phenocrysts of orthoclase, rectangular in cross section, which range from a third of an inch to 2 inches in length. They are scattered throughout a light-colored to medium greenish-gray rock containing profuse small to medium-sized phenocrysts of quartz, dull-white plagioclase, chloritized biotite, and rare prisms of altered hornblende. The relatively inconspicuous groundmass appears homogeneous to the naked eye. The name "Lincoln porphyry" has been widely used in mining districts of central Colorado and therefore is retained in this report. It corresponds to rocks labeled "quartz monzonite porphyry" at Breckenridge (Ransome, 1911, pp. 44–50; Lovering, 1934, pp. 15–16).

The Lincoln porphyry constitutes the bedrock of much of the area immediately east of the Blue River, where it forms one huge mass extending continuously from the Continental Divide to within a mile of Pennsylvania Creek and, jointly with quartz monzonite porphyry, forms smaller crosscutting bodies on each side of Pennsylvania Creek. It also forms numerous sills and a few dikes within the Pennsylvanian and Permian strata on both sides of the Blue River as well as scattered dikes within the area of pre-Cambrian rocks.

The huge mass of Lincoln porphyry along the east side of the Blue River seems to follow the crest of a broad anticline. Contacts are conformable with adjacent sedimentary strata at most places but are crosscutting locally. Whether the mass connects with a crosscutting feeder at depth or is an essentially conformable lenslike body that formerly connected with feeders along a postulated fault (see pl. 2) west of the Blue River cannot be determined.

GRANODIORITE

At the head of Lehman Gulch a stock and a small outlier a mile to the northeast are designated granodiorite on plate 1. The rock has granular texture devoid of groundmass, but otherwise is similar to Lincoln porphyry.

WHITE PORPHYRY

The White porphyry is comparatively rare. Most of its outcrops are narrow dikes, a few of which have been mapped, in the pre-Cambrian rocks of the Tenmile Range, but several dikes and at least one sill occur in sedimentary rocks near Boreas Pass. Most if not all bodies of White porphyry in the upper Blue River area correspond to the "later White porphyry" of the Mosquito Range (Singewald and Butler, 1941, p. 18) and not to the "earlier," or original White porphyry at Leadville (Emmons, Irving, and Loughlin, 1927, pp. 43–46). The rock is creamy or porcelain white and homogenous except for relatively scarce phenocrysts of quartz, earthy feldspar, muscovite, and dark mica. It commonly weathers with pronounced sheeted structure and develops spots and dendritic masses of manganese stain on the surface. The scarcity of phenocrysts and the white color makes it possible to readily distinguish it from other porphyries.

CONTACT METAMORPHISM

Contact metamorphic action by igneous rocks during Cretaceous or Tertiary time has been relatively slight within the mapped area. Pre-Cambrian rocks, even adjacent to the stock at the head of Lehman Gulch, show little evidence of change. Quartzites adjacent to the same stock have been recrystallized, dolomites converted to coarse-grained marbles, and impure shaly beds to hardened laminated rocks of dark color.

Pennsylvanian and Permian rocks in the vicinity of crosscutting bodies and thick lenses of porphyry east of the Blue River have locally been bleached and transformed into hard laminated rocks containing green heavily chloritized and epidotized bands. Contact effects in these rocks are particularly noticeable southeast of the Fredonia mine and in the southern part of sec. 20, T. 75 S., R. 77 W., but may also be found elsewhere; however, nothing comparable to the widespread contact metamorphism encircling the Montgomery Gulch stock in the Beaver-Tarryall district (Singlewald, 1942b) was seen.

Jurassic strata in the vicinity of the Seven-Thirty mine reveal that limestones have been recrystallized to marble and shales to hard laminated "hornfels," in part dark greenish-gray, in part porcelain white and pink, by contact action of the huge laccolithic sill of Bald Mountain.

STRUCTURE

PRE-CAMBRIAN STRUCTURE

Intense deformation occurred at least twice, once during the pre-Cambrian era and again during the Laramide orogeny following the Mesozoic era. As all known ore deposits are associated with Laramide structural features, the pre-Cambrian structural features have economic interest only insofar as they are patterns of later ones.

The most significant feature of pre-Cambrian structure is the somewhat greater deformation in some areas than in others. In areas of greater deformation strikes and dips of foliation vary greatly within short distances and drag folds are numerous, whereas in areas of less deformation the attitude of the foliation remains fairly constant or changes gradually. Also, granite and pegmatite are more profuse in areas of greater deformation. These differences are apparent even from data shown on plate 1, yet many details recorded in field notes have not been shown.

Two longitudinal zones of greater deformation were found. One is in the extreme eastern part of the pre-Cambrian area, east of longitude 106°5½′. It trends only a few degrees east of north and is characterized by highly variable strikes, longitudinal folds and drag folds, abundance of pegmatite, and one granite stock. The other occurs along and immediately east of the crest of the Tenmile Range; its eastern boundary trends approximately N. 10° E. Strikes and dips within the western zone are less variable than in the eastern zone, yet are much more variable than within the intervening area of less deformation.

Transverse zones of greater deformation are suggested by variability in foliation in Monte Cristo Gulch, along the south side of Crystal Gulch, and in the area north of Sawmill Gulch. Local zones of greater deformation less than a mile long are found at other places.

LARAMIDE STRUCTURE

GENERAL FEATURES

The Laramide orogeny in central Colorado included crustal compression, which folded the rocks and broke them along major and minor faults, and igneous activity. Nearly all faults were initiated during the Laramide period of compression, but movements along many continued into the subsequent period of stress relaxation and along some until recent times. Ore deposition followed soon after the intrusion of the bulk of the magma.

Compressive stress within the upper Blue River area folded all sedimentary rocks to a regional dip ranging from 15° to 45° and from east-southeast to north-northeast. Departures from the regional dip are found in long narrow zones associated with major faults, in more restricted areas surrounding some of the larger cross-cutting intrusive bodies, and in very small areas associated with minor faults and flexures.

Laramide structural features in addition to the prevailing dip, as shown on plate 1, may be regarded as including three major longitudinal ruptured folds, major transverse faults that are closely associated with longitudinal ruptured folds, a belt of major transverse and oblique faults 3 miles wide trending southeastward from Breckenridge toward Kokomo, and a host of minor faults. The main features are emphasized on plate 2, prepared to show relations between major faults, veins, and ore bodies. Plate 2 includes not only the faults shown on plate 1, which is a factual record of areal geology, but also postulated faults for which evidence is very indirect or for which the location is very indefinite. Plate 2 also shows the main faults mapped by Lovering (1934, pls. 1, 2) in the Breckenridge special area.

Major faults influenced the general distribution of ores and minor faults the localization of most individual ore bodies, so both are of economic interest. Major faults are characterized by comparatively large displacements, great lengths, and relatively wide associated zones of fractured rocks. As these faults also extend to great depths, they tapped deep sources of ore-forming solutions and served as main channels of ascent. The longest faults are longitudinal, that is, nearly parallel to the prevailing strike of the formations. Each is bounded on the west by a syncline and on the east by an anticline.

Major transverse and oblique faults, though individually much shorter and having much less throw than major longitudinal faults, are clustered within a belt several miles long.

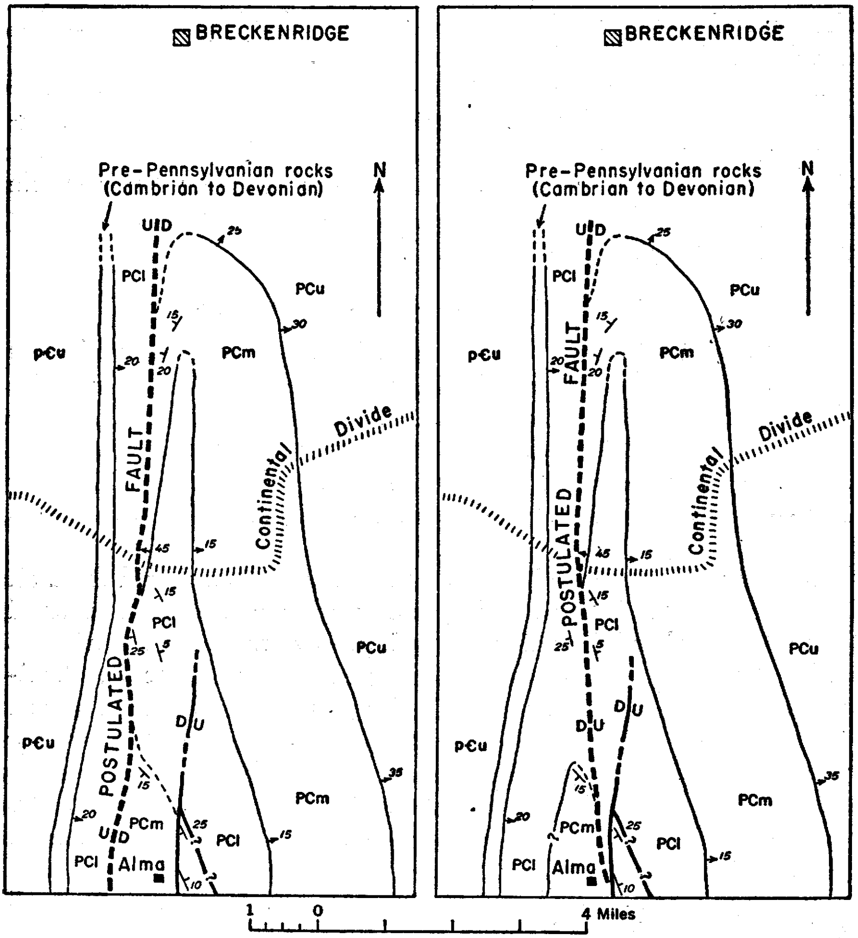
Faults of Laramide age, except where cut by underground mine workings or where mineralized and prospected, can rarely be recognized where pre-Cambrian rocks constitute both walls. This fact doubtless accounts for the apparent scarcity of major faults within areas of pre-Cambrian rocks as compared with areas of sedimentary rocks shown on plate 1.

STRUCTURE OF HOOSIER PASS AREA

Westerly dips in a zone extending at least 5 miles northward from Hoosier Pass reveal a major longitudinal structure feature, here designated the Hoosier Pass structure. The same structural feature continues southward down the Platte Valley for at least 5 miles, to Alma. It was described under the heading "Structure of Hoosier Pass—Windy Ridge area," in the Beaver-Tarryall report (Singewald, 1942b).

Details of the Hoosier Pass structure have to be inferred from all too meager data obtained mainly where moraine has been removed (see pl. 1) either by erosion or by highway excavation. Evidence at hand suggests a northward-trending fault that crosses the Continental Divide 800 feet west of Hoosier Pass and lies not more than 1,000 feet west of the Bemrose shaft, 2,000 feet west of the Governor mine, and 5,000 feet west of the confluence of Spruce Creek and the Blue River. The location of this inferred fault beneath moraine is much too indefinite to be shown on plate 1 but is roughly indicated on plate 2. A generalized sketch, figure 2, coordinating data from maps of the Alma (Singewald and Butler, 1941, pl. 1), Beaver-Tarryall (Singewald 1942b), and Upper Blue River districts also shows the approximate position of this postulated fault north of the Continental Divide and adds two alternative interpretations regarding its continuation southward.

The Hoosier Pass fault differs from all others in the region in having the west wall displaced relatively upward. The amount of throw, which increases northward, can be estimated only by assuming a thickness for the lower division of the Pennsylvanian and Permian strata. If the lower division is 2,000 feet thick, the throw is about 1,500 feet at Hoosier Pass and 2,500 to 3,000 feet at Spruce Gulch. According to one interpretation suggested in figure 2, the west wall remains the upthrown block south of Hoosier Pass, whereas according to the other, slightly preferred on the basis of available field data, displacement south of Hoosier Pass decreases to a pivot point, then again increases but with the east wall upthrown.



EXPLANATION

PCu, upper division, Pennsylvanian and Permian rocks; PCm, middle division, Pennsylvanian and Permian rocks; PCl, lower division, Pennsylvanian and Permian rocks; p€u, pre-Cambrian rocks undifferentiated

Contact, showing dip, dashed where approximately located

Fault, dashed where approximately located; U, upthrown side; D, downthrown side

Probable fault

Strike and dip of beds

FIGURE 2.—Diagrammatic sketch of area between Alma and Breckenridge, showing alternative possible location of the postulated fault that would explain reverse dips and areal distribution of strata along Hoosier Pass structure. Formation boundaries and faults projected to a datum plane at an altitude of 11,500 feet. All igneous rocks omitted.

Dips plotted on plate 1 and the data presented in figure 2 reveal a northward-plunging anticline located about three-fifths of a mile east of the postulated fault. The strike of strata on the west limb gradually changes from west through southwest to south, and the dip increases as the fault is approached. These relations can be seen by comparing dips recorded (see pl. 1) half a mile north of McCullough Gulch, at the Governor mine, and in the area south of the Bemrose shaft. Along the east limb a corresponding change in strike through southeast to south and an increase in dip take place. This simple, generalized picture of structural relations, however, is complicated by many local irregularities. For example, at Hoosier Pass relatively gentle southwesterly dips intervene between two zones of steep westerly dip; south of Hoosier Pass, as shown on figure 2, auxiliary faults and local variations of dip likewise complicate the western limb of the anticline; and along the east side of the Blue River Valley, although no dips are shown on plate 1, sedimentary strata beneath Lincoln porphyry at some places dip westward, at others eastward. Local flexures and faults near the crest of the anticline may result in part from the intrusion of irregular bodies of Lincoln porphyry at depth, analogous to the large mass that is exposed.

Strata at most places west of the postulated fault probably are folded into a narrow syncline, which, unlike the anticline, has little or no plunge to the north. At Hoosier Pass the syncline can be no more than a few hundred feet wide. Northward from Hoosier Pass beds in the west wall of the postulated fault are everywhere covered by moraine.

BOREAS PASS FAULT AND ASSOCIATED TRANSVERSE FAULTS

A northwestward-trending zone exhibiting reverse dips and anomalies in areal distribution of strata along the west base of Bald Mountain is herein interpreted as a major reverse fault with an associated fold and is designated the Boreas Pass fault. Deformation first produced the fold then ruptured the steep west limb and accentuated the fold by drag along the fault. The Boreas Pass fault is a dominant element of the structure, for it separates a thick section of the Pennsylvanian and Permian strata to the southwest from a thin section to the northeast.

Northeast of Bakers Tank, as shown on plate 1, the fault splits into a relatively minor eastern fork and a main western fork. The eastern fork eventually terminates against a large monzonite intrusive body near the southeast corner of the area mapped, but the western fork continues southward into the Beaver-Tarryall area. The fault has been described under the heading "Boreas Pass-Little Baldy Mountain fold" in a report on the Beaver-Tarryall area (Singewald, 1942b).

The dip of both forks is probably about 70° E., as determined by inclination of overturned strata within the fault zone at several outcrops. At a ravine 7,500 feet north of Boreas Pass beds adjacent to the fault are overturned even more, to an inclination of 50° to the east. This abnormal dip may be due either to a local auxiliary "flat" fault, similar to those which displace the London fault of the Mosquito Range (Singewald and Butler, 1941, pp. 41–42) or to a local decrease in dip of the main fault itself.

Section *B–B′* of plate 1 indicates a total apparent throw, due to folding and faulting, of about 3,500 feet on the base of Jurassic strata across the two forks of the Boreas Pass fault, whereas section *A–A′* indicates a total apparent throw of not more than 2,000 feet; thus, the throw diminishes northward. Owing to the difference in thickness of the Pennsylvanian and Permian strata on opposite sides of the fault, the throw measured on the pre-Cambrian surface would appear to be 10,000 feet or more.

The general distribution and dip of strata in the vicinity of the fault are shown on plate 1. Over part of this structural belt outcrops are numerous and the mantle of soil and rock debris is thin, so contacts are mapped with assurance. The ravines are particularly favorable places for obtaining geologic data. Elsewhere, certain areas are covered by thick accumulations of porphyry and other resistant rocks. The areas between the Seven-Thirty mine and Boreas Pass and the area to a distance of three-quarters of a mile east and southeast of Bakers Tank are particularly barren of outcrops.

Abrupt changes in formations cropping out along each wall of the Boreas Pass fault and offsets in the fault trace itself are due to displacements along strong transverse faults that die out within a mile on either side of the Boreas Pass fault. The different transverse faults strike N. 35° to 70° E., as shown on plates 1 and 2, yet each one is nearly straight. Their walls moved in a linear direction raking northeastward. A large horizontal component of movement is attested by the fact that along any one fault all contacts, regardless of whether they dip northeast or southwest, are displaced in the same relative direction, and a concomitant vertical movement is proved by stratigraphic changes in bedrock.

The Boreas Pass fault terminates northwestward at a major oblique fault, shown on plate 2 but beyond the border of the area shown on plate 1. Displaced 2,000 feet laterally by this oblique fault, the longitudinal structural feature probably continues as a "compressed syncline" in Benton and younger beds, which, according to Lovering (1934, p. 18), "extends northwest from Bacon to a point about 500 feet south of Little Mountain." It is to be expected that a fault in relatively brittle Dakota and older rocks would pass upward into a syncline in the thick shales above. The compressed syncline, in turn, terminates northwestward at a major transverse fault mapped by Lovering. (See pl. 2.) Terrace gravel and alluvium conceal the extension still farther northwest. The section of Pennsylvanian and Permian rocks found in the outskirts of Breckenridge is thin, which suggests that the Boreas Pass fault is displaced to the west of Shock Hill. Perhaps the fault is offset as much as 3 miles and is represented by the major fault at the head of Sawmill Gulch (see pls. 1 and 2); on the other hand, the Boreas Pass fault where concealed may resume its northerly trend and reappear as the major longitudinal fault that crosses the State highway a mile north of Breckenridge.

MAJOR FAULTS NORTH OF BRECKENRIDGE

The combination of complex structure and scarcity of exposures north and northwest of Breckenridge led Ransome (1911, pl. 12, p. 66) to insert "structure here unknown" in his geologic cross section through Shock Hill. For the same reason many structural details of this tract remain indeterminate, though the revised mapping shown on plate 1 reveals several important new features.

The distribution and attitude of rocks as determined from mine dumps and highway cuts north of Breckenridge strongly suggest that the pre-Cambrian rocks to the northeast are separated from the Pennsylvanian and Permian strata to the southwest by a major longitudinal fault, which strikes N. 40° W. across the State highway, three-quarters of a mile north of French Gulch. Plates 1 and 2 show the probable position of the fault beneath terrace gravels and alluvium along the western border of pre-Cambrian rocks mapped by Lovering (1934, pl. 2).

Along the southwest bank of French Creek a fault trends N. 35° W. Mesozoic strata form the southwest wall, and Pennsylvanian and Permian strata, revealed in placer workings, form its northwest wall. This fault doubtless continues beneath alluvium and connects with an inferred fault (pl. 1) west of the Blue River, where pre-Cambrian rocks to the northeast adjoin inferred Mesozoic bedrock to the southwest.

Two transverse faults trend east-northeastward across Shock Hill, northwest of Breckenridge. Between them is a horst or uplifted block, which contains all the known commercial ore of that area. The throw along the southern fault is approximately 600 feet; that along the northern fault is about 700 feet, though it cannot be determined precisely.

The westerly dip of strata capping Shock Hill suggests the possibility of a longitudinal fault not far to the west. The prevailing dip on Iowa Hill, half a mile farther north, seems easterly, yet local variations indicate complexity there too.

TRANSVERSE BELT OF MAJOR FAULTS

Plates 1 and 2 clearly reveal that major transverse and oblique faults are abundant within a belt 3 miles wide that trends southwestward from Breckenridge. This belt doubtless continues across the Tenmile Range, but the impossibility of locating faults in pre-Cambrian rocks precludes proof. A further southwesterly projection of the belt would carry it through Kokomo.

Structural details within this belt can best be observed at Breckenridge, where a wealth of data is available from underground mine workings. There, Lovering (1934, pp. 17–20, pls. 1, 2) mapped an abundance of faults, major and minor. The major faults, shown on plate 2, include "two broken, downfaulted belts" that "intersect near the central part of the [Breckenridge] special area. One of the belts trends north-northeast and the other east-northeast" (Lovering 1929, p. 18). The former has no exact counterpart within the area shown on plate 1, but the latter is analogous to many faults on either side of the Blue River.

East of the Blue River and south of Breckenridge there is evidence of several major transverse and oblique faults, as indicated on plate 2. One group of faults is inferred north of Pennsylvania Creek along the southeast border of a large crosscutting body of mixed rocks of Lincoln porphyry and quartz-monzonite porphyry, because the general pattern of the contact, as shown on plate 1, is a series of straight lines with very abrupt bends. This pattern suggests a sinuous main fault the trend of which ranges from N. 60° E. to N. 80° E., offset at several places by faults trending N. 25°–40° E., and at other places by faults trending about N. 5° W. Farther south, along the bottom of Pennsylvania Gulch, a fault trending N. 68° W. is inferred along a nearly straight, though concealed, boundary separating sedimentary strata to the north from mixed rocks of the Lincoln porphyry and quartz monzonite to the south. This fault is shown on plate 1. Still farther south four transverse faults ranging in strike from N. 80° W. to due west are inferred to explain the anomalous areal distribution of limestones and dolomites associated with nearly vertical crosscutting porphyry contacts mapped on plate 1 half a mile north of the Fredonia mine. The group as a whole consists of a horst or uplifted block having a maximum throw of about 1,000 feet. The two northernmost faults of the group may curve, as suggested on plate 2, and join another inferred fault trending N. 30° E. along a straight-line porphyry contact.

West of the Blue River, beyond the morainal border, strong transverse and oblique faults likewise abound. Each is briefly described in the paragraphs that follow.

The two faults between McCullough Gulch and Spruce Creek bound a horst of pre-Cambrian rocks, which abruptly terminates pre-Pennsylvanian strata on either side. (See pl. 1.) Some doubt as to whether pre-Pennsylvanian strata underlie Pennsylvanian beds within the horst is occasioned by the absence either of a ridge or of rock debris to indicate even extremely durable Cambrian quartzites beneath relatively thin moraine. Absence of pre-Pennsylvanian strata could best be explained by assuming that the horst moved a long distance westward as well as upward to bring an area originally located east of the early Paleozoic shore lines into juxtaposition with an area originally west of the shore lines. The inclination of the linear direction of movement in that case would be northeastward at an angle slightly greater than the dip of strata on either side of the horst. If, however, pre-Pennsylvanian strata are present but entirely concealed by moraine, simple vertical uplift of the horst block would explain the distribution of strata.

In Spruce Gulch a transverse fault (indicated on plate 2 but not on plate 1) is suggested by many local crenulations in foliation (partly shown on plate 1), by the considerable mineralization near the Glenn-Mohawk mine, and by the absence of pre-Pennsylvanian strata north of Spruce Creek at the place where they would be anticipated if projected northward from exposures south of Spruce Creek.

A transverse fault striking N. 55° E. and dipping steeply to the southeast can be traced 2,000 feet westward from the moraine between Spruce Creek and Crystal Creek. This fault separates slightly silicified pre-Cambrian rocks to the north from cherty rocks to the south. The cherty rocks may be either recrystallized Cambrian quartzites or intensely silicified pre-Cambrian rocks, but on plate 1 they are tentatively mapped as Cambrian quartzites.

A few hundred feet east of the Briar Rose mine lies a fault striking N. 35° W. and apparently dipping to the northeast. It separates pre-Cambrian rocks on the west from Paleozoic rocks on the east. Its throw is not less than 600 feet.

In Crystal Gulch a transverse fault at least a mile long trends S. 80° W. beneath and westward from the moraine-covered area, then curves and eventually trends N. 65° W. (See pls. 1 and 2.) This fault is offset along a smaller curving fault the average strike of which is N. 65° W. Throughout most of its mappable portion the main fault separates pre-Cambrian rocks to the north from Pennsylvanian strata to the south. The throw is not less than 1,000 feet and may be several thousand feet; furthermore, as the characteristic thick section of Pennsylvanian and Permian strata cannot be found north of the eastward projection of this fault, the north wall may have moved several miles westward relative to the south wall. On the other hand, some transverse fault not apparent within the pre-Cambrian rocks and concealed beneath moraine farther north may mark the northern limit of the thick Pennsylvanian and Permian section.

At the head of Sawmill Gulch an island of sedimentary strata, tentatively identified as Sawatch quartzite of the Peerless formation, forms the northeast wall of a stock of late Cretaceous or Tertiary age. The sedimentary strata are separated from pre-Cambrian rocks by a complex pattern of faults shown on plate 1. The main fault trends N. 45° W. (see pl. 2) and has a throw of not less than 1,000 feet. It may be a local oblique fault, yet it conceivably could be an offset segment of the Boreas Pass fault.

MINOR FAULTS

Minor faults abound throughout the area, but they are shown in great numbers on plate 1 only where exposures are good and where formation contacts, sill boundaries, or limestone beds serve as markers, the displacement of which can be recognized. All minor faults have less than 250 feet of throw and most of them less than 100 feet. They die out laterally within a few hundred or at most a few thousand feet, and therefore must have correspondingly shallow depths. Normal faults predominate.

Minor faults strike in almost all directions, yet certain prevailing trends are clearly evident. West of the Blue River prevailing trends are N. 20° W. to N. 20° E., N. 27°–45° E., and N. 51°–80° E., and subordinate trends are N. 55°–70° W. and N. 80°–89° W. Most veins occupy faults trending within the arc of N. 20° W. to N. 20° E. East of the Blue River prevailing trends are N. 40°–80° E. and N. 50°–60° W., and subordinate trends are N. 20°–30° E. and N. 70°–85° W. According to Lovering (1934, p. 19), at Breckenridge "faults that strike N. 40°–80° E. are by far the most common. * * * They are generally older than those that strike N. 10° W. to N. 20° E. * * * Nearly all veins in the district are found in fault fissures of the east-northeast system."

THEORETICAL ANALYSIS

An analysis of structural features in the upper Blue River area suggests the following theoretical interpretations: (1) Major longitudinal faults are ruptured folds the axes of which at most places trend nearly at right angles to local directions of maximum stress, except as modified by rock heterogeneity, by pre-Cambrian foliation, and by direction changes occasioned by differential movement along the fault itself; (2) major transverse and oblique faults, certain sets of minor faults, and short stretches of the major longitudinal faults are shear planes trending N. 40°–80° E. and N. 50°–80° W. in a theoretical strain ellipsoid; and (3) minor faults trending N. 20° W.–N. 20° E. are short relatively open tension cracks parallel to the plane of maximum elongation of the same strain ellipsoid. According to this interpretation, nearly all veins west of the Blue River occur in tension fractures developed during regional compression, whereas most veins east of the Blue River occur in shear zones that probably became relatively open during the period of stress relaxation that followed regional compression.

ORE DEPOSITS

OUTPUT AND HISTORY

The area shown on plate 1 lies within Colorado's northeastward-trending belt of mineralization but includes no major districts. It has contributed only a scant proportion, therefore, of the total mineral wealth of the State. Records of output are scarce and incomplete for individual mines as well as for the area as a whole. The largest mines, namely, the Brooks-Snider and Iron Mask at Shock Hill, the Warrior's Mark at the head of Indiana Gulch, the Ling and Vanderbilt in Monte Cristo Gulch (see pl. 2), and perhaps others, are all credited in local mining circles with outputs exceeding $100,000 in value. The aggregate value of output of the area certainly exceeds a million dollars.

The history of mining in the upper Blue River area is closely tied to that of the Breckenridge district. According to Ransome (1911, pp. 16–18),

> In 1859 * * * [a] party consisting mainly of Georgians ascended Michigan Creek, * * * pushed over the Continental Divide at what is now known as Georgia Pass, and discovered the rich placer ground of Georgia Gulch [east of Breckenridge] * * *.
>
> During the sixties placer mining was actively carried on. * * * Silver-bearing lodes were opened on Glacier Mountain, near Montezuma, as early as 1864, but it was not until 5 years later that any attempt at lode mining was made near Breckenridge. In 1869 some argentiferous lead ore was taken from the Old Reliable vein at [the former town of] Lincoln * * *. The Laurium [Blue Flag] mine * * * appears to have been opened about the same time * * *.
>
> The Warrior's Mark ore body was discovered in the late seventies * * * Shipments of high-grade silver-lead ore began [from the Iron Mask mine] in 1888 and continued with few interruptions for about 10 years.

According to J. D. Galloway (oral communication, 1941), United States mineral surveyor at Breckenridge, the Brooks-Snider and Governor mines were among the most productive of the region during the eighties.

Nearly all mines within the area shown on plate 1 were discovered between 1870 and 1900, and many of them attained their maximum output during this period. Because of transportation costs and the difficult accessibility of many workings, particularly those west of the Blue River, mining has been confined mainly to relatively high-grade ores.

GEOGRAPHIC DISTRIBUTION

The geographic distribution of mines and prospects reveals two productive areas or subdistricts, hereafter referred to as the western mineralized area and the eastern mineralized area. Outside of these the area is almost entirely barren.

The western mineralized area includes all of North Star Mountain and a triangular area extending northward therefrom to the Briar Rose mine at the head of Sawmill Gulch. This area continues southward into the Alma district and adjoins a small mineralized area in the head of Mayflower Gulch, west of the crest of the Tenmile Range. The value of output from the portion shown on plate 1 has probably amounted to between $750,000 and $1,500,000. The Fredonia and several smaller mines east of the Blue River are here treated as a part of this area, although they may be genetically related to a small independent center of mineralization.

The eastern mineralized area includes the outskirts of the Breckenridge district. It contains all mines and prospects of Indiana Gulch, Shock Hill, and the area north of Breckenridge. The aggregate value of their output cannot be accurately estimated but probably does not exceed half a million dollars.

WESTERN MINERALIZED AREA

STRUCTURAL CONTROL

The western mineralized area comprises about 20 square miles north of the Continental Divide and a smaller area, previously designated (Singewald and Butler, 1941, p. 34) as the "North Star Mountain area," within the Alma district. The zonal center lies near the intersection of the eastern longitudinal belts of greater pre-Cambrian deformation and the main transverse belt. Thus, these early pre-Cambrian major structural features evidently localized the Laramide fractures that gave access to ore-forming solutions. The Hoosier Pass structure, which includes a postulated major longitudinal fault, crosses the eastern part of the area and doubtless had some influence on the general distribution of ore, yet it cannot be regarded as the dominating structural control because it is much less centrally located than the pre-Cambrian structural features. It has been pointed out (Singewald and Butler, 1941, pp. 16, 28) that the southern part of the mineralized area lay within a belt of late Cretaceous or Tertiary stocks, abundant dikes, and general mineralization localized by pre-Cambrian structural features of the Mosquito Range. Individual ore bodies have all been localized by minor faults.

ZONAL PATTERN

As is apparent from plate 2, the area may be divided into an inner core containing gold deposits and an outer envelope containing silver deposits. The gold-bearing part has yielded commercial amounts of tungsten and iron and contains many molybdenum prospects. Minor quantities of lead, zinc, copper, and silver were doubtless extracted from some of the gold ores. Most of the silver deposits contain lead, and many contain zinc. Their gold content, however, rarely exceeds a few tenths of an ounce per ton.

The megascopic composition of the ores provides even more detailed evidence for zoning than does the metal content. The deposits clearly reflect decreasing temperature of deposition outward from an epicenter located under the eastern part of North Star Mountain. Magnetite, a mineral indicative of hypothermal (high-temperature) conditions, was found (as noted on plate 2) at the El Dorado, Vanderbilt, and Senator mines and at a prospect one-third of a mile west of the Senator. It was likewise found by Vanderwilt (see Singewald and Butler, 1941, p. 34) locally on the south slope of North Star Mountain. Deposits formed at temperatures slightly lower than those containing magnetite are widespread within most of the gold-bearing area. They are represented by veins of quartz and pyrite, many of which contain one or more of the following relatively high-temperature minerals: bismuthinite, specular hematite, huebnerite, molybdenite, pyrrhotite, tremolite, and manganese-rich carbonate.

The outer margin of the gold-bearing area and the inner part of the silver-bearing area are both characterized by typical mesothermal (medium-temperature) ores, essentially devoid of any minerals named above yet containing considerable quantities of pyrite with or without dark-colored sphalerite. On the outer margins of the silver-bearing area are deposits indicative of even lower temperatures, characterized by the presence of barite, the absence of dark-colored sphalerite, and the scarcity of pyrite.

On the outskirts of the productive area, particularly between Spruce Creek and Carter Gulch, and at places farther north are elongate or irregularly shaped masses of intensely silicified rock. The silica occurs as chert that is very similar to the "jasperoid" of many silver-lead deposits of the cooler mesothermal type. In Sawmill Gulch, on the northern margin of the silicified areas, are extensive masses of rock stained deep-brownish red by mixtures of earthy hematite and limonite. Both silicification and iron stain doubtless have been localized by faults or other fractures, yet their geographic distribution relative to the zonal pattern strongly suggests that they represent the outermost nonproductive zones of the central mineralized area. The reddish, iron-stained masses, according to W. S. Burbank (oral communication, 1942), closely resemble some deposits that flank productive areas in the San Juan Mountains.

MEGASCOPIC MINERALOGY OF ORES

The mineralogic content of the ores has been partly considered in the discussion of zoning. Deposits in pre-Cambrian rocks and in the Sawatch quartzite within the gold-bearing area are of two general types. In one, quartz and pyrite occur alone; in the other, quartz and pyrite are accompanied by noteworthy quantities of other hypogene (original) metallic minerals. The two types are about equally abundant, but the former is almost invariably barren.

The most common minerals that accompany quartz and pyrite are galena and sphalerite. These two minerals are not necessarily intergrown with pyrite but tend to occur independently and to vary greatly in quantity from place to place along the same vein. Gold content is highest where sphalerite and galena are at least moderately abundant, yet it does not conform closely with the content of these sulfide minerals. Apparently, intermineralization fracturing that localized deposition of the relatively late sulfides also localized the deposition of gold. Chalcopyrite normally is associated with galena and sphalerite but is subordinate to them. Molybdenite is a widespread though minor constituent of many veins in Monte Cristo Gulch. Specularite and magnetite may be regarded merely as subordinate or minor constituents of certain veins.

Huebnerite was recognized megascopically only in veins near the Navy property (see pl. 2), where it is a common constituent. It forms dark-brown needles and prisms as much as an inch in length, intergrown mainly with quartz and pyrite. Specimens seen at a cabin near the lower of the Blue Lakes, in Monte Cristo Gulch, contained flourite. The tungsten veins of Monte Cristo Gulch closely resemble those found on the south slope of North Star Mountain (Singewald and Butler, 1941, p. 34) and near the Sweet Home mine in Buckskin Gulch, 3 miles northwest of Alma. No tungsten veins are found at other places in the region. They apparently are a distinctive subtype.

Gold ores occurring in dolomites contain less quartz and more carbonate gangue than in the veins just described. At the Bemrose mine (see pl. 2) gold ore consists of a massive sulfide aggregate containing scant gangue.

The silver-bearing area shows mineralogic variations analogous to those in the gold-bearing area. Quartz-pyrite veins, however, are less common than barren quartz veins. Quartz-galena-sphalerite veins contain relatively minor amounts of pyrite and very little chalcopyrite. Carbonate gangue is more widespread in silver deposits than in gold deposits in pre-Cambrian and Cambrian rocks. Late quartz may occur as very coarse crystals having bladed structure or as crystals as much as half an inch in length lining vugs. Barite is restricted to the marginal deposits. At the Governor mine (see pl. 2) much unreplaced dolomite remains as gangue, and at the Fredonia mine "jasperoid," a microcrystalline variety of quartz, constitutes the gangue.

The intensity of oxidation and enrichment varies greatly according to location. Ore bodies located a few hundred feet beneath the preglacial land surface are thoroughly oxidized and presumably considerably enriched in gold or silver, or both, whereas those located at greater depths below the preglacial surface are progressively less oxidized. From a practical standpoint this generally means that deposits immediately under ridges west of the Blue River show greatest oxidation, whereas those nearest the creek bottoms show least. Ore in all the mines and prospects shown on plates 1 and 2 east of the Blue River within the central mineralized area is intensely oxidized. The oxidized ores are characterized by rusty-brown limonite stain or, locally, black manganese stain.

FORM AND STRATIGRAPHIC RELATIONS OF ORES

Most of the deposits are in pre-Cambrian rocks, in which the ore occurs in veins occupying steeply dipping minor fault fissures. Their prevailing strike ranges from N. 20° W. to N. 20° E., commonly at a small angle to the rock foliation, but a few strike in other directions. Individual veins in underground workings persist laterally no more than a few tens or a few hundreds of feet, but disconnected veins may aline and so extend several thousand feet along the strike. The veins range from less than a foot to 5 feet or more in width. The wider ones commonly consist of zones of broken rock permeated by stringers and veinlets of vein matter. Gouge is scarce or absent. Ore shoots, at the few places where they could be seen in Monte Cristo Gulch, almost invariably have been localized where veins are transected by a host of joints or by fault fractures devoid of gouge.

Deposits in Cambrian quartzites occur in Monte Cristo, McCullough, and Spruce Gulches, although noteworthy mines are restricted to North Star Mountain. The scarcity of deposits in Cambrian quartzites as compared with deposits in pre-Cambrian rocks north of Monte Cristo Creek implies that mineralization was more intense where the Cambrian rocks are eroded than where they now crop out, for in the Mosquito Range, where both groups occur in juxtaposition, the Cambrian quartzites prevailingly have been the more favorable host rocks. Most deposits in quartzite are steeply dipping veins in minor faults having a northeasterly trend. The veins widen at favorable horizons by replacing the host rock and thus form pod-shaped ore shoots. At the Vanderbilt mine, and elsewhere to a minor extent, actual bedded deposits result from incomplete replacement of a thin quartzite bed.

Deposits in the Dyer dolomite member of the Chaffee formation, represented by the Monte Cristo mine (see pl. 2) and numerous lesser mines and prospects, have had little economic value. Ores are typical bedded replacement bodies restricted to shattered ground near minor faults.

At the Bemrose, and probably also at the Governor mine, ore forms a replacement vein along a fault fissure nearly conformable with the bedding. The replaced rock is dolomite of the basal part of the middle division of Pennsylvanian and Permian strata. At the Fredonia mine bedded replacement ore bodies occur in limestone near the base of the redbeds where minor fractures have shattered the limestone near a large fault. In sandy Pennsylvanian and Permian strata as well as in porphyry the relatively few veins exhibit little evidence of replacement.

EASTERN MINERALIZED AREA

STRUCTURAL CONTROL

The eastern mineralized area includes about 10 square miles along the northeastern border of the area shown on plate 1. It comprises the western, southwestern, and southern outskirts of the Breckenridge district and extends southeastward along the Boreas Pass fault zone.

The Breckenridge district as a whole is localized within the general mineral belt by a threefold structural intersection—a broad anticlinal fold, which south of Breckenridge is clearly associated with the major longitudinal Boreas Pass fault; a major transverse zone of east-northeastward-trending faults; and a major oblique zone of north-northeastward-trending faults. The last two are features of a regional, southwestward-trending belt of major transverse and oblique faults.

The Blue Flag (Larium) and Mountain Pride mines, shown on plate 2 but just beyond the border of the area shown on plate 1, together with the Twin Sisters, Seven-Thirty, and Warrior's Mark mines are the most productive in the prong that extends southeastward from Breckenridge along the Boreas Pass fault. Many smaller mines and prospects in this prong, however, demonstrate widespread effects of mineralization. All are within a mile of the Boreas Pass fault, which served as the main structural control. The relations are analogous to those in the Mosquito Range (Singewald 1942a, pp.

93–95), where deposits extend along large longitudinal faults southward from the main mineral belt. In Indiana Gulch the two most southerly productive mines, the Seven-Thirty and the Warrior's Mark, are closely associated with a major transverse fault that cuts the Boreas Pass fault. At the Seven-Thirty ore bodies occur within the transverse fault itself, near its eastern termination, whereas at the Warrior's Mark ore bodies are in minor faults adjacent to the western end of the transverse fault. Productive ore bodies closer to the Breckenridge center, however, are localized by minor faults alone.

The Brooks-Snider, Iron Mask, and other lodes of Shock Hill, the Sultana and nearby lodes along the highway north of Breckenridge, and a group of prospects located in sec. 17 and in the eastern part of sec. 18, T. 75 S., R. 77 W., are all on the outskirts of Breckenridge and are therefore related to the main threefold structural intersection in that district. Each of these three areas, however, is associated with some additional structural feature that apparently served as a more local control. At Shock Hill mineralization in general seems closely related to two major transverse faults, but ore bodies have been localized by minor faults and joints, particularly within the horst block between the two main faults. North of Breckenridge ore bodies probably follow minor faults, including bedding-plane faults, auxiliary to a major longitudinal fault. Numerous prospects are found in secs. 17 and 18, T. 75 S., R. 77 W., but only the two largest are shown on plate 1. They have yielded little, if any, commercial ore. No information whatsoever could be obtained regarding their history and output, so they are not further discussed in this report. These prospects are located along mineralized minor faults within or near the margin of a large crosscutting porphyry mass, which itself is localized by major transverse and oblique faults.

MEGASCOPIC MINERALOGY AND ZONAL PATTERN

Oxidation and enrichment have played a major role in the eastern mineralized area, so the original minerals in many of the ores are not known. According to Ransome (1911, pp. 17, 161, 163), mining was confined to oxidized ore at the Brooks-Snider, Iron Mask, Germania, and Warrior's Mark properties. Specimens found by the writer at the Seven-Thirty and Twin Sisters mines reveal incomplete oxidation of ores there. At the Carbonate mine available specimens show complete oxidation.

The hypogene (original) ores of the Breckenridge district, according to Lovering (1934, p. 27), "consist largely of lead, zinc, and iron sulfides, with some native gold and some silver whose form in the primary ores is uncertain. The most common gangue minerals are ankerite, calcite, quartz, and sericite." His description would doubtless apply equally well to most deposits of the eastern mineralized area. At the Sultana and nearby mines, however, specimens from the dump reveal heavy sulfide ore, mainly pyrite, nearly devoid of gangue. Specularite was found at the Twin Sisters mine and barite at the Warrior's Mark.

Evidence for zoning is not especially conspicuous within the southeastern or Indiana Gulch area, for all the deposits belong to an extension of the outer main zone of the central area. Gradual decrease in temperature of deposition southeastward from Breckenridge and also outward from the Boreas Pass fault, nevertheless, is shown by the presence of specularite, a moderately high-temperature mineral, and the relative abundance of pyrite at the Twin Sisters mine located next to the Boreas Pass fault; the lesser abundance of pyrite and the absence of specularite at the Blue Flag (Larium) mine (Ransome, 1911, pp. 158–159) located slightly closer to Breckenridge but farther from the Boreas Pass fault than the Twin Sisters and the relative scarcity of pyrite at the Seven-Thirty and Warrior's Mark mines and the occurrence of barite at the latter. Both of these mines are near the southeastern limit of mineralization and are the most distant from the Boreas Pass fault. The presence of commercial amounts of zinc at the Blue Flag and not at the Twin Sisters mine seems to contradict the mineralogic evidence for higher-temperature deposition at the latter, yet all the output from the Twin Sisters mine came from partly oxidized ore from which original zinc minerals may have been leached. The distinction between deposits worked primarily for lead and those worked primarily for silver has no zonal significance, as it is largely due to the local effects of oxidation. Whether the substantial quantities of gold taken from the Mountain Pride mine represent a slight anomaly in the zonal pattern or are the result of enrichment through oxidation cannot be determined without much more information concerning the ore than is now available.

In the northern part of the eastern mineralized area the commercial production of gold along with silver at the Germania mine and of iron at the Sultana in contrast with either silver alone or silver with lead on Shock Hill vaguely suggests a decrease in temperature of deposition westward. Even more significant is the great abundance of pyrite in small mines and prospects north of Breckenridge and its scarcity on Shock Hill, a contrast that suggests a decrease in temperature of deposition away from the major longitudinal fault that crosses the State highway three-quarters of a mile north of French Gulch.

FORM AND STRATIGRAPHIC RELATIONS OF ORES

The deposits of the eastern mineralized area take the form of veins, of "blanket" lodes essentially conformable with bedding, and of irregularly distributed stringers and veinlets in areas of intensely fractured rock. Stratigraphically they occur in pre-Cambrian rocks, in sandy beds mainly of the uppermost part of the Pennsylvanian and Permian strata, in contact-metamorphosed Jurassic strata, in the Dakota quartzite, and in porphyry.

Veins occur in all the host rocks. In the more productive mines veins occur as follows: In pre-Cambrian rocks in the Blue Flag (Larium) mine (Ransome, 1911, pp. 158–159) ; in sandy strata near the top of the Pennsylvanian and Permian strata in the Iron Mask, Mountain Pride, Twin Sisters, and Warrior's Mark mines; in wall rocks partly of porphyry and partly of contact-metamorphosed Jurassic strata in the Seven-Thirty mine; and, according to Ransome's map, in porphyry alone at the Carbonate mine.

Blanket lodes or sheets of ore as much as 2 feet thick, that are conformable with the bedding, according to Ransome (1911, p. 161), occur enclosed within sandy strata in the Sultana mine and nearby prospects and between sandy strata and porphyry in the Iron Mask mine. All these occurences are restricted stratigraphically to the uppermost part of the Pennsylvanian and Permian strata.

Ore bodies composed of innumerable irregularly distributed stringers and veinlets in areas of intensely shattered rock are restricted to the brittle Dakota quartzite. The best examples within the area shown on plate 1 are in the Brooks-Snider and Germania mines.

SUGGESTIONS FOR PROSPECTING

GENERAL AREAS

Data given in the foregoing pages indicate that mineralization has been concentrated in two general areas, outside of which prospecting is almost certain to result in failure. Within these mineralized areas there remain possibilities for future ore production, but chances for discovering deposits much larger than those already worked are slight. The remainder of this section is devoted to a review of the general outlook in each mineralized area. More specific suggestions at certain mines are set forth in the section on mine descriptions, pages 37–72.

WESTERN MINERALIZED AREA

In the western mineralized area, although the combination of favorable rocks and abundant effects of mineralization are found, there are no major Laramide faults comparable to those that have localized large ore bodies elsewhere. Along the one major longitudinal structural feature (the inferred Hoosier Pass fault) that might have localized large ore bodies the favorable rock formations are too deeply buried to invite prospecting.

The most favorable formations are pre-Cambrian rocks and pre-Pennsylvanian strata, particularly the latter. Throughout most of the area in which these rocks crop out exposures are good; hence, few new veins or replacement bodies are likely to be discovered in them. Immediately east of their outcrop belt, pre-Pennsylvanian rocks at increasingly greater depths eastward are likely to contain bodies of relatively unoxidized ore. The most favorable localities for these rocks are beneath North Star Mountain and along Monte Cristo Creek. Very detailed mapping of areas not covered by moraine may disclose clues leading to the discovery of ore, but in moraine-covered areas prospecting will be hit or miss.

Work along known veins in pre-Cambrian rocks and in pre-Pennsylvanian strata has at most places been confined to shallow prospecting or to the extraction of relatively rich ore. Additional exploration may yield new ore shoots comparable in size and value to those already depleted and many more of lower grade. Some veins are so difficult of access, however, that exploration will be expensive.

Within rocks of Pennsylvanian age or younger, dolomites and limestones offer greatest economic interest. The two thickest, and therefore the most favorable beds, occur at the Bemrose and Fredonia mines, respectively. The dolomite of the Bemrose mine probably contains concealed ore bodies here and there between the mine and McCullough Gulch, but the moraine cover would necessitate hit-or-miss prospecting. Ore bodies in the same dolomite south of the Bemrose mine are not likely to be found, for the bed is almost continuously exposed by placer workings and road cuts as far as Hoosier Pass. The main ore-bearing bed at the Fredonia mine is exposed intermittently for half a mile to the north and very well exposed for 2 miles to the south but does not offer much hope for locating concealed ore. Some additional possibilities at the Fredonia mine are discussed on page 60.

The character of ore to be anticipated at any locality in this western mineralized area is apparent from the zonal pattern. Gold ores are to be expected in the central part and silver-lead-zinc ores in the outer part. Tungsten ores are likely to be restricted to a small area in the vicinity of the Navy vein. (See pl. 2.) Molybdenum-bearing ores may be found in many places in Monte Cristo Gulch and in scattered localities farther north. Data in hand do not indicate any possibility for commercial production of molybdenum, but the localities have not been studied in detail.

EASTERN MINERALIZED AREA

The outlook in the eastern mineralized area is difficult to evaluate. The rocks within the Indiana Gulch, or southeastern zone, are not particularly favorable for ore deposition, yet they have contained the ores at Breckenridge. The most promising ground is in the immediate vicinity of mines that have had noteworthy past production. Concealed bodies near the Boreas Pass fault may possibly exist beneath unconsolidated surface debris or talus between Baker Gulch and the ravine three-quarters of a mile farther to the north and at some other localities, but they would be difficult and expensive to locate.

Ore bodies similar to those at the Germania mine (Ransome, 1911, pp. 161–163) may be concealed by moraine immediately to the north and south; yet, again, prospecting for them would have to be at random within the Dakota quartzite.

Concealed ore bodies may exist beneath the northern and eastern flanks of Shock Hill. On the east side, within the horst block, prospecting should be at bedrock beneath alluvium of the Blue River valley. Immediately north of the horst block, prospecting would have to be carried not only to the base of the alluvium but also downward through Benton shale to the underlying rocks.

At least small concealed ore bodies of commercial grade are likely to exist within a mile north of Breckenridge, but the unconsolidated mantle over this area blankets all clues as to their whereabouts.

Throughout most of the eastern mineralized area new deposits are likely to be of the silver-lead-zinc type.

MINE DESCRIPTIONS

MONTE CRISTO GULCH

LING MINE

The Ling mine workings lie directly beneath the crest of North Star ridge, 2½ miles northwest of Hoosier Pass. (See pl. 2.) The relative inaccessibility of the mine has restricted mining operations, for only rich ore was shipped at a profit. In spite of transportation and climatic difficulties, output from the Ling mine, according to local mining circles, has totaled more than $100,000 in gold. No official records are available, but Galloway (1935) gives the following data:

Production of Ling mine

	Tons of ore	*Net smelter returns*
1884–89	161. 2	$16, 891. 50
1890–93	-----	304. 93
1894–97	179. 0	12, 303. 35
1898	16. 7	1, 053. 16
1900	195. 8	23, 219. 48
1901–2	55. 6	4, 929. 19
1903–4	65. 4	5, 247. 36
1905	None	None
1906	97. 7	4, 964. 52
1907–34[1]	-----	----------

[1]Production not recorded, but current reports credit an output of about 600 tons yielding $60,000.

Rocks cropping out in the general vicinity of the mine, as shown on plate 1, are pre-Cambrian gneiss, which contains some unmapped pegmatite; Cambrian quartzites; and Cretaceous or Tertiary igneous rocks, represented by small dikes and sills of quartz monzonite porphyry. Cambrian quartzites are eroded above and westward from the mine but cap the ridge to the east. Their base before erosion lay about a hundred feet above the present surface and so may have constituted the capping for the original ore body.

Underground workings are entirely in pre-Cambrian rocks, except where they cut an occasional porphyry dike too small to be shown on plate 1. Nonuniformity of dips measured on foliation near the mine suggests a local zone of faulting.

Plate 3 shows part of the underground plan of the mine, together with a longitudinal profile, both of which were furnished by Galloway. All workings were inaccessible in 1940 and 1941. The map indicates that the principal lode has an average strike of about N. 40° W. Galloway's report (1935) states that the main or "Ling" vein strikes N. 31° W., averages 5 feet in width, and contains high-grade streaks of ore that in general range from 2 to 10 inches in thickness but locally attain 3½ feet. The largest stope, as shown on plate 3, extended from the surface to a point below level 3, a vertical distance of more than 200 feet. The continuity and richness of the vein can be attributed to residual enrichment—by leaching of substances other than gold—in the zone of oxidation during preglacial weathering, for the present ridge crest is essentially a remnant of the preglacial land surface. The hypogene (original) vein material must be in general too lean to be worked, for below level 3 stopes are few and small. At least one stope, shown on level 5 of plate 3, occurs on a cross vein that strikes N. 13° E. The map vaguely indicates that stopes below level 3 may be localized at vein intersections.

According to Galloway, the Little Daisy vein, opened in the Jap tunnel, strikes N. 31° W., is 7 feet wide, and contains a pay streak from which half a ton of ore was mined and shipped. Smelter returns for this ore gave 12.36 ounces of gold per ton, 36.75 ounces of silver per ton, and 11.95 percent of copper.

Vein material is not abundant on the dumps. Quartz, the principal gangue constituent, is accompanied by considerable calcite that is wholly or in part supergene (secondary). Original metallic minerals are pyrite, sphalerite, chalcopyrite, galena, and huebnerite (?). Gold seems closely associated with sphalerite and chalcopyrite. The sphalerite is dark-colored and is in part fine-grained and in part coarse-grained.

ARCTIC MINE

Three adits, shown in figure 3, constitute the main workings of the Arctic mine. Above them the vein is exposed in several smaller open-

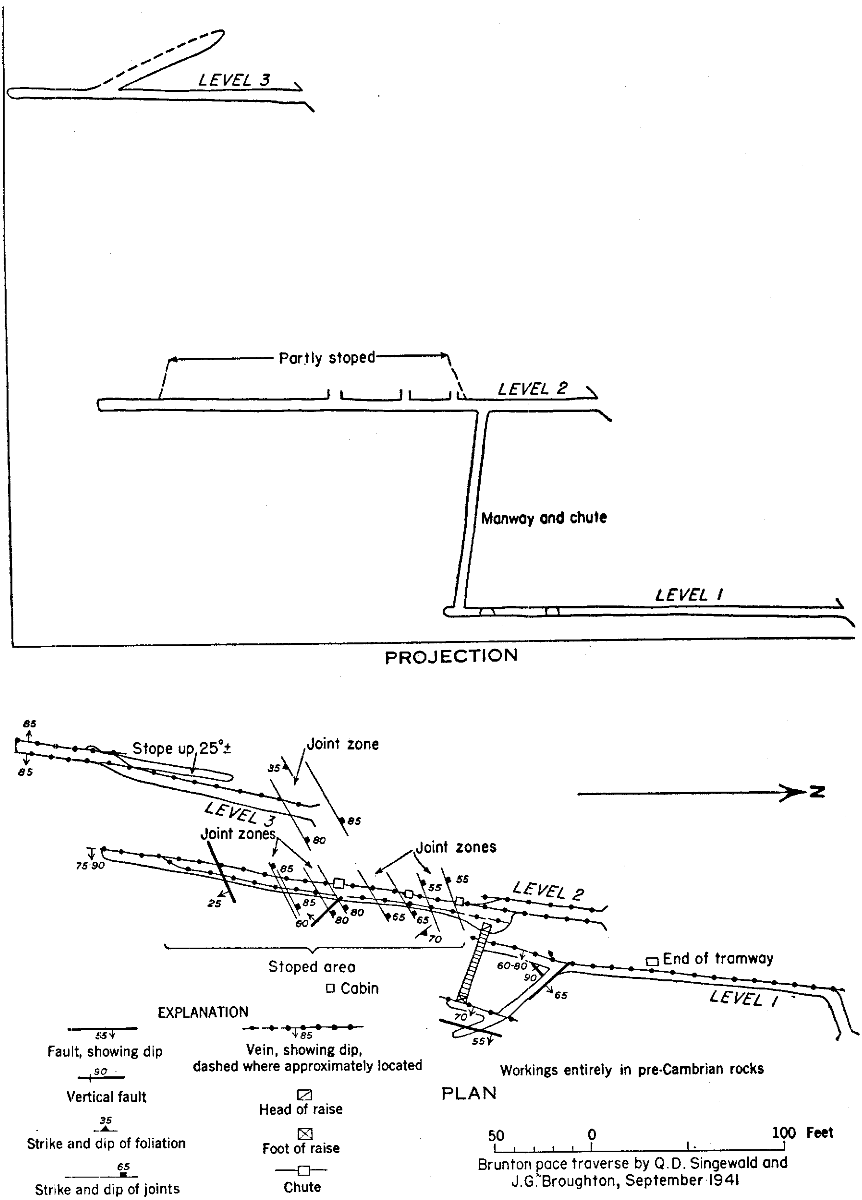


FIGURE 3.—Plan and projection of Arctic mine.

ings. Ransome (1911, p. 160) states that the Arctic mine, a source of gold, is "credited with a production of about $50,000, although this is probably exaggerated." No record of output since the time of Ransome's report is available. An aerial tramway connects the middle adit, which is at an altitude of approximately 11,900 feet, with a wagon road in Monte Cristo Gulch. The foot of the aerial tramway is 1½ miles west of the Alma-Breckenridge highway.

Rocks exposed in the mine and its immediate vicinity are the characteristic quartz-mica gneiss of the Idaho Springs formation and pegmatite. The two are so intimately associated that no distinction between them in underground mapping is feasible. No dikes or sills of Cretaceous or Tertiary igneous rock were seen, but possibility of their presence underground is not entirely precluded, for the walls at most places were coated with ice. The prevailing strike of the foliation in the gneiss is N. 65° to 75° E. and the dip 35° SE., but there are local variations.

The fracture pattern is readily seen in figure 3. The dominating fissures are fault zones ranging from less than an inch to several feet in width. They strike north-northeast, and all but one dip steeply to the southeast. Repeated movement along the faults is revealed by closely spaced fracture surfaces whose slickensides rake at different angles. Scarcity of gouge indicates that the faults are tension rather than compression fractures. Obliquely transecting these main faults are a host of fractures showing little or no displacement. At some places they are closely spaced; at others they are scarce. Their prevailing strike is N. 60° E. and their dip about 80° SE. Miscellaneous fissures having random strike and dip are found here and there.

Veins occur in the north-northeastward-trending faults and consequently tend to persist over considerable distances. Ore shoots, on the contrary, are local. In the middle adit stoping has been confined to a block in which the vein is transected by numerous east-northeastward-trending joints. In the remainder of the middle adit where the veins have not been stoped and in the lower adit east-northeastward-trending joints are absent or scarce. The ore shoot in the upper adit occurs at the juncture of a westward-dipping fissure with the Arctic vein and rakes southwestward along the intersection. The walls of this adit are too heavily coated with ice to disclose the existence of east-northeastward-trending joints.

Ore now available for study consists of coarse-grained quartz, considerable pyrite, less chalcopyrite, and scattered flakes and small nests of molybdenite. Ransome reported bismuthinite. Oxidized ore composed mainly of limonite and quartz occurs close to the surface. According to Mr. Harry Dunn, of Breckenridge, Colo., gold is particularly associated with pale-pink carbonate.

SENATOR MINE

The Senator mine is located south of Monte Cristo Creek, on the north side of North Star Mountain, about three-quarters of a mile east of the Arctic mine and about the same distance west of the Alma-Breckenridge highway. Its output, entirely of gold, probably has been somewhat less than that of the Ling and Vanderbilt mines. A map of the entire mine was published by Ransome (1911, p. 160, fig.

27); the present report includes only a map (pl. 4) of levels accessible during 1941.

The wall rocks in workings shown on plate 4 are pre-Cambrian quartz-mica gneiss and pegmatite. Gneiss greatly predominates. It is permeated by pegmatite bodies that are too small and too irregular to be mapped. Nearly pure pegmatite that locally approaches granite in texture forms one fairly large area on level 4. The prevailing foliation of the gneiss strikes north-northeast and dips about vertically, but the usual irregularities are widespread.

Several cuts in Cambrian quartzites, just above level 1 (shown on Ransome's map), indicate that on entering brittle sedimentary rocks the vein breaks up, with mineralization distributed in several closely spaced fissures, none of which contain sufficient ore for commercial exploitation.

Three types of fractures are seen in the underground workings—faults, zones of uniformly dipping joints, and random joints. All faults and all conspicuous joint zones are mapped on plate 4. The joint zones comprise two to a dozen closely spaced parallel fractures, along which little or no movement has taken place. Irregular, discontinuous joints having random distribution are far too numerous and have too little economic significance to warrant mapping.

Faults include a group trending north-northeastward, a group trending nearly due east, and a miscellaneous group having random strikes.

Faults of the group trending north-northeastward on the whole are longer and have wider shear zones than any others. Their prevailing dips range from 65° to 75° SE. Mine workings tend to follow them, so they do not appear as numerous on plate 4 as they would on an east-west cross section. These faults in places have single slickensided fracture surfaces, but more commonly they comprise a series of closely spaced fractures within a zone ranging from 1 to 5 feet in width. Variations in the width of any fault may occur within short distances along the strike. Gouge is scarce. The north-northeastward-trending faults are tension fractures, the relatively open character and persistence of which made them favored channels for ore-forming solutions.

The eastward-trending group actually includes faults ranging from west-northwest to east-northeast in strike and from 65° S. to 55° N. in dip. Most are narrow, decidedly minor fissures that doubtless do not continue many feet beyond the drift. Several have wide shear zones, however, comparable to those of the north-northeastward-trending set. The four most prominent fissures on level 4 are at 190, 540, and 675 feet, respectively, from the portal, and at the breast. They contain a little more gouge than the north-northeastward-trending fissures and thus are less likely to contain ore, but vein material occurs in them locally.

The miscellaneous group has little significance except to indicate that fault movements occurred at scattered places along fractures that do not conform with any consistent pattern.

Joint zones having a regular pattern are well-developed within the stoped area of level 3 but are absent or inconspicuous elsewhere. The many irregular, discontinuous fractures found throughout the mine workings, though more abundant in some places than in others, bear no apparent relationship to the ore.

The bulk of the output has come from the Senator vein, the principal stope of which is along level 3. The dimensions of the stope above the level are not known, but ore continued downward, with diminishing stope length, to level 4. Ransome (1911, p. 159) states:

> The veins as exposed in the tunnels below No. 1 are hard, tight, and unoxidized. Their principal constituents are quartz and pyrite, the latter in some places forming nearly the whole of the vein. Associated with these minerals are very subordinate quantities of chalcopyrite, sphalerite, galena, and specularite, with probably some magnetite. According to M. M. Howe, who was doing some work in the mine in 1908, the ore averages from 1.5 to 2 ounces of gold to the ton, with a small proportion of silver. This probably refers only to the best shoots, such as were stoped.

On level 4 there is a stoped ore body approximately 40 feet long, 16 feet in maximum width, and 20 feet high, localized along a complex group of closely spaced transverse (easterly) fissures. The ore body there has been called the Witch Hazel vein. On level 3 an area of highly fractured ground containing numerous and complexly branching and intersecting short fissures was followed by the winding crosscut 200 feet from the portal, but no commercial ore was found. This broken ground on level 3 is doubtless the upward continuation of the so-called Witch Hazel vein of level 4.

Though not now accessible, the continuous stope from level 4 to level 3 proves the vertical continuity of the Senator vein at that locality, but whether the vein continues northward to connect with the vein followed near the portal of level 4 is very doubtful. If not continuous with the Senator vein, however, the vein near the No. 4 portal has approximately the same trend. At several places on level 4, as shown on plate 4, north-northeastward-trending fissures thin out along the strike to be followed a little farther along by others.

VANDERBILT MINE

The Vanderbilt mine is reported to have supplied noteworthy quantities of gold ore, but no figures are available. According to J. D. Galloway, United States mineral surveyor at Breckenridge, Colo., its output was slightly greater than that of the Arctic mine.

The Vanderbilt mine is located between the Senator and El Dorado mines, near the foot of North Star Mountain, and is connected by trail with the El Dorado mill. A Brunton pace traverse map of the workings is shown in figure 4. The main workings comprise an adit and

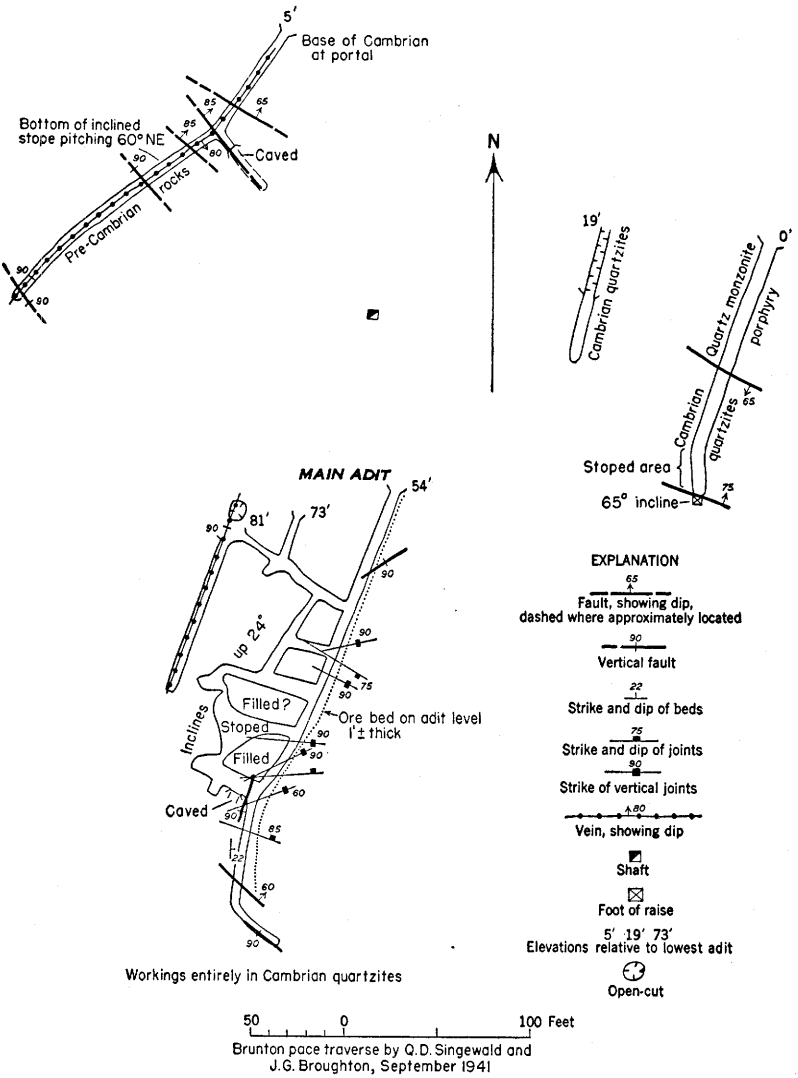


FIGURE 4.—Plan of workings of Vanderbilt mine.

a series of inclined stopes and drifts extending upward along the ore bed from the adit. They are in the upper part of the Cambrian quartzites. Two hundred and fifty feet north of the main workings is an adit that starts at the base of the Cambrian beds and extends southwestward through pre-Cambrian quartz-mica gneiss and associated pegmatite. A small stope, which doubtless reaches into the Cambrian quartzites, is indicated in figure 4. Northeast of the main adit are two other short adits that were accessible in 1941. The western one is on the same ore bed as the main workings, whereas the eastern one starts in quartz monzonite porphyry, cuts through a fault into the Cambrian quartzite, and has a small stope along an ore bed that is doubtless the same as the ore bed in the main workings.

The adit in pre-Cambrian rocks follows a sinuous vein that ranges from a very few inches to several feet in width. Visible minerals are coarse-grained quartz, pyrite, and minor limonite. The vein is within a fault having very little gouge, with an average strike of N. 45° E. and a dip ranging from 80° SE. to vertical. The vein is intersected by several northwestward-trending faults, as shown in figure 4. The most prominent cross fault is the one nearest the portal; it is several inches wide and contains much gouge. The next most prominent cross fault, located 65 feet from the portal, was followed about 40 feet southeastward but apparently yielded no ore. The other cross faults are inconspicuous. No cross faults or joints could be found at the stope.

The highest adit shown in figure 4 follows a prominent vertical fault trending N. 20° E. No ore shows in the adit, but the glory hole in front of the adit indicates a vein, probably productive in workings not now accessible.

The deposit worked from the main adit is a replacement body in Cambrian quartzite. The ore bed, 1 foot thick, seems to be the same stratum throughout the workings. This bed is about three-quarters of the distance stratigraphically from the base to the top of the quartzite. The boundaries of the ore bed are shale partings. At least minor bedding-plane movement along the base of the ore bed is revealed 70 feet from the breast by the displacement of a crosscutting joint; the footwall of the ore bed is displaced 1 foot southwestward relative to the hanging wall. The condition of the stopes makes it impossible to find fractures in their walls. The distribution of faults and joints along the adit level, however, is shown in figure 4. The joints show neither displacement nor gouge, and they probably persist only a few feet horizontally and vertically. The faults are narrow fissures containing minor amounts of gouge. Although these fractures exhibit no close relationship to stopes, they probably exerted some influence on the alinement of ore shoots.

The fissure along which ore-forming solutions ascended to the replaceable bed is not apparent. It was doubtless a northeastward-trending vein, similar to many exposed on the north face of North Star Mountain. Fracturing due to movement along bedding planes is the most logical explanation for localization within the particular bed selected, but, as several beds in this part of the stratigraphic section have a more calcareous cement than the remainder of the quartzites, this chemical factor may also have influenced selection. As a barren interval nearly 20 feet long was cut along the ore horizon near the portal of the main adit level, it is conceivable that the barren zone in the ore horizon at the breast may lead to another ore shoot farther southwest.

Where unoxidized, the ore in quartzite consists mainly of pyrite, greenish-gray sphalerite, quartz, dolomite, and irregular areas of unreplaced quartzite.

EL DORADO MINE

The El Dorado is a gold mine located on the south bank of Monte Cristo Creek, a quarter of a mile west of the Alma-Breckenridge highway. Remains of an old mill stand a few hundred feet north of the shaft and tunnel.

According to local reports the output of the El Dorado mine was somewhat greater than that of the Senator or the Arctic but less than that of the Ling and the Vanderbilt. All the ore was extracted from underground workings connected with the inclined shaft shown in figure 5. These workings now are under water. A newer tunnel driven a thousand feet through Cambrian quartzite into the underlying pre-Cambrian rocks did not disclose any ore. The geology of the tunnel is shown in figure 5.

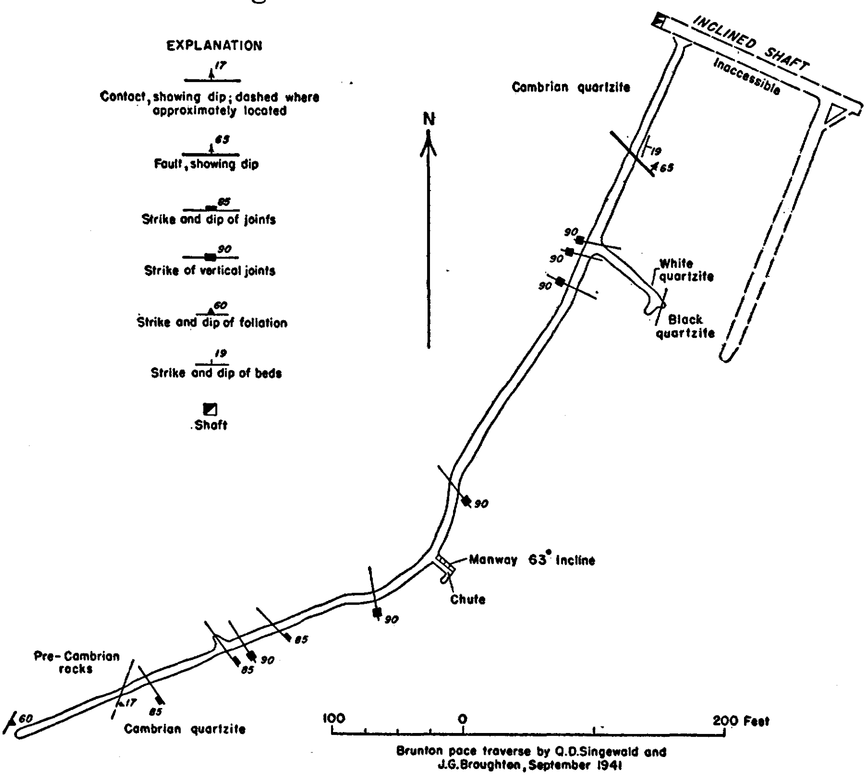


FIGURE 5.—Plan of El Dorado tunnel.

MONTE CRISTO MINE

The Monte Cristo mine, located on the north side of Monte Cristo Creek half a mile west of the Alma-Breckenridge highway, is accessible by truck. (See pl. 2.) The workings are mostly surface excavations, but several short adits extend a few feet underground. Only the foundation of the former Monte Cristo mill now remains.

The ore yielded mainly gold but, according to J. D. Galloway, was too low grade to be profitable, so there has been no substantial commercial output. Three samples from sulfide-rich material left at the mine were assayed by the London Gold Mining Co. and showed the following content of gold and silver: Gold 0.13 and silver 1 ounce per ton; gold 0.07 and silver 1.05 ounces per ton; and gold 0.31 and silver 1.40 ounces per ton.

Mine workings are on a dip slope of Dyer dolomite from which Pennsylvanian strata have barely been removed. The most important structural feature, apart from the prevailing easterly dip, is a fault trending N. 50°–55° E., the southeast side of which is downthrown a few feet. (See pl. 1.) Within the fault is a discontinuous fine-grained dark-colored dike.

Tremolite derived by hydrothermal alteration of Dyer dolomite forms coarse-grained masses within and adjacent to the fault and fine-grained layers or films conformable with bedding on the northwest side of the fault. Some of the bedded tremolite layers continue with progressively diminishing grain size for several hundred feet away from the fault.

The ore body lies southeast of the fault in greatly fractured ground where a principal set of fissures trending N. 45°–60° W. intersects a subordinate set trending N. 10°–20° W. Both sets are nearly vertical and show little or no displacement. A main ore channel about 75 feet wide strikes N. 55° W. and rakes about 20° SE. Mineralized ground extends in both directions from the main channel, however, to increasing distances as the bounding fault is approached, and so forms a triangular area approximately 500 feet on each side. Obviously, the ore was formed by replacement of the Dyer dolomite beneath impure Pennsylvanian shales, now eroded, where a highly broken but unfaulted area joined a northeastward-trending fault.

Hypogene (original) ore and gangue minerals reveal a local zonal pattern. Pyrite-rich specimens were found only at the western corner of the ore body, within and adjacent to the main fault. Away from the fault, the ore consists of galena, light greenish-gray sphalerite, minor chalcopyrite, and pyrite in a gangue of manganese-iron carbonate, unreplaced Dyer dolomite, and rare quartz; chalcopyrite decreases and sphalerite increases in abundance southeastward. A belt of jasperoid lies along the western margin.

Throughout the ore body black manganese stain and subordinate limonite coat exposed rock surfaces and occur as films along fractures, but they have penetrated into solid rock only to a minor extent. In spite of the widespread dark coloration the material cannot be considered manganese ore. Analyses by R. C. Wells of two samples across the main ore channel gave 15.9 and 16.0 percent of manganese, respectively.

BEMROSE MINE

The Bemrose shaft is situated close to the Alma-Breckenridge highway, half a mile north of Hoosier Pass. The shaft is 170 feet deep, with levels at the bottom and 110 feet below the surface. The short 170-foot level was not accessible, but the 110-foot level is shown in figure 6. A caved shaft leading to much older workings, about which no information is available, is located approximately 150 feet north of the present shaft.

Although primarily a source of gold ore, the mine has yielded iron ore, used as a flux in smelting. The aggregate value of output probably is not more than a few tens of thousands of dollars, but no records are available.

The mine is located in a zone of rocks having steep reverse dips that extends as a major longitudinal structural feature northward from Hoosier Pass. The wall rocks, except for a small mass of highly altered Lincoln porphyry located 230 feet northeast of the shaft, belong to the lower and middle divisions of the Pennsylvanian and Permian strata. Most important is a dolomite bed 9 to 15 feet thick, which on the surface can be traced almost continuously from Hoosier Pass to the mine. (See pl. 1.) This bed is the base of the middle division.

The Bemrose "vein" is actually a replacement deposit essentially conformable with the bedding. Throughout the northern part of the 110-foot level the vein and all its ore shoots occur at the base of the dolomite. Slickensides at numerous places indicate bedding-plane movement along the contact. Near the south end of the drift, as shown in figure 6, the vein cuts stratigraphically upward into the dolomite itself, and doubtless the fault does also.

A prominent zone of cross faulting was encountered some 230 feet northeast of the shaft. Geologic details in the fault zone cannot be observed, for heavy ground there required nearly solid timbering. Another less prominent zone at the end of the crosscut extending eastward from the shaft is likewise covered by timbers. Other cross fractures are mostly joint zones having little or no displacement. On the whole, the cross joints and minor faults are much more numerous within stoped areas than elsewhere; moreover, the vein itself is much more sinuous where productive than elsewhere. Only one stope was accessible. In it the ore shoot extended longitudinally along the in-

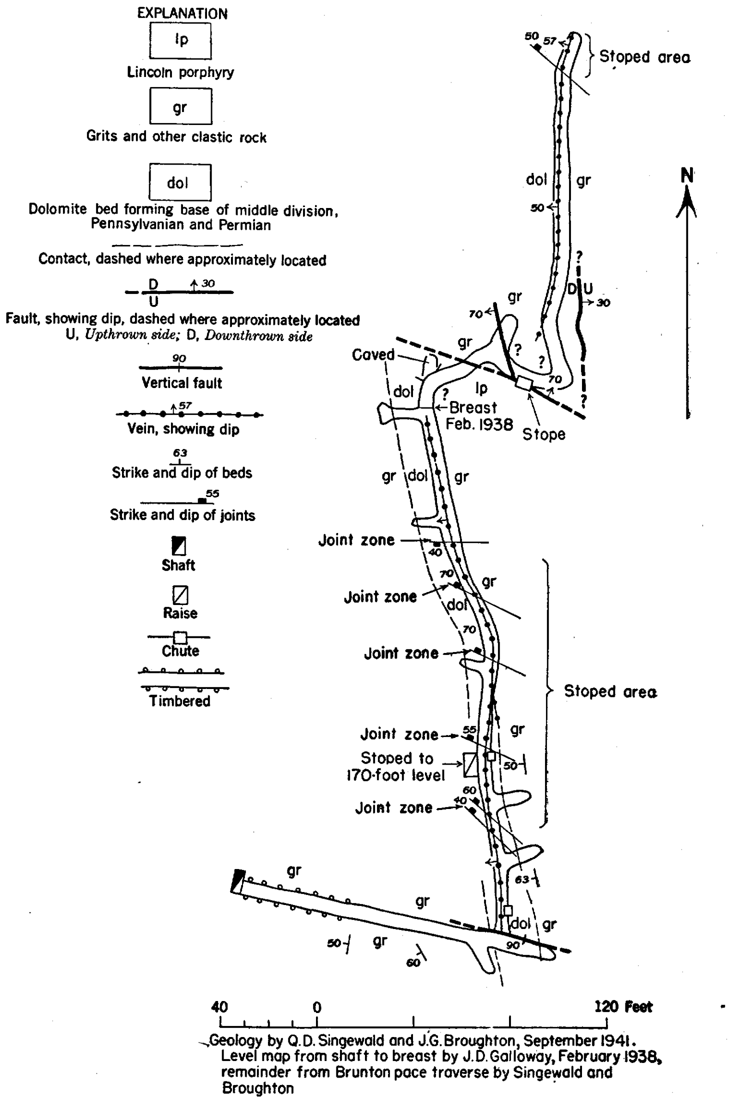


FIGURE 6.—Plan of 110-foot level, Bemrose shaft.

tersection of the vein with a very obscure fracture trending about N. 25° E. and dipping about 60° NE.

Although the vein is essentially continuous, the ore shoots are irregular kidney-shaped bodies containing several hundred pounds to several carloads each. No reason is yet apparent for thinking that ore shoots should not continue northward intermittently in the same dolomite bed.

The ore is a sulfide aggregate of pyrrhotite and pyrite with scant gangue of dolomite and quartz. At one place a small pocket of ore contained minor amounts of dark sphalerite and galena. Pyrrhotite and most of the pyrite are very fine grained. They occur both intergrown and in separate masses. Gold is associated with pyrite, for areas of massive pyrrhotite give very low assays. The greatest gold content, in general, occurs where the pyrite is coarse-grained, in more or less well-formed cubes, and associated with greater than average amounts of carbonate gangue. A pyrrhotite-rich specimen containing 56.44 percent of iron was analyzed for nickel by F. S. Grimaldi, of the United States Geological Survey, but none was present.

Smelter returns on two carloads of ore shipped during 1938 showed the following metal content.

Metal content of ore shipped from the Bemrose mine

	Weight (pounds)	Gold (ounces per ton)	Silver (ounces per ton)	Iron (percent)	Copper, lead, zinc
Car 1	36, 860	0. 85	0. 8	41	None
Car 2	30, 740	1. 34	. 5	46	None

ADIT LOCATED THREE-QUARTERS OF A MILE NORTH-NORTHEAST OF HOOSIER PASS

The geology of a 300-foot adit located 0.73 mile N. 35° W. of Hoosier Pass (see pl. 1) is shown in figure 7, in order to record an anomalous

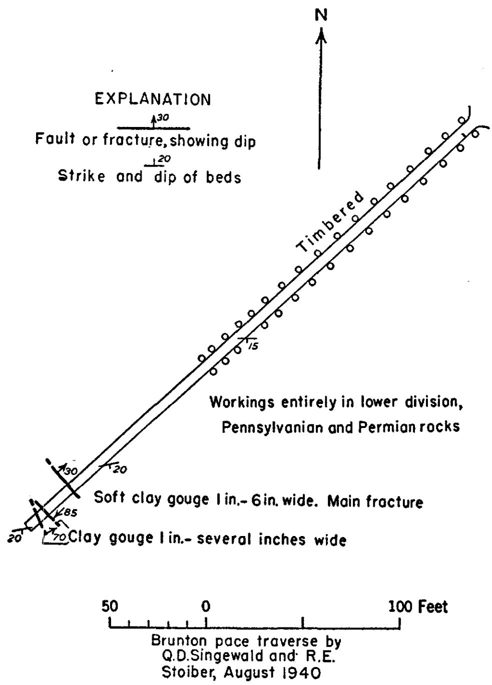


FIGURE 7.—Plan of adit located 0.73 mile N. 35° W. of U. S. L. M. Hoosier.

structural feature. The rocks consist entirely of beds belonging to the lower division of the Pennsylvanian and Permian strata. The chief feature of interest is the anomalous nearly due east strike of the beds. The areal extent of this structural feature cannot be determined, however, because outcrops for some distance from the adit are too poor. Several faults shown in figure 7 contain soft clay gouge, but none contain even traces of ore minerals.

McCULLOUGH, SPRUCE, AND CARTER GULCHES

BRIAR ROSE MINE

The Briar Rose is the northernmost productive mine within the western mineralized area. It is located (see pl. 2) at the head of Carter Gulch, close to the crest of the range. It is connected with Breckenridge by a wagon road, part of which may be traversed by trucks having extra-low gear.

The most important geologic feature in the vicinity of the mine is a large fault, which has displaced pre-Cambrian rocks on the west

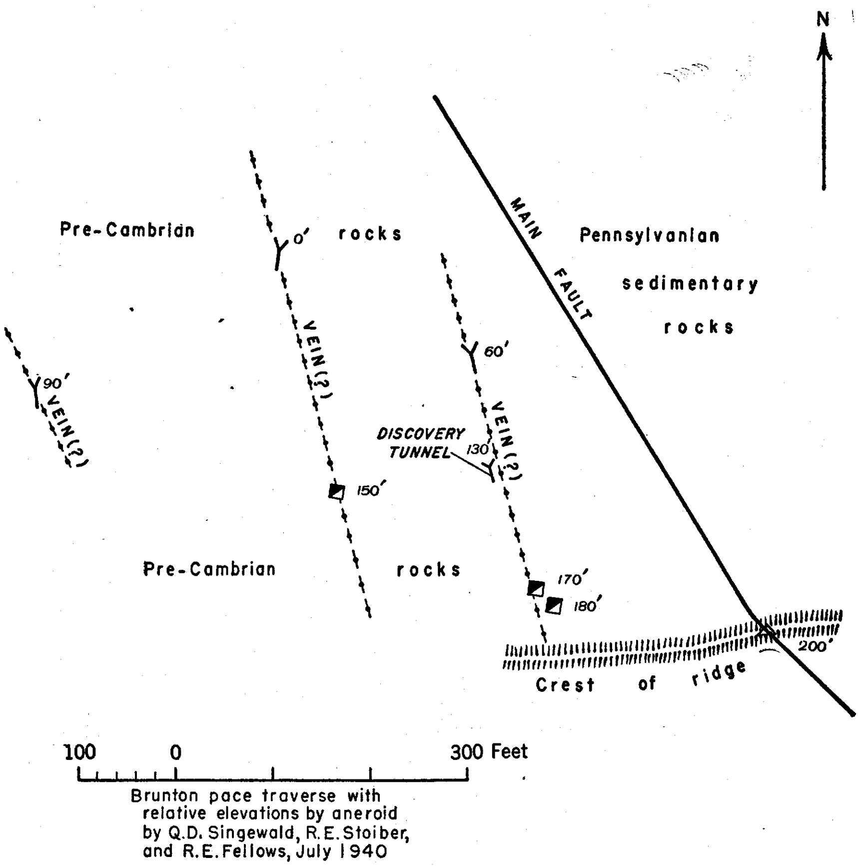


FIGURE 8.—Areal geology at Briar Rose mine.

against sedimentary strata on the east. The sedimentary strata are almost entirely clastic rocks belonging to the lower division of the Pennsylvanian and Permian strata, but there is a limestone bed in the fault where it crosses the divide between Carter Gulch and Crystal Creek. Furthermore, rocks uncertainly identified as Cambrian quartzite and shale of the Peerless formation crop out immediately beneath Pennsylvanian strata on the side of Carter Gulch. The pre-Cambrian rocks are typical quartz-mica gneiss and pegmatite.

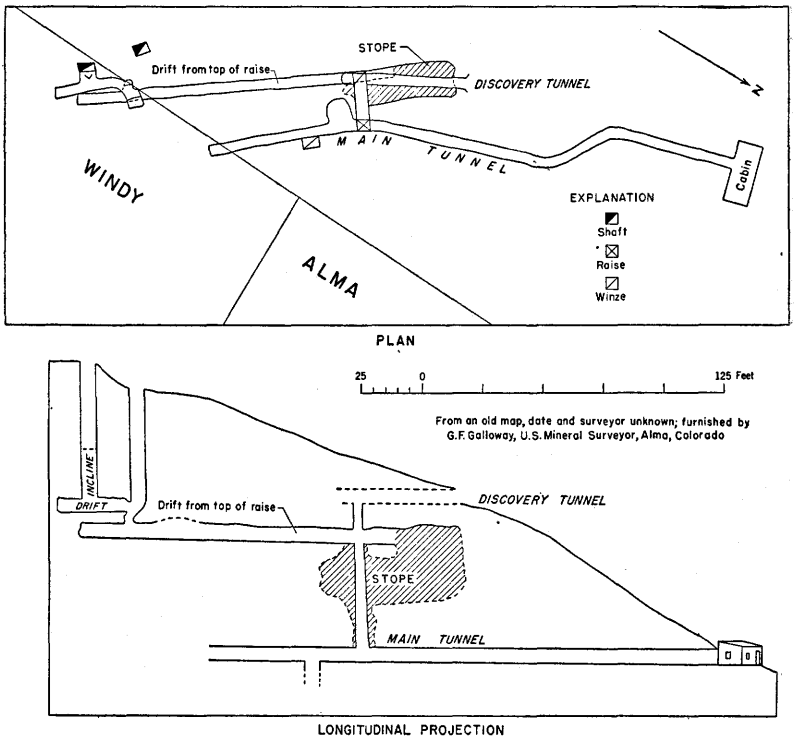


FIGURE 9.—Plan and section of the Briar Rose mine. Survey No. 7932.

None of the underground workings were accessible. Their locations with reference to one another and to the main fault are shown in figure 8, and some of the oldest workings are shown in the underground map, figure 9. From these two maps it is apparent that ore has been stoped along veins trending north-northwestward along minor faults auxiliary to the main Briar Rose fault. All prospecting has been in the pre-Cambrian rocks west of the main fault.

Specimens from several of the dumps contain quartz, galena, minor amounts of pyrite, copper stain, and very small amounts of barite. The ore was mined for silver. The quantity produced is not known, but, according to D. F. Miner of Breckenridge, its total value was not less than $10,000.

SOLITARY AND BIG BONANZA MINES

Close to the range crest, in the uppermost amphitheater of the north fork of Crystal Gulch, a tributary of Spruce Gulch, are several mine workings (see pl. 2) from which small quantities of rich silver ore have been shipped. Trails connect these workings with a group of cabins located at the main Crystal Lake, from which a wagon road extends down Crystal Gulch.

Except for fairly numerous porphyry dikes, the country rock is entirely pre-Cambrian. Veins consist of narrow fillings in fault fissures. The prevailing trend of the more continuous veins is north-northeast, at a small angle to the regional foliation. Adjacent to faults, nevertheless, the foliation commonly curves slightly and becomes nearly conformable with the fault. A less well defined set of veins trends northwestward.

At all localities the narrow veins consist mainly of coarse-grained quartz containing numerous vugs lined with quartz crystals. Sulfide minerals are moderately abundant; galena and light-colored sphalerite generally predominate, but pyrite and chalcopyrite are widespread. Barite is a fairly abundant constituent at one locality. (See pl. 2.)

The most extensive mine workings of upper Crystal Gulch constitute a group along the southwest shore of a small lake at an approximate altitude of 12,850 feet. They are shown in figure 10. The alinement of workings suggests the existence of two main veins, as indicated on the map.

LAST DOLLAR MINE

The Last Dollar claim is located in McCullough Gulch, 1¾ miles west of the Alma-Breckenridge highway at the terminus of a road passable by truck. The workings, consisting of two tunnels and a shaft, are mainly in gneiss, but they also cut local pegmatite masses and a dike of White porphyry. The veins contained gold and a few ounces per ton of silver. Plate 5 is a map of the mine workings.

The upper tunnel was driven about 150 feet along a sinuous, nearly vertical vein 1 to 3 feet thick, the average strike of which is approximately N. 10° W. A chimney-shaped ore shoot plunging about 70° was stoped in a 24-foot winze located 20 feet away from the breast and in a 70-foot raise at the breast. Approximately 20 feet above the tunnel level a nearly vertical branch from this chimney-shaped shoot was also stoped to the surface. Gross value of output probably amounted to $10,000. Visible minerals in the ore, in addition to those of the altered wall rock, are quartz, pyrite, moderately dark sphalerite, subordinate chalcopyrite, and rare tetrahedrite and galena. The ore was partly oxidized at the bottom of the stope.

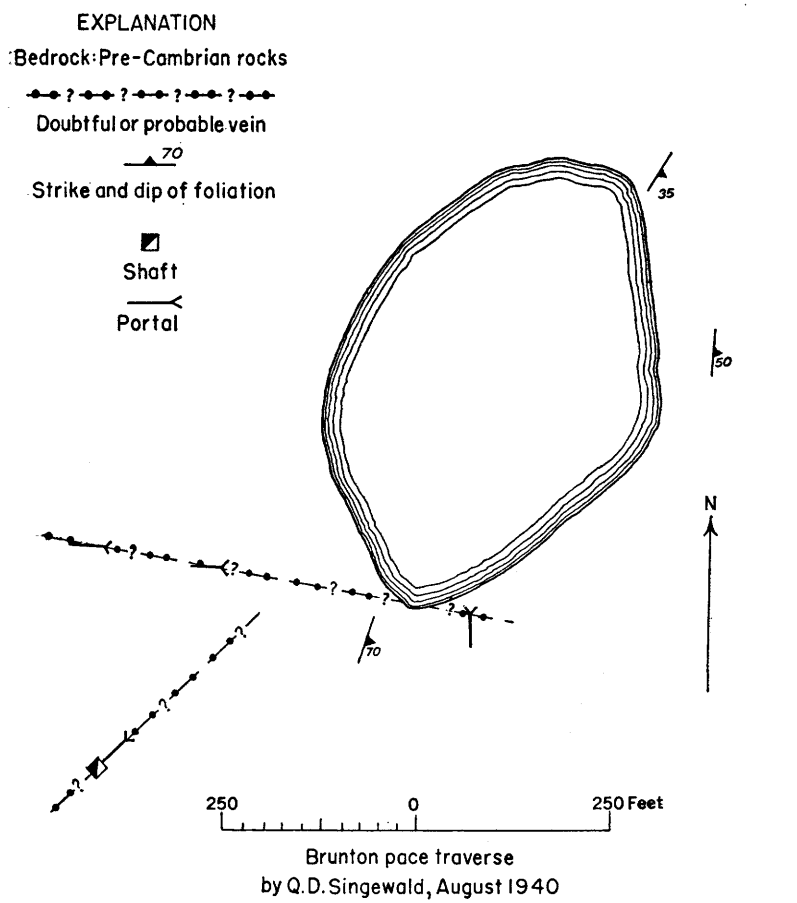


FIGURE 10.—Map of Solitary and Big Bonanza mines at upper lake in Crystal Gulch.

The shaft, now filled with water, was sunk along a vein trending N. 80° W. and dipping about 70° NE. At the surface rusty-brown limonite is interspersed in altered wall rock. Scarce specimens on the dump reveal quartz and pyrite with very small amounts of galena.

The lower tunnel has been driven to cut the surface veins at depth, but although several fissures contain pyrite no minable ore has yet been found. During 1940, five men were working. As shown on plate 5, the most prominent fissures cut by the tunnel form a closely spaced group that constitutes a shear zone containing considerable gouge. This zone trends about N. 40° W.

DIAMOND JACK MINE

The Diamond Jack mine is little more than a gold prospect located at an approximate altitude of 11,750 feet in the cliffs south of McCullough Gulch, 1¾ miles west of the Alma-Breckenridge highway. (See pl. 2.)

The lower adit, now caved, follows an east-northeastward-trending vein in wall rock of pre-Cambrian age, but it is located only a few feet from a sinuous dike of White porphyry. A second, less important, mineralized fissure crops out some 250 feet vertically uphill from the adit portal and follows the wall of an east-northeastward-trending dark-colored dike, which is probably of pre-Cambrian age. Some 600 feet vertically above the main adit is a small prospect adit on a north-northeastward-trending vein in pre-Cambrian rock, close to the same dike of White porphyry.

LITTLE FOOL PROPERTY

The Little Fool property, located on the north side of McCullough Gulch about a mile west of the Alma-Breckenridge road (see pl. 2), contains a cluster of small prospect adits, nearly all of which are in the lower part of the Cambrian quartzites. The adits follow quartz-pyrite veins along minor faults trending north-northwestward. Locally, carbonate and, more rarely, sulfides other than pyrite can be found. The veins contain small quantities of gold but have not yielded commercial amounts.

Figure 11 is a map of the largest of the workings in the upper of the two adits shown on plate 1. The best showing of ore was found

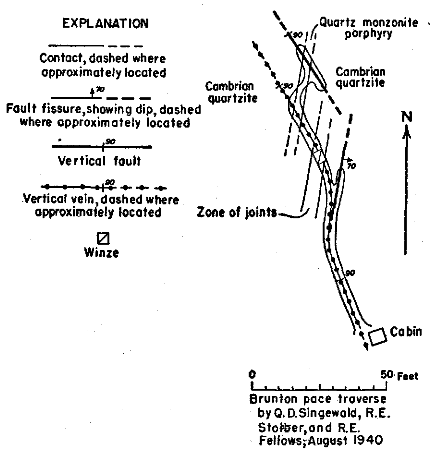


FIGURE 11.—Plan of upper adit at Little Fool property.

where a zone of north-northeastward-trending joints intersects the north-northwestward-trending vein. At this spot is a shallow winze.

A tenth of a mile southeast of the main adit is the site of development during 1941, where an adit and winze follow a nearly vertical vein striking N. 25° W. Quartzite wall rock strikes N. 5° E. and dips 25° SE. The vein, only a few inches thick, contains quartz and pyrite.

GOVERNOR MINE

The Governor mine is 5 miles south of Breckenridge, adjacent to the Alma-Breckenridge highway. Production records are incomplete. According to Galloway (1941), records show sales of $23,686.09 worth of ores and concentrates to the Denver Public Sampling Works; additional output for which no record exists may be valued at as much as $75,000. Silver is the only metal for which payment was made, but assays indicate considerable quantities of lead and zinc. Seventeen assays made in 1926 and 1928 from samples collected by Galloway showed a trace to 190 ounces of silver per ton and 0.7 to 15.5 percent of lead. Zinc was determined only in the richest sample, in which it amounted to 18 percent.

The mine lies within a zone of reverse dips that extends northward from Hoosier Pass to form one of the major longitudinal structural features of the district. Strike and dip of the strata in the main tunnel and in a prospect adit to the northwest are shown in figure 12. Sedimentary strata near the contact between the lower and middle divisions of the Pennsylvanian and Permian strata constitutes the prevailing country rock; they have been intruded by at least one sill of Lincoln porphyry, as shown in figure 12.

The caved ground shown in figure 12 occurs at a major fault trending transverse to the tunnel. The Governor vein, exposed about 260 feet from the portal according to Galloway (1941), strikes N. 10° E., dips 65° NW., and ranges in width from 5 to 16 feet. According to Mr. Kaiser, of Breckenridge, Colo., a drift extends about S. 30° W. for 530 feet along the vein to connect with an adit whose portal is 500 feet south of the mill. A stope 40 feet long and 80 feet high was mined immediately north of the main tunnel, and minor workings were reached at depths of 45 and 100 feet, respectively, through winzes on the tunnel level.

According to Galloway, vein showings occur in the main tunnel 60 feet east of the Governor vein and in a caved shaft on the steep slope west of the mine. Assays of ore from the latter revealed gold.

Ore specimens found at the mill, presumably from the main ore body along the Governor vein, show massive dolomite fractured and then cemented by a mixture of ferruginous carbonate and quartz, all of which are in turn impregnated, veined, and replaced by sulfide minerals and late carbonate. The sulfide minerals are galena and light-gray sphalerite, with minor amounts of chalcopyrite and pyrite.

The dolomite probably is the basal bed of the middle division of the Pennsylvanian and Permian strata, the same as the ore bed at the Bemrose mine. Information is not available to determine whether the "vein" follows a bedding-plane fault essentially conformable with the dolomite bed as at the Bemrose, or whether it cuts the strata

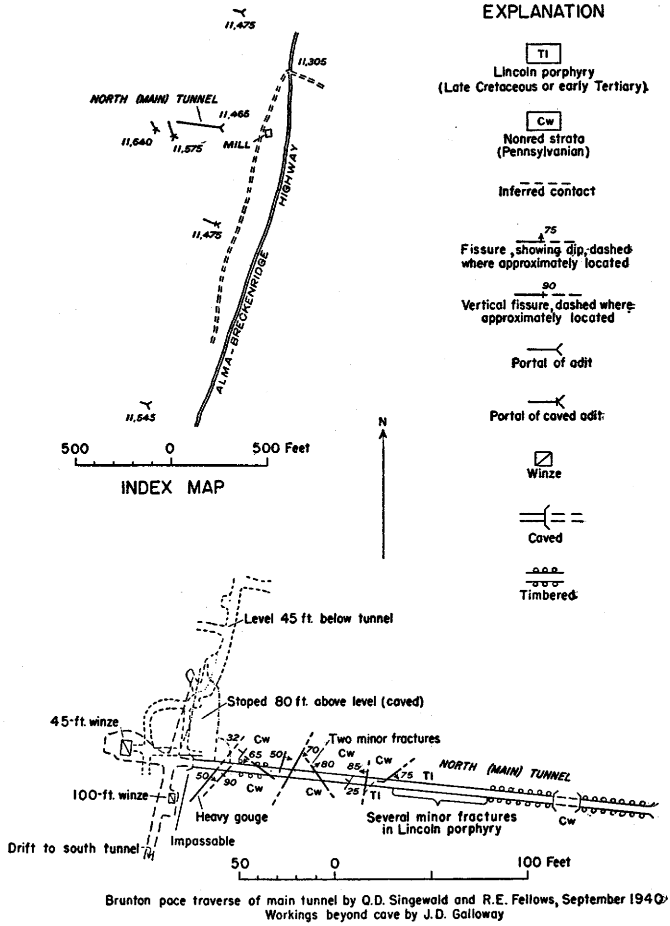


FIGURE 12.—Plan of north (main) tunnel of Governor mine.

at an oblique angle and is replaced by an ore shoot at its intersection with the dolomite. Whatever its structural relations, the dolomite bed where intersected by faults would seem, in the absence of definite information about ore occurrence in the Governor mine, to offer the best chances for success in future prospecting.

EAST SIDE OF BLUE RIVER VALLEY

FREDONIA MINE

Location, output, and character of ore.—The Fredonia mine is located approximately at timber line on the east side of the Blue River, 5 miles north of Breckenridge. A tortuous one-way automobile road connects the mine with the Alma-Breckenridge highway. Plates 1 and 2 show the general location of the mine, and plate 6 shows its underground workings.

Smelter returns furnished by D. F. Miner of Breckenridge, Colo., show a net value of output amounting to nearly $5,000 from 1938 to 1941, inclusive. Earlier records are not available, but the aggregate value of output has probably exceeded $25,000. All the ore has been mined for silver, but it contains both lead and zinc. Records of shipments from 1938 to 1941 indicate the following content of metals.

Metal content of ore shipped from the Fredonia mine

Date	Weight (pounds)	Settlement assay					
		Gold (ounces per ton)	Silver (ounces per ton)	Lead (percent)	Copper (percent)	Iron (percent)	Zinc (percent)
Sept. 23, 1938	109, 820	0	47. 4	3. 1	0. 0	2. 7	2. 6
Nov. 12, 1938	130, 480	0	47. 1	2. 6	. 0	3. 1	2. 5
June 7, 1939	103, 120	0	45. 15	2. 95	. 0	3. 25	2. 7
Oct. 29, 1940	52, 600	0	34. 25	2. 1	. 1	4. 1	2. 0
Do	22, 940	0	87. 7	5. 0	1. 15	4. 6	4. 6
Mar. 3, 1941	60, 380	0	28. 1	1. 8	. 0	3. 4	2. 6
Do	59, 120	0	27. 2	1. 7	. 0	2. 7	2. 7
June 11, 1941	79, 380	0	28. 75	1. 75	. 0	4. 75	. 6
June 21, 1941	80, 300	0	34. 6	2. 0	. 0	3. 2	1. 8

Typical high-grade ore in the Fredonia mine consists of vuggy jasperoid encrusted and permeated with green silver-chloride stain and minor amounts of limonite. According to D. F. Miner, as the amount of green stain becomes less, tenor decreases. Sulfide minerals, which are scarce, include relict cubes or small aggregates of galena and aggregates of light-colored resinous sphalerite. Only one grain of chalcopyrite could be found in all available specimens.

Geologic setting.—The areal geology in the general vicinity of the mine is depicted on plate 1, though a dearth of exposures near the mine itself makes some of the relations uncertain. Cropping out are Pennsylvanian and Permian strata and intrusive porphyries of Cretaceous or Tertiary age. The sedimentary rocks include the usual clastic types, ranging from pure shale to coarse conglomerate, with which are intercalated several beds of limestone. The part of the series that is cut by the mine workings is close to the bottom of the prevailingly red rocks, about a thousand feet above the base of the middle division.

The stratigraphic positions of the limestone beds are of paramount economic importance in the Fredonia mine. Relations are best observed on cliffs about half a mile north of the mine, where the principal limestone bed is about 50 feet thick. Three other limestone beds, each thinner and less persistent along the outcrop, occur at stratigraphic distances of approximately 110, 150, and 200 feet beneath the main bed; still another limestone bed, the thinnest and least persistent of all, lies 20 feet above the main bed. The one 110 feet beneath the main bed is the most persistent of the four minor limestones. As limestone on the west face of Red Mountain may be seen to grade laterally into green shale, and vice versa, it is impossible in the absence of outcrops to know whether all five beds are present in the immediate vicinity of the Fredonia mine or to predict the thickness of any bed. Lithologically, all the beds are similar.

All three types of porphyry—monzonite, quartz monzonite, and the Lincoln—crop out as sills, dikes, and irregular crosscutting bodies within a radius of half a mile from the mine. The largest are shown on plate 1.

Faulting probably has taken place along most of the crosscutting igneous contacts, both prior to and subsequent to intrusion, but the scarcity of exposures makes structural interpretation difficult. Unquestionably, a large block of ground extending from a point half a mile south of the mine to a mile north of it has been extensively faulted and intruded. The abundance of fissures permitted hot solutions to ascend subsequent to igneous intrusion. Evidence of slight contact metamorphism, shown by the presence of epidote, chlorite, and specularite in redbeds, appears in the cliffs several hundred feet above the mine, thus suggesting a minor local center of mineralization.

Rocks cut by mine workings.—Three types of rock were distinguished in underground mapping; their distribution along the adits is shown on plate 6. Limestone, because of its economic importance, has been distinguished from the other sedimentary rocks. Pre-ore alteration converted nearly all the limestone to jasperoid and the remainder to dolomite. The jasperoid is an aggregate of microscopic quartz grains. It ranges from dark gray to medium brownish gray in color and from nearly massive to extremely porous in texture. Early dark and massive jasperoid is extensively and irregularly veined by light-colored and coarser-grained chalcedony and quartz and contains vugs lined with quartz crystals as much as a quarter of an inch in length. Unsilicified parts of the original limestone have been changed to medium-grained brownish-gray dolomite.

Rocks designated "grits" and other clastic rocks shown on plate 6 range from pure shale to coarse conglomerate. Sandstone and conglomerate containing rather angular quartz grains predominate. Though locally mineralized, the clastic rocks do not contain ore.

Monzonite porphyry, cut in adits 3 and 4, is the only igneous rock exposed underground. Where least altered, it has a light greenish-gray groundmass enclosing profuse small and medium-sized phenocrysts of sericitized feldspar and chloritized biotite and hornblende. Adjacent to the ore this rock has been thoroughly bleached to a yellowish-white mass in which outlines of numerous phenocrysts are still visible. The monzonite porphyry has been mineralized at many places, but it has not yielded any ore.

The monzonite contact mapped on levels 3 and 4 forms the northeast wall of a fault, which has been regarded by the mine operators as a faulted dike contact. Nowhere has the northeast wall of the supposed dike been encountered, however, so its form is not actually known.

Geologic structure.—The attitude of the sedimentary rocks is remarkably constant throughout the mine. The prevailing strike is N. 15° W. but ranges from N. 15° to 20° W. Only adjacent to faults was any variation observed. The prevailing dip ranges from 25° to 28° SE. and averages about 26°.

The fault pattern reveals two intersecting sets of fissures. One set strikes N. 10°–48° W., and most of its members dip steeply to the southwest. The other set strikes N. 10°–78° E., and all but two of its members are either vertical or dip steeply to the northwest.

The most persistent fissure of the northwestward-trending, or longitudinal set, is the one between monzonite porphyry and sedimentary rock in adits 3 and 4. Its average strike is N. 31° W., and its dip ranges from 70° SW. to vertical. The next most prominent, in adit 5, has an average strike of N. 36° W. and a dip of 85° SW. to 85° NE. A few other longitudinal fissures exposed in the mine workings are relatively nonpersistent.

Fissures of the northeastward-trending set are abundant. Though the extreme range in strike is large, distribution by frequency reveals that the prevailing range is restricted to N. 28°–40° E., as may be seen from the following:

Strike	*Number of fissures in mine*
N. 1°–27° E	3
N. 28°–40° E	17
N. 41°–60° E	9
N. 61°–78° E	5

The longitudinal fissures in general are crushed zones, not more than 2 feet wide, and contain considerable gouge within the fault zone. The northeasterly set contains little or no gouge. The former, therefore, may be interpreted as planes of shear, the latter as tension fractures. Displacement along a longitudinal fault can be measured at only one place, in adit 5, where the southwest wall, which at that place is the hanging wall, has moved relatively upward about 10 feet. Most of the northeastward-trending fissures show little or no displacement, but on level 3 one having a throw of nearly 15 feet is exposed. Most of the northeastward-trending fissures cut those of northwesterly trend; lack of apparent displacement on the latter may be due to the nearly vertical dips of the adjoining strata.

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Ore bodies.—Ore bodies are restricted to the limestone beds and have highly irregular outlines characteristic of bedded replacement deposits. Stopes are closely associated with, and elongated parallel to, some of the northeastward-trending fissures; in addition, all known ore lies within 150 feet of the principal northwestward-trending fissure exposed along adits 3 and 4.

Geologic relations of the known ore bodies suggest that shattered ground within and adjacent to the open and relatively gouge-free fissures of the northeasterly set provided permeable areas for the circulation of ore-forming solutions. The most favorable place for ore deposition was at the juncture of closely spaced northeasterly fissures with a prominent northwesterly fault. With increase either in distance between northeasterly fissures or in distance from the longitudinal fault, ore deposition in general became less intense, though of course local factors modified the intensity to some extent. It seems probable that widespread silicification and dolomitization preceded deposition of the hypogene ore minerals, so the ore is not strictly a replacement of limestone but rather of material deposited in porous jasperoid in places where the jasperoid had been fractured by longitudinal and transverse fissures. Oxidation processes within the zone of weathering undoubtedly caused enrichment of the original ore.

DERILLA AND HUNTER BOY WORKINGS

The Derilla and Hunter Boy, together with several other small adits that now are caved, constitute the southernmost group of prospects along the east side of the Blue River. They lie opposite the Governor mine, between McCullough Gulch and Monte Cristo Creek (see pl. 2), and are connected by trail with the Alma-Breckenridge highway. Small quantities of silver ore are said to have been shipped from the Hunter Boy.

The geology of the three accessible adits is shown in figure 13. The Hunter Boy lies entirely within yet close to the contact of a huge body of Lincoln porphyry, whereas the Derilla adits are in the underlying monzonite porphyry and sedimentary strata belonging to the lower part of the middle division of the Pennsylvanian and Permian strata. Minor faults are abundant; the most prominent trend approximately north-northeastward and are intersected by a set trending northwestward. Figure 13 indicates that the prevailing strike of each set is slightly more northerly in the Lincoln porphyry than in the rocks beneath. Surface exposures near the mine workings are not good enough to disclose the prevailing dip with any certainty, but it probably is at a small angle to the northeast. A northwest dip at the Derilla No. 2, nevertheless, suggests that the eastern border of the regional belt of reverse dip that trends northward from Hoosier Pass is close by.

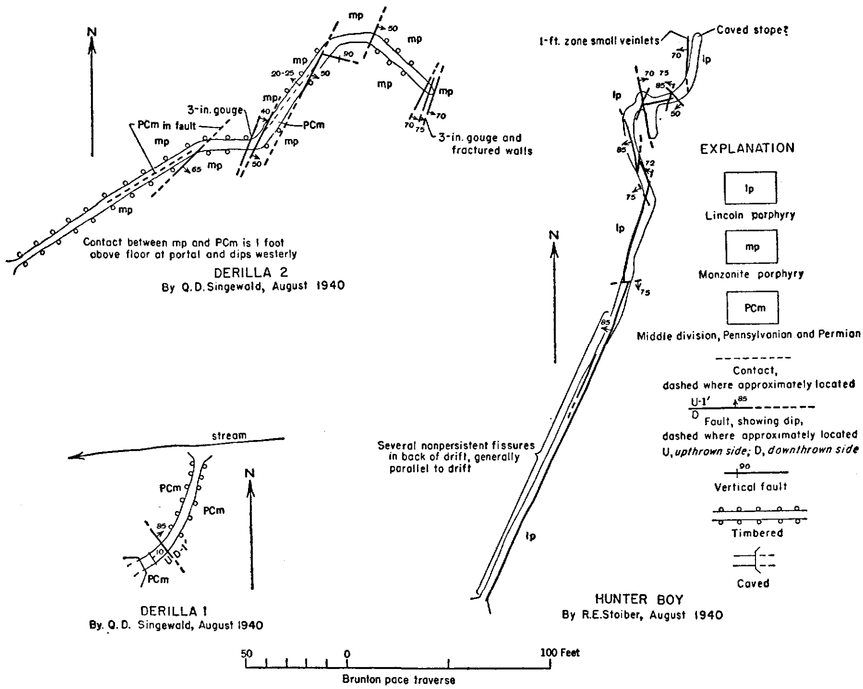


Figure 13.—Plan of Derilla and Hunter Boy workings.

Prospecting has been confined to veins of oxidized material within the minor faults, of which some are reported to contain gold greatly in excess of silver. If so, the area does not fit into the general zonal pattern for the remainder of the district, unless the process of oxidation has resulted in considerable enrichment of gold by elimination of other metals.

INDIANA GULCH

WARRIOR'S MARK MINE

The Warrior's Mark mine is located at the head of Indiana Gulch, between the east and west forks of Indiana Creek, 7 miles southeast of Breckenridge. A wagon road, passable for trucks in 1941, connects the mine with the Alma-Breckenridge highway. The mining property includes 14 claims, which are peppered with prospect pits, shafts, and adits. No underground workings were accessible in 1940 and 1941, but information gleaned through surface study by the writer has been supplemented by data from a private report prepared by Berger and Sayre (1923) and by information furnished by George Robinson, of Breckenridge, Colo. The principal mine workings and their geologic features are shown on plate 7.

According to Berger and Sayre, the Warrior's Mark mine was discovered in the late seventies, and within "a short period * * * ninety or one hundred thousand dollars worth of * * * unusually rich silver ore * * * [was] taken out right at the surface * * * from an open cut still to be seen." (See pl. 7.) The mine "has made an intermittent production for many years," but "the examining engineers had no opportunity of obtaining reliable statistics." According to Robinson the aggregate value of output has amounted to several hundred thousand dollars.

Rocks cropping out in the vicinity of the mine include the uppermost of the Pennsylvanian and Permian strata, the Entrada (?) sandstone, the Morrison formation, the Dakota quartzite, the Benton shale, the White porphyry, and the monzonite porphyry. All the sedimentary strata strike N. 20°–25° W. and dip 30°–40° NE. In general the dip gradually steepens northeastward. The White porphyry, shown on plates 1 and 7, forms a series of lenses conformable with the stratification. Whether the outcrops represent one lenticular sill that is offset in several places by faults or several sills occurring at different stratigraphic horizons cannot be determined. The body of monzonite porphyry may be a dike.

The general structural setting is obvious from plate 1. The mine is located in thoroughly fractured ground very close to the southwestern termination of the largest transverse fault that anywhere cuts the longitudinal Boreas Pass fault. These two large faults presumably controlled the general migration of ore-forming fluids. Detailed structure at the mine is shown on plate 7 as accurately as can be mapped from surface study alone. The principal veins follow minor faults striking northeast, nearly parallel with the main transverse fault, and dipping northwest. Prospects are too abundant to determine which ones are alined along the same fissure, so numerous minor faults that undoubtedly exist, cannot be shown on the map. It is highly probable that the productive area is cut by two conjugate sets of fissures, the main set trending northeastward, the subordinate set northwestward.

The productive ore mined has been confined to a relatively narrow stratigraphic zone, located about a thousand feet below the base of the Entrada (?) sandstone. This zone includes several thin impure limestone beds and also the sill of White porphyry. According to Berger and Sayre, "The vein filling on the Warrior's Mark consists of calcite, brecciated sandstone cemented by calcite, and, in subordinate quantities, quartz." In general there are three types of ore—"chalcocite accompanied by secondary copper minerals and carrying high silver values," silver-lead ore in a quartz-calcite gangue, and silver-bearing clay gouge. The first type occurs only as "small seams through the red sandstone." The Columbine vein "has every surface indication of strength and values comparable to the Warrior's Mark but without the enriched network of stringers which resulted in the open cut on the latter vein." A few specimens on the dump of the Shaffer tunnel consist of partly oxidized low-grade material revealing galena, pinkish carbonate, barite, late white carbonate, limonite, malachite, cerussite, and quartz. According to George Robinson, native silver was a prominent constituent of all the high-grade ore, and antimony-bearing minerals have been found. Thus, all available information strongly suggests that the output has been entirely from ore enriched by supergene processes in the zone of weathering but that the leaner hypogene (original) ore at depth has not been adequately tested.

Subsequent to surface mining in the open cut, the Warrior's Mark shaft was sunk 90 feet vertically and then 470 feet inclined along a vein dipping steeply to the northwest. Berger and Sayre state that the 65-foot level

> is supposed to extend 50 feet to the southwest and 35 feet to the northeast but was caved in both directions. * * * On the northeast side a sample of soft material 6 inches wide ran 343.8 ounces silver and a paying amount of copper. * * * A grab sample of * * * ore caved into the level [southwest of the shaft] * * * ran 14.90 ounces silver and pay copper. Above the cave a streak at the back 4 inches wide ran 453.50 ounces silver. This was the extent of underground sampling possible in the Warrior's Mark.

Berger and Sayre also state that the Shaffer tunnel "is connected with the old Snow Drift workings, which show but little ore." According to George Robinson, the 165-foot level from the Warrior's Mark shaft supplied much ore, some of it from under the open cut.

SEVEN-THIRTY MINE

The Seven-Thirty mine is located on the steep eastern face of Bald Mountain, 7 miles southeast of Breckenridge. Ore was transported by aerial tramway to a station on the Colorado and Southern narrow gage railroad. The tramway has collapsed, and the railroad was abandoned in 1938.

The location of several cabins, partly collapsed, at the head of the former aerial tramway are shown approximately on the 12,250-foot contour of plate 1. An adit driven from the southernmost cabin did not expose a vein. In a ravine northeast of the cabins, and at higher altitudes, are five adits along the Seven-Thirty vein, all of which disclosed ore. Figure 14 is a map of the Seven-Thirty workings made by H. J. Jay, Jr., deceased, and furnished by George Robinson. The Evans adit is the lowermost and the Welch adit the uppermost of the five adits shown along the Seven-Thirty vein on plate 2. One

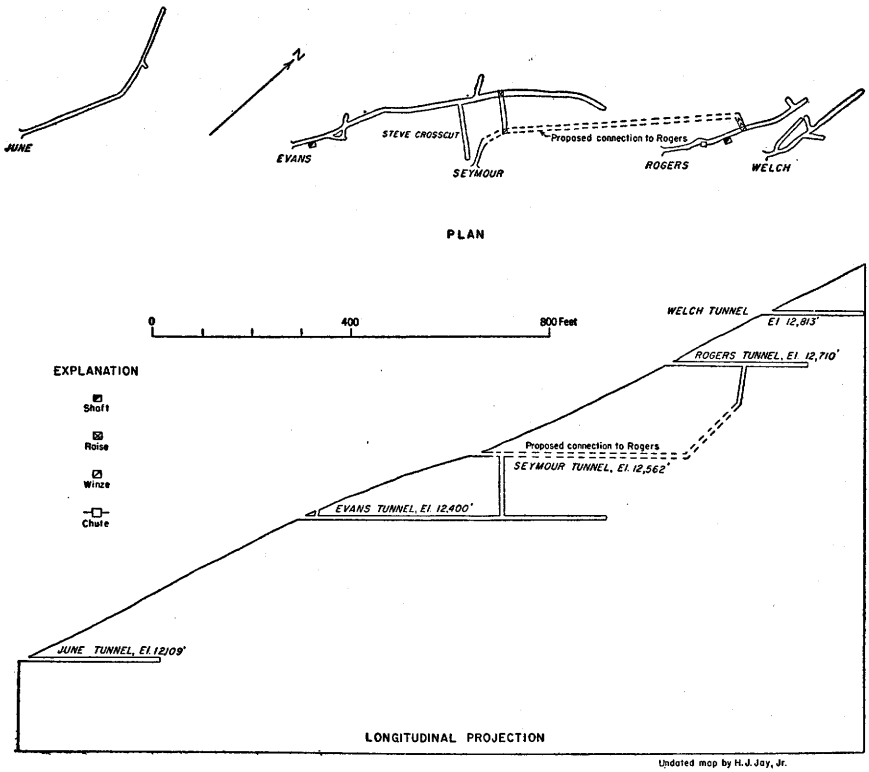


FIGURE 14.—Plan and section of part of Seven-Thirty mine.

adit now located between the Seymour and Rogers adits apparently had not been driven when Jay mapped the mine. The June adit of Jay's map did not disclose any ore and is not plotted on plates 1 or 2.

Shipments from the Seven-Thirty mine, according to George Robinson, were mainly of lead ore, and their aggregate value amounted to about $60,000. As shown on plate 1, the vein is either in or closely associated with a large fault transverse to the Boreas Pass major longitudinal fault. The Seven-Thirty fault probably continues more than a mile southwestward to the Warrior's Mark properties. It displaces all the sedimentary strata and the huge mass of monzonite porphyry capping Bald Mountain; however, discordance in the thicknesses of alternating layers of porphyry and sedimentary strata on opposite sides of the fault prove that the fault already existed when the porphyry was intruded. The seemingly anomalous displacement in some places up and in others down, along each side of the fault can be explained by a relatively large horizontal component of movement, with the north side displaced eastward relative to the south side. Mine workings cut monzonite porphyry and strata of the Morrison formation that are extensively contact-metamorphosed by the porphyry. Downhill from the mine are redbeds of the Pennsylvanian and Permian strata cut by the June adit.

Berger and Sayre (1923) state:

The lower Rogers tunnel * * * is caved * * * but the size of dump shows that it must extend several hundred feet. Undoubtedly in former operations the ore was sorted as carefully as possible and the high-grade picked out for shipment. Surface float from this point showing quartz, galena, limonite, and altered porphyry went gold 0.16 ounce, silver 4.92 ounces, and lead 8.75 percent. * * * The upper Welch tunnel is said to be two or three hundred feet long but is only accessible for the first 50 feet. Here, representative samples of the best ore on the dump ran gold 0.18 ounce, silver 18.16 ounces, and lead 55.80 percent, or a total value of around $55 a ton. In the tunnel there is only one place where the main vein is accessible on account of close timbering. About 15 feet from the mouth a streak 8 to 10 inches wide and exposed for 5 or 6 feet in length ran gold 0.08 ounce, silver 17.82 ounces, and lead 34.40 percent, or approximately $40 a ton. Much of the float occurs in pieces which would indicate a vein several feet wide so that the width of the samples taken from the upper tunnels would not seem a fair representation of the average mining width. Many of the boulders of float consisting of nearly pure lead and lead carbonate are so big that a man could not lift them. Above the upper Welch tunnel several open cuts and pits show ore continuing up towards the ridge, although the surface is soon covered with deep wash which gives no indication of the upper limit of the ore shoot. The 30-foot shaft [Gold shaft] in porphyry near the middle of the Silver Queen claim is the next opening below the vein. Here again the dump is filled with honeycomb float, but apparently the character of the ore has changed largely to an auriferous pyrite. A sample of this float ran gold 2.60 ounces, silver 1.90 ounces, lead 1.25 percent, or a value of $52 a ton in gold. Another sample went gold 0.44 ounce, silver 1.06 ounces, that showed very little value.

The lower Rogers tunnel was cleaned out a year or two ago by Sauers, the present superintendent, and he states that the ore averages $110 a ton in gold, silver, and lead.

Regarding the ore, Berger and Sayre state that the "values are almost entirely in argentiferous galena" in a gangue of quartz and subordinate calcite. Zinc is absent.

TWIN SISTERS MINE

The Twin Sisters is a lead mine that, according to George Robinson, has produced some $10,000 to $20,000 worth of ore. The property is near the head of Baker Gulch, on the south side of the ravine, 4 miles southeast of Breckenridge, and is accessible over a truck road that in part follows the old Colorado and Southern Railway bed. Two adits, shown in figure 15, constitute the mine workings. They are in the northeast wall of the Boreas Pass fault (see pl. 1) where redbeds, mainly fine-grained sandy strata, in the upper part of the upper division of the Pennsylvanian and Permian strata dip to the southwest.

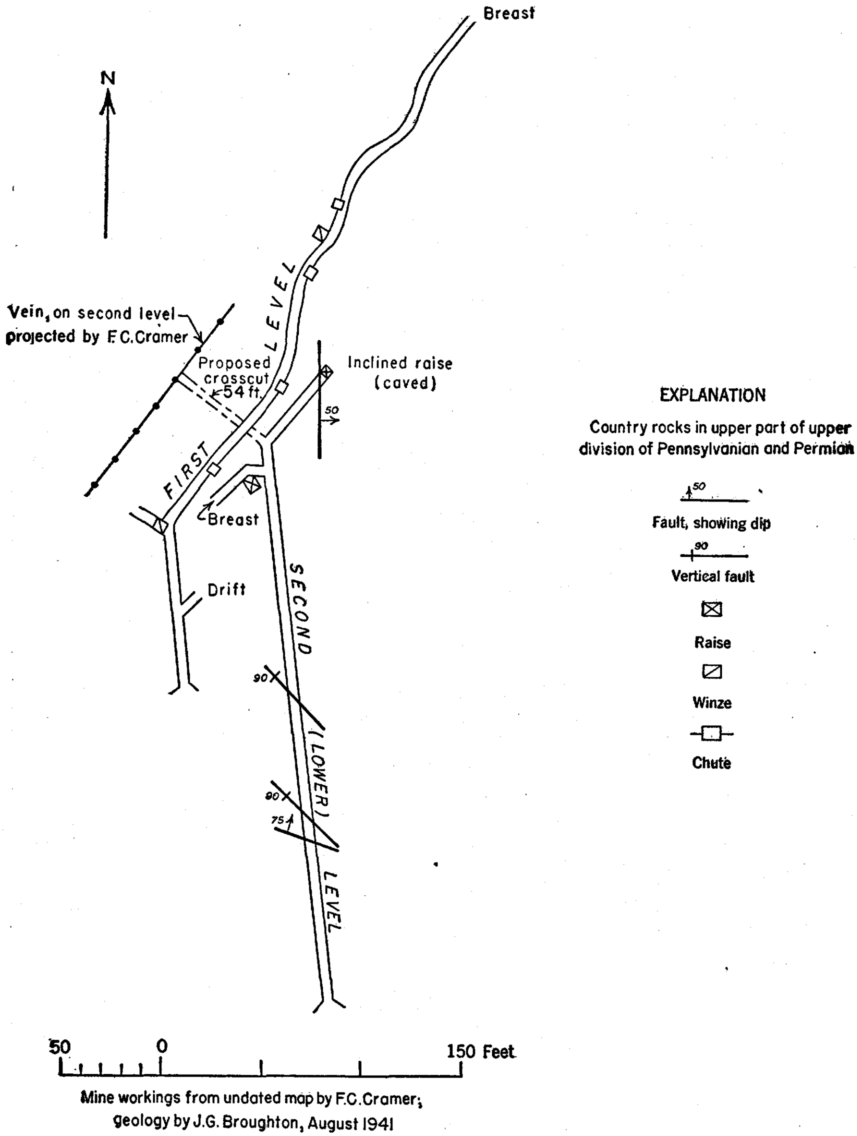


FIGURE 15.—Plan of Twin Sisters mine.

The upper adit, from which all the ore was mined, was not accessible in 1941. The mine map, however, indicates that a vein was cut 80 feet from the portal and followed from there to the breast. The average strike of the vein is N. 30° E., and the dip is about 60° NW. Presumably, the vein follows a transverse fault auxiliary to the Boreas Pass fault. The mine map indicates that stoping extended only about 200 feet along the vein.

The lower adit, as shown in figure 15, cut minor faults but revealed no vein.

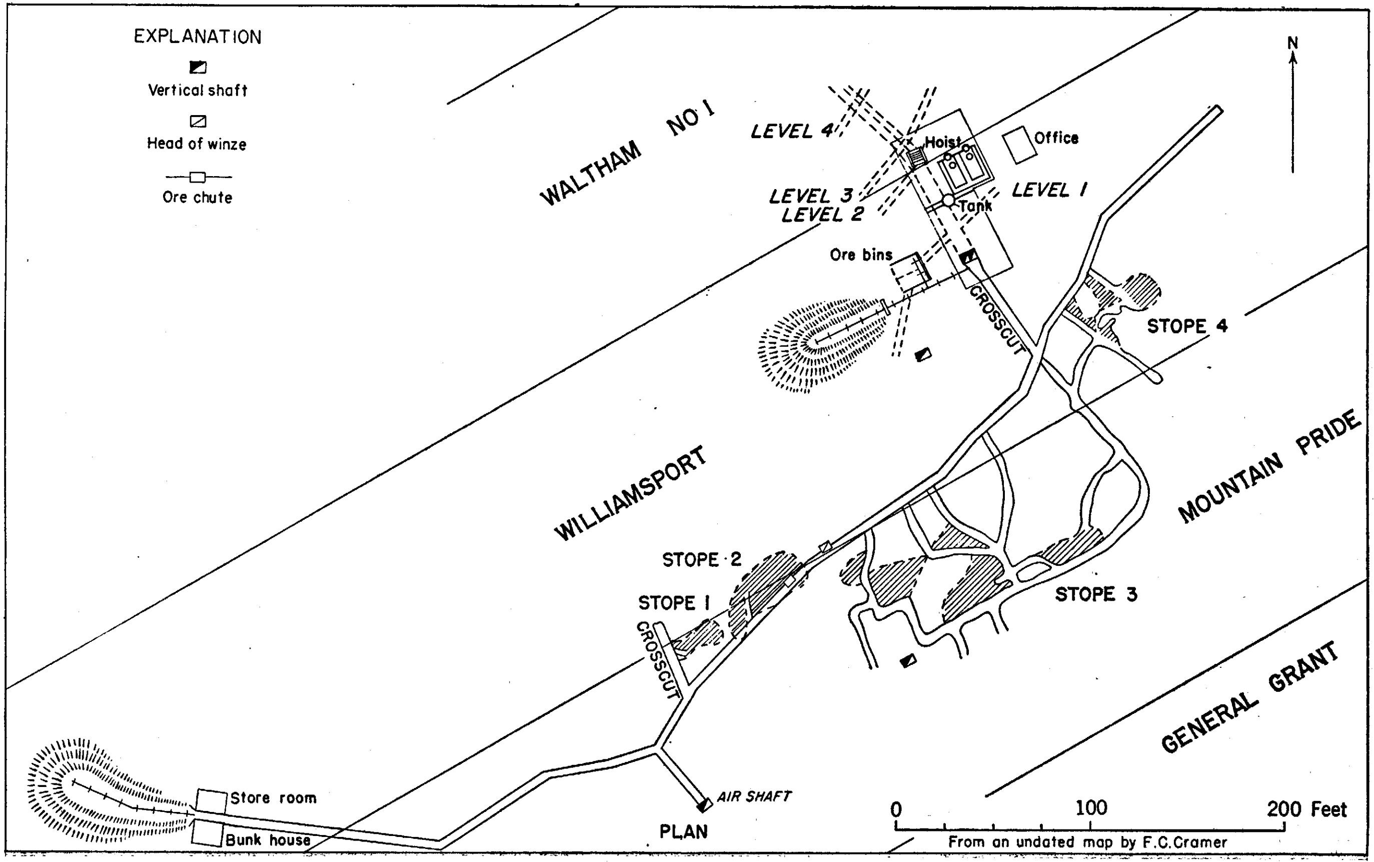
A few specimens found on the upper dump reveal pyrite, fine-grained quartz, galena, light-brown and resinous sphalerite, specularite, white carbonate, and limonite. These minerals occur as films, veinlets, and narrow veins transecting bleached sandstone and conglomerate. A porous mixture of pyrite and quartz is most abundant. Many pyrite grains are incomplete cubes. Specularite tends to form narrow veinlets along the margins of quartz-pyrite veinlets. Galena and sphalerite reveal no particular tendency to be associated either with each other or with pyrite but tend rather to form independent stringers and narrow veinlets.

MOUNTAIN PRIDE MINE

The Mountain Pride mine is located at the head of Illinois Gulch, about 3 miles southeast of Breckenridge. It is connected with the Breckenridge-Dillon highway by an automobile road by way of French Gulch. The mine lies outside the area shown on plate 1 but is briefly discussed in this report because it is not described in either Ransome's or Lovering's report on the Breckenridge district and because a map of the underground workings has become available.

According to George Robinson, aggregate output amounts to nearly a million dollars' worth of ore containing lead, gold, subordinate amounts of silver, and minor amounts of zinc. The precise date of discovery is not known. Ransome (1911, p. 18) states: "About the year 1896 shipments were resumed from the Mountain Pride, and this mine shortly afterward began extensive development and in 1898 was the leading producer of the district. This preeminence, however, was not long maintained and the mine had been idle for a number of years when visited in 1909." Ransome's map (1911, pl. 1), from which the general geology may be inferred, shows only Pennsylvanian and Permian strata in the immediate vicinity of the mine, but concealed bodies of monzonite porphyry may also be present. The sedimentary strata presumably include red clastic types ranging from shale to coarse conglomerate and perhaps several intercalated limestones not more than a few inches thick. They should be about 1,000 feet stratigraphically below the base of the Entrada (?) sandstone and less than 500 feet above the pre-Cambrian surface. Ore bodies apparently are localized by minor faults near the crest of an anticline associated with the Boreas Pass fault.

Figure 16 shows the underground workings as mapped by Cramer. This map was supplied by George Robinson. The principal ore shoots apparently are along a vein striking about N. 60° E. and dipping northwestward. No further information is available.


EXPLANATION
Vertical shaft
Head of winze
Ore chute
N
WALTHAM NO I
LEVEL 4
Hoist
Office
LEVEL 3
LEVEL 2
LEVEL 1
Tank
Ore bins
CROSSCUT
STOPE 4
WILLIAMSPORT
MOUNTAIN PRIDE
STOPE 2
STOPE 1
CROSSCUT
STOPE 3
GENERAL GRANT
Store room
Bunk house
AIR SHAFT
PLAN
0
100
200 Feet
From an undated map by F.C.Cramer

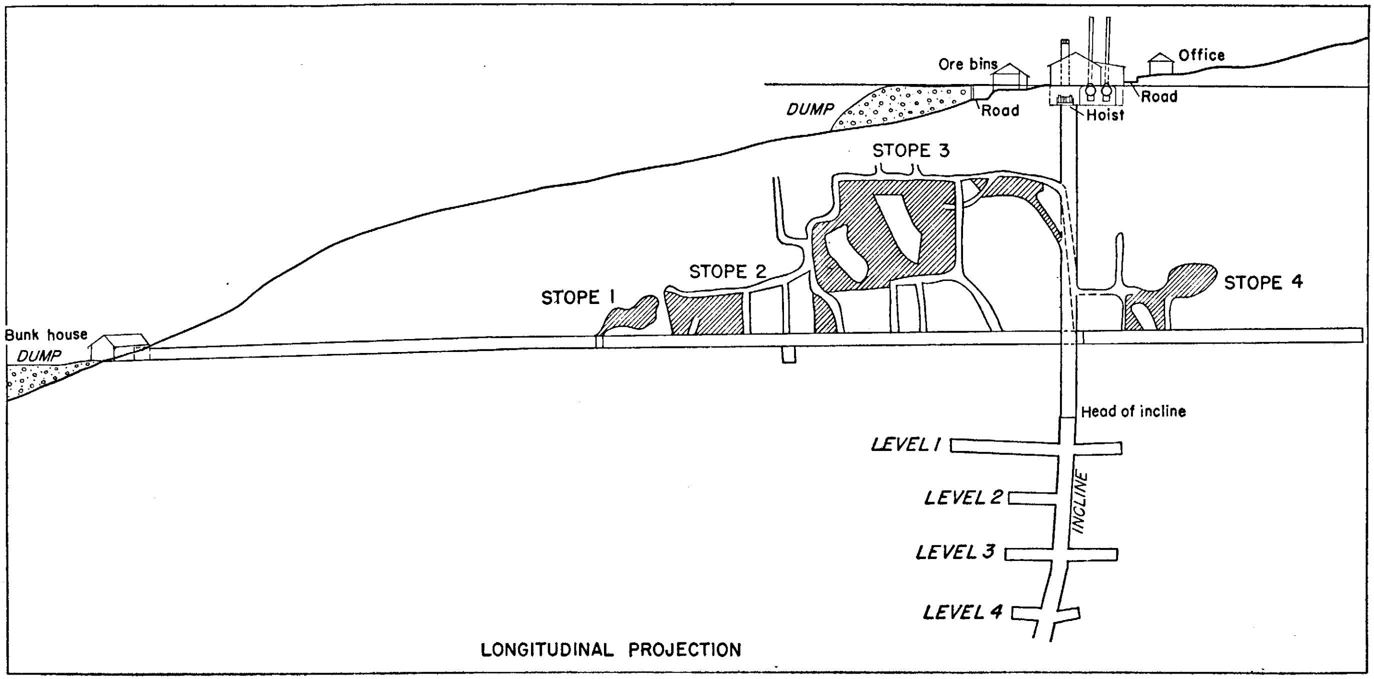


FIGURE 16.—Map and section of Mountain Pride mine.

SHOCK HILL

IRON MASK MINE

The Iron Mask mine is located on the northeast face of Shock Hill, just outside the town of Breckenridge. Information regarding its history and output is very meager. Ransome (1911, p. 18) states: "From this mine shipments of high-grade silver-lead ore began in 1888 and continued with few interruptions for about 10 years." No record of work done since that time is available.

The mine workings include several adits and a shaft. The main level has been the lowermost adit, or "tunnel," the plan of which as of 1903 is shown in figure 17. This map was furnished by George Robinson. The portal of the lower tunnel is in clastic Pennsylvanian and Permian strata located stratigraphically about 500 feet beneath the Entrada (?) sandstone. The dip of these strata cannot be determined at the mine, but doubtless it is about 17° WSW. (See pl. 1.)

The plan of the mine indicates that a very sinuous vein striking about N. 50° E. and dipping southeastward was cut 150 feet from the portal and followed for 750 feet. This vein apparently was stoped at three places, as indicated by the raises and winzes. Between two points located at 1,000 feet and 1,250 feet, respectively, from the portal, the tunnel seems to follow a vein striking N. 40° E. and dipping northwestward. Several sharp curves in the drift between the two veins suggest local cross faults. Ransome (1911, p. 161) states, "the Iron Mask ore is said to have occurred above and below a sheet of porphyry. * * * In some places the carbonate ore was accompanied by much free sulphur * * *. Nothing whatever could be seen of the ore bodies in 1909."

No ore specimens remain on the dumps. Heavy limonite and manganese stains are found on much of the rock. A few specimens of massive pyrite found on one dump apparently were worthless as ore.

BROOKS-SNIDER MINE

The Brooks-Snider mine comprises the open cuts and short adits that honeycomb the northwest face of Shock Hill. (See pl. 2.) Neither a history of the mine nor a record of the output is available, but the Brooks-Snider and Iron Mask are said to be the most productive mines of Shock Hill.

Ransome (1911, pp. 161, 163) states:

> At a few places, especially on Shock Hill and Little Mountain, oxidized gold-silver ores have been found at slight depth in the fissured [Dakota] quartzite. No large bodies of ore or persistent veins are known in this group of deposits. The gold and silver are either distributed rather generally along the many small irregular fractures in the * * * quartzite or segregated at a few favor-

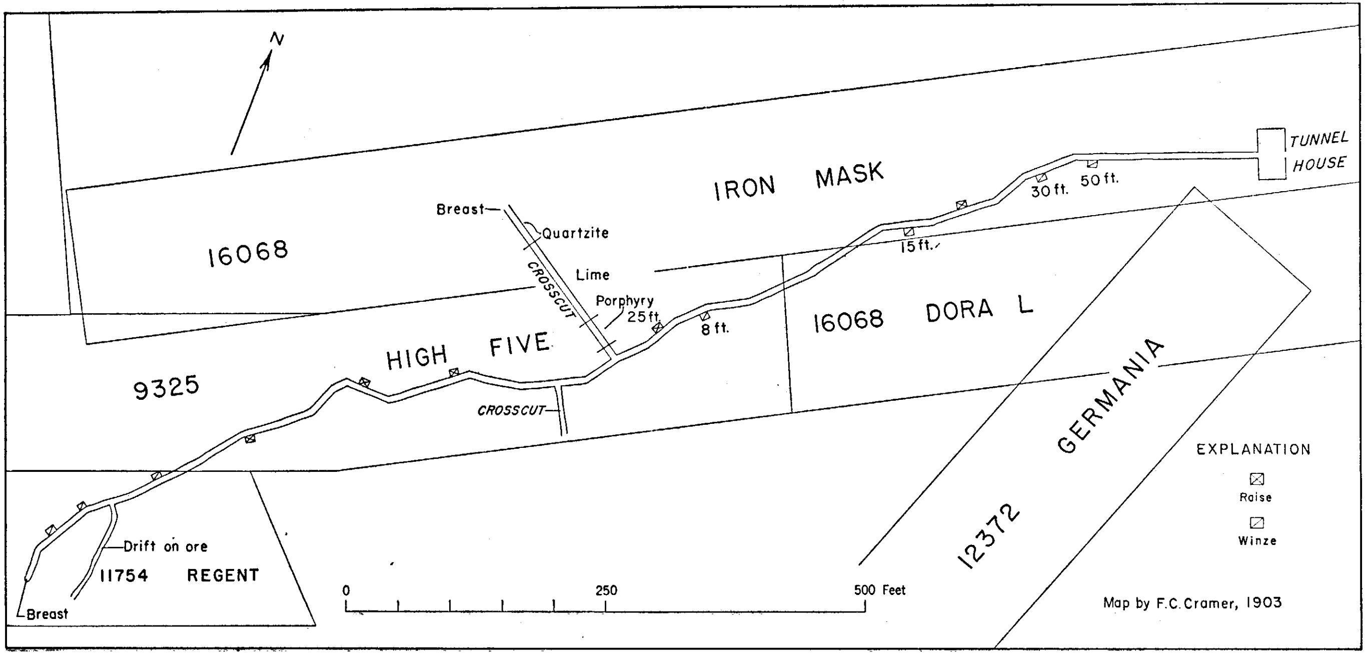


FIGURE 17.—Map of lower (main) tunnel of Iron Mask mine.

able spots into pockets of exceptionally rich ore, such as was found in the Germania workings on Little Mountain. * * *

The gold-silver ore in the quartzite of Shock Hill appears to have been generally similar in occurrence to that in Little Mountain—superficial, pockety accumulations of oxidized ore in the intricately fractured brittle rock. Nothing, however, could be seen in 1909 of the old Brooks-Snider and other workings in the hill. The mill appears to have been supplied by burrowing unsystematically after small streaks and bunches of ore. A part of the quartzite debris was washed by hydraulic means.

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