Geology and Ore Deposits of the Freeland-Lamartine District, Clear Creek County, Colorado

GEOLOGICAL SURVEY BULLETIN 1032-B

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By J. E. HARRISON *and* J. D. WELLS

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GEOLOGY AND ORE DEPOSITS OF THE FREELAND-LAMARTINE DISTRICT, CLEAR CREEK COUNTY, COLORADO

By J. E. Harrison and J. D. Wells

ABSTRACT

The Freeland-Lamartine district, Clear Creek County, Colo., forms part of the Front Range mineral belt, which is a northeastward-trending belt of coextensive porphyry intrusive rocks and hydrothermal veins of Tertiary age. About $18 million worth of gold, silver, copper, lead, and zinc had been produced from the mines in the district between 1868 and 1953.

The bedrock in the district is pre-Cambrian in age and consists of igneous rocks, some of which have been metamorphosed, and metasedimentary rocks. The metasedimentary rocks constitute the Idaho Springs formation and are biotite-quartz gneiss, sillimanitic biotite-quartz gneiss, amphibolite, and lime silicate gneiss. These older rocks have been invaded by quartz diorite and associated hornblendite, granite gneiss and pegmatite (which locally forms a migmatite with units of the Idaho Springs formation), granodiorite, biotite-muscovite granite, and granite pegmatite. During Tertiary time the pre-Cambrian rocks were invaded by dikes and plugs of quartz monzonite porphyry, alaskite porphyry, syenitic bostonite porphyry, and quartz bostonite. Solifluctional debris of Wisconsin age forms sheets in some of the high basins and fills narrow valleys; similar debris forms avalanche ridges in certain of the narrow valleys. Recent alluvium covers the valley floor of the major stream.

Two periods of pre-Cambrian folding can be recognized in the district. The older folding crumpled the metasedimentary rocks into a series of upright and overturned north-northeastward-plunging anticlines and synclines. Granodiorite, quartz diorite and associated hornblendite, and granite gneiss and pegmatite were metamorphosed during this period of folding. The second period of folding appears to have been less intense and resulted in a series of warps trending north-northwestward across the older folds. The biotite-muscovite granite, which is the youngest major pre-Cambrian rock unit, was intruded late in the period of north-northeastward folding and before the period of north-northwestward folding.

Arching of the Front Range highland during Laramide time is believed responsible for the formation of a regional joint pattern. During Tertiary time the bedrock was intruded by porphyritic dike rocks. A regional shear stress caused fractures in the bedrock that were the loci of deposition of hydrothermal veins subsequent to the intrusion of the porphyries.

The fractures formed under the regional shear stress are long, cymoid-shaped fissures composed of three elements that can be dated in a sequence. The first set of fractures formed approximately parallel to north-northeastward-trending

axial planes of major pre-Cambrian folds; those fractures now form the middle segment of the cymoid fissures. Subsequent fractures formed at both ends of the early fractures, one set with east-northeasterly trends and the final set with easterly trends.

The veins in the district are typical mesothermal fissure fillings. The veins are lodes that have smooth bounding walls and abundant slickensides; the fissures are fairly regular in strike and dip, and irregularities, where present, commonly provided favorable structures for the deposition of the ore minerals.

Two principal types of ore, pyrite-gold and galena-sphalerite, have been mined in the district. A third type, composite ore, is found where galena-sphalerite ore locally overlaps pyrite-gold ore. Mineralization took place in two stages during the period of fracturing; the veins were deposited in open space and show a well-defined zoning—individual veins have a central segment of pyrite-gold ore bounded at both extremities by galena-sphalerite ore. In the first stage of mineralization quartz and auriferous pyrite with some chalcopyrite and tetrahedrite filled the early fractures, chiefly the north-northeasterly set and adjacent parts of the east-northeasterly set. In the second stage galena and sphalerite with minor amounts of quartz, pyrite, chalcopyrite, tetrahedrite, and carbonate filled the younger fractures near the ends of the cymoids. Veins formed during the second stage of mineralization locally cut the earlier veins in the east-northeastward-trending segments of the fissures, forming composite veins.

Structural control of ore shoots in mines of the district is generally well defined. Vein intersections and deflections in dip of veins have formed openings favorable for the deposition of ore; locally deflections in strike of veins appear to have formed openings; and one example of an ore shoot controlled by deflection of a fault upon entering a rock unit of different competency occurs in the district. These controls, or combinations of them, can be found on all three elements of the long, cymoid-shaped fissures.

Every accessible mine in the district was examined for radioactivity, and the dumps of inaccessible mines were traversed with a scintillation counter. Secondary uranium minerals—torbernite, autunite, and dumontite(?)—occur in vugs or fractures or in gouge, along several veins. Hydrous iron oxides from veins and from recent deposits on mine walls commonly show an unusual amount of radioactivity. In most of the radioactive material sampled, however, no discrete uranium minerals could be identified. It is tentatively concluded that large areas containing only pyrite-gold veins are poor in uranium and that areas of pyrite-gold or galena-sphalerite veins containing chalcopyrite are more favorable localities in which to look for uranium deposits.

INTRODUCTION AND ACKNOWLEDGMENTS

The Freeland-Lamartine mining district, in Clear Creek County, Colo., about 3 miles due west of Idaho Springs (figs. 3 and 4), forms a part of the Front Range mineral belt, a northeastward-trending belt of coextensive Tertiary veins and porphyry intrusives (Lovering and Goddard, 1950, p. 72–73, pl. 2, and fig. 21). The district occupies about 4 square miles and includes the abandoned mining towns of Freeland and Lamartine.

Gold, silver, copper, lead, and zinc ores worth at least $18 million have been produced in the district from mesothermal veins of Tertiary age. These veins occupy fractures that cut metamorphic and igneous rocks of pre-Cambrian age and porphyritic intrusive rocks of Tertiary age.

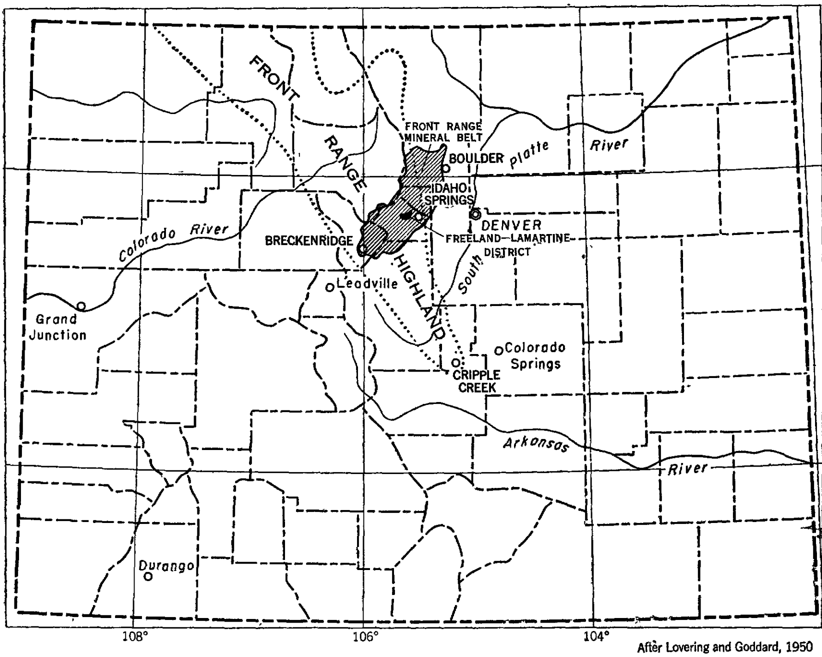


FIGURE 3.—Index map of Colorado showing the location of the Freeland-Lamartine district with reference to the Front Range highland and the Front Range mineral belt.

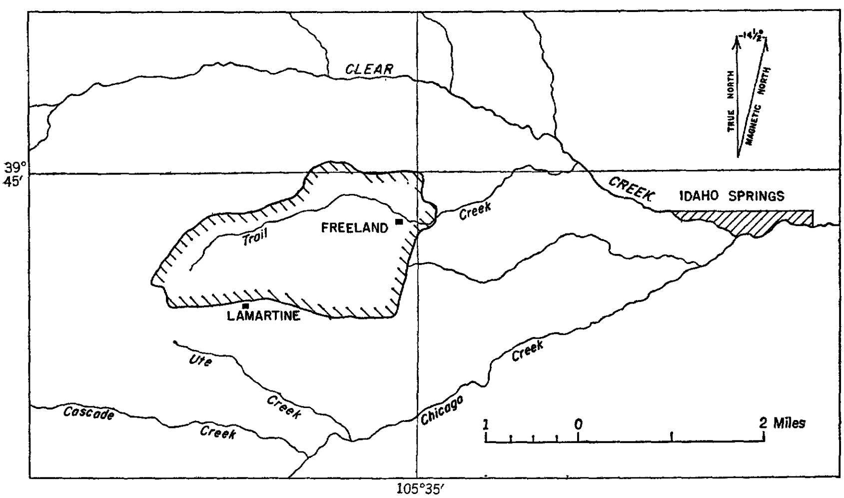


FIGURE 4.—Index map showing the location of the Freeland-Lamartine district, Clear Creek County, Colo.

The first study of the geology of the district was made by Spurr, Garrey, and Ball (1908) as part of their investigation of the Georgetown quadrangle. Brief summaries abstracted from this report are given by Vanderwilt (1947, p. 63), Goddard (1947, p. 308–313), and Lovering and Goddard (1950, p. 191–193). The original mapping of the district was on a scale of 1:62,500.

During the period May–October 1952, the district was mapped by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. The topographic base map (on a scale of 1:6,000 with a contour interval of 20 feet) was made by the Geological Survey from aerial photographs taken in 1951. In general, the part of the district mapped by Wells was mapped in detail equivalent to a scale of 1:24,000, and the remainder of the district was mapped in greater detail on a scale of 1:6,000. In addition, 16,000 feet of accessible mine workings were mapped on scales of 1:600 or 1:240. The area mapped by each author is shown in plate 2.

This report represents a part of the Survey's studies in the Idaho Springs–Central City area of the Front Range.

The writers wish to thank C. L. Harrington, U. S. Mineral Surveyor, Idaho Springs, Colo., for the use of many maps of inaccessible mines. Much of the production data since 1906 was obtained from files of the U. S. Bureau of Mines. Thanks are due A. J. Martin of the U. S. Bureau of Mines for his assistance in providing the data. The Montana Mining Development Corp. loaned maps and assisted the writers in their examination of the Lamartine mine and mill. Thanks are also due the local miners who aided in the identification of abandoned mines and who provided information on the workings and location of ore in inaccessible mines.

HISTORY

About April 1, 1859, pay gold ore was discovered in a placer near the mouth of Chicago Creek (Spurr, Garrey, and Ball, 1908, p. 311). Soon after this initial discovery a search for gold veins spread into the area along Trail Creek. The Freeland vein was discovered in 1861, the Lamartine vein in 1867, and the Great Western vein in 1878. By 1952 at least $18 million worth of gold, silver, copper, zinc, and lead had been produced from these and several smaller veins. Since about 1910, mining in the district has been intermittent and generally on the decline. During 1952, 1 mine was operated for 6 months; 3 mines were worked on a small scale; and only 1 mine was operated throughout the year. Most of the mines in the district are now partly or completely inaccessible.

GENERAL GEOLOGY

The general geology of the Freeland-Lamartine district has been described by Ball (Spurr, Garrey, and Ball, 1908) and by Lovering and Goddard (1950, pl. 2). The mapped area (pl. 2) consists predominantly of igneous rocks, some of which have been metamorphosed, and complexly folded metasedimentary rocks of pre-Cambrian age. Dikes and plugs of bostonite and monzonite have been intruded into the pre-Cambrian complex during Tertiary time. Gold-silver-lead-zinc-uranium-bearing fissure veins occur in the same fracture systems as the dikes but are slightly younger. Quaternary debris sheets and avalanche ridges cover some of the high basins and narrow valleys. Recent alluvium fills the valley flat of Trail Creek.

PRE-CAMBRIAN ROCKS

Ball (Spurr, Garrey, and Ball, 1908, pl. 2) and Lovering and Goddard (1950, pl. 2) indicate that most of the bedrock in the Freeland-Lamartine district belongs to the Idaho Springs formation. This formation was named by Ball (1906, p. 374) who considered it to be metamorphosed sediments. The Idaho Springs formation includes several lithologic types that are distinct and large enough to be mapped on a scale of 1:6,000 (pl. 2). In this report the rock types in the Idaho Springs formation that the writers have distinguished will be referred to by lithologic name. The approximate equivalents between the units in the Idaho Springs formation mentioned by Ball and those mapped by the writers are shown below.

Ball (1906)	*Harrison and Wells*
Biotite schist	Biotite-quartz gneiss.
Biotite-sillimanite schist	Sillimanitic biotite-quartz gneiss.
Quartz gneiss	Sparse in the Freeland-Lamartine district; included with lime silicate gneiss.
Lime silicate member	Lime silicate gneiss. Amphibolite.

In addition, the writers mapped migmatite as a rock unit. The term "migmatite" is used by the writers to denote a rock unit that contains a finely interlayered mixture of two types of rock-forming material—commonly a mixture of one of the biotite-rich gneisses and granite. The migmatite is equivalent to the "injection gneiss" of Ball and is partly of metasedimentary origin. Therefore, the migmatite of this report belongs, in part, to the Idaho Springs formation of Ball.

The rocks in the Idaho Springs formation are the oldest in the district. During pre-Cambrian time they were invaded by quartz diorite and associated hornblendite, granite gneiss and pegmatite, granodiorite, and finally by biotite-muscovite granite and pegmatite.

The complex resulting from these successive emplacements of younger rocks has been described by Ball (1906, p. 372) as follows—

Some idea of the complexity of injection may be gained from the fact that in a distance of one mile, on the ridge between Silver Creek and Clear Creek, six formations alternate seventy-six times, or at the rate of one alternation to 70 feet. This is exclusive of a number of minor injections and inclusions.

IDAHO SPRINGS FORMATION

The rock units of the Idaho Springs formation are referred to in this report by lithologic name. These names have been selected on the basis of quantitative mineral content, presence of diagnostic minerals easily recognized in the field, and structure of the rock. An attempt has been made to choose mineral modifiers that most nearly describe the prominent features of the rock seen in the field. Thus, rather than name one of the units quartz-biotite-plagioclase-microcline gneiss using all of the principal minerals as modifiers, the writers have named this unit biotite-quartz gneiss because of its characteristic black color due to the biotite, and its characteristic hardness due to the high quartz content. In the garnet-bearing varieties of this rock, garnet is conspicuous, and garnetiferous has been added to the lithologic name at places in the text to denote that garnet is locally present in the rock unit (biotite-quartz gneiss).

Ball (1906) interpreted the Idaho Springs formation to be a series of metamorphosed sedimentary rocks that originally consisted of interlayered sandstones, shales, and calcareous sandstones although age relations among the various rock units are not known. He concluded that under regional metamorphism the sandstone yielded quartz gneiss, the shales yielded biotite schist and biotite-sillimanite schist, and the calcareous sandstones yielded the lime silicate rocks. In general, Ball's generalized interpretation is acceptable to the writers although it appears to need modification concerning parts of certain of the rock units that appear to have been changed by metasomatic processes and are not the simple result of thermodynamic metamorphism as he implied.

BIOTITE-QUARTZ GNEISS

Biotite-quartz gneiss is exposed at a few places in the district, and it can be seen best in the workings of the Little Johnie group of mines and on the ridge just south of the abandoned mining town of Freeland (pl. 2). The gneiss also occurs as layers and lenses, too small to be mapped, in sillimanitic biotite-quartz gneiss and granite gneiss and pegmatite. At many places the biotite-quartz gneiss is slightly migmatitic owing to scattered 1-inch-thick conformable layers of granitic material.

The contacts between the biotite-quartz gneiss and the other rock units of the Idaho Springs formation are gradational.

The biotite-quartz gneiss is a black to mottled gray and black, fine- to medium-grained gneiss that commonly is well foliated, except in local quartz-rich facies that appear fine grained and uniform.

The principal minerals in the gneiss are quartz, biotite, and plagioclase; varietal accessories include microcline, muscovite, magnetite, and garnet; many varieties containing garnet are fine grained and poorly foliated. All varieties of the biotite-quartz gneiss have a pronounced lineation, expressed by biotite alinement, and in some more feldspathic facies by streaking or crenulations along biotite-rich planes in the rock.

The structures of both the garnetiferous and nongarnetiferous varieties of the biotite-quartz gneiss are similar in thin section. The rock is foliated by segregation of the minerals into layers and through elongation of mineral grains and alinement of platy minerals. Layering is more prominent in the garnetiferous varieties and biotite alinement more common in the nongarnetiferous varieties.

The biotite-quartz gneiss ranges considerably in composition from outcrop to outcrop as shown by the modes (volume percent) given in table 1. In general, the gneiss contains from 20 to 40 percent biotite, from 30 to 60 percent quartz, and from 10 to 20 percent plagioclase. The garnetiferous variety commonly contains more magnetite and less feldspar than the nongarnetiferous variety.

Two samples of garnet were handpicked from specimens from widely separated localities of garnetiferous biotite-quartz gneiss.

TABLE 1.—*Modes (volume percent) of biotite-quartz gneiss*

	2-5-78	2-6b-8	2-6a-56a	OS-5	BC-6	370-1	2-2a-172a	2-6b-47	358-1
Microcline	4.0	------	12.0	22.0	6.0	9.0	------	------	------
Quartz	39	64.0	46	49	64	37	37.0	45.0	39.0
Plagioclase	39	12	7	21	9	11	7	14	------
Biotite	19	21	20	8	20	39	28	30	9
Muscovite	------	2	10	Trace	Trace	------	------	------	------
Garnet	------	------	------	------	------	1	19	11	22
Magnetite	------	1.5	2	Trace	1	2	10	1	30
Sillimanite	------	.5	3	------	------	------	------	------	------
Apatite	------	------	------	Trace	------	------	------	------	.5
Epidote	------	------	------	Trace	------	------	------	------	------
Zircon	------	------	------	------	Trace	------	Trace	------	------

2-5-78: Feldspar-rich layer in sillimanitic biotite-quartz gneiss, 500 feet N. 15° W. from the portal of the New Era south tunnel.
2-6b-8: Biotite-quartz gneiss layer in migmatite from outcrop on the north side of the road where the Trail Creek road crosses Trail Creek near Freeland.
2-6a-56a: Biotite-quartz gneiss layer in migmatite from outcrop along road 800 feet east of the portal of the Old Stag tunnel.
OS-5: Feldspar-rich facies of biotite-quartz gneiss from the Old Stag tunnel.
BC-6: Biotite-quartz gneiss from the Belle Creole tunnel.
370-1: Garnet-bearing biotite-quartz gneiss from the upper tunnel, Little Johnie group of mines.
2-2a-172a: Garnetiferous biotite-quartz gneiss from the upper tunnel, Little Johnie group of mines.
2-6b-47: Garnetiferous biotite-quartz gneiss from layer in granite gneiss and pegmatite 250 feet west of the portal of the Bell of the West tunnel.
358-1: Magnetite-rich garnetiferous biotite-quartz gneiss from the lower tunnel, Little Johnie group of mines.

Garnets from both samples had a refractive index of 1.811. The a_0's were determined by A. J. Gude 3d, U. S. Geol. Survey laboratory, Denver, Colo., to be 11.542 and 11.555 angstrom units. According to the data presented by Fleischer (1937) and Levin (1950), the garnet is probably almandite.

The biotite-quartz gneiss is mainly fine grained and granoblastic, though some of the garnetiferous varieties contain coarser pods of poikilitic garnet, magnetite, or quartz. Biotite flakes are alined along grain boundaries, and quartz grains are commonly elongate parallel to the biotite alinement. In the garnetiferous variety the quartz grains tend to have a more sutured boundary than in the nongarnetiferous varieties. The cores of most of the garnet poikilitically enclose small grains of biotite, magnetite, and quartz. Although subrounded garnet crystals locally transect planes of biotite, many of the biotite flakes within the garnet are oriented parallel to the biotite laths outside of the garnet crystal. Magnetite in this rock type occurs with biotite (commonly as laths and wedges along cleavage planes) or in cores of garnet crystals. Magnetite in a thin section from an exceptionally magnetite-rich specimen of garnetiferous biotite-quartz gneiss (358–1) poikilitically encloses quartz, biotite, garnet, and apatite. The magnetite forms both patches that cut across contacts between garnet and quartz and small anhedral blebs oriented parallel to foliation along grain boundaries.

SILLIMANITIC BIOTITE-QUARTZ GNEISS

The largest exposed body of sillimanitic biotite-quartz gneiss is on the north side of Trail Creek, in the north-central part of the mapped area (pl. 2). It also forms small, scattered lenses and layers in migmatite and granite gneiss and pegmatite throughout the district. Parts of the sillimanitic biotite-quartz gneiss contain as much as 30 percent of 1-inch thick conformable granitic layers. At the eastern edge of the district, on the north side of Trail Creek, small layers of sillimanitic biotite-quartz gneiss occur on minor fold crests and troughs as inclusions in granite gneiss and pegmatite.

The sillimanitic biotite-quartz gneiss is mottled black and gray, medium grained, and has a conspicuous gneissic structure. The principal minerals are biotite and quartz; varietal accessories include sillimanite, microcline, plagioclase, and muscovite; the minor accessories are magnetite, sphene, and hematite. The foliation is produced by segregation of the minerals into mica-sillimanite layers and quartz-rich layers, and the lineation is given by the biotite and sillimanite. Modes of this gneiss are shown in table 2. The presence of sillimanite in amounts greater than 5 percent serves to distinguish this gneiss from other members of the Idaho Springs formation.

Examination of this gneiss in thin section shows that it contains elongate, subrectangular crystals of quartz that form a layered network. Biotite and sillimanite form bands parallel to the layering in the quartz network. Biotite occurs in fine- to medium-grained crystals, some of which fill tiny fractures in some of the quartz crystals. Sillimanite is in short, subhedral to euhedral crystals and appears to embay both biotite and quartz. The microcline, plagioclase, and sphene grains are distributed through the rock. Muscovite is associated with biotite in the biotite-rich layers. Magnetite occurs chiefly along cleavages and grain boundaries of the micas. Hematite is in flakes and dust coating or surrounding magnetite.

TABLE 2.—*Modes (volume percent) of sillimanitic biotite-quartz gneiss*

	2-5-41c	2-5-85	OS-11
Microcline	2	Trace	16
Quartz	44	51	49
Plagioclase	10	Trace	3
Sillimanite	5	12	6
Biotite	25	30	22
Muscovite	15	6	5
Magnetite	Trace	1	Trace
Sphene	Trace	Trace	Trace
Hematite	Trace	Trace	Trace

2-5-41c: Sillimanitic biotite-quartz gneiss layer in migmatite from outcrop along road 75 feet east of the portal of the New Era north tunnel.
2-5-85: Sillimanitic biotite-quartz gneiss from outcrop along road 900 feet west of the portal of the New Era north tunnel.
OS-11: Sillimanitic biotite-quartz gneiss from the Old Stag tunnel.

AMPHIBOLITE

Exposures of amphibolite are sparse but are most common in the east-central part of the district. The amphibolite occurs as conformable layers and lenses intercalated with, and gradational into, other rock types of the Idaho Springs formation and the granite gneiss and pegmatite.

The amphibolite is a black to greenish-black fine- to medium-grained gneiss consisting principally of hornblende, andesine-labradorite, and quartz; it is distinguished with difficulty from metamorphosed quartz diorite. (See page 47.) Locally, the amphibolite contains layers of pyroxene gneiss. Modes of the amphibolite and related rocks are shown in table 3.

Marked by the segregation of the minerals into light and dark layers, foliation is well shown in the amphibolite; lineation is produced by the alinement of hornblende crystals.

The amphibolite has a fine- to medium-grained granular texture. The hornblende crystals are commonly about 2 millimeters long and are in a matrix of fine- to medium-grained equigranular quartz and plagioclase. Most of the plagioclase grains are twinned. The twins are predominantly albite and pericline (or acline) or, less commonly, combinations of the two types. In 3 thin sections, only 1 carlsbad-albite-pericline, and 2 carlsbad-albite twin combinations were noted.

TABLE 3.—*Modes (volume percent) of amphibolite and related rocks*

	2-5-8a	2-5-8b	2-5-8c
Hornblende	55	58	9
Clinopyroxene	----------	Trace	34
Plagioclase (Andesine-Labradorite)	25	25	37
Quartz	16	11	11
Biotite	1	----------	----------
Magnetite	3	----------	----------
Epidote	Trace	3	8
Sphene	----------	2	2
Apatite	Trace	Trace	Trace
Calcite	----------	Trace	Trace

2-5-8: Suite of specimens from outcrop of amphibolite containing pyroxene gneiss layers on the north side of the road at Freeland.
a, Amphibolite.
b, Amphibolite 1 inch from contact with 6-inch pyroxene gneiss layer.
c, Pyroxene gneiss layer in amphibolite.

LIME SILICATE GNEISS

Lime silicate gneiss is sparse in the Freeland-Lamartine district; the best exposure of this rock is on the north side of Trail Creek, about 700 feet west of the collar of the New Era shaft. At this exposure, the rock is intimately folded with other members of the Idaho Springs formation and granite gneiss and pegmatite. A thin layer of quartz-magnetite gneiss (quartzite?) is exposed along parts of the south edge of this outcrop and has been included with the lime silicate gneiss on the map (pl. 2).

The lime silicate rocks were considered by Ball (1906) to be a member of the Idaho Springs formation. In a later report (Spurr, Garrey, and Ball, 1908, p. 41–44) he included within this member four rock types which he called quartz-magnetite gneiss, hornblende-diopside gneiss, quartz-epidote-garnet rock, and calcite-lime silicate rock.

The writers include varieties of Ball's quartz-epidote-garnet rock and calcite-lime silicate rocks in the rock group mapped as lime silicate gneiss. Skarns and skarnlike rocks that may have formed from calcium-rich rock layers of the Idaho Springs formation by metasomatism rather than simple thermodynamo metamorphism are also included in the lime silicate gneiss. The quartz-magnetite gneiss occurs only in small, unmappable layers in the district; a variety of the hornblende-diopside gneiss has been mapped by the writers as amphibolite.

In the Freeland-Lamartine district the lime silicate gneiss is a bright-green to greenish-black fine- to coarse-grained massive to layered rock. Epidote or intergrowths of epidote and clinozoisite commonly are the major constituents of the massive varieties, and hornblende, feldspar, and clinopyroxene are more common in the layered varieties. The layers range in thickness from fractions of an inch to as much as a foot and are due to segregation of the minerals into light and dark layers. The layers of many of the hornblendic rocks are crosscut by irregular patches and pods of quartz and epidote as much as 2 feet in diameter. The layered rocks are commonly cut by microscopic to 1-inch-thick stringers of epidote-microcline-hornblende.

The composition of the rocks mapped as lime silicate gneiss varies from layer to layer within one outcrop. Generally the rock contains hornblende, epidote, and quartz in varying proportions that make up about 50 percent of the rock by volume. The remainder of the rock consists largely of clinopyroxene or clinozoisite, and plagioclase (andesine to bytownite), also in varying proportions. Sphene is commonly present in amounts of from 1 to 4 percent; and magnetite and apatite are accessory minerals in most of these rocks.

Examination of these rocks in thin section indicates that if epidote and clinozoisite are both present in the gneiss they tend to form large (as much as one-half inch in diameter) compound porphyroblasts consisting of irregular intergrowths of diversely oriented crystals of the two minerals. Hornblende commonly is in short, stubby crystals about 2 millimeters long although at places in this rock hornblende crystals as much as 1 inch across and 3 inches long are present.

ORIGIN

The gradation between the rock units in the Idaho Springs formation and the interlayering and interlensing of the units suggests to the writers that the Idaho Springs formation represents metamorphosed sedimentary rocks. The broad regional distribution of rocks of similar character has been pointed out by Ball (Spurr, Garrey, and Ball, 1908), Bastin (Bastin and Hill, 1917), and Lovering and Goddard (1950). Probably the rocks of the Idaho Springs formation were formed by regional metamorphism of sedimentary rocks, and the mineralogic variations in the rocks are principally the result of differences in original mineral composition of the sediments that appear to have been under pressure and temperature conditions necessary for the formation of the amphibolite facies.[1] In a broad sense, this is probably true, but certain local differences in the rock units suggest to the writers that the metamorphic rocks derived from regional metamorphism have been modified, at least in part, by metasomatism.

The biotite-quartz gneiss contains a mineral assemblage that could

[1] In the Freeland-Lamartine district all of the rock units of the Idaho Springs formation approximate the same grade of metamorphism. The mineral assemblages are those described by Turner (1948, p. 76–88) for various subfacies of the amphibolite facies. The term "amphibolite facies" is used here to describe mineral assemblages that are compatible throughout the region.

be derived from original sandy beds. A slight decrease in the amount of potash in the original sediment would favor the formation of garnet instead of microcline, and the garnetiferous biotite-quartz gneiss may, therefore, represent a facies of the biotite-quartz gneiss. The close field association between the garnet-bearing rock and the biotite-quartz gneiss—the former everywhere forms lenses or layers in the latter—supports the belief that the two types of rocks are genetically related. A metasomatic modification of parts of these two varieties of biotite-quartz gneiss is indicated by field and laboratory observations. In the Little Johnie group of mines several 1- to 2-inch-thick granitic stringers were seen crosscutting biotite-quartz gneiss and a ⅛- to 1-inch-thick band of garnet was noted in the biotite-quartz gneiss adjacent to and following the irregular contacts between the granitic stringer and the gneiss. As the layer of biotite-quartz gneiss was not garnetiferous except for the thin band along the granitic stringer, the writers infer that the garnet formed by metasomatic processes. Examination of the magnetite-rich varieties of the biotite-quartz gneiss showed irregular patches of magnetite that crosscut grain boundaries and poikilitically enclose corroded mineral grains. The uncommon concentration of magnetite, its textural distribution, and its lateness in the paragenetic sequence of the gneiss suggest to the writers that much of the magnetite in the magnetite-rich varieties has been introduced into the rock.

The sillimanitic biotite-quartz gneiss contains a mineral assemblage that could have been derived from original alumina-rich sediments. The interlayering and interlensing of this rock type with other rocks of the Idaho Springs formation along flanks of open folds suggests that much of this gneiss was derived from sediments that originally contained alternating sandy and shaly beds.

A metasomatic origin for part of this rock unit is, however, entirely plausible. It is particularly significant that in the migmatitic parts of the sillimanitic biotite-quartz gneiss the amount of sillimanite present seems to be proportional to the amount of granite in the rock. Thus, even if the more sillimanitic gneiss were more subject to migmatization, the proportionality of thickness of sillimanite layers to thickness of granite stringers is suggestive of local change in the original bulk chemical composition of the gneiss.

The amphibolite and lime silicate gneiss are calcium-rich layers and lenses intercalated with the other rocks of the Idaho Springs formation. These calcium-rich rocks may represent limy sandstones or impure limestones in an original sedimentary sequence. Some local metasomatic modification of these rocks is indicated in most outcrops by crosscutting stringers, pods, and patches of quartz-epidote rock. Where these patches are in amphibolite, they represent a considerable loss of iron from the rock. Metasomatism of calcareous rocks by granitic solutions to produce skarns and skarnlike assemblages of minerals is too common to be overlooked as a possible origin for some of the lime silicate gneiss.

QUARTZ DIORITE AND ASSOCIATED HORNBLENDITE

Quartz diorite and associated hornblendite form sparsely scattered, small, rounded plugs (?) and short, conformable and disconformable, dikelike bodies in the older pre-Cambrian rocks. As the contacts between this rock unit and other rocks of the district are poorly exposed, no definite age relations can be established from this study. However, Ball (Spurr, Garrey, and Ball, 1908, p. 56–57) found that at certain localities these rocks appear to be younger than what he mapped as quartz monzonite and at other localities appear to be older. The quartz diorite clearly intrudes metasedimentary rocks of the Idaho Springs formation and is definitely intruded by Silver Plume granite (Spurr, Garrey, and Ball, 1908, p. 37–60).

Although some of the quartz diorite and associated hornblendite in the district is massive, most of these rocks contain a foliation caused by a faint to prominent mineral layering in the rock. In general, the smaller bodies as well as the margins of the larger bodies of this rock type contain a foliation, and the central parts of the larger bodies are massive. The layering in the foliated rocks is concordant with the foliation in the adjacent pre-Cambrian rocks regardless of whether the gross outline of the body is concordant or crosscutting. Certain of the foliated facies cannot be distinguished in the field from amphibolite of the Idaho Springs formation; certain facies resemble granodiorite but can be distinguished by the abundance of hornblende which is sparse in granodiorite.

The quartz diorite is a black to mottled black and white fine- to coarse-grained hypidiomorphic granular rock consisting principally of hornblende, andesine-labradorite, and quartz. Varietal accessories in the rock are pyroxene and biotite; and minor accessories include apatite, magnetite, epidote, and sphene. At places the rock is a hornblende-biotite-quartz diorite (tonalite); and at other places it is a diorite. (See table 4.)

The layering in the foliated facies of the quartz diorite is due to segregation of the minerals into mafic-rich and quartz-plagioclase-rich layers. The formation of this layering appears related to the mineral composition of the rock. An increasing degree of gneissic structure as shown by more continuity and regularity of the layering is accompanied by an increase in the amount of plagioclase and biotite and a decrease in the amount of hornblende. (See table 4, specimens 2–5–41a, 2–6b–52, 2–5–49b, and 2–5–49c.) This same change is

TABLE 4.—*Modes (volume percent) of quartz diorite and associated hornblendite*

	I-16b	2-5-49a	1-2-24a	2-10-31	1-2-11	2-5-41a	2-6b-52	2-5-49b	2-5-49c
Hornblende	27	95	82	69	36	65	53	56	31
Pyroxene	11	---------	---------	---------	---------	---------	---------	---------	---------
Plagioclase	38	---------	7	3	25	30	36	39	50
Quartz	8	1	8	16	16	4	7	.7	3
Biotite	14	---------	---------	5	22	.6	2	3	13
Magnetite	Trace	1	Trace	Trace	.4	Trace	2	---------	1
Epidote	Trace	---------	Trace	6	---------	---------	---------	.6	2
Sphene	Trace	---------	Trace	Trace	1	---------	---------	---------	---------
Apatite	1	3	---------	---------	---------	.3	---------	.3	Trace

I-16b: Quartz diorite from the Jo Reynolds area, about 1 mile northwest of the district.
2-5-49a: Hornblendite from the sill on the north side of the road 300 feet east of the portal of the New Era mine.
1-2-24a: Weakly foliated hornblendite(?) from the top of the ridge 600 feet east of the collar of the Silver Queen shaft.
2-10-31: Weakly foliated hornblendite(?) from an outcrop along the road 500 feet east of the point where Trail Creek road crosses the head of Trail Creek.
1-2-11: Moderately foliated hornblendite(?) from a dikelike body on the ridge to the north of the head of Trail Creek.
2-5-41a: Weakly foliated quartz diorite from the sill on the north side of the road 300 feet east of the portal of the New Era mine.
2-6b-52: Weakly foliated quartz diorite from the Bell of the West mine.
2-5-49b: Moderately foliated quartz diorite from the sill on the north side of the road 300 feet east of the portal of the New Era mine.
2-5-49c: Moderately to strongly foliated quartz diorite from the same locality as 2-5-49b.

reflected in thin section by a textural change trending from hypidiomorphic granular in the massive facies to allotriomorphic granular in the better foliated facies. This textural change is partly due to the increasing proportion of biotite flakes, parallel to the layering, that cut through former euhedral hornblende or plagioclase crystals. The plagioclase in the massive quartz diorite is subhedral and twinned. Most of the plagioclase has combination twins of albite-pericline (or acline), carlsbad-albite, carlsbad-pericline, or more complex and rarer varieties. Although the plagioclase in the foliated facies has the same compound and complex twinning characteristic of the massive facies, anhedral crystals of altered plagioclase embaying all the other minerals except biotite are characteristic of the quartz-plagioclase-rich layers.

The massive hornblendite is a black to greenish-black fine- to medium-grained rock composed essentially of hornblende. Accessory minerals in this rock include magnetite, apatite, and quartz. The foliated facies of the hornblendite is mottled black or greenish black and white and consists essentially of hornblende, andesine-labradorite, and quartz. Biotite is a subordinate mineral found in this facies, and magnetite, epidote, and sphene occur as accessory minerals. The massive hornblendite and the dark parts of the foliated hornblendite consist of hypidiomorphic granular hornblende with minor amounts of quartz. The white areas in the foliated hornblendite are patches or irregular stringers of altered andesine-labradorite containing fragments of irregular-shaped hornblende and biotite and rounded blebs of quartz. The small amount of unaltered plagioclase has simple albite twinning, or, uncommonly, an albite-pericline combination twinning.

In general, the same trend toward decrease in hornblende and increase in plagioclase and biotite is shown from the massive to foliated hornblendite as is shown from massive to foliated quartz diorite (table 4).

DISTINCTIONS BETWEEN AMPHIBOLITE, QUARTZ DIORITE, AND HORNBLENDITE

Certain of the better foliated facies of quartz diorite and associated hornblendite are difficult or impossible to distinguish in the field from amphibolite of the Idaho Springs formation. A laboratory study of these two groups of amphibolitic rocks was undertaken because Turner (1951) had suggested that the genesis of some amphibolitic rocks can be deduced from the amount and complexity of the twinning in the plagioclase. The results of the writers' study are shown in table 5. The amphibolite indicated in this table represents a group of layered rocks gradational into rocks of the Idaho Springs formation; the hornblendite is included only to place emphasis on its lack of plagioclase; the quartz diorite is from a body containing pigeonite along pyroxene cleavages (specimen I–16b, table 4); and the discordant and concordant bodies represent rocks considered to be quartz diorite and hornblendite which have been grouped by field occurrence.

The difference between the type and amount of twinning in the plagioclase of the amphibolite and the better foliated facies of quartz diorite and associated hornblendite is that the latter have a greater variety of plagioclase twinning and the twins tend to occur in combinations.

TABLE 5.—*Amount and type of twinning in plagioclase feldspars in amphibolitic rocks*

[Varieties: Ab, Albite; Pe, Pericline; Ca, Carlsbad. Occurrence: X, present; C, common; O, occasional; R, rare]

	Amount and type			Varieties						
	Untwinned grains	Mostly simple twinning	Mostly combination twinning	Ab	Pe	Ab-Pe	Ca-Ab	Ca-Pe	Ca-Ab-Pe	Other complex
Amphibolite	A few	X	--------	C	C	--------	R	--------	R	--------
Hornblendite (no plagioclase).	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Quartz diorite	None	--------	X	--------	R	C	C	O	O	C
Discordant bodies (massive to weakly foliated).	do	X	--------	C	C	R	--------	--------	--------	--------
Concordant bodies (massive to weakly foliated).	do	X	--------	C	--------	--------	--------	--------	--------	--------
Discordant bodies (moderately to strongly foliated).	do	--------	X	R	--------	C	C	--------	C	C
Concordant bodies (moderately to strongly foliated).	do	--------	X	O	--------	C	C	--------	--------	O

ORIGIN

Turner (1951, p. 585) stated that the plagioclase of schists and hornfels differs from the plagioclase of undoubtedly igneous rocks by the prevalence of simple twins and the lack of variety of types (mostly either simple albite or pericline, or both, carlsbad rare, complex combinations even rarer, albite-pericline combinations in one crystal are infrequent). He also noted (p. 583)—

> In amphibolites of igneous origin, coarse plagioclase (in some cases retaining relict idiomorphic outlines) is liable to show twinning just as complex as that of igneous plagioclase—albite-Carlsbad-pericline combinations especially.

This argument, when taken in conjunction with the data in table 5, suggests that the plagioclase of the better foliated facies of quartz diorite and associated hornblendite is of igneous origin and that the plagioclase of both the weakly foliated facies and the amphibolite is of metamorphic origin.

The foliation in the quartz diorite and associated hornblendite results from the plagioclase layers, stringers, and patches. The orientation of the foliation is the same as the orientation of the foliation in the enclosing rocks whether the major outlines of the body are concordant or discordant. This fact, in conjunction with the textural change from hypidiomorphic to allotriomorphic and the mineralogic trend from hornblende to plagioclase in going from the massive to foliated facies, suggests to the writers that the foliation in the rock is not due to flow structure but is due to shearing and recrystallization of the rock. If the foliation is due to metamorphism, then some of the plagioclase in these rocks is of metamorphic origin. Because the hornblendite originally had no plagioclase (or only accessory amounts), any plagioclase found in these rocks now would have the characteristics of metamorphic plagioclase.

The writers tentatively conclude from the limited data available that the quartz diorite and associated hornblendite are basic intrusive rocks that have been metamorphosed to varying degrees principally by shearing and recrystallization. The writers infer that the bodies of hornblendite were more resistant to shearing than equal sized bodies of the quartz diorite and that the hornblendite is, therefore, more likely to occur as a massive or faintly foliated rock.

One further possibility should be mentioned. The rocks mapped as quartz diorite and associated hornblendite, and the metamorphosed facies of each, may not all be of the same age. The apparent difference in amount of shearing and recrystallization of the massive varieties may be due to posttectonic intrusion. The better foliated, concordant varieties may have been intruded into the Idaho Springs formation before or during the principal period of pre-Cambrian folding.

MIGMATITE

Definition.—Migmatite as used in this report refers to a rock consisting of intimate mixtures of metasedimentary rocks and granitic rocks. All degrees of migmatization occur in the Freeland-Lamartine area. An arbitrary classification was used in the field in mapping migmatite of the Idaho Springs formation and granite. This classification was based on two considerations—first, the structure of the interlayering, and second, the amount of granitic material present in the rock. To be classified as migmatite, a rock had to be finely interlayered somewhat in the manner of rocks that have been called "injection gneisses," and the rock had to contain at least 30 but not more than 70 percent of granitic material. If the rock contained less than 30 percent granitic material, it was mapped as the appropriate unit of the Idaho Springs formation; if the rock contained over 70 percent of granitic material, it was mapped as the appropriate granite (usually granite gneiss and pegmatite).

Description.—Migmatite is well exposed at several places in the district, particularly on the north side of Trail Creek near the eastern edge of the mapped area (pl. 2). Good exposures of this rock type also can be seen underground in the workings of the New Era mine and in the crosscut part of the Old Stag tunnel.

Although most migmatite in the district is a mixed rock consisting principally of quartz-biotite gneiss and generally conformable discontinuous 1-inch-wide layers and pods of granitic material along foliation planes in the gneiss, migmatite is locally composed of sillimanitic biotite-quartz gneiss and intercalated granitic layers, and at a few places it consists of garnetiferous biotite-quartz gneiss and granitic material.

Contacts between the migmatite and biotite-muscovite granite are fairly sharp, and at most places usually little or no migmatite occurs at contacts between biotite-muscovite granite and units of the Idaho Springs formation. However, contacts between the migmatite and the granite gneiss and pegmatite are gradational, commonly over several tens of feet. The proportion of granitic material in the migmatite gradually increases toward the granite gneiss and pegmatite and approximate contacts have been drawn where granitic material exceeds 70 percent of the rock. Likewise, contacts between the migmatite and biotite-quartz gneiss or sillimanitic biotite-quartz gneiss are also completely gradational, and the contacts drawn are approximate. As mapped most migmatite occurs in a broad zone separating large bodies of sillimanitic biotite-quartz gneiss from granite gneiss and pegmatite. Smaller bodies of metasedimentary rocks and granite gneiss and pegmatite may be interlayered, and the transition zone of migmatite is commonly too small to map even though it is present. The interlayering of the granite gneiss and pegmatite, migmatite, and biotite-quartz gneiss is shown in the geologic section (pl. 2).

Origin.—The origin of a mixed rock unit obviously involves the origin of its component parts. As has been previously stated, the metamorphic rocks of the Idaho Springs formation are believed to be principally metamorphosed sedimentary rocks. The origin of the granitic component of the migmatite and the manner of its emplacement in the metasedimentary component involve the origin of biotite-muscovite granite and the granite gneiss and pegmatite. The writers interpretation of field and laboratory data suggests that the biotite-muscovite granite is of magmatic origin and thus that the part of the migmatite containing biotite-muscovite granite could be called injection gneiss or attributed to assimilation affects. The data gathered on the granite gneiss and pegmatite are not conclusive as to whether this body is of metamorphic, metasomatic, or magmatic origin. The migmatite containing granite gneiss and pegmatite may have formed by metamorphic differentiation, metasomatism, or injection.

GRANITE GNEISS AND PEGMATITE

About 50 percent of the mapped area (pl. 2) contains scattered outcrops of granite gneiss and pegmatite. Some of the best exposures of this rock type are along the west side of the small valley extending southerly from Freeland. Other good exposures are on the north side of Trail Creek, near the eastern edge of the district.

All surface and underground exposures of contacts between granite gneiss and pegmatite and rocks of the Idaho Springs formation show that this unit is conformable. The contacts are gradational, commonly over zones that are several tens of feet wide, and the rock unit mapped as migmatite appears to represent this gradation between the gneiss and rocks of the Idaho Springs formation, principally biotite-quartz gneiss.

The granite gneiss and pegmatite unit ranges greatly in composition and contains rocks that could be classified as alaskite, granite, quartz monzonite, and granodiorite. The range in composition of the unit is indicated by figure 5*A* and by the approximate modes shown in table 6. The rock consists principally of quartz, microcline, and plagioclase (oligoclase-andesine) with some biotite and muscovite. The common accessory minerals are magnetite and sphene, but sillimanite, garnet, epidote, and zircon are present locally. Some of the alaskitic gneiss contains magnetite as the only iron-bearing mineral.

The granite gneiss and pegmatite is a pink to white medium- to coarse-grained and pegmatitic rock. Pegmatite forms irregular

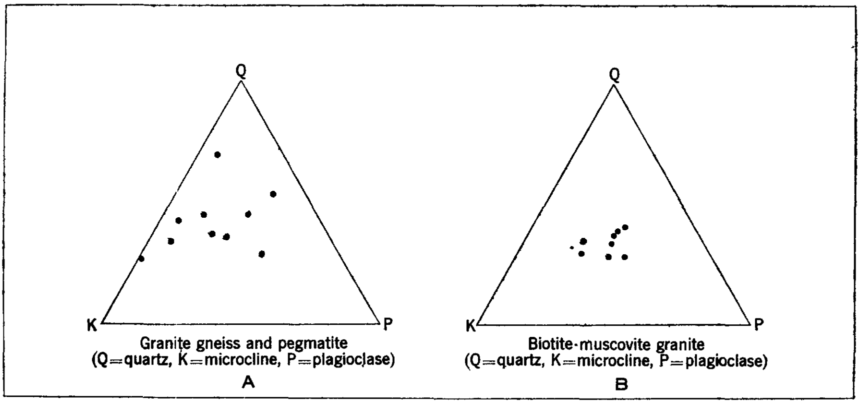


FIGURE 5.—Triangular diagrams showing variations in modal composition (volume percent) of granite gneiss and pegmatite and biotite-muscovite granite.

patches, lenses, and pods that are scattered through the rock and range in size from 1 inch to 500 feet in diameter. The alaskitic facies is commonly more pegmatitic than are the other facies, although all facies contain patches of pegmatite.

All but the alaskitic facies contain discontinuous streaks and wisps of mafic-rich materials and, commonly, 1 inch to 10 feet wide discontinuous layers, lenses, and pods of metadsedimentary rocks. Many of the inclusions in granite gneiss and pegmatite are highly contorted, and at some places only faint shreds of biotite strands in scroll-like patterns remain.

TABLE 6.—*Modes (volume percent) of granite gneiss and pegmatite*

	2–2a–154	2–5–13	2–5–49d	2–6a–56b	2–6a–109b	2–6b–70	358–6	370–3	BC–8	357–6
Microcline	19	54	24	9	39	41	28	40	33	70
Plagioclase	6	8	29	30	15	6	42	21	25	1
Quartz	58	32	44	44	44	34	29	38	33	27
Biotite	9	2	2	14	Trace	8	2	1	5	----
Muscovite	5	3	1	3	1	12	Trace	----	5	1
Magnetite	.5	Trace	Trace	.3	.4	Trace	Trace	Trace	Trace	Trace
Sillimanite	2	Trace	----	Trace	----	----	----	----	----	----
Sphene	----	Trace	----	Trace	Trace	----	----	Trace	Trace	----
Epidote	----	----	Trace	----	----	----	----	----	----	Trace
Zircon	----	----	----	Trace	----	----	Trace	Trace	----	----

2–2a–154: Medium-grained thinly layered granite gneiss from granite gneiss and pegmatite layer in migmatite on top of hill 700 feet northeast of the collar of the Crazy Girl shaft.
2–5–13: 1-inch-thick alaskitic granite gneiss and pegmatite layer in migmatitic granite gneiss outcrop on north side of road at Freeland.
2–5–49d: Alaskitic granite gneiss and pegmatite granulite on north side of quartz diorite sill 300 feet east of the portal of the New Era mine.
2–6a–56b: Coarse-grained granite gneiss layer in migmatite along road 600 feet east of the portal of the Old Stag tunnel.
2–6a–109b: Cataclastically deformed alaskitic granite gneiss and pegmatite from prospect pit 700 feet southwest of the collar of the Brighton shaft.
2–6b–70: Cataclastically deformed granite gneiss and pegmatite from outcrop on the nose of the ridge 800 feet southeast of the portal of the Teller tunnel.
358–6: Cataclastically deformed alaskitic granite gneiss and pegmatite from the lower tunnel, Little Johnie group of mines.
370–3: 1-inch-thick layer of alaskitic granite gneiss and pegmatite in migmatite from the upper tunnel, Little Johnie group of mines.
BC–8: Cataclastically deformed alaskitic granite gneiss and pegmatite from the Belle Creole mine.
357–6: Cataclastically deformed alaskite from the middle tunnel, Little Johnie group of mines.

The degree of gneissic structure and the composition of this gneiss are related to the abundance of inclusions in the gneiss. The greater the number of inclusions in the gneiss, the more apparent is its gneissic structure. Outcrops of the gneiss that contain no inclusions are poorly banded or massive. In composition, granite gneiss and pegmatite with few or no inclusions is an alaskite, and gneiss with abundant inclusions is granite, quartz monzonite, or granodiorite.

The foliations and lineations in the granite gneiss and pegmatite, in the layers and lenses of inclusions, and in the contorted inclusions are all oriented with the foliations and lineations of other pre-Cambrian rocks in the district. Minor local variations in the broader structural pattern have been traced from metasedimentary rocks into granite gneiss and pegmatite.

Most of this rock has a fractured appearance in outcrop. In some of the rock the large crystals have been broken but not shattered; in other parts of the rock, the large crystals consist of an aggregate of small crystals having irregular but smooth mutual grain boundaries—perhaps a hundred small crystals forming a patch half an inch in diameter. Quartz and feldspar commonly fill the fractures in the larger crystals and form tiny veinlets around and through the patches of the smaller crystals. This fabric is similar to that described by Ball (Spurr, Garrey, and Ball, 1908, p. 49–51) for the rock unit he called "gneissoid granite."

In thin section the gneiss is allotriomorphic granular. Foliation in the gneiss is a weak to moderate layering resulting from the concentration of the minerals into biotite-rich and quartz-feldspar-rich layers or into biotite-rich, quartz-rich, and feldspar-rich layers. Biotite is commonly in flakes along grain boundaries or in strands and is alined parallel to the layering. In the very weakly foliated varieties, the mineral layers are irregular and discontinuous.

Most of the plagioclase is partly altered—some grains have clear rims and altered cores and others in similar positions with respect to the same minerals have clear cores and altered rims; no explanation is apparent for this difference. Where fresh microcline forms irregular patches projecting into plagioclase or forms thin irregular veinlets along twin lamellae, plagioclase grades into antiperthite. About 50 percent of the plagioclase is twinned according to the albite, pericline (or acline), or carlsbad laws, or combination of these. Most microcline is fresh and slightly perthitic. Grains of microcline occur scattered through the rock, as well as in pods consisting of aggregates of small disoriented crystals. In the granulated parts of the granite gneiss and pegmatite, microcline has fractures filled with quartz, and contacts between grains commonly show a mortar structure formed by fine-grained quartz and microcline in a thin irregular band around a single grain or a group of grains. The quartz commonly shows strain shadows and is in large and elongate crystals, in pods or irregular strands parallel to the foliation, or in thin bands with microcline around microcline grains. Muscovite laths occupy fractures in the rock or form netlike patches in biotite, microcline, or altered plagioclase.

Origin.—The mortar textures and rehealed crystals indicate that the granite gneiss and pegmatite has been deformed by cataclasis subsequent to the crystallization of the original rock. The podlike agglomerations of crystals with mutual grain boundaries are interpreted as glomeroporphyroblasts, and, because the pods locally have mortar texture around or through them, they are believed to represent recrystallization of the gneiss (with or without introduction of new material) prior to cataclasis. Thus, the granite gneiss and pegmatite has been deformed at least once by cataclasis, and recrystallization has affected the rock to a limited extent at the time of cataclasis and to an unknown extent prior to this granulation. The geologic history of this rock unit is, therefore, very complex, and the ultimate origin of this granitic unit cannot be inferred from the data gathered in the district.

One conclusion seems clear from the field evidence—the granitic part of the migmatite and the granite gneiss and pegmatite are genetically related. No conclusive evidence has been found to show whether this genetic relation resulted from lit-par-lit injection of the Idaho Springs formation by an alaskitic magma, from either metamorphic differentiation or partial syntexis of the Idaho Springs formation, or both, or from transformation of the Idaho Springs formation by metasomatism.

GRANODIORITE

A few small bodies of granodiorite crop out in the western and southwestern parts of the mapped area (pl. 2), but because these bodies are small and poorly exposed, little could be determined about their age relations to the adjacent rocks of granite gneiss and pegmatite and biotite-muscovite granite.

The granodiorite is probably equivalent to the quartz monzonite mapped in the Georgetown quadrangle (Spurr, Garrey, and Ball, 1908, p. 51–54). About half of the Georgetown quadrangle as mapped by Ball is underlain by quartz monzonite, and the northern contact of a large mass of this rock is about half a mile south of Lamartine.

The small bodies of granodiorite in the Freeland-Lamartine district are usually well foliated, and much of the unit is granulated. These bodies may not be typical of the large masses, however, for Lovering and Goddard (1950, p. 27) stated that the small bodies of this rock are strongly crushed and granulated and that foliation is best shown in small bodies and at the margins of the larger bodies.

In the mapped area the granodiorite is a gray or mottled black and white medium- to coarse-grained gneissic rock. It is readily distinguished from granite gneiss and pegmatite by the more even distribution of the biotite and from the biotite-muscovite granite by its abundant biotite and deformed texture.

Origin.—The outcrops of granodiorite are too few and too poorly exposed in the Freeland-Lamartine district to allow a complete study of this rock unit. Ball (Spurr, Garrey, and Ball, 1908, p. 51) and Lovering and Goddard (1950, p. 27) believed this rock to be of igneous origin.

BIOTITE-MUSCOVITE GRANITE

The youngest granite in the Freeland-Lamartine district is a relatively undeformed biotite-muscovite granite that occupies about 10 percent of the mapped area (pl. 2). It is best exposed on Alps Mountain and on both sides of Trail Creek near Freeland. This granite is similar in fabric, mineralogy, and color to the Silver Plume granite from the type area at Silver Plume, Colo. Correlation of the biotite-muscovite granite with Silver Plume granite is not certain, and the writers prefer to call this rock by lithlogic name in this report.

Most of the bodies of the biotite-muscovite granite in the district are concordant, although some are sharply discordant. Many of the bodies are hook shaped and crescent shaped in their surface exposure and are in axial regions of folds (pl. 2).

Contacts between biotite-muscovite granite and other pre-Cambrian rock units are generally sharp, but locally the contacts are indistinct and transitional over a width of a few feet. At a few localities where this granite is in contact with metasedimentary rocks a transition zone of vaguely defined layers or irregular pods of granite and metasedimentary rocks separates typical granite from typical metasedimentary rock. This type of contact is rare in the district, and the transition zone is generally only a few inches wide. Most of the sharp contacts have a few inches to a few feet of pegmatite along them.

The granite ranges from a nearly massive rock to a foliated rock; the foliation results from nearly parallel arrangements of tabular microcline crystals and biotite laths. The foliation is subparallel to the contacts of the granite bodies.

At places the granite contains prominent subparallel fractures that commonly are spaced as close as one-eighth of an inch; at other places these fractures are only faintly visible in outcrops though prominent in thin sections, and at still other places these fractures are not megascopically visible though visible in thin sections. In this report the writers will refer to these fractures as incipient fractures. At localities where the incipient fractures are best formed, the surfaces of these fractures have slickensides outlined by ¼- to 1-inch-wide streaks of chlorite, biotite, and muscovite. The few slickensides observed are not consistent in bearing from layer to layer through the rock. At outcrops where the incipient fractures transect the foliation, individual crystals and planes of crystals are disrupted with the result that the foliation is almost destroyed.

In the Freeland-Lamartine district, the biotite-muscovite granite is a gray to tan or buff fine- to medium-grained rock that has seriate porphyritic texture. At places a fine-grained equigranular facies occurs in small, irregular bodies within the seriate porphyritic facies. All the facies are composed principally of microcline, plagioclase (oligoclase to sodic andesine), and quartz; biotite and muscovite are minor constituents. The accessory minerals include zircon, apatite, monazite, and magnetite. Eight modes of typical Silver Plume granite are shown in table 7, and the variation in composition is indicated by the triangular diagram (fig. 5*B*).

TABLE 7.—*Modes (volume percent) of biotite-muscovite granite*

	2-2a-135	2-6a-53	2-6b-7	2-7a-18a	2-7a-18b	BC-5	La-19	La-20
Microcline	26	30	42	21	25	28	42	35
Plagioclase	33	30	22	31	29	28	21	32
Quartz	24	31	28	38	34	31	33	28
Biotite	9	3	.6	6	4	4	1	2
Muscovite	6	4	6	4	7	8	3	2
Magnetite	1	1.3	.9	.6	Trace	Trace	Trace	.8
Apatite	Trace	Trace	Trace	Trace	Trace	----------	Trace	Trace
Zircon	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Monazite	Trace	----------	Trace	Trace	Trace	Trace	----------	----------

2-2a-135: Biotite-muscovite granite containing incipient fractures from outcrop on the ridge east of Freeland.
2-6a-53: Well-foliated granite from a small pod 800 feet southeast of the collar of the Gum Tree shaft.
2-6b-7: Well-foliated granite from an outcrop along Trail Creek 200 feet east of the point where the road crosses Trail Creek near Freeland.
2-7a-18a: Well-foliated granite from the east peak of Alps Mountain.
2-7a-18b: Well-foliated granite adjacent to a 2-inch pegmatite dike on the east peak of Alps Mountain.
BC-5: Faintly streaked granite from the Belle Creole tunnel.
La-19: Massive gray granite from the Lamartine tunnel.
La-20: Massive buff granite from the Lamartine tunnel.

In thin section the granite is allotriomorphic to hypidiomorphic-granular. Most of this rock has a seriate porphyritic texture—fresh microcline in anhedral to subhedral laths commonly forms crystals 6 millimeters long; altered plagioclase and quartz form crystals 1 to 3 millimeters in diameter; and quartz, plagioclase, biotite, and muscovite occur in the fine-grained groundmass. Opaque hairlike inclusions (rutile?) are abundant in most of the larger quartz crystals and in some of the larger plagioclase crystals. Myrmekite is common at the edges of plagioclase crystals where they contact microcline or quartz.

Thin sections of rocks containing the incipient fracture have a weakly formed mortar structure similar to that seen in the granite gneiss and pegmatite.

Most of the muscovite in the deformed rock occurs in the incipient fractures interleaved with biotite or in irregular patches and networks in microcline or plagioclase.

The granite has a high radioactivity—one typical fresh sample from the Lamartine mine assayed 0.006 percent equivalent uranium, 0.004 percent uranium, and 0.006 percent thorium. No discrete uranium minerals were recognized in the thin sections, but George Phair (oral communication, 1953) reported that from separations and analysis of accessory minerals he had tentatively concluded that the principal source of radioactivity in the granite is monazite.

Origin.—The small amount of deformation of the biotite-muscovite granite combined with an internal structure in the granite which parallels irregular contacts that crosscut older foliated rocks suggest to the writers that the granite is of magmatic origin. The foliation in the granite is, therefore, interpreted as flow structure rather than planes of minerals formed by metamorphic processes.

The incipient fractures are believed to be related to a postgranite stress distinct from the stress prevailing at the time of intrusion of the granite. Cloos (1933, p. 239) states that continued stress and subsequent movement after crystallization of a pluton results in fractures that are parallel to the flow structure. The incipient fractures in biotite-muscovite granite commonly transect the flow structure in the granite. The bearing of the slickensides on the incipient fracture surfaces does not parallel that of the foliation planes as described by Balk (1937, p. 106–107) for flat-lying normal faults. The texture of this granite containing the incipient fractures is similar to that of the deformed parts of the granite gneiss and pegmatite. The writers have tentatively concluded that the incipient fractures in biotite-muscovite granite are related in time to the cataclasis of the granite gneiss and pegmatite and that the cataclasis occurred after solidification of biotite-muscovite granite.

GRANITE PEGMATITE

Dikelike and podlike bodies of granite pegmatite cut all other pre-Cambrian rocks in the mapped area (pl. 2). One body, irregular in shape, was large enough to be mapped. The dikes range in width from 1 inch to 10 feet, and the pods are as much as 500 feet in diameter. The dikelike bodies are most common along joint surfaces in biotite-muscovite granite and older pre-Cambrian rocks, and as subconcordant layers in metasedimentary rocks. The podlike bodies of pegmatite are abundant in granite gneiss and pegmatite.

The pegmatite is a pink to white coarse-grained granite composed essentially of microcline (commonly perthitic) and quartz with minor albite. Locally the pegmatite contains black tourmaline or one-half of an inch thick books of muscovite or biotite. Pegmatite associated with the granite gneiss and pegmatite locally contains subhedral to euhedral crystals of magnetite as much as an inch in diameter; discontinuous stringers of magnetite as much as one-fourth of an inch thick are present in some outcrops.

Origin.—Most of the pegmatite in the district is believed to be genetically related to either biotite-muscovite granite or granite gneiss and pegmatite. The magnetite-bearing pegmatite and the nonmagnetite-bearing irregular patches and pods of pegmatite in the granite gneiss and pegmatite are believed related to that unit. The pegmatite around the margins of and in joints in the biotite-muscovite granite are believed to be related to that granite. Much of the pegmatite in the district, however, is not visibly connected with either of these granite rocks. As most of the nonmagnetite-bearing pegmatite throughout the district has a similar mineralogy and degree of deformation, masses of pegmatite not visibly connected with a granitic body cannot be readily separated into distinct age groups. Ball (Spurr, Garrey, and Ball, 1908, p. 60–64) found a similar problem in distinguishing between pegmatites of three different ages that occur in the Georgetown quadrangle.

TERTIARY INTRUSIVE ROCKS

Porphyritic intrusive rocks—quartz monzonite, alaskite, syenitic bostonite, and quartz bostonite—occur as dikes and small plugs that cut the pre-Cambrian rocks in the Freeland-Lamartine district. So far as known, the intrusive rocks are confined to the southeastern part of the mapped area (pl. 2). The dikes range in length from 200 to 2,600 feet, and in width from a few feet to 100 feet; generally the width is about 15 feet. Most of the dikes trend northeasterly, but a few trend northwesterly. Because of the sparse exposures, little is known concerning the true dip of the dikes, but their surface traces suggest that all are vertical or dip steeply to the north. The age of the dikes has been established as early Tertiary by Lovering and Goddard (1950, p. 47).

The sequence of intrusion of the porphyries in the Freeland-Lamartine district cannot be determined. Phair (1952, p. 20–22) inferred from work in the Central City district that the sequence is monzonite, syenitic bostonite, quartz bostonite. The alaskite is indicated by Lovering and Goddard (1950, p. 44–47) to be younger than the monzonite and older than the bostonite.

An alaskite plug with a radiating dike pattern occurs near the eastern boundary of the mapped area, and a syenitic bosonite plug was mapped on the ridge southwest of the collar of the Invincible shaft. The geometric pattern of those bodies, particularly of the alaskite, suggests that they were forcefully intruded.

CLASSIFICATION

Phair (1952) classified the Tertiary intrusive rocks of the Central City district, 5 miles to the northeast, according to overall texture, groundmass texture, quartz content, type of feldspar, and presence or absence of mafic minerals. Phair also presented a correlation between the type of intrusive and a range of radioactivity. In this report Phair's classification has been followed with but slight modification because of minor differences in the mineralogy and radioactivity (table 8). Phair gave the range of radioactivity for the syenitic bostonite in the Central City district as greater than 0.004 percent and less than 0.007 percent equivalent uranium; in this report the upper limit has been extended to 0.009 percent equivalent uranium. A rock type has been added to Phair's table, the alaskite porphyry, that has a moderate range of radioactivity and a usual mineral content for alaskites. The samples of quartz bostonite from the district are so intensely altered that the data on their radioactivity is unreliable and is not presented in this table as characteristic.

TABLE 8.—*Classification of the Tertiary intrusive rocks.*

[Classification modified from Phair (1952)]

Rock type	Average equivalent uranium (percent)	Diagnostic features
Nonporphyritic quartz bostonite	>0.014	5-15 percent quartz, <5 percent phenocrysts, bostonitic texture, usually reddish brown in hand specimen.
Quartz bostonite porphyry	>.007, <.014	5-15 percent quartz, potash feldspar, >5 percent phenocrysts, bostonitic texture, usually lilac in hand specimen.
Syenitic bostonite porphyry	>.004, <.009	<5 percent quartz, potash and plagioclase feldspar phenocrysts, may contain hornblende or garnet, faintly to well-defined bostonitic texture, lilac to brown in hand specimen.
Alaskite porphyry	>.006, <.007	High quartz content in groundmass, no plagioclase phenocrysts, <5 percent mafic, poikilitic granular groundmass texture, gray to buff in hand specimen.
Quartz monzonite porphyry	>.002, <.007	5-15 percent quartz, potash and plagioclase feldspar phenocrysts, may contain quartz, hornblende, or biotite phenocrysts also, granular texture, gray in hand specimen.

In spite of the intense alteration of the rocks in the district, reasonably certain identification of the rocks has been made from the combined megascopic, microscopic, and radioactivity data. Only rarely was it possible to determine the type of plagioclase in the rock, and in some specimens the plagioclase could not be distinguished from the potash feldspar. Secondary quartz is present in a few of the specimens complicating the estimation of original quartz content. The ferromagnesian minerals can be recognized only by crystal outline and alteration products in most slides.

The bostonites are distinguished from the monzonite and alaskite on the basis of groundmass texture and hand-specimen color (see table 8); the quartz bostonite from the syenitic bostonite, on the basis of quartz content and presence of mafic minerals in the syenitic bostonite; and the monzonite from the alaskite, by the presence of plagioclase phenocrysts in the monzonite.

QUARTZ MONZONITE PORPHYRY

South of Trail Creek near the abandoned town of Freeland, the quartz monzonite porphyry forms branching dikes that trend northeasterly and easterly. The quartz monzonite is a gray to buff with black flecks fine- to medium-grained seriate porphyritic rock consisting essentially of quartz and plagioclase. The rock commonly contains 5 to 15 percent of quartz, feldspar, and hornblende phenocrysts, some of which are zoned. The weathered rock is buff to yellowish brown with white phenocrysts.

Microscopically the groundmass is fine grained (0.05 to 0.2 mm), allotriomorphic to poikilitic granular (term described under Alaskite porphyry), and consists predominantly of quartz with magnetite flecks. The phenocrysts of plagioclase, sanidine, ferromagnesian minerals, apatite, and topaz are euhedral and range in size from the groundmass to 4 millimeters in length. Some plagioclase phenocrysts are twinned, others are not. The completely twinned plagioclase phenocrysts are albite and exhibit albite or, more rarely, carlsbad-albite twinning. The few crystals with untwinned centers are compositionally zoned; the centers are oligoclase, and the margins are nearly pure albite. An analysis of one thin section of a specimen with allotriomorphic granular groundmass gave a mode of 66 percent quartz, 2 percent potash feldspar, 28 percent plagioclase, 4 percent ferromagnesian minerals, and trace amounts of magnetite, apatite, and topaz.

The radioactivity of the quartz monzonite in this area is low, from 0.003 to 0.004 percent equivalent uranium.

ALASKITE PORPHYRY

Alaskite porphyry occurs as a small plug with radiating dikes near the eastern boundary of the district and as a short northwestward-trending dike near the central part of the district.

The alaskite is a gray to buff fine- to medium-grained porphyritic rock commonly containing 15 to 20 percent of phenocrysts. The rock consists essentially of quartz and potash feldspar. The groundmass has a porcelaneous to flinty surface, and the phenocrysts are equidimensional. The weathered surface is gray to buff and generally is pitted owing to the removal of the phenocrysts.

Microscopically the rock is characterized by a poikilitic granular groundmass in which small (0.1 to 0.4 mm), irregular to circular quartz grains with mutually sutured boundaries include small euhedral to subhedral grains, probably feldspar. These small grains are cloudy with a leucoxenelike appearance in the more altered specimens. The phenocrysts are orthoclase, sanidine, and small quantities of ferromagnesian minerals, magnetite, sphene, and topaz. The orthoclase phenocrysts are generally more abundant, more altered, and larger (2 to 3 mm) than the sanidine (1 to 2 mm). The ferromagnesian minerals (1 to 2 mm in length) are completely altered to sericite and magnetite. The approximate mode (volume percent) is 44 percent quartz, 52 percent orthoclase, 2 percent ferromagnesian minerals, and trace amounts of topaz, sphene, and magnetite.

The radioactivity of the alaskite porphyry ranges from 0.006 to 0.007 percent equivalent uranium although one sample, taken near a radioactive vein, assayed 0.011 percent equivalent uranium.

SYENITIC BOSTONITE PORPHYRY

Syenitic bostonite is the most abundant type of dike rock in the district and forms small elongate plugs and branching dikes that trend northerly and northeasterly across the east-central part of the mapped area. The northward-trending dikes are in a group geographically separate from a group of northeastward-trending garnet-bearing dikes.

Syenitic bostonite is a lilac to brown fine- to medium-grained seriate porphyritic rock that commonly contains 10 to 65 percent of phenocrysts. The weathered rock is gray to buff, and the surface may be pitted owing to the removal of phenocrysts, especially of the mafic minerals. The rock consists essentially of orthoclase, plagioclase, and amphibole; black garnet occurs in subordinate amounts. The feldspar phenocrysts are both zoned and unzoned, and the amphibole commonly occurs as radiating aggregates.

Microscopically, the groundmass has a trachytoid or faintly trachytoid texture that commonly shows marked flow structure around the phenocrysts. The feldspar phenocrysts are as much as 1.5 centimeters long and are plagioclase (albite, showing albite twinning) and orthoclase.

The unaltered rock contains less than 5 percent of primary quartz; the altered rock, however, commonly has veinlets or pods of fine-grained and chalcedonic quartz that at places amounts to several percent. The ferromagnesian minerals are as much as 1.5 millimeters long and have been altered so that only pseudomorphs of chlorite, sericite, quartz, and magnetite remain. The accessory minerals are sphene, magnetite, and zircon. The approximate mode, considering the groundmass as orthoclase feldspar is 75 to 80 percent orthoclase, 8 to 19 percent plagioclase, 2 to 4 percent ferromagnesian minerals, 1 percent garnet, and trace amounts of magnetite, zircon, apatite, and calcite. The garnet content may be relatively large as shown by one specimen that contained 4 percent garnet. The quantity of orthoclase as phenocrysts is relatively constant at about 21 percent.

In thin section the garnet forms euhedral crystals as much as 2 millimeters in diameter. The garnet is brown and is generally altered to limonite, chlorite, and calcite. The index of refraction determined in oils is about midway between 1.852 and 1.861. An X-ray analysis by A. J. Gude 3d, U. S. Geol. Survey laboratory, gives a_0 to be 12.013 angstrom units. The refractive index and a_0 of the garnet indicate that it consists principally of the andradite molecule.

The radioactivity of the syenitic bostonite porphyry ranges from 0.003 to 0.009 percent equivalent uranium. The garnetiferous variety has lower radioactivity (0.003 to 0.006 percent equivalent uranium) than the nongarnetiferous variety (0.006 to 0.009 percent equivalent uranium).

QUARTZ BOSTONITE

The quartz bostonite in the district consists of both the porphyritic and nonprophyritie varieties. The nonporphyritic quartz bostonite occurs as dikes on the ridge near the north boundary of the area. This rock is fine grained and intensely altered to a tan. The characteristic quartz grains poikilitically enclosing feldspar laths and the trachytiod texture, though poorly formed, can be seen in thin sections of this rock.

Only one specimen of porphyritic quartz bostonite was found in the district. This specimen, from the dump of the Diamond Mountain mine, is not considered representative because it is intensely altered.

The radioactivity of the samples of quartz bostonite from the district is lower (0.006 to 0.010 percent equivalent uranium) than that of the quartz bostonites in the Central City district (Phair, 1952). The low radioactivity may be due to the intense alteration of the rock.

QUATERNARY DEPOSITS

Three types of unconsolidated Quaternary deposits were mapped in the Freeland-Lamartine district—solifluctional debris, avalanche ridges, and alluvium. The solifluctional debris occurs in sheets as broad high-basin deposits as well as in valley fills and consists of unsorted material ranging in size from boulders to silt. Avalanche ridges, consisting of poorly sorted material ranging in size from silt to cobbles, occur in some of the tributary valleys of Trail Creek. The alluvium is on the valley floor of the major stream.

SLUMP DEPOSITS

Two solifluctional debris sheets of unsorted heterogeneous rock fragments are at the head of Trail Creek between altitudes of 10,200 and 10,700 feet (pl. 2). The sheets occur in broad basins and have irregular terraces marking their surfaces. One is about 1,500 feet wide and 3,000 feet long; the other is about one-fifth as large. The thickness of these debris sheets is unknown, but similar sheets are reported by Spurr, Garrey, and Ball (1908, p. 87) to range from 20 to 100 feet in thickness. Debris similar to that in the sheets fills parts of the valleys of the tributaries to Trail Creek.

The debris sheets and valley fills are composed of material from the surrounding ridges. The rock fragments range in size from boulders to silt; they are not sorted. The deposits appear to be colluvial and slump material of local origin. Gerald Richmond, who has studied the Pleistocene geology of parts of the Front Range, stated (oral communication, 1953) that the solifluctional debris sheets at the altitude of those at the head of Trail Creek are Wisconsin in age and are probably early Wisconsin.

AVALANCHE DEPOSITS

Small ridges of poorly sorted silt, sand, and cobbles occur along two of the small tributaries of Trail Creek. The ridges are about 50 feet wide on the crest and have a relief of about 20 feet above the valley floor. These ridges have been noted only in small valleys on north-facing slopes. The ridges are probably the result of movement of water-saturated slump debris. These deposits according to Richmond (oral communication, 1953) are also Wisconsin, probably early Wisconsin, in age.

ALLUVIUM

A thin cover of Recent alluvial material is present along the valley flat of Trail Creek. Some of this material is mill tailings from mills no longer working. An old 10-stamp mill below the dump at the Lamartine shaft contributed much of the material mapped as alluvium on the north-facing slope at the head of Trail Creek (pl. 2).

STRUCTURE

The bedrock in the Freeland-Lamartine district is a generally conformable series of metamorphic and igneous rocks. The rocks were folded during pre-Cambrian time, and many of the folds are now outlined by the lithologic layering. The rocks are jointed and are cut by numerous faults; some of the joints now contain porphyry intrusive rocks of Tertiary age, and many of the faults locally contain gold-silver-lead-zinc ores of Tertiary age.

The structural history of the bedrock in the Freeland-Lamartine district is complex. Several of the elements involved in creating the present structural pattern cannot be dated with much accuracy. A general summary of the structural history follows: (1) Late pre-Cambrian northeast folding accompanied by intrusion of biotite-muscovite granite; (2) northwest warping and cataclastic deformation of biotite-muscovite granite and granite gneiss and pegmatite; (3) early Laramide(?) arching resulting in the formation of the regional joint pattern; and (4) Tertiary fracturing and faulting followed by intrusion of dikes and deposition of hydrothermal veins.

FOLDS

Two fold systems can be recognized in outcrops in the district. Broad arcuate patterns of some of the rock units serve to outline some of the larger folds, and traces of axial planes of the folds are shown on the geologic map (pl. 2). The most prominent fold system trends northeasterly, and the axis of this system is called b_1 in this report. The selection of b_1 is based upon evidence of a strong crumpling of the rocks into compressional folds trending in a northeastward direction. A much less prominent fold system trends northwesterly, and the axis of this system is called b_2 in this report. The selection of b_2 is considered tentative as it was chosen on the basis of a persistent northwesterly lineation and observed warping along northwesterly trends of the major folds.

Lineations related to both of the fold systems are present in outcrops of the district. The types of lineations present include mineral alinement, streaks, crinkles (small crenulations whose amplitude to wave length ratio is about 1:1), warps (crenulations whose amplitude to wave length ratio is about 1:2 or smaller), drag folds, and fold axes. All of these types of lineations are found on both fold systems in both the *a* and *b* directions. Most of the lineations are in *b* directions; that is, parallel to the axis of the major or minor fold system. A few lineations were found in *a* directions; that is, perpendicular to the major or minor fold axes.

All of the lineations measured in surface outcrops were plotted on the lower hemisphere of a Schmidt equal-area net. The net was then contoured, and the resulting diagram is shown in figure 6. Both of the fold systems recognized in the field are represented on this diagram. The major fold system (b_1) is indicated by the strong "bullseye" and has an average plunge of 27° N. 20° E. The minor fold system (b_2) is indicated by the smaller "bullseye" and has an average plunge of 47° N. 28° W. Because the lineations in b_1 tend to be deflected as

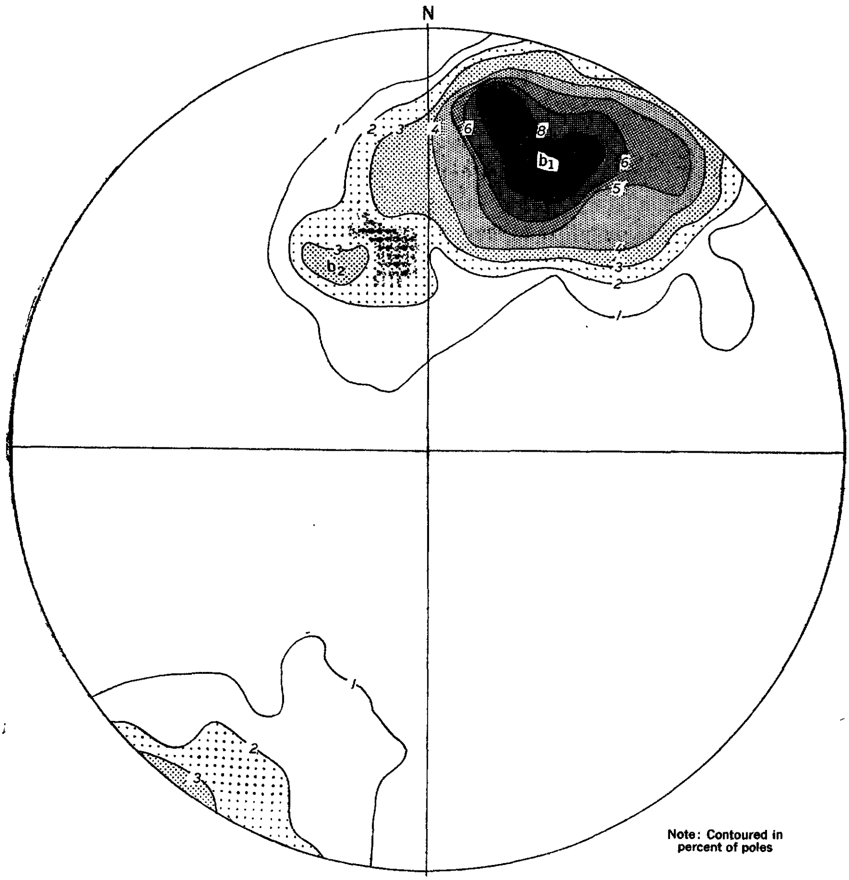


FIGURE 6.—Contour diagram of lineations, lower hemisphere plot of 344 poles.

they pass over the crests of the b_2 folds, the minor fold system is considered to be younger than the major fold system.

The fold axes are sinuous both horizontally and vertically. Changes in strike of the traces of axial planes (pl. 2) represent somewhat the change in direction of fold axes; variation in amount and direction of plunge of one of the folds is shown on the cross section (pl. 3) which is almost parallel to the axial plane of one of the major folds.

Upright, overturned, and recumbent folds are observed in the district. The recumbent folds are sparse and most of them are small (1 to 8 inches across). Overturned folds are common along the flanks of the major folds which trend northeasterly across the center of the mapped area (pl. 2). Details of some of the overturned folds are shown in the vertical section along the Old Stag tunnel (pl. 4) which has been driven through the northwest flank of a major fold.

Because the folds open out into upright folds toward the axial region and the axial planes of the folds on the flanks converge upward, the major fold could best be described as an abnormal anticlinorium. Toward the eastern edge of the mapped area (pl. 2), the major folds are more open and exhibit little overturning on their flanks. The vertical section through the Freeland-Lamartine district (pl. 2) is approximately perpendicular to the trend of the major fold axes and illustrates both open and overturned folds on the flanks of certain of the major folds.

The distribution of certain of the rock units is clearly related to the folds. One of the most apparent relations shown on the geologic map occurs where phacoliths of biotite-muscovite granite outline fold crests and troughs. In addition, most of the metasedimentary rocks in the granite gneiss and pegmatite are found on fold crests or troughs (pl. 2), and the pinch and swell of rock layers along fold axes appears to be partly related to changes in plunge of the fold axis (pl. 3 and fig. 7).

Age relations of the folding.—Dating of the folding is based primarily on whether rocks in the district have been plastically or cataclastically deformed, or both. The older folding was plastic, and the younger folding was cataclastic in part. The only rock unit that appears to show only cataclastic effects is the biotite-muscovite granite—the youngest pre-Cambrian rock in the district. This granite is, however, in phacoliths along folds of the older system. These data are interpreted as indicating that the older fold system plastically deformed all rocks younger than biotite-muscovite granite which was intruded in phacolithic bodies into fold crests and troughs late in the northeast folding. A later warping of the older northeastward-trending system produced the minor northwestward-trending fold system. The final stages of the warping caused cataclasis that is now most evident in the granite gneiss and pegmatite and the biotite-muscovite granite.

FAULTS

GENERAL STATEMENT

Although most of the faults in the Freeland-Lamartine district dip steeply to the north, the Freeland group and the Turner-Falu are exceptions in that they dip only 30°–50° NW. Many of the faults are bordered by zones of sheeting and fracturing, indicating repeated movement along the fault or fault zone. Although local areas on a fault may show slight reverse movement, the overall movement has been normal. In addition to dip-slip movement, strike-slip movement has occurred, causing the northwest blocks to move northeast relative to the southeast blocks. As the faults all dip to the north,

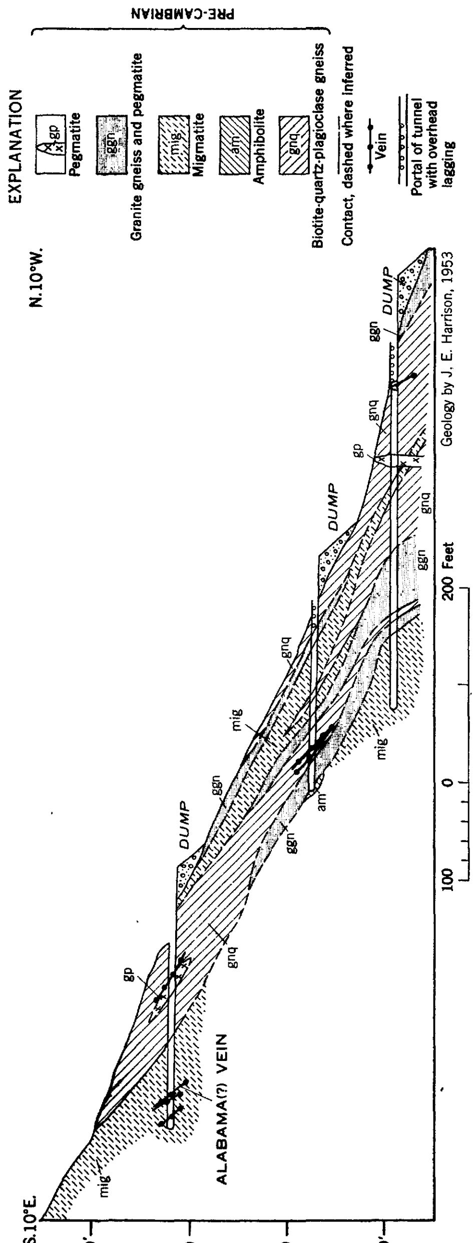


FIGURE 7.—Vertical projection through the Little Johnie group of mines.

the general movement on the faults in the district is for the northwest blocks to move down and to the northeast relative to the southeast blocks. The age of the faulting has been established as Tertiary by Lovering and Goddard (1950, p. 44–47).

The amount of movement on the faults generally has been small. Many veins of the district cross without noticeable displacement. An apparent horizontal offset, however, of about 100 feet was mapped on the surface where a Tertiary dike is offset along the Freeland vein.

Evidence that the faults containing the veins were formed under regional shear stress is presented by Lovering and Goddard (1950, p. 80) who have concluded that the main shear couple was composed of stresses exerted toward the northeast on the northwest side of the mineral belt and toward the southwest on the southeast side of the mineral belt. This conclusion is borne out by the movement on faults in the Freeland-Lamartine district.

SEQUENCE OF FAULTING

Three principal sets of faults, those trending north-northeastward, east-northeastward, and eastward, have formed under the regional shear stress. In plate 2 and figure 8 the faults are indicated by the veins which occupy them. In figure 8 the major veins in the district have been projected to 9,500 feet altitude to eliminate the effect of topography on the true strike.

Data on age relations among the fault sets, although not abundant, are consistent. The north-northeastward-trending faults, represented by the Oneida, Great Western, Lone Tree, New Era, and Freeland veins, are crosscut and sometimes offset by east-northeastward- and eastward-trending faults. The Great Western vein is offset along the Mendick (east-northeast) vein in the New Era mine. In this same mine, in an exposure at the junction of the main tunnel and the southernmost crosscut, the New Era vein is offset along an eastward-trending vein. The Oneida vein is cut by eastward-trending veins in at least two places along the Lamartine tunnel.

The trace of axial planes of pre-Cambrian folds and the trace of veins occupying the oldest faults is essentially parallel as is shown in plate 2. Mapping of the New Era, Old Stag, and Lamartine mines has shown that the north-northeasterly veins tend to follow axial planes of pre-Cambrian folds. The first breakage of the bedrock under Tertiary shear stress was selective in that the rock broke along preexisting planes of weakness.

The east-northeastward-trending faults, represented by the Mendick, Golden Rod, Alabama, Crazy Girl, and Miller veins, are younger than the north-northeastward-trending faults but older than the eastward-trending faults. Near the junction of the Oneida vein (here

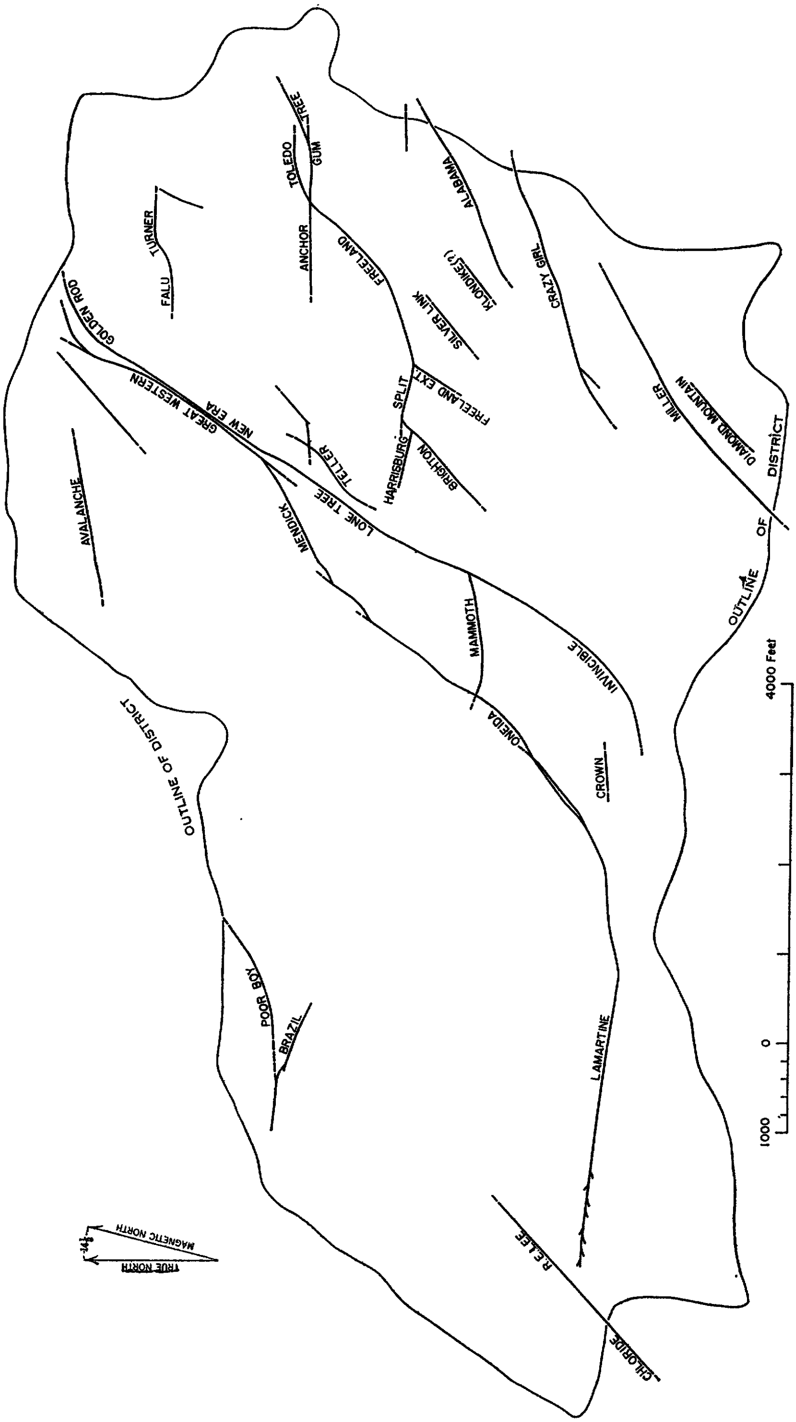


FIGURE 8.—Traces of major veins in the Freeland-Lamartine district projected to an altitude of 9,500 feet.

trending east-northeastward) and the Lamartine vein (eastward-trending vein) in the Lamartine tunnel, eastward-trending fractures not only cut through the Oneida vein but are also filled with minerals characteristic of the Lamartine vein. In the Turner mine, the east-northeastward-trending part of the vein is cut by eastward-trending faults. The relations are particularly well exposed on the third level to the west of the underground shaft.

The east-northeastward-trending faults have the position of tension fractures related to the north-northeastward-trending faults, but the movement on them has been by shear, at least in part.

Eastward-trending fractures cut through and locally offset both north-northeastward- and east-northeastward-trending faults. The eastward-trending faults are represented by the Lamartine, Mammoth, Crown, Harrisburg, Split, and Anchor veins. These faults are clearly the youngest in the district. They may either be tension fractures related to the east-northeastward-trending faults or pre-existing joints along which later movement has taken place. As the two most prominent preshearing joint sets in the district trend slightly north of east and slightly south of east (see p. 70 and figs. 10, 11), and as these joints are weakly mineralized in many outcrops of the district, the writers prefer the explanation that the eastward-trending faults formed by movement on preexisting joints.

Interpretation of the data on the age relations among the three fault sets has led to the determination of age relations expressed diagrammatically in figure 9. The total amount of time expressed in this diagram is probably a small part of the Tertiary period; the east-northeastward-trending faults are essentially contemporaneous with, but slightly younger than, the north-northeastward-trending faults; and the eastward-trending faults are essentially contemporaneous

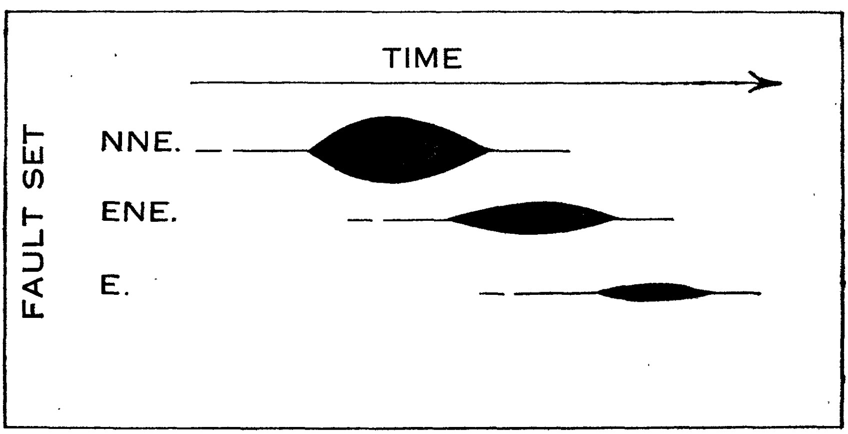


FIGURE 9.—Diagram illustrating the age relations among the fault sets.

with, but slightly younger than, the east-northeastward-trending faults.

In general, faults belonging to the younger sets formed principally at the ends of the next previous set. The north-northeastward-trending faults formed approximately parallel to axial planes of folds in the pre-Cambrian bedrock; these faults were followed by east-northeastward-trending tension fractures which formed at both ends of the north-northeastward trending faults; and finally, eastward-trending faults formed at the ends of the east-northeastward-trending fractures probably as a result of movement along preexisting joint surfaces. The pattern resulting from the combination of fractures in this manner is one which shows long cymoid-shaped fissures.[2] These are well illustrated by the Freeland, Oneida, and Lone Tree veins (fig. 8). The central parts of these cymoids are the oldest fractures, and the ends of the cymoids are the youngest.

JOINTS

GENERAL STATEMENT

Joints are present in all of the rocks in the Freeland-Lamartine district, and considerable data concerning them were collected during surface geologic mapping. The joints were plotted on the upper hemisphere of a Schmidt equal-area net by using the pole of the plane which describes the joint surface in the field (fig. 10). The upper hemisphere was chosen for this plot because the pole thus plotted falls into the quadrant of its true dip direction; that is, the pole of a plane dipping northeastward falls into the northeast quadrant of the diagram.

REGIONAL JOINT PATTERN

A statistical representation of the regional (district-wide) joint pattern is shown in figure 10. The poles of 1,680 joints in all rock types were plotted on a net which was then contoured. The data shown on this diagram are approximately in proportion to the areal extent of the rock types; about 50 percent of the data is from granite gneiss and pegmatite; 25 percent, from metasedimentary rocks; and 25 percent, from biotite-muscovite granite.

The contour diagram discloses four prominent joint sets. The most prominent joints strike N. 74° W. and N. 82° E. and dip 68° and 62° N. respectively. Field data are insufficient to state whether the prominent joints at N. 77° W., 82° SW. are related to the N. 74° W., 68° NE. joints or represent pre-Cambrian cross joints. Next most prominent are joints which strike N. 22° W. and dip 79° NE. The

[2] A cymoid is a reverse curve in which a line swerves from its course and then swings back again, resuming a direction parallel to its former course but not in line with it (McKinstry, 1948, p. 315).

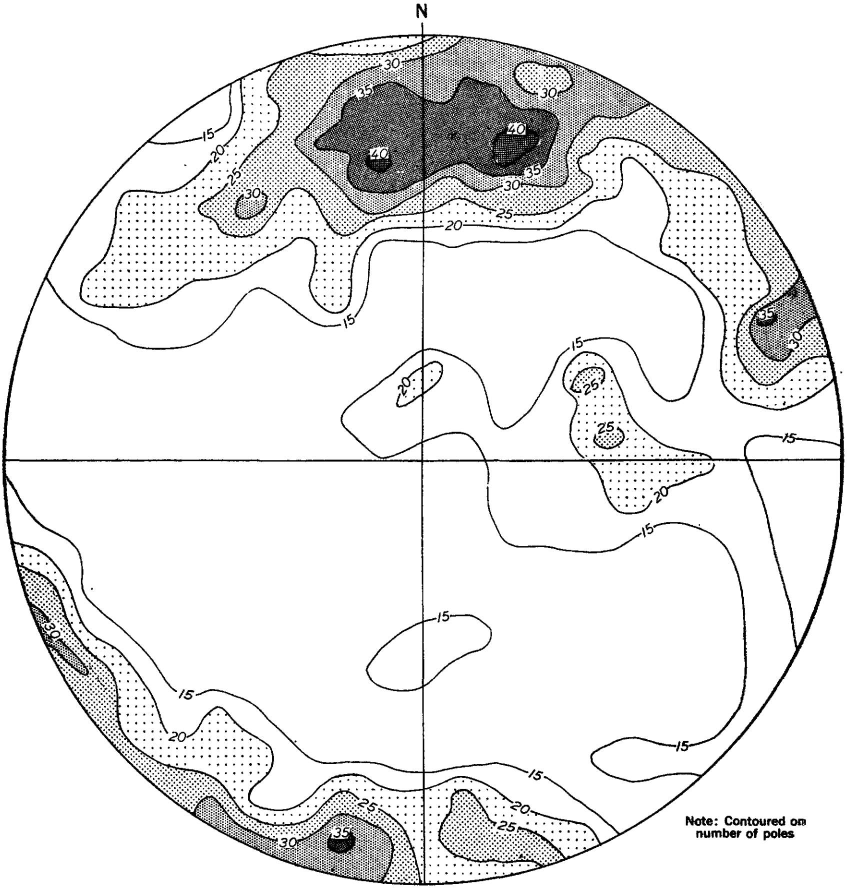
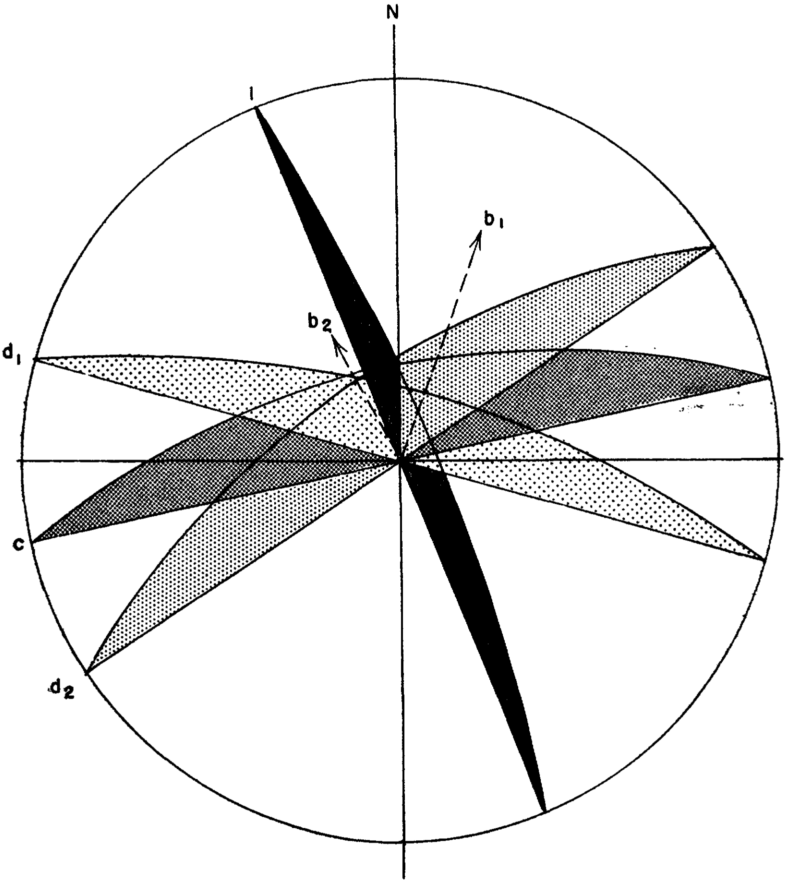


FIGURE 10.—Contour diagram of joints, upper hemisphere plot of 1,680 poles.

fourth and weakest recognizable joint set strikes N. 56° E. and dips 63° NW. These joint sets were plotted on the lower hemisphere of a stereographic net; the resulting diagram is shown in figure 11.

This diagram is interpreted to indicate that a joint system is present containing longitudinal (*l*), cross (*c*), and two diagonal (d_1 and d_2) joint sets. The major fold axis (b_1) and the minor fold axis (b_2) have been plotted on this diagram for comparison. The strike of the longitudinal joint (*l*) should coincide with the bearing of one of the pre-Cambrian fold axes if the regional joint pattern is related to pre-Cambrian folding. In addition, the cross joint (*c*) should be approximately at right angles to a related fold axis. The trend of the major fold axis (b_1) does not parallel the strike of the longitudinal joint set (*l*). Although the trend of the minor fold axis (b_2) is near the strike of the longitudinal joint set (*l*), the cross joint (*c*) dips 62° NW., whereas



l–longitudinal joint; d_1 and d_2–diagonal joints; c–cross joint; b_1–major fold axis, b_2–minor fold axis

FIGURE 11.—Stereographic diagram showing main joint sets and principal fold axes.

it should dip 43° SE. if related to the minor fold axis (which plunges 47° NW.). The tentative conclusion drawn from these data is that the regional joint pattern is not related to the pre-Cambrian folding. This is not to say that there are no joints in the district that are related to the folding but rather that the most prominent and extensively formed joint sets are not related to the folding.

The formation of the regional joint pattern cannot be dated with great accuracy. The regional joint pattern does not appear to be the result of Tertiary fracturing, yet it has been imposed upon the pre-Cambrian folding; therefore, the pattern can only be dated as post-pre-Cambrian and pre-Tertiary. Lovering and Goddard (1950, p. 57–58) gave a brief summary of the Laramide structural history of the Front Range region. They stated that the Front Range highland (as shown in fig. 3) was a positive area intermittently during the Paleozoic and Mesozoic eras and that the last uplift of the Front Range probably began in Late Cretaceous (Pierre shale) time. The present Front Range highland is an oblong area trending about N. 22° W., and this trend is the same as that of the longitudinal joint set in the Freeland-Lamartine district. The cross joint set in the district suggests a fold or warp related to this joint which would plunge about 28° SE. The Front Range highland disappeared under younger sedimentary rocks south and southeast of Cripple Creek, Colo., southeast of the Freeland-Lamartine district. The accordance between the regional joint pattern of the Freeland-Lamartine district and that expected from a study of the Laramide structural history of the Front Range has led the writers to infer that the regional joint pattern is early Laramide in age.

ECONOMIC GEOLOGY

The Freeland-Larmartine district, in the Front Range mineral belt, contains gold-, silver-, copper-, lead-, and zinc-bearing veins that were formed as hydrothermal fissure fillings in faults. Replacement of the wall rocks by the ore minerals was unimportant as a method of formation of the ore deposits. Most of the veins have smooth walls; slickensides are abundant but inconsistent in bearing and plunge. The fissures are fairly regular in strike and dip, and irregularities, where present, commonly provided favorable structures for the deposition of the ore minerals.

The principal ore minerals are sulfides and sulfosalts of iron, copper, lead, and zinc, but locally some free gold was found. Three types of veins have been mined in the district: pyrite-gold veins mined chiefly for gold; galena-sphalerite veins mined chiefly for silver, lead, and zinc; and composite veins mined for gold, silver, and lead. Most of the veins in the district are of the galena-sphalerite or composite type. Quartz is the most abundant gangue mineral, but carbonates locally form as much as 80 percent of the gangue.

Lead-uranium determinations on pitchblende from veins in the Central City district (about 5 miles northeast of the Freeland-Lamartine district) made by Holmes (1946) and by Phair and others (George Phair, written communication, 1954), indicate an age for those veins of about 60 million years (early Tertiary). As the veins in the Freeland-Lamartine district are in the same geologic setting as the veins in the Central City district, it seems probable that these two groups are the same age.

PRODUCTION FROM THE DISTRICT

Production records for the mines of the district are nearly complete for the period 1905 to 1953.[3] Previous to 1905 systematic records were not kept for all mines in the district. On the basis of existing information, however, the writers estimate that from 1868 to 1905 ore valued at $5 million or more was extracted. The production figures given in this report for mines that were operated prior to 1905 should be considered as minimum values.

From 1905 to 1953 the total recorded yield of metals from the district was about 100,000 ounces of gold, 3,277,000 ounces of silver, 250 tons of copper, 6,000 tons of lead, and 800 tons of zinc. The value of this ore at 1953 market prices was more than $13 million. Most of the ore came from the Lamartine-Great Western and the Freeland groups of veins.

CLASSIFICATION OF THE VEINS

Spurr, Garrey, and Ball (1908, p. 97–101) recognized two types of veins in the Georgetown quadrangle: silver-bearing veins without important amounts of gold (galena-blende ores) and gold-bearing veins with or without silver (pyritic ores). They also recognized that at places both types of ores occurred together and stated (p.100) that "these phenomena were characteristically found on the borders between an area of predominantly gold-bearing veins and an area of silver-bearing veins." Bastin and Hill (1917, p. 105–114) recognized similar vein types in Gilpin County and referred to the mixture of the two types of ore as "composite ore." Bastin notes (Bastin and Hill, 1917, p. 113) that in the composite ore, veinlets of the galena-sphalerite type sharply crosscut ore of the pyritic type. The general classification of vein type proposed by Spurr and Garrey and by Bastin and Hill is followed in this report. Two main types of ore are recognized: (1) pyrite-gold ore and (2) galena-sphalerite ore. A third type is composite ore, which occurs where ore of type (1) is crosscut by veinlets of ore of type (2).

The pyrite-gold ore consists predominantly of pyrite and auriferous pyrite, with subordinate amounts of chalcopyrite and tetrahedrite-tennantite and traces of galena and sphalerite. The gangue is quartz, and carbonate, if present, is usually siderite. This type of ore is usually massive but locally is weakly banded in part. Pyrite-gold ore is characteristic of the Oneida, Freeland, and part of the Lone Tree veins.

The galena-sphalerite ore consists predominantly of galena, argentiferous galena, sphalerite, and pyrite with subordinate amounts of

[3] U. S. Bureau of Mines, published with permission.

chalcopyrite and tetrahedrite-tennantite. In most veins the gangue accompanying this type of ore is composed of about equal amounts of quartz and carbonate. The carbonate gangue is mostly rhodochrosite and calcite with smaller amounts of ankerite and dolomite. This type of ore is usually banded. Galena-sphalerite ore is characteristic of all veins in the district with the exception of the Oneida, Freeland, and Lone Tree veins.

The composite ore is in a transitional zone along a single vein between pyrite-gold and galena-sphalerite ore. A good exposure of a transition zone containing composite ore is along the Lamartine tunnel, in the area southwest of the Johnston shaft. The large scale observation of Spurr and Garrey on the geographic distribution of composite veins (see p. 74) appears to be a feature that can also be observed on a small scale.

The limits of the zones of composite ore are difficult to delineate, and, accordingly, the veins are classified into the two principal types (pl. 5); the data for some veins was insufficient to assign it to one of the principal vein types, so it is reported as "type not known." The data on which the division into the two principal vein types is based are given on pages 87–123. Along each vein composite ore occurs for varying distances in both directions from the point where pyrite-gold veins join galena-sphalerite veins.

Mineralization of the veins appears to have taken place in two stages; the first stage resulted in the deposition of pyrite-gold ores, and the second stage resulted in the deposition of galena-sphalerite ores. Both stages of mineralization deposited pyrite, chalcopyrite, tetrahedrite, galena, and sphalerite but in strikingly different ratios and generally with different gangue minerals. It seems reasonable to assume that the two stages of mineralization are closely related in time and that the second ore stage probably represents a continuation of a briefly interrupted process of mineralization.

Because of the close spatial relationship between the porphyry intrusive rocks and the Tertiary veins in the Front Range mineral belt, Lovering and Goddard (1950, p. 75–76) have inferred that the Tertiary magmas were the source of the solutions that deposited the ores.

MINERALOGY OF THE VEINS

The most common primary metallic minerals in the veins are pyrite, auriferous pyrite, galena, argentiferous galena, sphalerite (both marmatite and resinous sphalerite), tetrahedrite-tennantite (copper antimony-arsenic sulfide), chalcopyrite, and free gold. Pyrite and auriferous pyrite form fine- to coarse-grained cubes and pyritohedrons in those parts of the veins that are not fractured or sheared. Most galena forms coarse grains and cubes, but the argentiferous variety appears to constitute fine-grained aggregates. Sphalerite occurs in medium- to coarse-grained masses and pods. Tetrahedrite-tennantite occurs in small veinlets and patches scattered through the ores. Sight identification of this mineral in the field is impossible as it has the steel-blue color and reddish-brown streak of hematite. When ore containing tetrahedrite-tennantite is drilled, the sludge from the drill hole is reddish; and, accordingly, some of the miners refer to tetrahedrite-tennantite bearing ore as "bloody ore." Chalcopyrite forms tiny blebs in sphalerite and occurs as veinlets and patches scattered through many of the ores. The occurrence of free gold was not observed.

Oxidized parts of the veins at places contain cerussite as an important lead ore and malachite, azurite, and covellite as alteration products of tetrahedrite-tennantite and chalcopyrite. Yellow flakes of wulfenite (lead molybdate) are scattered through the ore and associated gouge in the oxidized part of the Diamond Mountain vein. Scattered flakes of torbernite (hydrous copper uranium phosphate) and autunite (hydrous calcium uranium phosphate) were observed in gouge or along fractures in several mines of the district, and needles or prisms of dumontite(?) (hydrous lead uranium phosphate) were noted along fractures in biotite-muscovite granite on the dump at the collar of the Ariadne shaft.

The gangue is predominantly quartz, either in the form of clear crystals or chalcedony. The chalcedonic quartz generally is tan to buff, but locally it is black because of inclusions of powdered pyrite or galena. Quartz commonly cements brecciated fragments of sulfide ore. Carbonates are common in some of the ores. Siderite is generally associated with pyrite-gold ores, and rhodochrosite, calcite, ankerite, and dolomite are associated with galena-sphalerite ores. Purple fluorite was observed with galena-sphalerite ore in specimens from the lower tunnel of the Little Johnie group of mines.

PARAGENESIS OF THE ORES

PRIMARY ORE MINERALS

The paragenesis of the primary vein minerals is similar throughout the district; the generalized paragenetic sequence is given in figure 12.

The paragenetic sequence was determined from field observations and from the study of 74 polished surfaces and polished thin sections of ores from the district. The microscopic determination of paragenetic sequence was worked out using the criteria suggested by Bastin and others (1931).

The pyrite-gold type of ore is characterized by a coarse intergrowth of clear quartz and euhedral pyrite. Some of the pyrite contains tiny blebs of chalcopyrite, and a weathered vein of this material has a

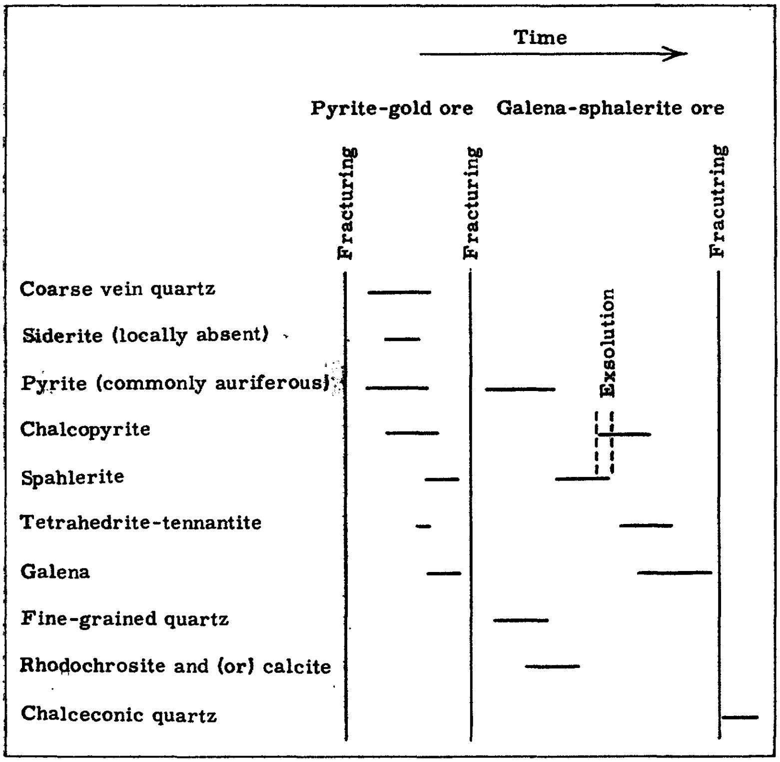


FIGURE 12.—Generalized paragenetic diagram for the primary vein minerals.

tarnish characteristic of chalcopyrite. Sphalerite (var. marmatite) usually containing small blebs of chalcopyrite, fills vugs in the quartz-carbonate-pyrite vein material. At places tetrahedrite-tennantite or galena partly replaces the older vein minerals, particularly sphalerite.

Narrow galena-sphalerite veins typically are banded: a section from margin to center of a typical 4-inch vein contains half an inch of fine-grained quartz and pyrite on the margin; the next layer inward consists of three-fourths of an inch of sphalerite (var. marmatite); and the center consists of galena. In many places rhodochrosite and calcite form layers between the quartz-pyrite and the sphalerite. Chalcopyrite forms blebs along cleavage planes in sphalerite and tiny veinlets filling fractures in sphalerite. Tetrahedrite-tennantite occurs chiefly as veinlets replacing chalcopyrite or sphalerite, or as fracture fillings in sphalerite or gangue. Some "eutectoid" intergrowths of tetrahedrite-tennantite and galena occur in these ores. Galena commonly replaces all of the earlier sulfides as well as the gangue. Most of the ores show postgalena fracturing, and some, such as those in the

Turner mine, have been strongly brecciated. The fractures or breccia fragments are commonly cemented by chalcedonic quartz.

In the composite type of ore, the paragenetic sequence is a combination of the sequence of the pyrite-gold type of ore and the galena-sphalerite type of ore. In the Freeland-Lamartine district, the composite ore is formed by galena-sphalerite ore filling fractures in pyrite-gold ore.

Many mines in the district show minor variations from the general mineralogy described above. The ore in the lower tunnel of the Little Johnie group of mines contains ankerite and fluorite; the lower workings of the Turner mine expose brecciated ore that contains fragments of light-amber sphalerite free from chalcopyrite blebs; and the New Era ore is noted for its abundance of chalcopyrite and lack of sphalerite. The overall pattern of mineral associations and their sequence of deposition is, however, strikingly consistent throughout the district.

SECONDARY ORE MINERALS

The secondary ore minerals in the district are considered to have no economic significance. Malachite, chalcanthite, and azurite, characteristic of the upper workings of the Crazy Girl mine, occur in small quantities in most of the other mines. Wulfenite is scattered along fractures and in gouge along the margins of the eastward-trending vein of the Diamond Mountain mine. Cerussite is characteristic of the ore from the upper workings of the Brazil mine (Spurr, Garrey, and Ball, 1908, p. 319). Barite has been reported (Spurr, Garrey, and Ball, 1908, p. 330) from the Harrisburg and Brighton mines.

Secondary uranium minerals, torbernite, autunite, and dumontite(?) occur in vugs or fractures or in gouge along several veins. Hydrous iron oxides from veins and from recent deposits on mine walls commonly show an unusual amount of radioactivity. In most of the radioactive material sampled, however, no discrete uranium minerals could be identified. None of the material assayed occurs in sufficient quantities to be commercial. Analyses of samples collected from mines and mine dumps in the district are given in table 9.

TABLE 9.—*Radioactivity of samples collected from mines and mine dumps*

[All samples are grab samples]

Mine no. (pl. 5)	Mine name	Material sampled	Sample no.	Equivalent uranium (percent)	Uranium (percent)
1	Poor Man	Limonitic vein material on dump	JEH-439-1	0.028	0.023
2	Brazil lower tunnel	do	Bra-1	.040	.038
4	Brazil main shaft	do	BM-1	.013	.008
20	Mammoth	do	2-6a-133	.003	
21	Falcon	do	FD-2	.004	
25	Harrisburg	do	Har-1	.015	.013
29	Lone Tree tunnel	do	LT-1	.006	.005
30	Lamartine tunnel	Pyritic-gold vein	La-1	.007	.002
30	do	Recent limonitic coating on tunnel wall	La-2	.083	.15
30	do	Gouge on footwall of cross vein	La-3	.12	.11
32	Old Stag	Limonitic coatings on wall	OS-1	.007	.002
60	Little Johnie lower tunnel	Gouge lead	358-2	.017	.013
61	Little Johnie middle tunnel	Thin gouge lead	357-1	.037	.033
61	do	Thin composite vein	357-2	.005	.002
66	Crazy Girl	Hanging wall of vein on second level	CG-1	.033	.026
66	do	Alaskite porphyry; east end of second level	CG-10	.011	.006
69	Belle Creole	Quartz-pyrite vein	BC-1	.010	.002
69	do	Gouge lead	BC-2	.037	.033
69	do	Limonitic vein material on shaft dump	JEH-174-1	.006	.002
70	Ariadne	Fractured granite with thin coatings of torbernite and dumontite (?)	Ar-1	.039	.032
71	Miller	Weakly mineralized composite vein containing scattered flakes of torbernite	Mi-1	.006	.003
71	do	do	Mi-2	.009	.004
71	do	do	Mi-3	.014	.001
73	Diamond Mountain lower tunnel	Pyritic gouge lead	DM-1	.16	.046
73	do	Gouge pod in back on sublevel	DM-2	.30	.35
73	do	Mill concentrate from ore in main shoot	JEH-4	.078	.041

ABNORMAL RADIOACTIVITY OF VEINS

Concentrations of radioactive materials in amounts greater than usual (or normal) is called abnormal radioactivity in this report. Every accessible mine in the district was examined for abnormal radioactivity; the dumps of inaccessible mines were traversed with a gamma scintillation counter. A previous report on results from the examination for radioactive materials (Wells and Harrison, 1954) in the Freeland-Lamartine district and the surrounding 20-square-mile area describes the distribution of abnormal radioactivity. In this report it is tentatively concluded that large areas containing only pyrite-gold veins are poor in uranium and that areas of pyrite-gold or galena-sphalerite veins containing chalcopyrite are more favorable sites in which to look for uranium deposits. Data from the district are insufficient to warrant a correlation between abnormal radioactivity and zoning of individual veins. The Diamond Mountain mine is the only mine in the district that might warrant a limited amount of exploration work to search for uranium ore.

The mines and mine dumps that contain radioactivity of at least twice the background on a rate meter with a 6-inch beta-gamma probe are listed in alphabetical order; the assay data have been condensed in table 9.

Ariadne.—About 75 percent of the dump shows abnormal radioactivity. A sample of the fractured granite containing visible torbernite and dumontite(?) along the fractures assayed 0.039 percent equivalent uranium and 0.032 percent uranium.

Belle Creole.—Two small areas (each about 1-foot square) of abnormal radioactivity were sampled in the mine. A sample (BC–1) taken near the winze on the split vein assayed 0.010 percent equivalent uranium and 0.002 percent uranium; a sample (BC–2) from the crosscut from the main tunnel assayed 0.037 percent equivalent uranium and 0.033 percent uranium. About 10 percent of the dump at the shaft southwest of the tunnel portal (pl. 5) is abnormally radioactive. A grab sample of limonitic vein material from this dump assayed 0.006 percent equivalent uranium and 0.002 percent uranium.

Bell of the West.—The two stronger veins exposed in drifts have abnormal radioactivity of almost twice background. As these anomalies were so slight, no samples were collected for assay.

Brazil.—Radioactive material was found on the dumps of the lower adit and shaft. A grab sample from the lower adit dump assayed 0.040 percent equivalent uranium and 0.038 percent uranium, and a grab sample from the shaft dump assayed 0.013 percent equivalent uranium and 0.008 percent uranium. The samples consisted of limonitic vein material.

Crazy Girl.—One sample of radioactive vein material was collected from the hanging wall of the vein on the second level of the mine. The material assayed 0.033 percent equivalent uranium and 0.026 percent uranium. A sample of alaskite porphyry from the east end of the second level assayed 0.011 percent equivalent uranium and 0.006 percent uranium.

Diamond Mountain.—A sample of mill concentrate of ore from the lower stope on the ore shoot near the breast of the workings assayed 0.078 percent equivalent uranium and 0.041 percent uranium. A grab sample (DM–1) of the gouge on the eastward-trending vein near the breast of the workings in the lower tunnel assayed 0.16 percent equivalent uranium and 0.046 percent uranium; a grab sample (DM–2) of gouge from and split on the sublevel assayed 0.30 percent equivalent uranium and 0.35 percent uranium. The uranium mineral or minerals could not be separated from the gouge for identification.

Falcon.—About 10 percent of the surface of the dump contained abnormal radioactivity, and one grab sample of limonitic vein material from the dump of the Falcon tunnel assayed 0.004 percent equivalent uranium.

Harrisburg.—One small area of weathered vein material on the Harrisburg dumps is abnormally radioactive. A grab sample of the radioactive material assayed 0.015 percent equivalent uranium and 0.013 percent uranium.

Lamartine.—Abnormal radioactivity was noted on the Lamartine tunnel level and on the Old Stag tunnel level. In the Lamartine tunnel, intermittent abnormal radioactivity was noted in the area 600 to 1,660 feet from the portal. Three samples for assay were collected in this area. Sample La–1 consists of pyritic vein material and assayed 0.007 percent equivalent uranium and 0.002 percent uranium. Sample La–2 composed of limonitic material (about one-fourth inch thick when sampled), which was being deposited on the walls of the tunnel by water dripping from an old gold stope, gave 0.083 percent equivalent uranium and 0.15 percent uranium. Sample La–3, gouge from the footwall of a cross vein, was collected in an old drift about 25 feet above the Lamartine tunnel and gave 0.12 percent equivalent and 0.11 percent uranium.

In the Old Stag tunnel abnormal radioactivity resulting from radon was noted near the portal and gradually increased in intensity toward the breast of the workings. No specific area of abnormal radioactivity could be isolated. A grab sample of limonitic material (OS–1, pl. 4) from the tunnel walls assayed 0.007 percent equivalent uranium and 0.002 percent uranium.

Little Johnie group.—One small area 2 feet square of abnormal radioactivity was noted in the lower tunnel. The area is in one of the gouge leads about 360 feet from the portal. A grab sample (358–2) of the gouge assayed 0.017 percent equivalent uranium and 0.013 percent uranium.

In the middle tunnel, two local areas of abnormal radioactivity were noted. Both of these areas are near the west end of the main drift. A grab sample from a thin gouge lead (357–1) assayed 0.037 percent equivalent uranium and 0.033 percent uranium. A grab sample from one of the eastward-trending veins (357–2) assayed 0.002 percent uranium.

No abnormal radioactivity was noted in the upper tunnel.

Lone Tree.—Slightly anomalous radioactivity was noted on the dumps at the Lone Tree and Lone Tree Extension shafts. The anomaly was noted over most of these dumps and was partly the result of fragments of bostonite. Radioactive material other than that in the dike rock could not be isolated well enough to sample.

Some of the vein material on the dump at the Lone Tree tunnel portal also is abnormally radioactive. A grab sample of limonitic vein material had assay values of 0.006 percent equivalent uranium and 0.005 percent uranium.

Mammoth.—Abnormal radioactivity on the order of twice background was noted on the dump of the Mammoth shaft. A sample of limonitic vein material assayed 0.003 percent equivalent uranium.

Miller.—Three small areas, each about 2 feet square, of abnormal radioactivity in composite vein material were noted in the mine. Grab samples (Mi–1, Mi–2, and Mi–3) were collected and assayed 0.006, 0.009, and 0.014 percent equivalent uranium and 0.003, 0.004, and 0.001 percent uranium, respectively. A few scattered flakes of torbernite were observed in the samples.

Poor Man.—A grab sample of limonitic vein material taken from the dump assayed 0.028 percent equivalent uranium and 0.023 percent uranium.

WALL-ROCK ALTERATION

The country rock found within the lode has been broken, silicified, and bleached. The feldspars are altered to sericite, and the biotite is bleached and partly pyritized. Minor amounts of pyrite are scattered through the altered feldspars. The biotite-rich gneisses commonly have been bleached to white or dull-greenish-gray sericite-rich rocks that have layers of sericite-pyrite instead of biotite.

Outside of the lode, beyond the smooth footwall and hanging wall, the alteration is less intense, and usually visible alteration extends only a foot or less into the wall rock. The alteration along minor fractures, which are common for several feet beyond the lode zone, usually is only an inch or less wide; the same alteration minerals are formed here as within the lode.

Most of the wall rocks found in the district contain abundant silica and iron in the form of quartz, feldspar, biotite, and magnetite. It seems reasonable to believe that part of the quartz and pyrite found in the veins has been derived by metasomatic processes from the wall rock. Many small fractures in wall rock outside of the lode zone contain traces of quartz and pyrite regardless of whether the fracture is associated with the pyrite-gold or galena-sphalerite type of ore. These minor traces of quartz and pyrite in small fractures in the wall rock could well have been derived from the wall rock by metasomatic processes which added, at least, a small amount of sulfur.

LOCALIZATION OF THE ORE BODIES

Most of the ore bodies in the Freeland-Lamartine district occur as shoots, lenses, or pods that are localized principally at vein intersections, changes in strike or dip of veins, or by a combination of these factors. At one locality an ore body is present at a deflection in the vein caused by the change in strike of a fault through a rock type of different competency. A chemical control related to the type of wall rock apparently has not been a factor in the deposition of the ores.

Vein intersections.—Vein intersections are the loci for ore bodies in several mines. In the New Era mine some of the richest ore was found at the junctions of the Flat, Oldbury, and Great Western veins. Spurr, Garry, and Ball (1908, p. 318) attributed localization of the ore body near the Lamartine shaft to the intersection of the Oneida and Lamartine veins.

At several localities horses in the veins occurring between vein splits are enriched by stringers of ore as well as by thickening of the ore at the perimeter of the horse.

Deflections in strike of veins.—The ore bodies in the Turner and Old Stag mines appear to be related to changes in strike along the vein. At the Turner mine the only ore shoot in the mine is located on a very prominent strike change. Dip control in conjunction with strike control is apparent in the Turner mine, and the same may be true for the ore body that was mined above the Old Stag tunnel. In general, strike control is less evident than dip control in the mines of the district.

Deflections in dip of veins.—Many ore bodies in the district clearly are localized by changes in dip along a vein. Ore bodies along veins that have a relatively uniform strike and little change in dip along the direction of strike are consistently in the steeper part of the veins. Accordingly, the writers have concluded that the hanging wall of the faults in the district moved down relative to the footwall.

Miners at the Lamartine and Crazy Girl mines report that the ore is always thicker on the steeper parts of the vein. The main Freeland ore body appears to be definitely related to a prominent change in dip (see discussion on page 100), and the widest part of the ore in the Turner mine is near the second level, where the dip of the vein is steeper than elsewhere. Even in small detail, dip control is prominent; in an old stope at the east end of the drift in the middle tunnel of the Little Johnie group of mines, the flat part of one of the veins contains ¼ inch of ore, but the steep part contains 1½ inches of ore. This change from flat to steep to flat dip occurs within a length of 12 inches along the vein.

The control of ore shoots by deflections in strike and dip has been discussed at some length by Newhouse (1940). The writers wish to call attention to the fact that both principal types of ore have been localized by deflections in strike and dip. Such features occur on all three sets of fractures in the district. This detailed structural control along all parts of the long cymoid-shaped fissures indicates, as suggested by Newhouse (1940), that the long cymoids are not simply large examples of the small cymoids that have helped localize the ore bodies. The long cymoids have been opened all along their length at some time during the formation of the fracture system and the deposition of the ore. Offsets of steeply dipping pre-Cambrian rock units and Tertiary dikes indicate that the strike-slip component of movement on the faults in the district was northwest side to the northeast; a slight dip-slip component accompanied the strike-slip movement. As the ends of the large cymoids have about the same dip as the central segments, such movement should have its principal bearing area along the north-northeast fault surfaces and should form openings along the east-northeast and east fractures. The north-northeast fractures, however, are neither barren nor less strongly mineralized than the other fractures. This information considered in conjunction with the data previously presented on the sequence of fracturing suggests that the long cymoids are not the result of one simple shear but represent a series of breaks, each fracture in the series having been mineralized at the time of opening. The ore deposits along the large cymoids were localized by small changes in strike and dip that created openings along each succeeding fracture set as it was formed.

Fault deflections due to rock type.—One ore body in the district appears to have been localized by the deflection of a fault caused by a difference in competency of two rock types traversed by the fault. Harrington's detailed map of part of the Diamond Mountain mine shows this deflection clearly. The ore shoot along the fault is confined to a bostonite dike in biotite-muscovite granite. The deflection of the fault is particularly evident on the lower tunnel level where a weakly mineralized fracture trending eastward is deflected as it enters the dike. The fracture trends east-northeasterly through the dike and contains minable ore.

Newhouse (1942) has summarized observations of several geologists on this type of fault deflection. According to theory, the fault deflection in the Diamond Mountain mine should result from strike-slip movement on the fault in which the northwest block moved to the northeast relative to the southeast block if the dike is less competent than the granite. If the dike is more competent than the granite, then the deflection is that expected from movement on the fault in which the northwest block moved southwest relative to the southeast block, the reverse of the movement on the other faults in the district. The answer to this enigma could not be obtained because, unfortunately, the dike does not appear to be offset.

PERSISTENCE OF ORE WITH DEPTH

The deepest mine workings in the district are along the McClelland tunnel level of the Freeland mine. Ore was mined along the Freeland and Shaffer veins from several small stopes above the tunnel, and a shallow winze is reported to have reached ore of about the same grade as that found in these nearby stopes. Accordingly, ore has been found along the Freeland vein over a vertical distance of about 1,600 feet, between an altitude of 7,900 and 9,500 feet. This is equivalent to about 2,700 feet measured in the plane of the vein. Ore has been found in the mine workings along the Lamartine-Great Western group of veins at altitudes from 10,500 feet down to 8,900 feet.

None of the mines has been explored sufficiently to establish a bottom for the effective depth of mineralization. The effective height of mineralization appears to be at an altitude of about 10,500 feet. Although several shafts have been sunk on veins at altitudes above 10,500 feet, none of the workings have reached ore above that altitude. The Lamartine ore body was found at a depth of 100 feet below the collar of the shaft, which is at an altitude of 10,600 feet. The ore shoot in the Diamond Mountain mine pinches out before it reaches the surface, which has an altitude of about 10,450 feet over the apex of the ore shoot.

In general, the values in the ore decrease with depth. In the Lamartine ore body, which was a blind ore body inasmuch as it did not reach the surface and had not been affected by supergene enrichment, the best values were near the top of the ore shoot.

HYPOGENE ZONING OF THE ORE DEPOSITS

The veins of the Freeland-Lamartine district show zoning confined to a single cymoid vein. The geographic pattern of this zoning is rectilinear along the trace of the vein instead of subcircular and does not involve several veins as is common in many districts showing the classic "onionskin" type of zoning described by Emmons (1940, p. 194–196) or as found at Butte.

The zoning in the district is believed to be the result of a combination in space of two processes, a sequence of fracturing and a sequence of mineralization; the two sequences occurred essentially contemporaneously. The first, and hotter, solutions deposited ore of the pyrite-gold type in the earliest set of fractures which formed approximately parallel to axial planes in the pre-Cambrian bedrock. This first stage of ore-bearing solutions probably deposited large bodies of pyrite-gold ore below and small (?) bodies of galena-sphalerite ore above. As the process of fracturing continued, younger fractures (first east-northeast and finally east) formed at the ends of the older fractures. Solutions that were slightly later, and cooler, than those that deposited the pyrite-gold ore deposited ore of the galena-sphalerite type in the younger fractures. The composite type of ore is found where younger fractures, containing minerals deposited by the cooler solutions, cut through the ends of the older pyrite-gold type of veins. The ideal geographic expression of this combination of processes is a long, cymoid-shaped vein containing pyrite-gold ore in the center, composite ore along the curving part, and galena-sphalerite ore at the extremities.

Effect of topography.—The present geographic pattern of any zonal distribution of ores is related to the local topography. As the effective height of mineralization in the Freeland-Lamartine district extended about 1,000 feet above the average altitude of the present topography, the geographic pattern of any original zonal arrangement of the ores would have been modified by erosion to the present surface. This modified pattern of the distribution of the two main ore types is shown in plate 5 and is described below.

Longitudinal zoning.—Three complete cymoid-shaped vein systems occur in the Freeland-Lamartine district; namely, the Freeland, the Lamartine-Great Western, and the Lone Tree. Zoning along the strike of the cymoids is apparent from the geographic distribution of the ores as shown in plate 5. Veins of the pyrite-gold type are found only on north-northeast segments of the long cymoids, and the ends of the cymoids contain the galena-sphalerite ore. In the Freeland group of veins this pattern of longitudinal zoning is nearly perfect. Along the Lamartine-Great Western cymoid the pattern is well formed but along the Lone Tree cymoid the pattern is very weakly formed. The changes in the degree of formation are probably related to the effect of topography on an original depth zoning.

Vertical zoning.—Limited information from the two largest mines, the Freeland and the Lamartine, suggests the presence of vertical zoning in these mines. On the north-northeast Freeland vein galena was found in bunches near the surface, but none was found at depth with the pyrite-gold ore. Some good zinc ore was reported from the near surface stopes on the north-northeast Oneida vein, but only traces of sphalerite are present in the lower workings of the part of the mine that contained pyrite-gold ore. A cautious inference drawn from these data is that the shallow workings of the Lone Tree mine have cut only the top of the pyrite-gold zone, and that the poor agreement with the ideal pattern is due to insufficient erosion of a vertically zoned vein.

This vertical zoning is related to the longitudinal zoning in the fracture systems. The pyrite-gold veins are in the oldest part of the cymoids, the north-northeast segments, and these ores appear to be vertically zoned; the lower part of the ore is of the pyrite-gold type and the upper part of the ore is of the galena-sphalerite type. In addition, the pyrite-gold ores are locally cut by galena-sphalerite ores at the margins of the pyrite-gold zones along the veins. In theory the younger galena-sphalerite ores could also cut the older galena-sphalerite ores deposited as the outer zone by the first stage of mineralization. Although this feature was not seen in the accessible mines of the district, such a feature might be overlooked. The most productive galena-sphalerite ores, however, have been found in the east-northeastward- and eastward-trending fracture systems.

DESCRIPTION OF MINES

Because many of the mines in the district are now inaccessible, much of the underground geology in the district was not available for study by the writers. Information on the underground workings of inaccessible mines was obtained from several sources and is acknowledged on the appropriate maps.

The mining terms used in this report are those that are in general usage in the district. Any nearly horizontal passageway from the surface is called a tunnel in the district; as none of these passageways extend completely through a hill, they are preferably called adits.

ARIADNE MINE

The Ariadne mine is on the northeast slope of Alps Mountain (pl. 5). The collar of the shaft is at an altitude of 9,820 feet.

Because in 1952 the shaft was almost entirely filled with water, it was not possible to determine accurately the depth and extent of the mine. However, the quantity of broken rock on the dump indicates about 350 feet of underground workings.

The rock on the dump is highly sheared and fractured biotite-muscovite granite and associated pegmatite. The vein seen at the collar of the shaft strikes N. 50° E. and dips 72° N., and it may be correlated as the northeasterly extension of the Miller vein. (See pl. 5.) Vein material on the dump includes quartz, limonite, torbernite, and dumontite(?). Disseminated crystals of torbernite and dumontite(?) thinly coat some of the fractures in the granite, and quartz and limonite fill vugs in the granite.

No record of production from the Ariadne mine could be found.

AVALANCHE MINE

The portal of the Avalanche tunnel, at an altitude of 9,480 feet, lies in a small gulch about 4,800 feet N. 60° W. from Freeland (pl. 5). A caved shaft 110 feet east from the tunnel portal is on the vein. Only the 240-foot tunnel, driven westward along the vein (fig. 13), is now accessible. A water-filled winze, 85 feet from the portal, and two small stopes 15 and 20 feet high near the winze are inaccessible.

Granite gneiss and pegmatite, migmatite, and biotite-muscovite granite are exposed in the tunnel. These rocks have been folded into a series of small anticlines and synclines that plunge about 30° to the south.

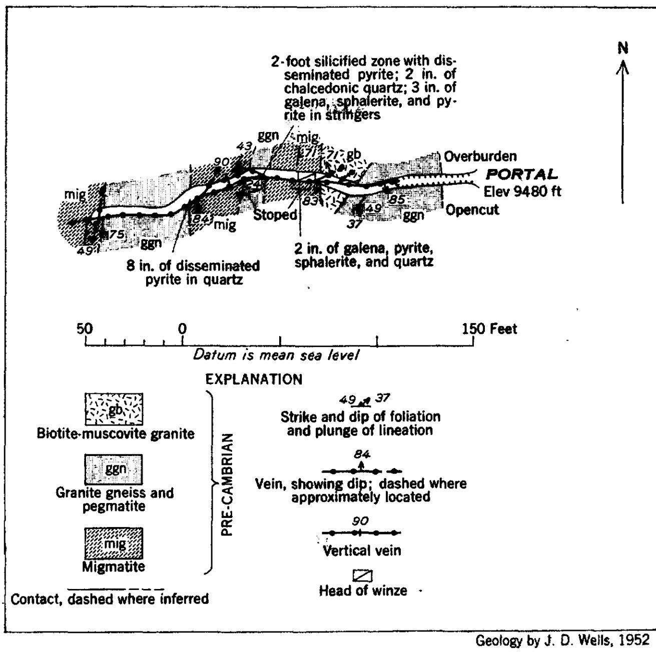


FIGURE 13.—Geologic map of the Avalanche tunnel.

The vein in the accessible drift trends from N. 84° W. to N. 70° E. and has an average strike of N. 82° E; the dip is about 84° S. The width ranges from ½ inch to 2 feet; the widest part is 110 feet from the portal. Disseminated quartz and pyrite occur along the length of the vein. In the area between the stopes, stringers of galena, sphalerite, pyrite, and quartz cut the disseminated quartz-pyrite vein. Some chalcedonic quartz occurs in the widest part of the vein.

The vein is widest at changes in strike and at vein intersections (fig. 15). No evidence is available to determine what influence, if any, changes in dip might have.

U. S. Bureau of Mines records show that between 1910 and 1915, 32 tons of ore was shipped from the Avalanche mine. The ore yielded a per ton average of 0.5 ounce of gold, 5.0 ounces of silver, and 25 percent lead.

BALTIMORE MINE

The portal of the Baltimore tunnel, at an altitude of 10,160 feet, is about 2,900 feet N. 40° W. from the western peak of Alps Mountain (pl. 5). The Baltimore mine consists of a short tunnel and a winze that connects with two short drifts (fig. 14). The tunnel was found caved at the portal.

The tunnel was driven on a vein that strikes N. 65° E. and dips about 60° NW. (fig. 14). The more northeastward-trending vein that cuts the main vein about 128 feet from the portal probably is the Lone Tree vein.

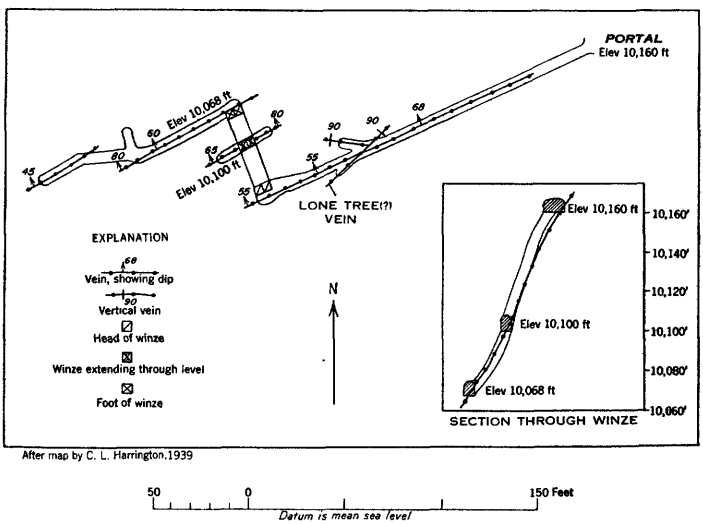


FIGURE 14.—Plan and section of the Baltimore mine.

The rock on the dump indicates that the mine workings are mostly in granite gneiss and pegmatite. The vein material on the dump consists of pyrite, chalcopyrite, galena, and sphalerite in a quartz gangue.

No record of production from the Baltimore mine could be found.

BELLE CREOLE TUNNEL

The Belle Creole tunnel is about 2,000 feet N. 20° E. of the western peak of Alps Mountain (pl. 5). The portal is at an altitude of 9,800 feet. The tunnel is 356 feet long; 80 feet from the portal a drift follows a vein split for 140 feet (fig. 15). A winze has been sunk on the branch vein about 80 feet from the junction with the main vein. As the winze was full of water in 1952, the extent of the winze was not observed. No extensive stoping has been done in this mine. A small shaft, 300 feet southwest of the tunnel portal, probably is on the same vein, but the shaft does not connect with the workings on the tunnel level.

The tunnel is principally in biotite-muscovite granite, but small patches of amphibolite, migmatite, and granite gneiss and pegmatite are present at the extremities of the mine workings.

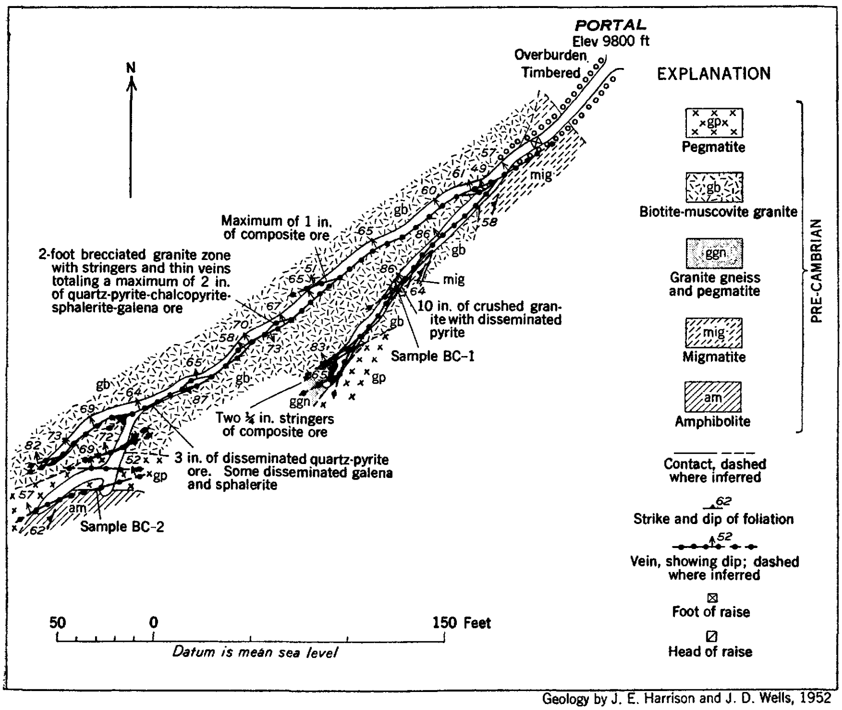


FIGURE 15.—Geologic map of the Belle Creole tunnel.

The main vein strikes about N. 59° E. and dips on the average 65° NW.; probably, it is the western extension of the Crazy Girl vein (pl. 5). The vein that splits from the main vein, 80 feet from the portal, strikes about N. 43° E. and dips about 85° NW. The winze was put down on the split vein where it reached a maximum width of 10 inches of crushed granite and disseminated pyrite. The vein consists of pyrite, chalcopyrite, chalcocite, galena, and sphalerite in a quartz gangue. Several small horses occur along the main vein (fig. 15), and they appear to have influenced localization of the ore. The maximum thickness of ore observed, however, was only 2 inches.

No record of production for the Belle Creole could be found, but indications are that little ore has been produced from this mine.

BELL OF THE WEST TUNNEL

The portal of the Bell of the West tunnel, at an altitude of 9,280 feet, is about 2,000 feet southwest up the valley from Freeland (pl. 5). The mine workings consist of a crosscut tunnel that trends N. 63° W. for the first 345 feet and then N. 13° W. for 177 feet to the breast (fig. 16). Two short drifts have been driven southwesterly at distances of 73 feet and 245 feet from the portal.

The tunnel cuts across the general northeasterly trend of foliation in the wall rocks, and exposes 20- to 80-foot layers of biotite-quartz gneiss, migmatite, amphibolite, and granite gneiss and a small body of biotite-muscovite granite.

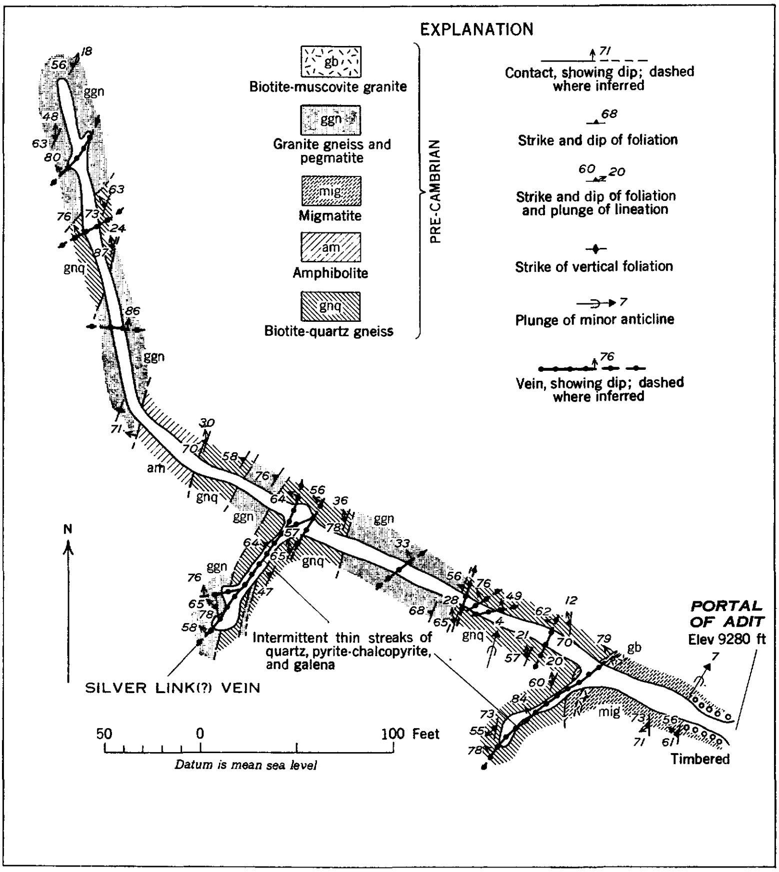
Several small, weakly mineralized veins, most of which are thin streaks of gouge that contain a small amount of pyrite, are cut by the tunnel. Two of the stronger veins contain thin stringers of pyrite, chalcopyrite, and galena in a quartz gangue. Both of these veins have been drifted on for about 65 feet, but no stoping has been done along them. The first of the stronger veins nearer the portal strikes N. 54° E. and dips on the average 81° NW. The second strikes N. 37° E. and dips about 62° NW.; this vein probably is a northeast extension of the Silver Link vein (pl. 5).

As there are no stopes in the mine, there probably has been no production of ore.

BRAZIL MINE

The Brazil mine is near the head of Trail Creek with the lower tunnel 150 feet north of the stream at an altitude of 10,084 feet (pl. 5).

The workings, all caved at the surface, consist of three adits and two shafts. The main shaft lies northwest of the lower adit at an altitude of 10,351 feet. The other shaft, which was sunk on the vein, is 120 feet northwest from the lower adit. The other two adits, one on the vein, the other to the south of it, are at altitudes of 10,198 and



Geology by J. E. Harrison, 1952

FIGURE 16.—Geologic map of the Bell of the West tunnel.

10,205 feet respectively. Spurr, Garrey, and Ball (1908, p. 319) reported that more than 800 feet of the lower adit was open at the time of their visit and that there was a 150-foot stope on the N. 85° W. part of the vein.

At the surface, the mine area is in granite gneiss and pegmatite, and this is the only rock type found on the dump. Vein minerals identified from the dumps include galena, sphalerite, chalcopyrite, pyrite, quartz, and barite (?). The general strike of the vein is N. 75° W., but it ranges from N. 55° W. to N. 85° W., and the dip ranges from 50° to 60° NE. (Spurr, Garrey, and Ball, 1908, p. 319).

Production records of the U. S. Bureau of Mines indicate that the Brazil mine was worked from 1904 to 1905, from 1916 to 1917, and in 1920, 1941, and 1942. During the different periods of operation a total of 88 tons of ore was shipped. The ore contained a total of 28.5 ounces of gold, 2,193 ounces of silver, 5 pounds of copper, 204 pounds of lead, and 210 pounds of zinc.

BRIGHTON MINE

The collar of the Brighton shaft is at an altitude of 9,730 feet and is about 3,200 feet N. 5° W. of western peak of Alps Mountain (pl. 5).

The Brighton mine was worked almost continually from 1903 to 1909. The mine was worked for a short time during 1917 and again during 1927. According to the records of the U. S. Bureau of Mines about 4,085 tons of ore has been shipped from the mine. This ore yielded a total of 596 ounces of gold, 25,387 ounces of silver, 77,803 pounds of copper, 1,041,824 pounds of lead, and 7,757 pounds of zinc.

The Brighton shaft is caved at the collar, and none of the mine is accessible. Accordingly, the following information has been taken from Spurr, Garrey, and Ball (1908, p. 325–332).

The Brighton vein was worked from an inclined shaft that connects with drifts on five levels (fig. 17). The vein, which has an average strike of N. 45° E. and an average dip of about 31° N., is probably part of the Freeland vein system. The vein material is mostly galena with some sphalerite, chalcopyrite, and pyrite in a quartz and carbonate gangue.

Work done since the report of Spurr, Garrey, and Ball (1908) suggests that the Brighton vein joins the Split vein in the Freeland mine at a point several hundred feet west of the junction between the Split and the Freeland Extension veins (fig. 10).

CRAZY GIRL MINE

The Crazy Girl mine consists of a shaft that connects with drifts on three levels, a tunnel that crosscuts into the first level, and the Baby Eddy tunnel, which was driven to connect with the third level but was never completed (fig. 18). The collar of the Crazy Girl shaft is about 2,800 feet N. 40° E. of the western peak of Alps Mountain, at an altitude of 9,700 feet (pl. 5). The portal of the Crazy Girl tunnel is in a small gulch, about 380 feet N. 37° W. of the collar of the shaft. The portal of the Baby Eddy tunnel is about 800 feet north of the Crazy Girl tunnel portal.

At the time of the writers' visit the mine was under lease to K. J. King and J. M. East of Boulder, Colo. Ore was being taken from a stope at the east end of the second level. Because of a sharp drop in the market value of lead, the mine was shut down almost overnight in July 1952. While the air was still good the writers were able to make a plan of the accessible parts of the mine, but a geologic map could not be completed.

Production records in the files of the U. S. Bureau of Mines for the years 1902 to 1952 indicate that the mine was operated intermittently during these years, and a total of 1,928 tons of ore was shipped. This

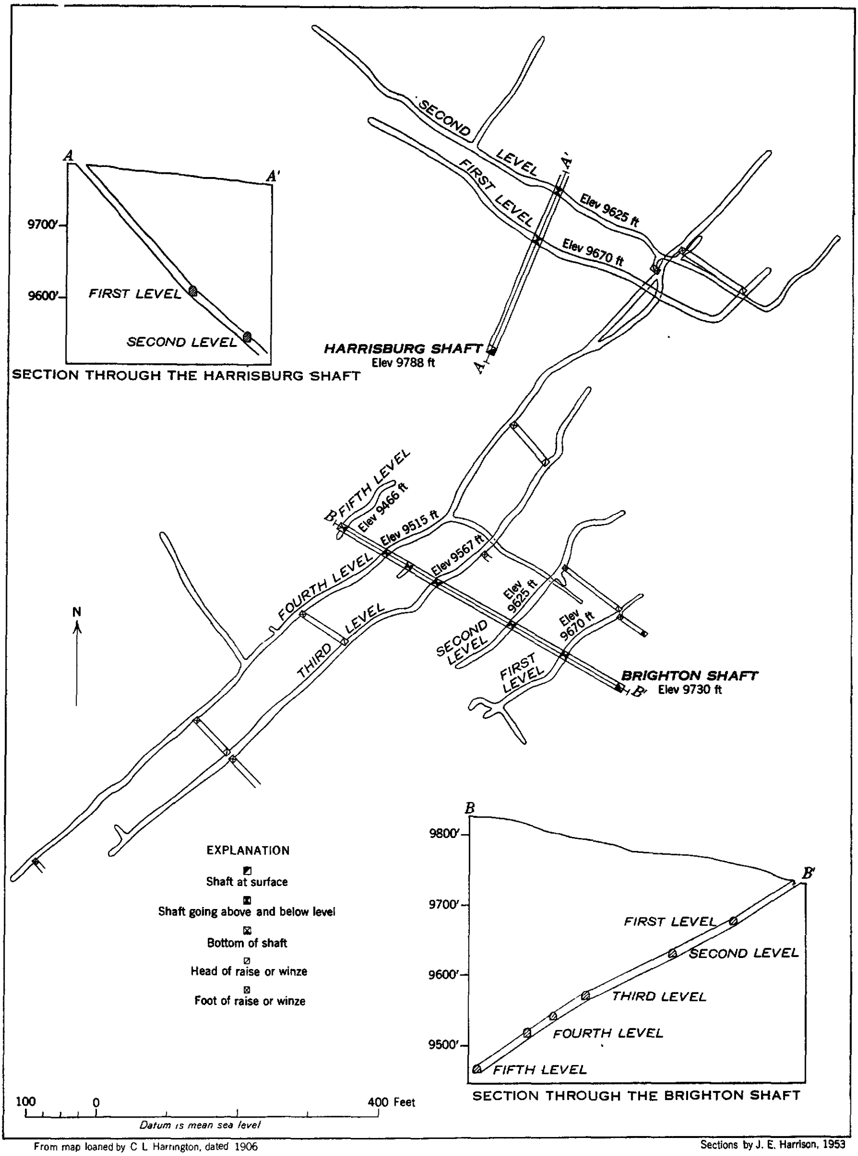


FIGURE 17.—Plans and sections of the Brighton and Harrisburg mines.

ore yielded 231 ounces of gold, 6,885 ounces of silver, 4,591 pounds of copper, 412,818 pounds of lead, and 73,881 pounds of zinc. A settlement sheet loaned by Mr. East shows that one shipment of 7.08 tons of ore made in 1952 yielded 2.76 ounces of gold, 90.7 ounces of silver, 78 pounds of copper, 4,548 pounds of lead, and 1,266 pounds of zinc.[4]

[4] Published with permission of sublessee, J. F. James.

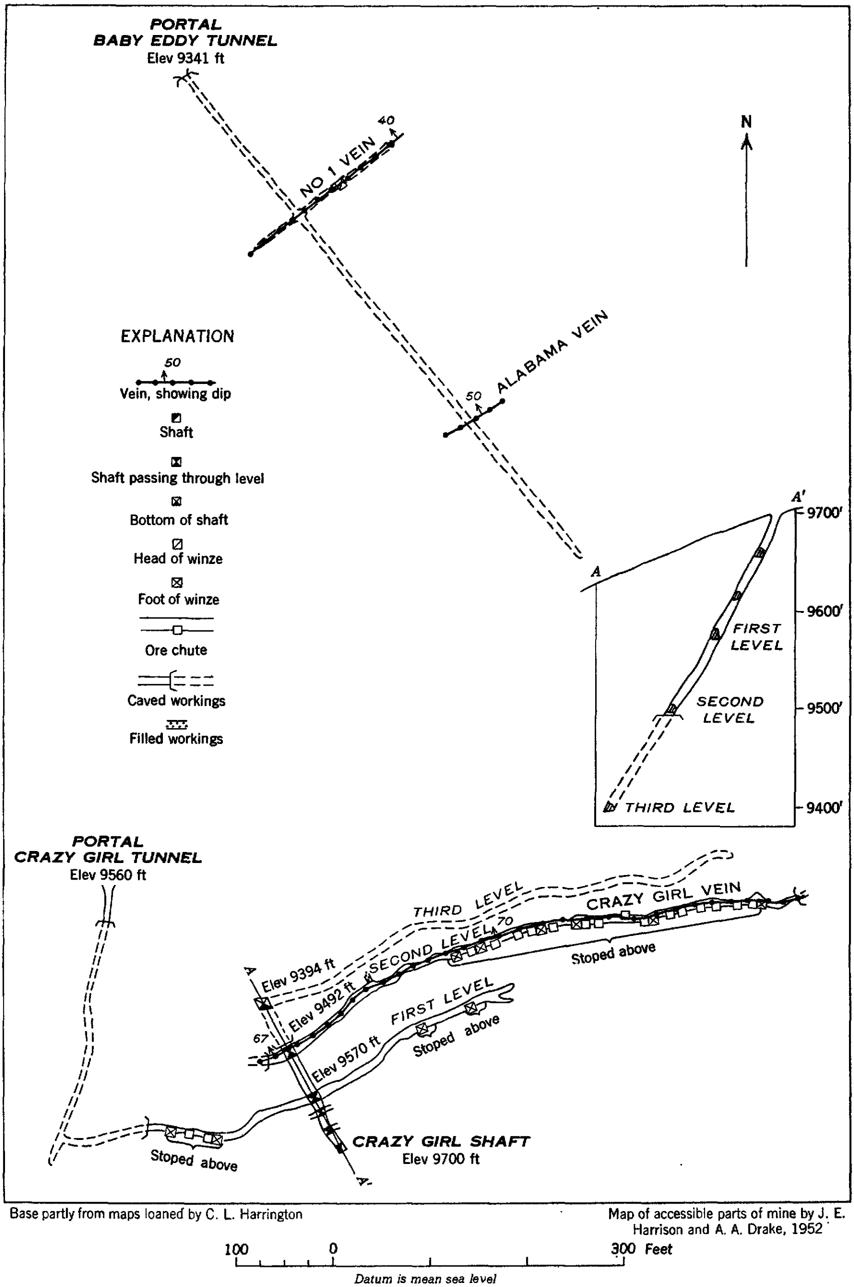


FIGURE 18.—Plan and section of the Crazy Girl mine.

The wall rock in the accessible part of the mine consists principally of biotite-muscovite granite and alaskite porphyry, with some biotite-quartz gneiss and migmatite. The dump of the Baby Eddy tunnel indicates that granite gneiss and pegmatite was the principal rock type found in the tunnel.

The Crazy Girl vein strikes N. 50°–80° E. and dips about 70° NW.; its probable continuation to the northeast is seen in the Yankee Girl shaft and to the southwest in the Belle Creole tunnel (pl. 5). Two veins were found in the Baby Eddy tunnel. Both of these veins trend about N. 50° E. and dip 40°–50° NW. The vein nearest the portal of the Baby Eddy tunnel cannot be traced on the surface; the vein nearer the breast of the workings is probably the Alabama vein which on the surface can be traced to the northeast.

The Crazy Girl vein contains pyrite, chalcopyrite, tetrahedrite, galena, and sphalerite as the principal ore minerals. The upper levels of the workings also contain malachite and azurite. The gangue is principally quartz and some carbonate.

The main ore shoot in the mine appears to be confined to the more eastward-trending part of the vein, and according to the miners, the ore is thicker on the steep parts of the vein than on the flat parts. As the eastward-trending part of the vein is slightly irregular and the ore pinches and swells, the ore has been found in a series of lenses or pods. In more recent years the mine has been operated at times when the price of the metals would allow mining of the thinner ore between richer pods.

So far as known, stoping has not been done between the second and third levels of the mine.

DIAMOND MOUNTAIN (LANAGAN) MINE

The Diamond Mountain mine is on the north shoulder of Alps Mountain (pl. 5). The portal of the upper tunnel is at an altitude of 10,312 feet, and the portal of the lower tunnel is at an altitude of 10,178 feet.

The upper tunnel is about 510 feet in length and is along a thin vein that trends S. 46° W. (pl. 6). About 300 feet from the portal a cross vein has been stoped for about 60 feet. The first 430 feet of the lower tunnel is a crosscut; at this point the tunnel turns S. 46° W. and extends about 350 feet along the vein. Two small stopes connect the upper and lower tunnels, and a shallow winze and short sublevel drift are present near the breast of the lower tunnel workings. The stopes were inaccessible in 1952, but a plan of the stope near the breast of the workings was loaned by C. L. Harrington and is shown in plate 6.

Both drifts follow a bostonite dike that has been intruded into biotite-muscovite granite, which contains local layers and bodies of pegmatite. The dike is present discontinuously on the walls of the upper tunnel, and, although it is principally on the footwall, locally it is in the hanging wall. The same dike is present in the lower drift, generally occurring in the hanging wall, but 80 feet from the breast of the workings it is in the footwall. Both the granite and the bostonite locally have been sheared and brecciated along the vein.

Both a footwall and a hanging wall vein occur along the bostonite dike. These veins are approximately parallel to the dike, although locally they are separated from the dike by several feet of granite. The veins and the dike have an average strike of N. 46° E. and a dip of 57° to 68° N. An eastward-trending vein that dips about 70° N. cuts through the dike near the breast of the workings in both tunnels. Where metallized, the veins consist of pyrite, auriferous pyrite, chalcopyrite, tetrahedrite-tennantite, galena, sphalerite, and wulfenite in a quartz and carbonate gangue. The presence of wulfenite suggests that the ore body exposed in the workings is in the oxidized zone.

Spurr, Garrey, and Ball (1908, p. 333–334) gave a brief discussion of this mine which was then called the Lanagan mine. At the time of the visit by Spurr and Garrey, only the upper tunnel had been driven. Spurr and Garrey concluded that the ore body then being mined had been deposited at the junction of two intersecting veins. C. L. Harrington (written communication, 1941) later concluded from an examination of a larger amount of workings that the ore shoot in the mine was deposited in the bostonite dike on a cross vein (pl. 6); the writers' study substantiates this conclusion.

The only productive ore shoot in the mine occurs where the eastward-trending vein cuts through the dike (pl. 6). The ore shoot plunges about 55° N. 5° E. Harrington's detailed map (pl. 6) shows that it decreases in width and thickness from the upper to the lower tunnel levels. In the upper tunnel the ore shoot has a stope length of about 60 feet and has a maximum thickness of about 30 inches; in the lower tunnel the ore shoot has a stope length of about 40 feet and has a maximum thickness of 12 inches. The ore shoot appears to be a lens-shaped body confined to the bostonite dike.

Spurr, Garrey, and Ball (1908, p. 334) gave the value of the ore in the upper stope which, when recalculated at 1953 market for gold, silver, and lead (average), is $216 per ton. Company assays indicate that the value of the ore in the lower stope was about $180 per ton.[5] Most of the production has been in silver (some assays show as much as 296 ounces per ton), and the upper stope also averaged slightly more than 2 ounces of gold per ton. The ore shoot has been very low

[5] Published with permission.

in base metals and has averaged only about 1 percent total lead, zinc, and copper.

FREELAND GROUP OF MINES

The Freeland group of mines as discussed in this report includes the Freeland, Freeland Extension, Toledo, Gum Tree, and Shakespeare mines (pl. 5). The veins in these mines include the Freeland, Freeland Extension, Split, Toledo, Gum Tree, and Anchor (pl. 5).

History.—The Freeland vein, discovered in 1861, was probably the first vein found in the Freeland-Lamartine district. The vein was first worked in 1868, and parts of the Freeland group of veins were worked almost continuously until 1942. The McClelland tunnel was begun in 1900 and completed in 1917 and was to serve as a drainage and haulage tunnel. However, a raise to connect with the 6th level of the old mine was not driven until 1935. From 1936 until 1942 some stoping was done on the veins above the McClelland tunnel level.

Production.—Complete production records of the Freeland group of mines extend back only as far as 1902. Spurr, Garrey, and Ball (1908, p. 327) reported that the management of the mine estimated that the Freeland mine had produced $4,655,000 worth of ore from 1861 to 1905. Since 1902, the total production from the Freeland group of mines as recorded in the files of the U. S. Bureau of Mines has been 37,859 tons of ore which yielded 11,125 ounces of gold, 98,865 ounces of silver, 216,642 pounds of copper, 3,344,532 pounds of lead, and 173,612 pounds of zinc.

Mine workings.—The portal of the Freeland tunnel is on the south bank of Trail Creek and is about 500 feet northwest of the abandoned mining town of Freeland (pl. 5). The Freeland group of mines has about 30,000 feet of drifting and 9,300 feet of raises and shafts. A plan of the workings is shown in plate 7. At the time of the writers' visit to this group of mines only the upper few feet of the Gum Tree shaft and about 3,400 feet of the McClelland tunnel were accessible.

Wall rock.—Spurr, Garrey, and Ball (1908, p. 328–329) gave some information on the wall rocks of the Freeland group of mines; some additional information was presented by Carl Belser (written communication, 1940). Apparently most of the mine workings are in granite gneiss and pegmatite, which contains layers of biotite-rich metasedimentary rocks. Some monzonite dikes and bodies of biotite-muscovite granite were also found in the workings. These units are the same as those mapped on the surface along the trace of the veins (pl. 2).

The traces of axial planes of two anticlines bracket the trace of the Freeland vein (pl. 2). The dip of the axial planes of the anticlines is probably slightly steeper than the dip of the Freeland vein.

Nature of the veins.—The Freeland group of veins represents a complex fracture system. This group, together with the Brighton, Harrisburg, and Turner veins, appears to form a unit of relatively flat-dipping veins. Most of the flat-dipping veins have a dip of 45° or less, and only a few local dips on any of these veins exceed 60°.

Correlation of the veins is complicated by a lack of work in critical areas and by a fault (pl. 7) that crosses between the Toledo-Gum Tree workings and the Freeland-Shakespeare workings. Spurr, Garrey, and Ball (1908, p. 324–325) suggested that the Freeland vein connected with the Toledo vein and that the Gum Tree vein connected with the Anchor vein. In addition, the Anchor vein in the Shakespeare tunnel probably correlates with the Shaffer vein in the McClelland tunnel (pl. 7). The vein called the Anchor in the McClelland tunnel is probably the unnamed vein found near the portal of the Shakespeare tunnel. The New vein in the McClelland tunnel is possibly the same vein as the split off of the Anchor vein in the Shakespeare tunnel. Belser (oral communication, 1953) stated that the names of the veins on the McClelland tunnel level were those given by the miners and that he had used the names even though they were probably incorrect. Belser's correlation of veins between the 6th level and the McClelland tunnel level seems questionable, but any attempt by the writers to solve problems of vein correlation or decipher the complexities of the fracture pattern in inaccessible workings is not warranted at this time.

The mineralogy of the veins is given by Spurr, Garrey, and Ball (1908, p. 329–330), and by Belser (written communication, 1940), and can be inferred from dump specimens and production records. In the Freeland mine, the Freeland vein is composed principally of quartz, auriferous pyrite, chalcopyrite, and tetrahedrite with some siderite. Galena occurred chiefly in bunches near the surface. Renewed movement along the Freeland vein in the area between the portal of the Freeland tunnel and the junction with the Freeland Extension vein has resulted in what Spurr and Garrey called "friction breccia"—a breccia consisting of rounded pebble-sized fragments of vein material which often is loosely cemented and has the appearance of a gravel "vein." The Shaffer vein on the McClelland tunnel level has a mineralogy similar to that of the Freeland vein. The Anchor vein in the Shakespeare tunnel is composed mostly of quartz and pyrite with a little chalcopyrite and sphalerite. The Toledo, Gum Tree, Split, and Freeland Extension veins are somewhat different in character in that the ore from them consists principally of galena and sphalerite with some tetrahedrite, chalcopyrite, and pyrite.

The location of the ore shoots, according to Spurr, Garrey, and Ball (1908, p. 330) and Belser (written communication, 1940), is controlled principally by vein intersections; in addition, however, the writers have noticed what appears to be a strong dip control. The main ore body in the Freeland mine was located between the Fourth level (Freeland Extension shaft) and the 2d level (Freeland shaft) and extended along the vein from the Freeland shaft to the junction of the Freeland, Split, and Freeland Extension veins. Vertical sections through the Freeland and Freeland Extension shafts show that the main ore shoot is, therefore, confined to the steeper part of the Freeland vein. (See pl. 7.)

GOLDEN ROD MINE

The collar of the Golden Rod shaft is on the ridge about one-half mile northwest of Freeland at an altitude of 9,550 feet. The shaft was inaccessible.

The only record of production that could be found in the files of the U. S. Bureau of Mines was of a shipment of 126 tons of ore in 1940. This shipment yielded a total of 10.8 ounces of gold, 14 ounces of silver, 30 pounds of copper, 146 pounds of lead, and 105 pounds of zinc. In 1952, part of the dump was being hauled to a mill for recovery of gold.

A dump inspection indicated that the wall rock is exclusively altered biotite-muscovite granite. Surface mapping shows that the granite is a small dikelike body occurring between migmatite and granite gneiss and pegmatite.

The vein strikes N. 66° E., dips 68° W., and probably is an extension of the New Era vein.

HARRISBURG MINE

The collar of the Harrisburg shaft is at an altitude of 9,788 feet and is about 3,700 feet N. 5° W. of the western peak of Alps Mountain (pl. 5). The mine consists of an inclined shaft connecting with drifts on two levels (fig. 17). The shaft was almost entirely filled with water.

Only scanty information could be found on the production from the Harrisburg mine. According to records of the U. S. Bureau of Mines a total of 21.5 tons of ore was shipped from the mine during periods of operation between 1935 and 1937, and from 1941 to 1942. This ore yielded 1.85 ounces of gold, 56 ounces of silver, 75 pounds of copper, 1,790 pounds of lead, and 272 pounds of zinc. Spurr, Garrey, and Ball (1908, p. 327) indicated that the mine was worked before 1900, but no production records previous to 1901 could be found for the mine.

The Brighton and Harrisburg mines are connected by two raises driven near the junction of the two veins (fig. 17). Spurr, Garrey, and Ball (1908, p. 326) mentioned a report that the Brighton appears to be the main vein as it continues past the junction, whereas the Harrisburg does not appear to cross the Brighton.

The material on the Harrisburg dump indicates that bostonite, granite gneiss and pegmatite, migmatite, lime silicate gneiss, and biotite-quartz gneiss were found in the workings of the mine.

The Harrisburg vein strikes about N. 58° W. and dips about 48° NE. and probably is part of the Freeland vein system. Although the Harrisburg is subparallel to the Split vein, which was found in the Freeland mine, the Harrisburg appears to be a distinct vein and not an extension of the Split (fig. 8).

INVINCIBLE MINE

The collar of the Invincible shaft, at an altitude of 10,360 feet, is about 2,850 feet N. 60° W. of the western peak of Alps Mountain (pl. 5). A possible caved tunnel portal is at road level just below the shaft (pl. 2). The shaft was found caved at the collar.

Only one shipment of ore from the mine is recorded in the U. S. Bureau of Mines files. In 1908, a shipment of 8 tons of ore yielded 6.5 ounces of gold and 25 ounces of silver.

According to Spurr, Garrey, and Ball (1908, p. 333) the Invincible vein probably strikes about N. 53° E. and dips 70° NW. From the surface mapping, the writers have concluded that the Invincible vein is probably a southwest extension of the Lone Tree vein. On the surface the vein is along the hanging wall of a bostonite dike for about 1,000 feet southwest of the collar of the shaft.

The rock on the dump is mostly granite gneiss and pegmatite and bostonite. Vein material on the dump is chiefly galena and pyrite in a quartz gangue.

LAMARTINE MINE

The Lamartine mine has the most extensive workings of any mine in the district. The mine has more than 12 miles of workings, but only about 1½ miles of workings is now accessible. The collar of the Lamartine main shaft is about 1,000 feet N. 60° E. of the abandoned town of Lamartine, at an altitude of 10,610 feet (pl. 5). The portal of the Lamartine tunnel is about 3,900 feet N. 45° E. of the Lamartine shaft at an altitude of 9,705 feet (pl. 5). The lowest workings in the mine are accessible through the Old Stag tunnel, whose portal is on Trail Creek at an altitude of 9,360 feet and is about 1,300 feet N. 12° E. of the Lamartine tunnel portal (pl. 5). Other openings of the Lamartine mine include the Falcon tunnel and shaft, the Ben Harrison shaft, the Silver Queen shaft, the Money Musk shaft, (pl. 5) and the Oneida tunnel, whose portal is covered by the dump of the Lamartine tunnel. A 100-ton mill near the portal of the Lamartine tunnel is used to concentrate the ore.

History.—The early history of the mine is given by Spurr, Garrey, and Ball (1908, p. 314–315) as follows—

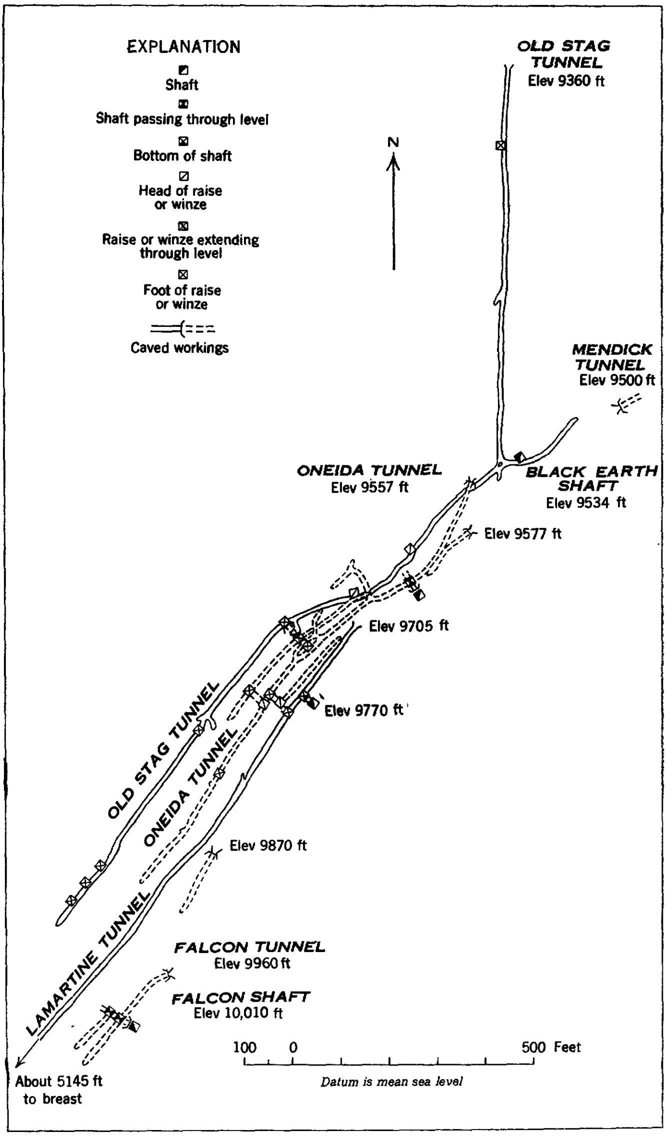
The Lamartine mine . . . . was located in 1867. The original discovery was made by Peter Cooper, John J. Bougher, and Peter Chavanne, who were searching for a gold mine. As the surface indications of this lode were not favorable, one of these men sold a fourth interest for $25, another for $250, and Chavanne sold out for $5. The property was acquired by Peter Himrod, of New York City, who in 1887 let a contract for sinking a shaft in the vein. The shaft encountered the Lamartine ore body at a depth of about 100 feet, in May, 1888, one month after the death of Mr. Himrod. Fred E. Himrod, his son, gave a lease on a small block of ground to Messrs. Armstrong, Burns, Williams, and Hanchett, who produced $616,000 from it in 16 months. At the expiration of this lease, vigorous development work was carried on by the owner, under the direction of Silas Hanchett.

The following statement of the production of the mine was taken from the record books by the courtesy of the present owners: Total production to August, 1905, ore, net weight, dried, 67,946,019 pounds, yielding 39,291.81 ounces of gold, 2,677,470.79 ounces of silver, and 3,232,020 pounds of lead, having a total actual value of $2,361,039.15. No copper appears in the returns.

At present not much work is going on at the mine, and many of the old workings are inaccessible.

The mine lay idle for several years until reopened by Morris Jule in 1937. The old workings had been principally in the area west of the main shaft along the Lamartine vein, but the new workings were east of the main shaft along the Oneida vein. Also, the old workings were in ore which had principal values in silver and lead, but the new workings were in ore whose principal value was in gold. Along one streak of free gold (see pl. 8 for location) it is reported that $158,000 worth of ore was collected in powder boxes. Early in 1942 government regulations and shortages of men and equipment forced the mine to shut down. In 1949 the property was leased to the Montana Mining Development Corporation, who were operating the mine in 1952. Most of the work during 1949–52 had consisted of milling dump material from the main shaft dump. Some explorative drifting and raising was done along the Lamartine tunnel level during 1952.

Production.—Production records from the Lamartine mine include ore produced from the Lamartine, Falcon, Ben Harrison, Oneida, Old Stag, and Money Musk mines. A record of production from this mine from 1867 to 1952 was obtained by combining the data presented by Spurr, Garrey, and Ball (1908) with the more recent records of the U. S. Bureau of Mines. About 300,000 tons of ore has been produced from this group of mines along the Lamartine-Oneida veins. This ore has yielded 78,184.71 ounces of gold, 3,092,962 ounces of



From company map by W. H. Wiley, 1911, with additions by J. E. Harrison, 1952. Published with permission of the owners

FIGURE 19.—Plan of part of the workings on the Oneida-Mendick veins.

silver, 162,802 pounds of copper, 5,601,598 pounds of lead, and 1,258,136 pounds of zinc.[6]

Mine workings.—The mine has been opened through several adits and shafts. The principal openings are the main shaft, which con-

[6] Published with permission of owner.

nects the Lamartine tunnel (10th level) with the surface; the Lamartine tunnel, which is about 9,000 feet long; the Oneida tunnel; and the Old Stag tunnel. (See pls. 4 and 8, and fig. 19.) In addition, several smaller adits and shafts, notably the Silver Queen and Money Musk, (pl. 5) have served to explore the veins. The main underground shaft (Johnson shaft in pl. 8) was used to raise ore from below the Lamartine tunnel. The approximate extent of the stopes in the mine is shown in plate 3. Only a relatively small part of the mine was accessible at the time of the writers' visits. A cave on the Lamartine tunnel level about 300 feet east of the main shaft blocks access to the older workings around the main shaft. The Johnson shaft is caved, and the portal of the Oneida tunnel has been buried under the Lamartine tunnel dump. The Montana Mining Development Corporation cleared several caved areas from the Old Stag tunnel in order to drain the workings and make them accessible.

Wall rock.—Most of the accessible mine workings have been driven through migmatite (pls. 3, 4, and 8; fig. 19). Local layers of biotite-quartz gneiss and granite gneiss and pegmatite are exposed in some parts of the mine. Layers and small bodies of biotite-muscovite granite and pegmatite also occur locally in the mine. According to Spurr, Garrey, and Ball (1908, pl. 65), the workings west of the main shaft are in "massive granite," "gneissoid granite," and pegmatite. The surface exposures west of the main shaft are principally granite gneiss and pegmatite with some biotite-muscovite granite and granodiorite. The gneissoid granite mapped by Spurr and Garrey probably is equivalent to the granite gneiss and pegmatite of this report; the massive granite is probably biotite-muscovite granite and not the granodiorite which is characteristically well foliated where exposed on the surface in this area. In addition, Spurr and Garrey showed a bostonite dike along the footwall of the vein west of the main shaft.

The structure of the wall rock indicates that the accessible part of the Lamartine tunnel and that part of the Old Stag tunnel on the vein have been driven approximately parallel to the trend of a major abnormal anticlinorium. The vertical projection shown in plate 3 shows the change in plunge of the axis of this major fold. Although the plunge of the axis is principally to the northeast, locally it is to the southwest. The vertical section along the crosscut part of the Old Stag tunnel (pl. 4) shows some of the small folds on the flank of the anticlinorium to be overturned and to grade into upright folds as the axial region of the major fold is approached. The principal gold-bearing part of the Lamartine-Great Western vein group is in the axial zone of the major anticlinorium.

Veins.—The names given to parts of the Lamartine-Great Western vein group are shown in figure 8. The eastward-trending part of the group at the southwestern end is called the Lamartine vein; the adjacent part that trends northeasterly is called the Oneida vein; the diagonal link is called the Mendick vein; and the northeast end of the group is called the Great Western vein. All of these veins dip steeply to the north. A vein found underground about parallel to the Lamartine vein but a few feet to the north has been called the Crown vein. The Crown vein has been mined extensively along with the Lamartine vein in the area west of the main shaft.

This group of fissures has been strongly mineralized from about 3,000 feet west of the Lamartine shaft eastward to the portal of the New Era south tunnel (pl. 5). Both ends of the system break up into a series of weakly mineralized or barren fractures. This horsetailing is very noticeable west of the Silver Queen shaft (Spurr, Garrey, and Ball, 1908, fig. 119). The mines located on the minor veins west of the Lamartine shaft (Chloride, Collateral, Financier, R. E. Lee, St. Louis) have produced little or no ore.

Spurr, Garrey, and Ball (1908, p. 315) described the ore from the Lamartine vein west of the shaft as follows—

> The vein material contains abundant galena and blende, with some pyrite. The product has been chiefly galena ore which has been selected from ore containing blende. The zinc-bearing ore as a rule is poor in gold and silver. The best ore appears to be fine galena, much of the coarse galena being of lower grade as regards gold and silver. . . .

The ore from the Oneida vein consists principally of pyrite, gold, and chalcopyrite. Southwest of the Johnson shaft (pl. 8) the vein contains pods and stringers of galena and sphalerite that cut the older pyrite-chalcopyrite vein material, thus forming what has been called composite ore by Bastin and Hill (1917, pp. 112–113). The quantity of galena and sphalerite in the composite ore increases toward the main shaft, and west of the main shaft the vein (there called the Lamartine) is composed of galena-sphalerite type ore. The Oneida vein also is composite in character near the Mendick split. Quartz is the gangue mineral accompanying the pyrite-gold ore type, and both quartz and carbonate are gangue minerals accompanying the galena-sphalerite ore type.

As so much of the mine is inaccessible, control of the ore deposits is conjectural. Spurr, Garrey, and Ball (1908, p. 318) suggested that the ore body west of the main shaft resulted from mineral deposition at the junction of the Oneida and Lamartine veins. The miners report that the ore is thicker on the steep parts of the vein and thinner or absent on the flat parts. On the Old Stag tunnel level the location of the ore bodies seems to be influenced by a change in strike (pl. 4). The vertical projection along the veins (pl. 3) suggests a northeastward-plunging shoot structure for the ore bodies below the Falcon shaft and below the portal of the Lamartine tunnel. Junction of the unnamed vein southwest of the Mammoth vein with the Oneida vein also may have influenced the location of an ore body. These data seem to indicate clearly that the type of host rock is not a factor controlling location of these ore bodies.

Milling of dump material.—An increase in metal prices since the 1890's has made reworking of old dumps profitable at certain times. During 1951–52 the Lamartine mill processed material from the dump at the Lamartine shaft. Harold Anderson, superintendent of the Lamartine mine and mill for the Montana Mining Development Corporation, supplied the information that 100 tons of dump material yields about 3,000 pounds of concentrate which is worth about $290 to $300 per ton. From the assay information supplied by Anderson, the tenor of the dump was calculated to be 0.15 percent lead, 0.15 percent zinc, 0.0223 ounce of gold, and 1.5 ounces of silver per ton. All figures given are averages.

LITTLE JOHNIE GROUP OF MINES

The Little Johnie group of three mines is on the south side of Trail Creek about 800 feet southeast of the abandoned town of Freeland (pl. 5). The portals of the three tunnels are at altitudes of 8,988, 9,071 and 9,215 feet.

All three tunnels have been driven approximately along the axis of an anticline. The distribution and relation of the main veins and rock layers along the anticlinal crest are shown in figure 7.

Lower tunnel.—The lower tunnel is a crosscut adit that bears S. 35° W. for a distance of 70 feet from the portal to an eastward-trending vein; beyond the vein the adit crosscuts to the south for about 30 feet then follows a southwestward-trending gouge lead for about 300 feet at which point it turns and follows another gouge lead trending S. 35° E. (fig. 20). The only stope in the mine is on the short westerly drift near the portal.

The lower tunnel is driven into the northwest limb of an anticline that trends about N. 5° E. and plunges 28° to 40° NE. Layers of garnetiferous biotite-quartz gneiss, migmatite, and granite gneiss and pegmatite are exposed in the mine. A pegmatite dike 16 feet wide cuts through the older pre-Cambrian rocks at a point 180 feet from the portal (fig. 20).

The only metallized vein in the lower mine strikes N. 85° W. and dips to the north. The stoped area of this vein was inaccessible in 1952. Samples of ore found on the dump show pyrite, chalcopyrite, galena, and sphalerite in a quartz, carbonate, and fluorite gangue. If the samples collected from the dump are representative of the ore body, then the vein is somewhat different from most of the veins in

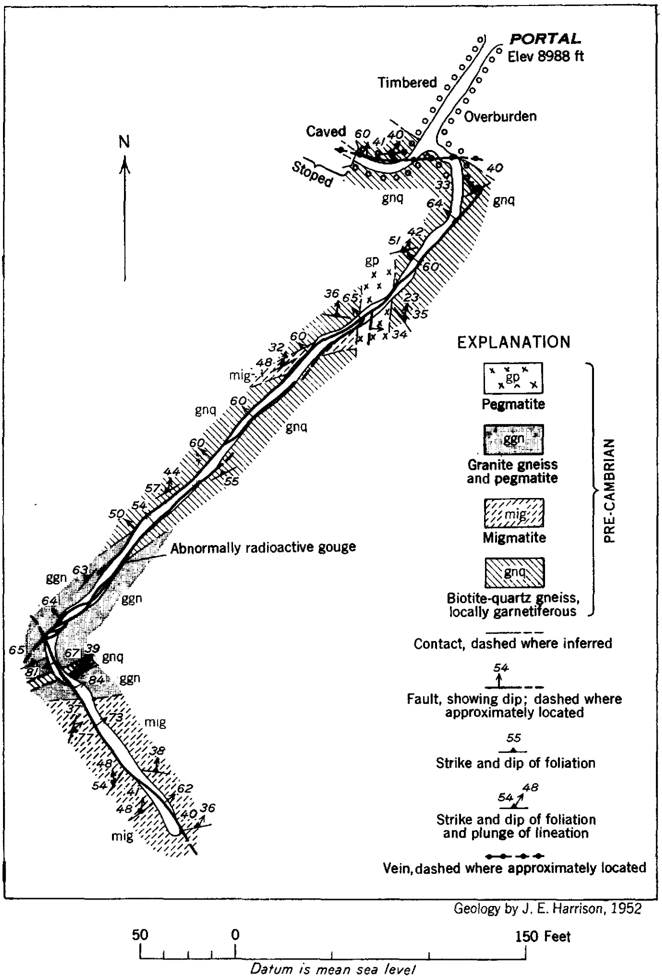


FIGURE 20.—Geologic map of the lower tunnel, Little Johnie group of mines.

the district. The two principal distinguishing features of this vein are that carbonate rather than quartz forms most of the gangue and fluorite, usually uncommon, is present in fairly large quantities. The vein is a fissure filling in brecciated garnetiferous quartz-biotite gneiss, and is very vuggy. Crustification of the vein minerals allows a simple deduction as to paragenetic sequence. Following brecciation and fracturing of the host rock, quartz and pyrite partly replaced the wall rock along the margins of the fractures; some quartz crystals formed a thin crust along open fissures. Renewed movement along the main fault reopened some of the old fissures and opened new fractures. White calcite and ankerite, buff dolomite, pink rhodochrosite, and euhedral cubic and octahedral galena were deposited as new crusts on the older quartz-pyrite material. Some disseminated galena, sphalerite, pyrite, and chalcopyrite were also deposited during this second stage. The carbonates also filled some of the new fractures accompanying the second stage of shearing. The second stage ended with the deposition of fluorite and chalcopyrite in the centers of the vuggy openings and as crusts completely filling some of the fissures. The fluorite-chalcopyrite phase overlapped the strong carbonate phase to some extent.

Middle tunnel.—The first 155 feet of the middle tunnel is a crosscut adit driven S. 7° W. The tunnel then bifurcates, extending about 75 feet west and 115 feet east along the principal veins. A shallow winze, several short side drifts, and two small stopes complete the mine workings (fig. 21).

The crosscut adit was driven approximately on the axial plane of an anticline. The workings expose layers of garnetiferous biotite-quartz gneiss, amphibolite, migmatite, and granite gneiss and pegmatite, some of which is alaskitic. A pegmatite dike 1 foot thick cuts through the older pre-Cambrian rocks at an angle of about 45° to the fold axis (fig. 21).

The drift follows two veins, each of which range in strike and dip, but which on the average trend due east and dip 38°–70° N. The eastward-trending veins are intersected by two veins that trend N. 30°–40° E. and dip 60°–70° NW. (fig. 21). Both the eastward- and northeastward-trending sets of vein fissures are weakly mineralized and contain pyrite, chalcopyrite, sphalerite, and galena in a predominantly quartz gangue. Some carbonate gangue occurs with the sulfides in the thicker parts of the ore streaks. The veins range in width from ¼ to 1½ inches.

Two local controls for the thickening of the ore streak can be seen in the mine. Intersection of the two eastward-trending veins at points about 30 feet east and 30 feet west of the crosscut (see fig. 21) has formed small ore pods. On the southwest wall of the room near the breast of the east drift, the southernmost vein has several changes in dip in the space of about 30 feet vertically down the vein. On the flat parts of the vein only ¼ inch of ore appears, but on the steep parts 1½ inches of ore is present. The intersections between the northeastward-trending vein and the eastward-trending veins do not appear to be enriched.

Upper tunnel.—The upper tunnel is a 200-foot crosscut adit that trends, in general, about S. 10° E. The adit has been driven into the east flank of the anticline not far from the anticlinal axis. Layers of garnetiferous biotite-quartz gneiss and migmatite are exposed in the tunnel; two pegmatite bodies are also exposed, a 12-foot-thick con-

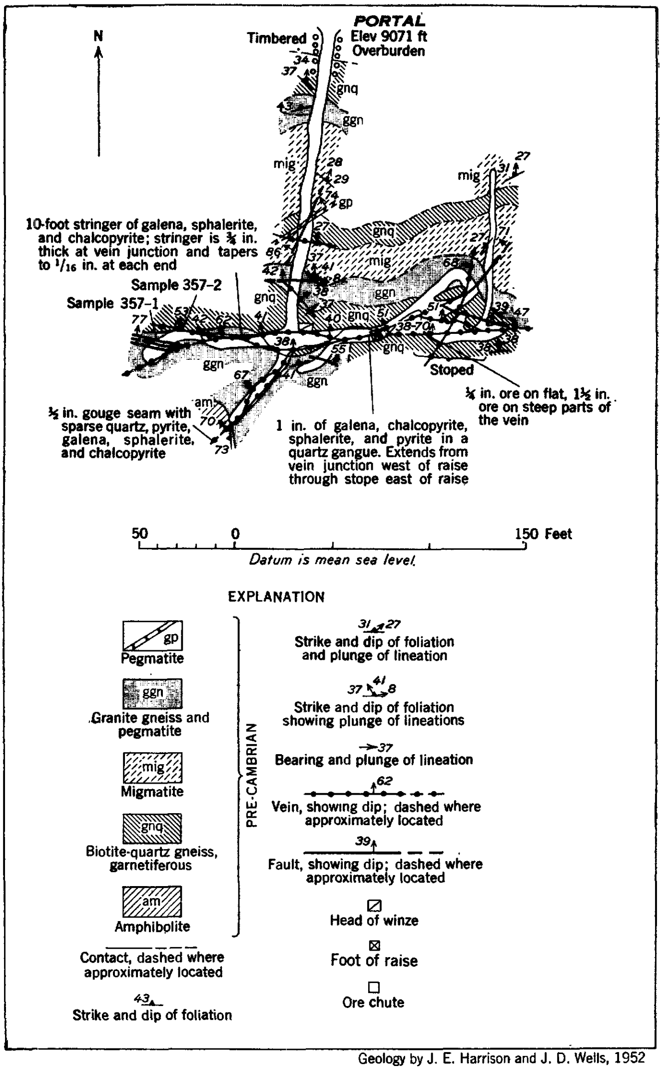
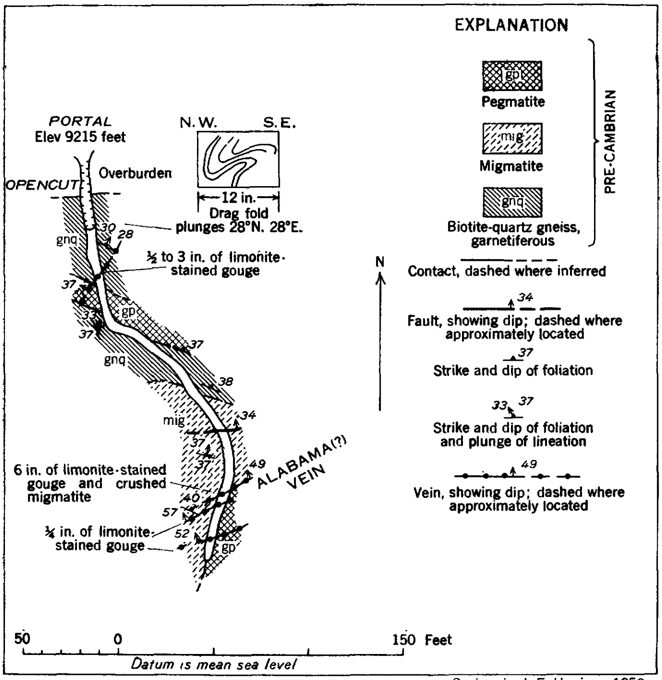


FIGURE 21.—Geologic map of the middle tunnel, Little Johnie group of mines.

formable body near the tunnel portal and a crosscutting body near the breast of the workings (fig. 22).

No strongly mineralized veins are exposed in the crosscut. A 6-inch-wide zone of limonite-stained gouge and crushed migmatite is exposed about 40 feet from the tunnel breast. This zone may be a northeasterly extension of the Alabama vein (pl. 5).

Production from the group.—Production of ore from the Little Johnie group of mines has been small. No ore has been produced



Geology by J. E. Harrison, 1952

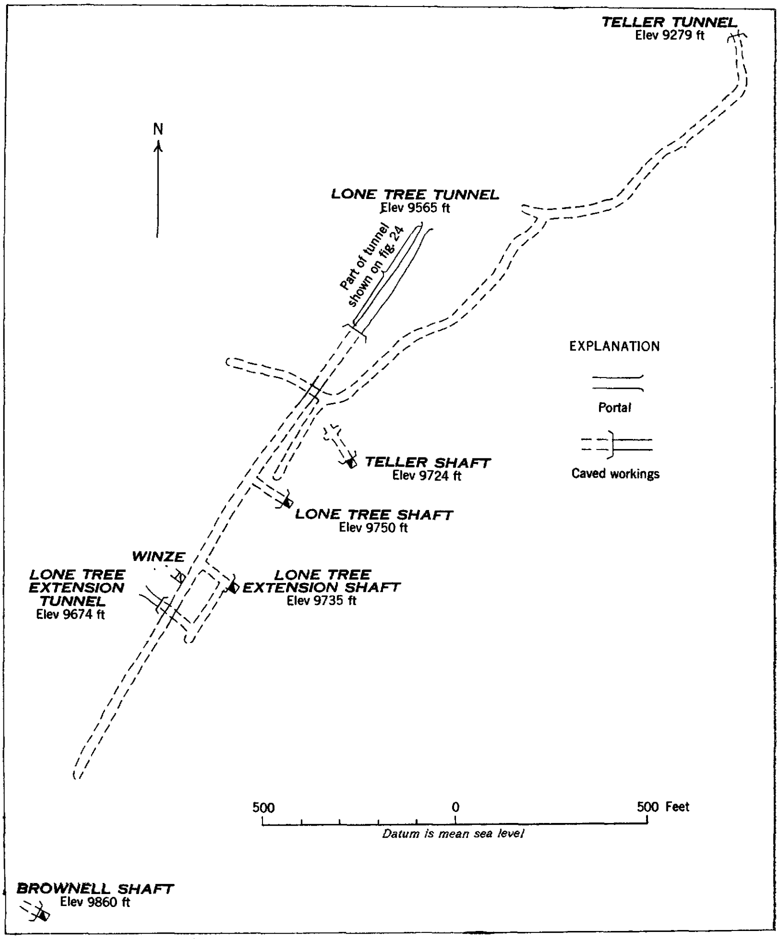
FIGURE 22.—Geologic map of the upper tunnel, Little Johnie group of mines.

from the upper tunnel, and indications are that only a few tons of ore have come from the middle and lower tunnels.

LONE TREE MINE

The Lone Tree mine consists of a tunnel and two shafts that connect with the tunnel workings (fig. 23). The tunnel portal is at an altitude of 9,565 feet and is about 3,300 feet S. 87° W. of Freeland (pl. 5). The Lone Tree shaft is about 800 feet S. 29° W. of the tunnel portal, and the Lone Tree Extension shaft is about 300 feet farther from the tunnel portal along the same line. A shallow shaft (Brownell), which is probably on the Lone Tree vein, is about 1,000 feet southwest of the Lone Tree Extension shaft.

Although the location of the portal of the Lone Tree tunnel is indicated by Spurr, Garrey, and Ball (1908, pl. 17), no mention of the mine is made in the text of their report. Undoubtedly the mine was worked as early as 1905, but the first record of production in the files of the U. S. Bureau of Mines is for the year 1913. Production records indicate that the mine was worked from 1913 to 1914, in 1920, and from 1936 to 1945. The first development along the Lone Tree tunnel exploited ore that was rich in gold and low in silver, lead, and



Modified from maps loaned by C L. Harrington

FIGURE 23.—Plans of the Lone Tree and Teller mines.

zinc. Subsequent work found ore rich in silver, lead, and zinc, but low in gold. During the different recorded periods of operation, a total of 1,757 tons of ore was shipped from the mine. This ore yielded 775.7 ounces of gold, 2,345 ounces of silver, 582 pounds of copper, 24,352 pounds of lead, and 16,300 pounds of zinc.

Only the first 315 feet of the tunnel were accessible (fig. 24), however, a map loaned by C. L. Harrington shows the main tunnel to be about 1,650 feet long (fig. 23).

The wall rock in the accessible part of the tunnel is mostly migmatitic biotite-quartz gneiss, with some pegmatite and quartz gneiss. The dump at the tunnel portal contains sillimanitic biotite-quartz gneiss, migmatite, granite gneiss and pegmatite, quartz diorite, and

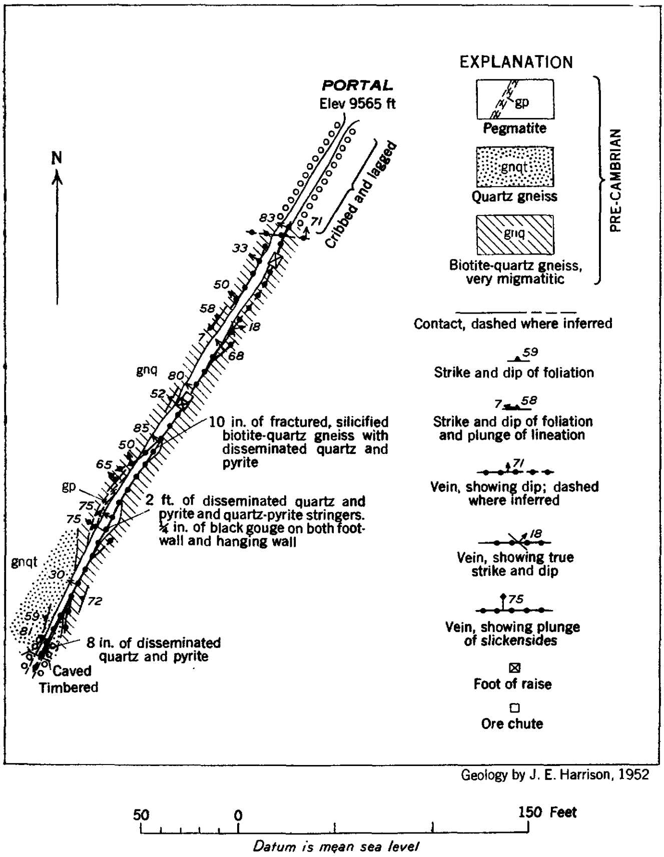


FIGURE 24.—Geologic map of part of the Lone Tree tunnel.

biotite-muscovite granite. The dumps at the shafts include bostonite in addition to those rock types found on the tunnel dump.

The Lone Tree vein appears to have an average strike of about N. 34° E. and an average dip of about 70° NW. This vein is probably a southwesterly extension of the New Era vein.

Examination of vein material on the dump indicates that the ore mined consisted of pyrite, chalcopyrite, tetrahedrite, sphalerite, and galena in a gangue composed of quartz, calcite, and siderite.

MENDICK MINE

The portal of the Mendick tunnel, at an altitude of about 9,500 feet, is in a small gulch and about 4,300 feet S. 87° W. from the abandoned town of Freeland (pl. 5).

U. S. Bureau of Mines production records on the Mendick mine indicate that the mine was operated during 1916, and then again from

1938 to 1940. A total of 174 tons of ore was shipped from the mine during the two periods of operation. This ore yielded a total of 35.8 ounces of gold, 67 ounces of silver, and 120 pounds of zinc.

In 1952 the tunnel was caved at the portal. The vein is exposed in two places on the side of the hill above the tunnel where old stopes have caved. The vein appears to strike about N. 60° E. and dip 78° NW. Only quartz-pyrite vein material was seen on the dump.

The Mendick vein connects the Lamartine-Oneida vein with the Great Western vein (fig. 8). Short drifts have been made on the Mendick vein in the Old Stag tunnel (pl. 4) and in the New Era mine.

MILLER MINE

The portal of the Miller tunnel is 1,650 feet N. 35° W. of the western peak of Alps Mountain (pl. 5), at an altitude of 9,921 feet. The Miller tunnel is on patented ground and is owned by Diamond Mountain Mines, Inc.

Early production figures for the Miller mine are not available, but the production from the mine since 1908 has been recorded by the U. S. Bureau of Mines. The available production records show that ore was shipped in 1908, 1928, 1933–35, and in 1939 and 1940. During these periods a total of 160 tons of ore was produced from the mine. This ore yielded 43.2 ounces of gold, 1,960 ounces of silver, 35 pounds of copper, 3,484 pounds of lead, and 652 pounds of zinc.[7]

The first 80 feet of the tunnel is a crosscut trending almost due south to the vein. From this point the tunnel has been drifted S. 63° W. along the vein for about 1,200 feet (pl. 9). At 210 feet from the portal a raise extends through to the surface, and at 850 feet a winze extends down 80 feet to a short level. The tunnel was inaccessible beyond the winze in 1952.

The wall rock in the accessible part of the tunnel is principally biotite-muscovite granite (pl. 9). A few thin layers or inclusions of biotite-quartz gneiss and granite gneiss and pegmatite are exposed near the portal. A small bostonite dike that cuts through the pre-Cambrian rocks is exposed in the crosscut from the portal.

The Miller vein strikes about N. 63° E. and dips on the average about 80° NW. Where observed this vein is accompanied by a 6-inch to 4-foot-wide sheared zone containing disseminated pyrite and local disseminated chalcopyrite, sphalerite, and galena in a quartz gangue. Locally horses of country rock occur in the vein (pl. 9), and some of the horses contain disseminated pyrite cut by thin stringers of chalcopyrite, sphalerite, and galena.

[7] Published with permission of the company.

At the junction between the crosscut from the portal and the main drift, a bostonite dike is offset along the vein. A friction breccia has formed locally between the footwall and hanging wall veins. This friction breccia contains fragments of bostonite, granite gneiss and pegmatite, biotite-muscovite granite, biotite-quartz gneiss, and quartz-pyrite vein material. The breccia is cemented in part by quartz-pyrite and in part by chalcedonic quartz. The breccia extends about 100 feet southwest along the vein from the point where the crosscut joins the main tunnel.

Spurr, Garrey, and Ball (1908, p. 334–335) gave a brief description of the Miller mine. They attributed the ore shoot at the winze to the intersection of two slightly mineralized fissures which form "a small trough of ore pitching to the southwest and containing 1 to 4 inches of galena-sphalerite ore."

NEW ERA MINE

The main part of the New Era mine is on the south side of Trail Creek about 3,000 feet upstream from the abandoned town of Freeland; a smaller part of the mine is on the north side of Trail Creek. The main tunnel portal is at an altitude of 9,183 feet (pl. 5). The mine exploits two subparallel veins which locally are less than 50 feet apart.

History.—A brief history of the mine taken from the owner's application for an exploration loan (Conwell, C. N., written communication, 1950) is quoted in the following paragraph.

In 1878 H. G. Mils recorded the claims, Great Western and Great Eastern. These were not worked much until leased to the New Era Mining Company in the 1890's. This company purchased the mines in 1903 and the Oldbury claim in 1904. The owners erected a mill 1¼ miles east of the mine and operated successfully until 1912, at which time the mine was purchased by the Trail Creek Mining Company. A new mill was constructed near the portal of the south tunnel and operated successfully until 1914. In 1914 the mines were operated for two years by the Calumet Corbin Mining Company and then regained by the Trail Creek Mining Company. However, they were not operated during World War I. During the early years of operation, gold was the principal value as lead was then selling for approximately three cents a pound; some of the ore at this time carried as much as 50 percent lead. It has been reported that in operations above the tunnel level (4 stopes and over 3,000 feet of drifting along the 3 main veins) that over $700,000 worth of ore has been taken out. Dr. James Underhill, recently retired Professor of Mining at the Colorado School of Mines, was left to dispose of the property as he had been the company Engineer and Trustee. The title of the mines passed to Lucy Underhill in 1939. A few records and some maps have been made, but the mine was never reopened. The mines were purchased from Lucy Underhill by Cleland N. Conwell. Since 1946 mapping, general history research, and some exploration work has been carried on.

In 1952 Mr. Hans Mosch began development work in one of the old winzes.

Production.—Complete production records of the New Era mine are not available for the period 1890–1907. The records in the files of the U. S. Bureau of Mines show that the mine was operated intermittently from 1908 to 1949. During the period when records had been kept, 36,762 tons of ore had been produced from the mine. This ore yielded 8,512 ounces of gold, 32,595 ounces of silver, 28,268 pounds of copper, 904,248 pounds of lead, and 82,193 pounds of zinc.[8]

Mine workings.—The mine is accessible through two adits and a shaft. The main adit, called the south tunnel, is on the south side of Trail Creek, and the shaft and a smaller adit, called the north tunnel, are on the north side of Trail Creek (pl. 5). The south tunnel (pl. 10) has been driven on the New Era vein for 1,055 feet in a general S. 32° W. direction. Two crosscuts connect with about 1,100 feet of drifting on the Great Western vein. In addition, about 120 feet of drifting has been done on the Mendick and Oldbury veins. The north tunnel (fig. 25) has been driven 311 feet N. 32° E. on the New Era vein. Two short crosscuts to the west show the Great Western vein to be 40 to 70 feet west of the New Era vein. The shaft connects with what is called the 200-foot level, and Spurr, Garrey, and Ball (1908, p. 320) stated that about 1,000 feet of drifting on the Great Western vein and 500 feet of drifting on the New Era vein had been done on this level.

Wall rock.—Except for one small pegmatite dike, all of the accessible workings of the New Era mine have been driven in migmatite. The migmatite is highly contorted, and the fold symbols on the maps (pl. 10 and fig. 25) represent minor rolls on the flank of a major anticline lying west of the mine workings. Both the New Era and the Great Western veins are approximately parallel to the general trend of the foliation. The veins are slightly steeper than the foliation, and they have a pronounced tendency to split, roll out into the foliation, and become a weakly mineralized fracture.

Veins.—The New Era vein strikes N. 15°–35° E. and dips on the average about 73° NW. The New Era vein probably connects with the Golder Rod vein to the northeast and with the Lone Tree vein to the southwest (pl. 5). The Great Western vein strikes approximately parallel to the New Era vein for most of its length in the New Era mine workings. A slight divergence between these two veins is apparent at the northeast end of the north tunnel and at the southwest end of the south tunnel. Where the two veins are exposed at directly opposite points, the Great Western vein is everywhere slightly flatter. More of the mine workings were accessible on the Great Western vein at the time of the visit by Spurr and Garrey. They reported (1908, p. 321) that the Great Western vein offsets the cross vein (Oldbury

[8] Published with permission of owner.

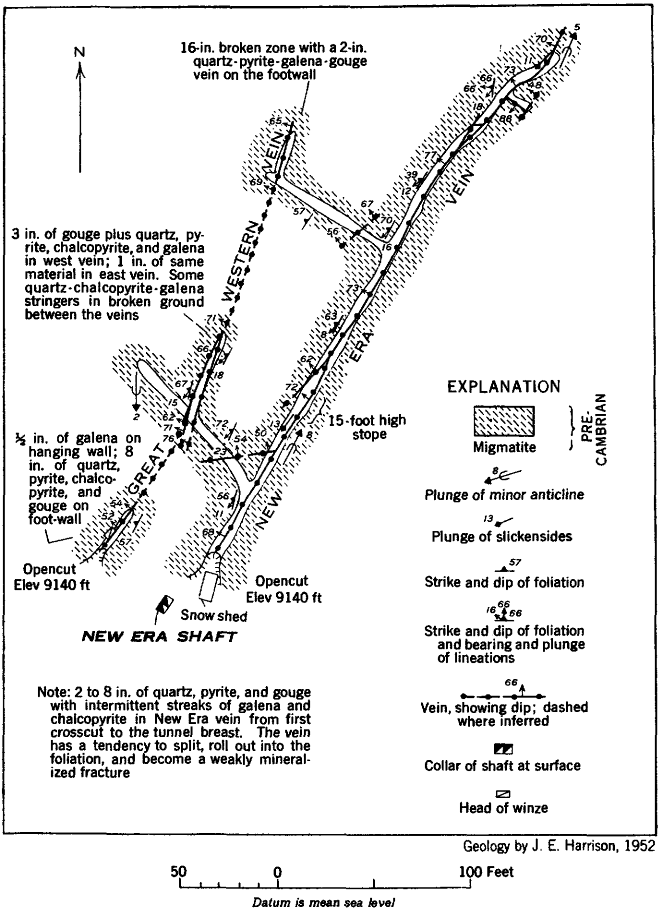


FIGURE 25.—Geologic map of the north tunnel of the New Era mine.

vein) in the southernmost crosscut in the south tunnel; the cross vein in turn offsets the New Era vein (pl. 10). The Mendick vein was not seen at the time of the visit, but the owner reports that the Great Western vein is offset along the Mendick vein. None of the offsets are more than a few feet in apparent horizontal displacement. The Mendick vein apparently does not extend to the New Era vein. The Great Western vein is connected to the Lamartine vein by the Mendick vein. The continuations of the Great Western and the Lamartine veins are less well mineralized north and south, respectively, of their junction with the Mendick vein. The Mendick vein thus has the geometric position of a diagonal link (McKinstry, 1948, p. 314) between two well-mineralized, possibly related, veins (fig. 8).

The mineralogy of the veins is similar to most of the silver-lead-zinc veins in the district. The Great Western vein is notable for its relative lack of sphalerite and abundance of chalcopyrite. Two stages of mineralization can be recognized: the first is represented principally by quartz and pyrite; the second, which locally can be recognized by mineralized stringers cutting the first-stage minerals, consists of quartz, pyrite, chalcopyrite, and galena which were deposited together with minor carbonate, sphalerite, and tetrahedrite.

At least two local controls for the ore bodies were observed in the mine. Horses of country rock tend to be enriched by stringers and disseminated ore, and vein intersections appear to be favorable areas for the deposition of ore.

Most of the ore produced from the mine has come from the Great Western vein. This vein has been stoped along most of the tunnel level workings in the south tunnel. According to Spurr, Garrey, and Ball (1908, p. 322), "The first-class ore of the mine . . . carries from 1¼ to 2 ounces of gold, 5 to 21 ounces of silver, and 45 to 50 percent of lead (per ton). Copper up to 5 percent and zinc up to 3 percent have at times been obtained. . . ."

POOR MAN MINE

The Poor Man mine is near the head of Trail Creek, on the north side of the stream, at an altitude of 10,136 feet (pl. 5).

Records of the U. S. Bureau of Mines indicate that the Poor Man mine was operated from 1902 to 1909, in 1921, and from 1933 to 1935. During this time, 222 tons of ore yielding a total of 82.5 ounces of gold, 8,259 ounces of silver, 625 pounds of lead, and 159 pounds of zinc was produced.

At the time of the writers' visit, the tunnel was caved at the portal. Spurr, Garrey, and Ball (1908, p. 319–320) reported that the workings in 1906 consisted of a 250-foot crosscut and a drift on a vein that strikes a few degrees south of west and dips 75° NW. This vein probably intersects the Brazil vein west of the Brazil shaft.

The waste rock on the dump and the rock exposed at the surface is principally granite gneiss and pegmatite. Limonite and quartz were the only vein minerals found on the dump.

SILVER LINK MINE

The collar of the Silver Link shaft is about 2,500 feet southwest of the abandoned town of Freeland, at an altitude of about 9,465 feet (pl. 5).

In 1952 the workings were inaccessible because the head frame of the hoist had partly fallen into the shaft. A mine map loaned by C. L. Harrington shows the workings to consist of a shallow shaft connected to a 130-foot drift. One small area has been stoped.

At the collar of the shaft the Silver Link vein has a strike of N. 48°

E. and a dip of 62° N. Specimens on the dump indicate that the vein material consists of pyrite, chalcopyrite, galena, and sphalerite in a quartz and siderite gangue. The wall rock is granite gneiss and pegmatite which contains local 10- to 20-foot layers of biotite-quartz gneiss. The vein cuts across the general trend of foliation in the bedrock at a low angle.

Production of ore from the Silver Link mine has been small.

TELLER MINE

The Teller mine consists of a tunnel and a shallow shaft (fig. 23). The portal of the Teller tunnel, at an altitude of 9,279 feet, is in a small gulch about 2,500 feet N. 81° W. of the abandoned town of Freeland (pl. 5). The collar of the Teller shaft is 1,500 feet S. 41° W. of the tunnel portal. In 1952, the tunnel was caved at the portal, and the shaft was beginning to cave.

The Teller mine was worked from 1902 to 1912, in 1922, and in 1935. During the periods of operation a total of 126 tons of ore was produced from the mine. According to records of the U. S. Bureau of Mines, this ore yielded 60.8 ounces of gold, 359 ounces of silver, 558 pounds of copper, 5,939 pounds of lead, and 625 pounds of zinc.

A plan (fig. 23) loaned by C. L. Harrington shows the workings of the mine. The adit has been drifted about 1,800 feet in a general S. 50° W. direction.

A geologic map of part of the Teller tunnel given by Spurr, Garrey, and Ball (1908, p. 323, fig. 122) shows the wall rock to be gneiss. The dump consists mostly of migmatite and sillimanitic biotite-quartz gneiss, with a few fragments of bostonite. Spurr and Garrey also reported (p. 323) that only weakly mineralized veins of composite ore had been found up to the time of their visit. The production records indicate that better ore was found along the southwestern end of the present workings. A feature worth noting is that Spurr, Garrey, and Ball (1908, p. 323) reported that the main northeastward-trending vein was slightly offset along a nearly eastward-trending vein about 300 feet from the mine portal.

TURNER MINE

The Turner mine has two surface openings, a tunnel portal and a shaft. The portal, at an altitude of 9,277 feet, is on the north side of Trail Creek about 1,850 feet N. 31° W. of the abandoned town of Freeland (pl. 5). The collar of the Turner shaft is about 600 feet N. 71° E. of the tunnel portal and is on the top of a ridge at an altitude of 9,389 feet.

Production.—The Turner mine has been operated intermittently since the late 1890's. As the mine has been operated at times by the same company that worked the Freeland, Toledo, and Anchor mines, the production records for the Turner are not always discrete from the records of these other mines. Production from the Turner was reported separately to the U. S. Bureau of Mines in 1909, 1910, and from 1942 to 1950. During these periods, 864 tons of ore was produced from the mine. This ore yielded 487.1 ounces of gold, 1,283 ounces of silver, 1,564 pounds of copper, 50,531 pounds of lead, and 878 pounds of zinc.

Mine workings.—The accessible part of the mine consists of a tunnel from which a raise extends to an upper level, and an underground shaft connecting the tunnel level with drifts on four lower levels (pl. 11). Extensive stoping has been done above the upper level and between the tunnel level and the fourth level. A shaft from the surface and part of the upper level are inaccessible.

Wall rock.—The mine workings are mostly in migmatite although most of the surface exposures in the area over the mine consist of granite gneiss and pegmatite. Granite gneiss and pegmatite was found in the westernmost parts of the tunnel level, the second level, and the fourth level. A layer of amphibolite is exposed on the tunnel level between the granite gneiss and pegmatite and the migmatite. Biotite-muscovite granite is exposed in the eastern end of the fourth level drift (pl. 11).

Wall-rock alteration along the veins is most noticeable in the migmatite. For about 6 inches on both sides of the veins the migmatite contains pyrite-sericite layers as a replacement of the biotite layers.

Veins.—The Turner mine exploits a lode-type ore deposit. The main veins strike N. 35°–90° E. and dip 25°–62° NW. The vein system probably connects with the Falu vein to the west (pl. 5).

The ore minerals are pyrite, chalcopyrite, sphalerite (both marmatite and resin sphalerite), galena, and minor amounts of tetrahedrite-tennantite. The gangue is principally vein quartz and chalcedonic quartz with minor amounts of carbonate.

Supergene alteration of the ore is strong on the tunnel level but decreases rapidly toward the first level and is not apparent on the second level. The greatest depth of supergene alteration noted was 120 feet vertically below the present surface.

Localization of the ore.—Structural control of this ore deposit is quite striking. The geologic map of the mine (pl. 11) illustrates strike-slip control in that the ore is concentrated on a prominent change in strike. The vertical section through the underground shaft (fig. 26) illustrates the dip-slip control in that the thickest galena ore is concentrated on the steeper part of the lode zone. The combined movement in the fracture zone has been such that the northwest

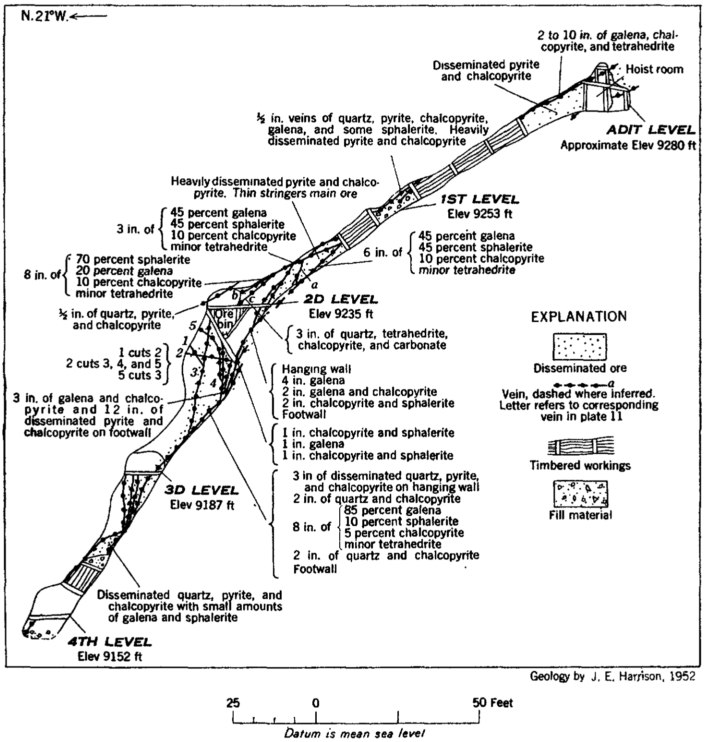


FIGURE 26.—Vertical section through the Turner underground shaft.

blocks have moved down and to the northeast relative to the southeast blocks. The total amount of movement could not be determined accurately, but it appears to be only a few feet both horizontally and vertically.

The principal ore shoot below the tunnel level plunges about 28° N. 30° E. The shoot structure has resulted from a combination of strike-slip and dip-slip movement along a cymoid-shaped fracture zone. Paragenetic relations suggest that the first movement was principally strike-slip and was followed by quartz-pyrite-chalcopyrite mineralization. The second movement resulted principally in dip-slip and was followed by the main galena-sphalerite mineralization. Minerals of both ore stages have been brecciated and recemented by chalcedonic quartz indicating that minor postmineralization movements took place.

An undiscovered ore body may be present some few feet out in the hanging wall between the second and third levels. The veins *b* and *c* split off from the main vein system and enter the hanging wall at the second level (fig. 26). Cross fractures having disseminated ore between them and containing thin ore streaks occur between the second and third levels and extend a short distance below the third level. Such

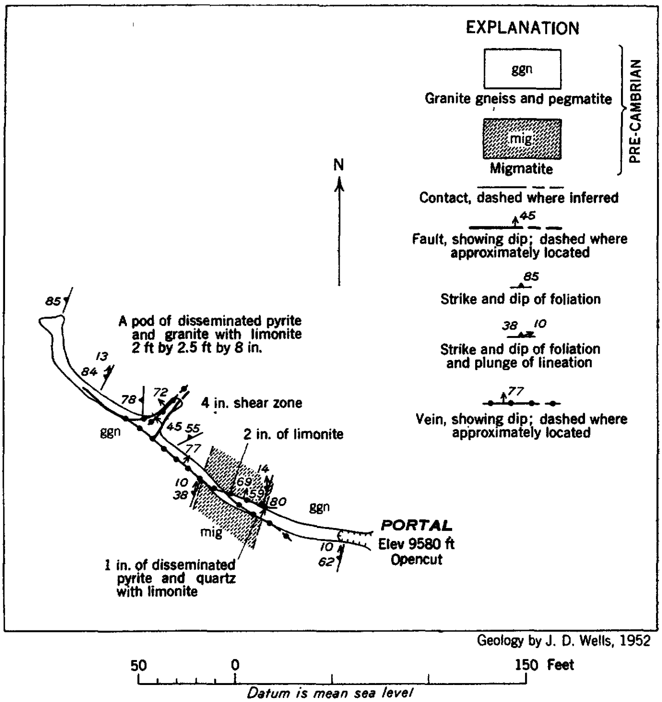


FIGURE 27.—Geologic map of the West London tunnel.

disseminations of ore and mineralized fractures characteristically appear only between two mineralized veins in the mine. As the strong change in dip on the main vein system, and consequently the thickest part of the galena ore body, occurs just below the second level, the possibility exists that veins *b* and *c* also have a prominent dip change out in the hanging wall and may, consequently, contain thicker ore.

WEST LONDON TUNNEL

The West London tunnel is about 6,100 feet west of the abandoned town of Freeland, at an altitude of 9,580 feet. The portal is about 100 feet north of the westernmost switchback on the Trail Creek road (pl. 5).

The mine workings consist of a 209-foot drift on one vein and a 20-foot drift on a cross vein (fig. 27). No stoping has been done in the mine.

The wall rock is granite gneiss and pegmatite, and migmatite. The foliation has an average strike of N. 20° E. and a dip from 38° to 85° NW.

The vein exposed in the tunnel is a weakly mineralized fracture that strikes N. 55° W. and dips about 80° N. The cross vein is also weakly mineralized and has an attitude of N. 45° E., 70° N. Both veins consist of an inch or less of quartz and py ite. A small pod of quartz and pyrite occurs at the intersection of the veins.

No record of production from the West London tunnel could be found.

SMALL INACCESSIBLE MINES AND PROSPECTS

The district contains many small inaccessible mines and prospects. No production information could be found for any of these workings. The information that could be gathered on the more important of these mines is given in table 10.

TABLE 10.—*Data on small inaccessible mines and prospects*

Mine no. (pl. 5)	Mine name	Type of surface opening	Probable vein explored	Ore minerals identified on dump	Host rock on dump
63	Alabama	Inclined shaft	Alabama	Pyrite, galena	Granite gneiss and pegmatite, migmatite, biotite-quartz gneiss.
54	Anchor	Tunnel	Anchor	do	Biotite-muscovite granite.
72	Ariadne Extension	do	Split off Miller vein		Do.
18	C. M. Welch	Inclined shaft			Granite gneiss and pegmatite, migmatite.
49	Ethel	Tunnel		Pyrite	Granite gneiss and pegmatite.
48	Etruria	Inclined shaft and tunnel.	Etruria	do	Granite gneiss and pegmatite, bostonite.
43	Falu	Inclined shaft	Turner	do	Granite gneiss and pegmatite, biotite-muscovite granite.
47	Giant Warrior	do	Turner (?)	do	Granite gneiss and pegmatite.
20	Mammoth	do	Mammoth	do	Biotite-muscovite granite, granite gneiss and pegmatite.
40	Mary Ann	Shaft	Avalanche		Biotite-muscovite granite, pegmatite.
23	Mint	do		Pyrite, galena, chalcopyrite, sphalerite.	Granite gneiss and pegmatite, migmatite.
44	Sherman	do		Pyrite	Do.
41	Trembath	Inclined shaft and tunnel.		Pyrite, galena, chalcopyrite, sphalerite.	Sillimanitic biotite-quartz gneiss, biotite-muscovite granite.
64	West Alabama	Tunnel	Alabama	Pyrite, galena	Granite gneiss and pegmatite, biotite-muscovite granite.
68	Yankee Girl	Shaft	Crazy Girl	Pyrite, galena, chalcopyrite.	Granite gneiss and pegmatite, migmatite, pegmatite.

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