Geology and Ore Deposits of the Boulder County Tungsten District Colorado

GEOLOGICAL SURVEY PROFESSIONAL PAPER 245

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By T. S. LOVERING *and* OGDEN TWETO

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By T. S. Lovering and Ogden Tweto

ABSTRACT

The tungsten district of Boulder County, Colo., is on the east flank of the Front Range, about 30 miles northwest of Denver. It forms a narrow belt 9½ miles long that extends from Arkansas Mountain, 4 miles west of Boulder, west-southwestward to the vicinity of Nederland. Gold and silver were mined in the eastern part of the district as early as 1870, but the heavy black material found widely distributed in the district was not recognized as the tungsten mineral ferberite until 1900. From that time until about 1918 Boulder County was the chief source of tungsten in the United States. Although the rate of output declined after 1918, production continued with only minor interruptions through 1945.

The district lies entirely within a terrane of pre-Cambrian rocks, the most extensive of which is Boulder Creek granite. A small area at the west end is in older schists and gneisses of the Idaho Springs formation. Within the mapped area this formation consists of quartz-biotite and quartz-biotite-sillimanite schist, related injection gneiss, and minor quartzite. The schist and quartzite were derived from shale and small lenticular beds of sandstone; the schistosity is nearly everywhere parallel to the original bedding. The schist and related rocks are isoclinally folded, and the fold axes are about parallel to the edge of the adjacent batholith of Boulder Creek granite. They strike north-northwest and dip east at a steep angle. All the metamorphic rocks are extensively intruded by small masses and irregular bodies of Boulder Creek granite and related aplite and pegmatite.

The so-called granite of the Boulder Creek batholith is in most places a coarse-grained gneissic quartz monzonite containing abundant biotite. The granite is cut by many dikes of pegmatite and aplite. On Hurricane Hill, about a mile east of Nederland, the border zone of the batholith is marked by a belt of aplite, aplitic granite, pegmatite, and alaskite ½ to 1½ miles wide. Much of the aplite in the district, both in the granite and in the metamorphic rocks, is strongly gneissic, and the foliation is parallel to the walls of the dikes.

Hornblende diorite, in part gneissic, occurs in a few small dikes and is related in origin to the Boulder Creek granite. The dikes are widely scattered both in the Idaho Springs formation, where they follow the schistosity, and in the Boulder Creek granite. Most of them are closely associated with dikes of pegmatite and aplite.

Pink, medium-grained, trachytoid Silver Plume granite, a pre-Cambrian granite younger than the Boulder Creek type, occurs in a few dikes in the north-central part of the tungsten district.

No Paleozoic or Mesozoic rocks have been recognized in the district.

Several porphyry dikes, all probably of early Tertiary age, cut the pre-Cambrian rocks. The earliest of these is the Iron dike, a persistent gabbroic dike that trends northwest across the eastern part of the tungsten district. A few small dikes of much-altered felsite have been found near the east and west ends of the district. Hornblende monzonite porphyry forms persistent eastward-trending dikes in the west half of the district, and a single dike of hornblende latite porphyry lies just south of Nederland. Limburgite porphyry, some of which is amygdaloidal, forms small, discontinuous, northeastward-trending dikes in the central and eastern parts of the district. Although it predates the ore, the limburgite porphyry was intruded relatively late in the intrusive period. Biotite latite porphyry and latitic intrusion breccia form short dikes, found chiefly in the eastern part of the district. They were intruded just prior to ore deposition and follow vein fissures and veins of early quartz. Field relations and the presence of a trace of tungsten in the latitic rocks suggest that the mineralizing solutions are closely related to them.

Several Tertiary erosion surfaces have been recognized in the tungsten district. Of these the Overland Mountain surface, probably of Oligocene age, is the most widespread. Tungsten Mountain, about a mile south of Nederland, is a monadnock on this surface. It is capped by coarse gravel, the age and origin of which are in doubt. The gravel was probably formed either by sheet wash or by glacial action and may be either Tertiary or early Pleistocene in age. Small remnants of pre-Wisconsin moraine occur on the valley slopes at Nederland, and moraine of Wisconsin age lies just west of the town.

The structural features of the district are of pre-Cambrian and Laramide age. The dominant pre-Cambrian structural feature is the Boulder Creek batholith. The foliation of the schist and gneiss of the Idaho Springs formation is parallel to the edge of the batholith, as is the primary foliation of the granite in a belt 1 to 2 miles wide near the contact. About a mile east of Hurricane Hill, the foliation of the granite swings from north-northwest to nearly west, and it maintains this general strike as far as the mountain front at Boulder. It dips 50°–70° N. and is roughly parallel to the regional dip of the schist that lies a short distance north of the tungsten district. Primary flow structures of the Boulder Creek batholith indicate that the granite magma was intruded from a center near Gold Hill, a few miles north of the east end of the district.

The earliest Laramide structural features are persistent northwestward-trending brecciated fracture zones and shear zones of early Paleocene age, commonly marked by hematite and white quartz, and are known as breccia "reefs." Many of the reefs follow zones of aplite and pegmatite dikes, and some of them can be traced for more than 15 miles. The major breccia reefs of the tungsten district are 2 to 3 miles apart and include, from west to east, the Maine-Cross, Hurricane Hill, Rogers, Livingston, and Hoosier reefs. All of them are earlier than the fractures that contain the tungsten veins.

Fissures occupied by the tungsten veins trend northeast or east-northeast. The east-northeastward-trending fissures are grouped in three distinct zones. The most pronounced zone lies a short distance north of Middle Boulder Creek and extends for

almost the full length of the district. A second zone of intersecting fissures that strike east and northeast extends along Gordon Gulch, near the north edge of the district. These two zones converge westward and join near the north end of Hurricane Hill. In the area west of this locality, production has come from short northward striking veins in a narrow belt that extends west-southwestward along Sherwood Gulch. A third east-northeastward-trending zone of vein fissures extends across the Beaver Creek district, 1½ miles southeast of Nederland. The north walls of most of the east-northeastward-trending fissures and the southeast walls of most northeastward-trending fissures moved down and west at a low angle. As the northeastward-trending fissures commonly branch from the north sides of the fissures trending east-northeast, the westward-pointing wedge-shaped blocks formed by the intersection of the two systems evidently moved down and west in response to a nearly horizontal compressive force.

From 1900 to 1945 the Boulder district produced about 24,000 tons of concentrates containing 60 percent WO_3, valued at about \$23,000,000. Although the annual output was relatively small after World War I and was soon far outranked by that of the large scheelite-producing districts in other states, the total output of the Boulder district up to 1945 was nevertheless almost 50 percent greater than that of any other tungsten district in the United States.

Many minerals have been found in the veins of the tungsten district, but most of the tungsten ore consists only of ferberite and fine-grained horn quartz. The ferberite commonly forms the matrix of a breccia of country rock and earlier vein quartz or occurs in veinlets or bands within veins of horn quartz. There are many drusy openings in the ore, and some of them contain small quantities of barite, sulfides, or clay minerals. Genetically most significant among the minor constituents of the tungsten veins, in general order of deposition, are hematite, dickite, marcasite, siderite, pyrite, sphalerite, tetrahedrite, adularia, beidellite, scheelite, and calcite. The tungsten deposits have been enriched by residual concentration of ferberite near the outcrops but not by other processes of oxidation and weathering.

Most of the tungsten veins are 6 in. to 3 ft thick. Almost all the tungsten occurs in irregular ore shoots separated by barren stretches along the vein fissure that may not even carry quartz. Many of the ore shoots pinch out within 100 ft of the surface, and only a very few extend to a depth of as much as 500 ft, but blind ore shoots lying partly or entirely below the near-surface ore bodies have been found in some mines. The most persistent ore shoot in the district, that of the Conger mine, bottomed at a depth of less than 600 ft. Most ore mined in the district contains 1 to 20 percent tungsten trioxide. Medium-sized ore shoots yield 25 to 50 tons of concentrates containing 60 percent, or 1,500 to 3,000 units, of WO_3; large shoots may yield 10 to 20 times as much. The ore shoots are commonly localized at places where the course or the dip of the vein changes—or where the vein crosses a dike or other small body of some brittle or resistant rock such as aplite.

Silver-bearing gray copper ores older than the tungsten deposits have been mined in the extreme northeastern part of the district, and gold telluride veins have been worked in many small mines near the Hoosier and Livingston breccia reefs. The gangue of the telluride veins is strikingly similar to that of the tungsten veins, and a few veins contain both ferberite and gold telluride. As a result of oxidation, gold in both the early sulfide and the gold telluride veins is more abundant at the outcrop than in the primary ores, but silver is most abundant in the zone of supergene enrichment, which is generally at a depth of less than 150 ft.

The wall rocks of most of the tungsten veins are strongly altered, although there are a few veins in fresh rock. Along most veins, a thin casing of sericitized and slightly silicified rock next to the ore passes abruptly into an outer envelope of argillized rock which contains many different hydrothermal clay minerals. The intensity of alteration decreases outward, and the outer edge of the altered zone is poorly defined. From the vein outward the zone of altered rock is divisible into four mineral subzones based on microscopic studies and characterized successively by (1) sericite, hydrous mica, orthoclase (adularia), and quartz; (2) dickite; (3) beidellite; and (4) allophane, hydrous mica, and sericite. Zone 4 is the earliest and zone 1 the latest in this sequence.

The character and paragenesis of the minerals in the altered wall rocks and in the veins indicate that the solutions passing through the fissures were originally acidic but became alkaline at or shortly after the time when the ferberite was deposited. The source of the mineralizing solutions was probably a biotite latite magma heavily charged with volatiles. Spectroscopic analyses of fresh biotite latite porphyry and latitic intrusion breccia from the eastern part of the district show the presence of tungsten and other heavy metals. It is believed that emanations from a latitic magma rose through hot porous intrusion breccia with little change in character until they entered the fissures above, where the acidic solutions became neutralized and finally alkaline through the acquisition of bases from the wall rocks. The solutions also became progressively less acidic at the source with passing time. Deposition of quartz probably began while the solutions were acid, but no ferberite was precipitated until the solutions were almost neutral. The sulfides and gold tellurides were probably deposited from alkaline solutions.

The mineralogy and the paragenetic relations of the veins, as well as the geologic history of the area, suggest that the deposits were formed at temperatures between 200 and 300 C and under pressures of less than 100 atm.

Because of the small size and high grade of the tungsten ore bodies, the ore is mined as rapidly as it is found, and at no time in the history of the district have the known reserves exceeded a year's production. Thus, at the time of declining tungsten prices and output at the end of World War II, the known reserves were almost zero. However, there are doubtless many undiscovered blind ore shoots remaining in the district, and some ore will be mined whenever the ratio of tungsten prices to mining costs is favorable. The areas near the breccia reefs have been the most productive in the district, and veins in these areas offer the most promise for future production. Specific recommendations for exploration are made in many of the mine descriptions.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Boulder County tungsten district lies on the east flank of the Front Range a short distance west of Boulder, Colo., and about 30 miles northwest of Denver (fig. 1). The tungsten deposits occur in a narrow belt that extends from Arkansas Mountain, 4 miles west of the mountain front near Boulder, west-southwestward to Nederland, a distance of 9½ miles. Throughout most of its length this belt is 1 to 2 miles wide, but near its west end it flares to a width of 3 miles. Its total area is approximately 20 sq mi.

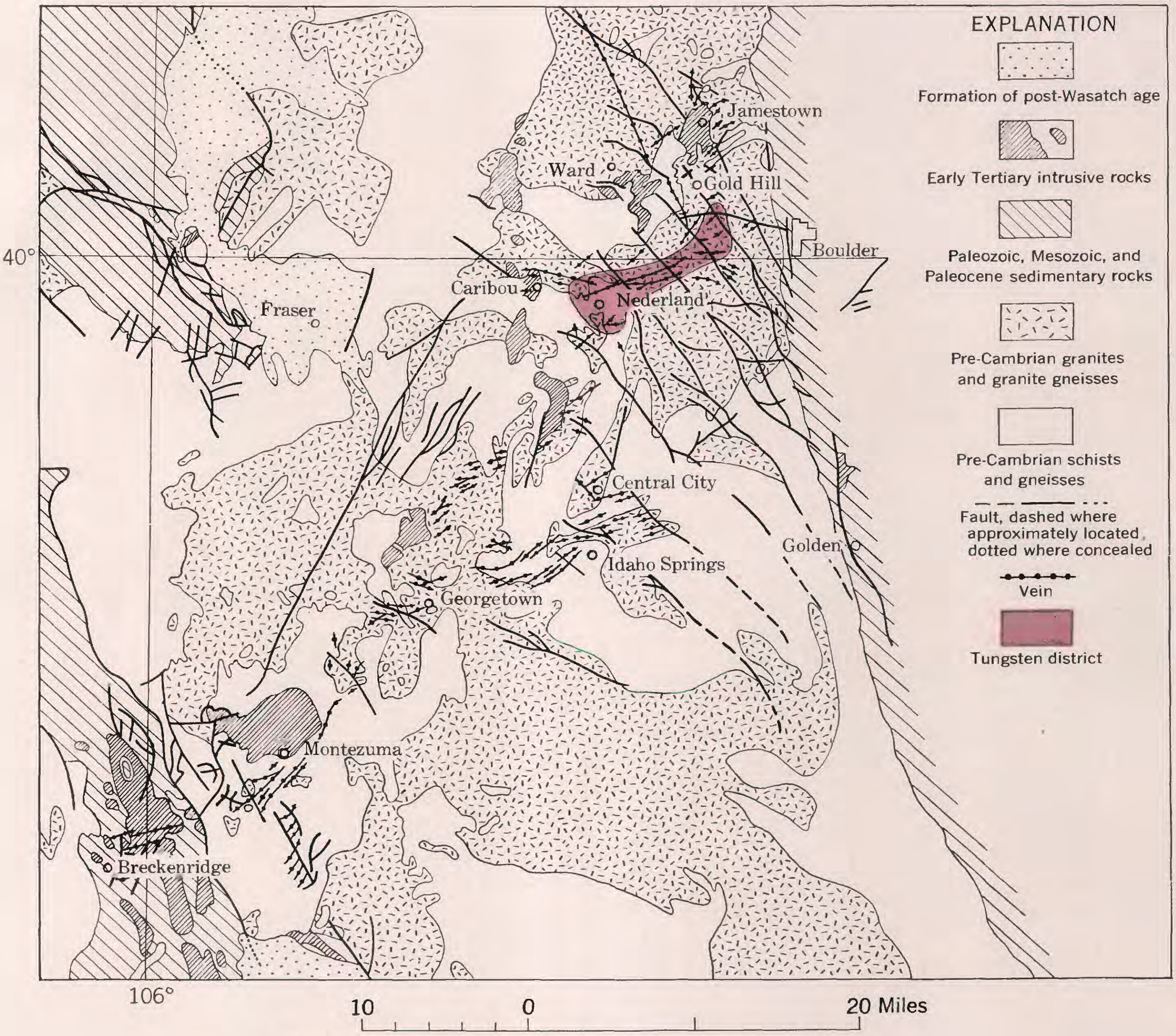

FIGURE 1.—Index map showing the location of the Boulder County tungsten district, Colo.

The village of Nederland is the principal settlement in the district. In 1945 there also were post offices and small settlements at Tungsten, 1½ miles east of Nederland, and at Sugar Loaf, near the head of Bummers Gulch, in the eastern part of the district.

Good automobile roads give ready access to the district. The main traffic route follows Middle Boulder Creek from Nederland to Boulder, a distance of 18 miles by road (pl. 3). The Peak-to-Peak Highway passes through Nederland and furnishes a means of communication with the mining towns to the north and south. The northern part of the district is served by a good, though steep, graveled road that follows Bummers Gulch to Sugar Loaf and then follows Gordon Gulch westward. All the active mines are accessible by automobile. Many of the mine roads fall rapidly into disrepair when not in use, but they are easily restored.

Boulder, on the Colorado & Southern Railway, is the principal rail shipping point, although some ore has been shipped in the past from Rollinsville, a station on the Denver & Rio Grande Western Railroad, 3 miles south of Nederland. The district was also served in earlier times by the Colorado & Northwestern Railroad and its successor, the Denver, Boulder & Western, but this road was dismantled in 1918. The principal station was at Cardinal, about 2 miles west of Nederland, and another was maintained for a time at Tungsten, at the end of a spur line extending eastward from Cardinal.

CLIMATE, INDUSTRY, AND POPULATION

The climate is temperate, and travel by automobile is possible throughout the year except for short periods following exceptionally heavy snows or cloudbursts. The summer months are moderately cool, and July and August are punctuated by many thunderstorms. Locally a few of these storms reach the intensity of cloudbursts and may do considerable damage to roads in the valleys and gulches. Some snow generally falls as early as September, but until November snow seldom remains on the ground for long. The fall months are typically dry and cool and are among the most pleasant of the year. The cold winter weather, marked by many subzero days, arrives in November, but the snowfall generally remains light until February. The heaviest snowfalls of the year occur in March and April, although most of the winter snow melts during warm spells in these months.

A few ranches are scattered over the broad upland and along the alluvial stretches of the main valleys, but mining is by far the most important industry in the area. In the eastern part of the district, where gold as well as tungsten is found, some mining is almost always in progress; but in the western part, where activity depends largely on the price of tungsten, mining is carried on somewhat sporadically.

The region is well timbered except for scattered small clearings or parklike open spaces, but most of the original stand of yellow pine has long been logged off. The present-day forest comprises lodgepole pine, spruce, and the scrub or second-growth yellow pine that is locally called jack pine. Lumbering has ceased to be an important industry, but almost all the timber used in mining is cut within the district.

Electric power is supplied by the Public Service Co. of Colorado which has a hydroelectric plant in the valley of Middle Boulder Creek, just east of the tungsten district, operated with water from Barker Reservoir at Nederland.

The population of the district fluctuates with the fortunes of the mines and with the seasons. Nederland normally has a population of a few hundred, and Tungsten and Sugar Loaf each have 25 to 50 inhabitants. During periods when the mines are active the population increases somewhat, but most of the extra manpower comes from Boulder, a city of about 20,000 people. During the summer months the mountains of the district attract many vacationers, and with the gradual decline in mining, recreation may become as important to the area as its mines.

TOPOGRAPHY AND DRAINAGE

Nederland lies at the east edge of a rugged, glaciated area that extends westward for 10 miles to the crest of the Front Range. The lower slopes of the Front Range east of the glaciated area form a dissected upland, which, within the tungsten district, ranges in altitude from 8,500 ft in the western part to about 7,500 ft in the eastern part (pls. 1, 2). In the western part of the district, broad valleys with a comparatively gentle slope lie only 200 to 300 ft below the general level of the upland surface. Farther east, the valleys deepen rapidly and become steep-sided canyons. Where Middle Boulder Creek leaves the district it occupies a canyon that is 1,000 ft below the general level of the upland surface on each side.

The highest point in the district is Tungsten Mountain, a mile south of Nederland, which reaches an altitude of 8,925 ft. Hurricane Hill, a mile north of Nederland, is nearly as high and rises 300 ft above the general level of the surrounding country. Sugarloaf Mountain, just north of the area covered by the topographic map (pl. 2), is as high as Tungsten Mountain and dominates the eastern part of the area (pl. 3). The lowest point in the tungsten district is at the east edge, in the valley of Middle Boulder Creek, where the altitude is about 6,300 ft.

Middle Boulder Creek is the principal stream in the area; it marks the south edge of the tungsten district from Tungsten Post Office eastward. North Boulder Creek, its largest tributary, enters the district at Lakewood Reservoir and flows east, nearly parallel to Middle Boulder Creek, to a point about a mile south of Sugar Loaf, where it turns abruptly south and joins Middle Boulder Creek just below Boulder Falls. Sherwood Creek flows northeast from Sherwood Flat and joins North Boulder Creek at the site of the former town of Lakewood, about 1½ miles north of Barker Reservoir. The small stream that follows Gordon Gulch, in the northern part of the district, flows east and joins North Boulder Creek near Switzerland Park. Bummers Gulch, in the eastern part of the district, trends nearly due east from Sugar Loaf for about 3 miles and then turns sharply southeast to join Middle Boulder Creek a short distance east of the tungsten district. The southwestern part of the district is drained by Beaver Creek, a tributary of South Boulder Creek, and is generally known as the Beaver Creek district.

HISTORY OF THE PRESENT REPORT

The topographic map (pl. 2) that accompanies this report was made in 1930 by C. R. Fisher and C. A. Ecklund. Geologic mapping for the Geological Survey in cooperation with the Colorado Geological Survey Board and the Colorado Metal Mining Fund was begun by Lovering in 1930 and was continued, with many interruptions, until 1938. The eastern part of the district was mapped with the assistance of E. B. Eckel and James Boyd during the early summer of 1932 and the entire summer of 1933. The western part was mapped with the assistance of Vernon E. Scheid in 1930 and of Ogden Tweto in 1938. In 1941 Tweto began mapping mines that had been reopened in response to the wartime demand for tungsten. Many mines that had been partly or wholly inaccessible during the preceding decade were mapped, and detailed surface maps of several areas were made for use in connection with exploration programs. This work continued, with some interruptions, until 1944, much of it with the assistance of J. W. Odell.

The present report, like the field work that led to it, is a product of two stages of effort. The original manuscript for the report was completed by Lovering in 1940, but before it could be published the war intervened. New data gathered during the war years made advisable a rewriting and expansion of the original manuscript, a task performed largely by Tweto. As the report now stands, it is a blend of the observations, deductions, and efforts of both writers. In a general way, however, the sections on geologic setting, rocks of the district, geomorphology, structure, and ore deposits are primarily by Lovering; the section on history and production and the mine descriptions, except those of the Cold Spring, Clyde, Logan, and Yellow Pine mines, are mainly by Tweto.

Acknowledgment is made of the uniform courtesy extended by mine owners and operators throughout the district. Although it is impossible to list each individual, special mention should be made of William Loach and the late William and Naylor Todd, of the Wolf Tongue Mining Co.; the late J. G. Clark, of Gold, Silver, & Tungsten, Inc.; Robert Sterling, of the Vanadium Corp. of America; the late J. H. Rodgers, of Boulder Tungsten Mills, Inc.; and George Teal.

Spectroscopic analyses of many rocks from the district were made by J. M. Bray and R. F. Jarrel; R. M. Rigg made a preliminary study of some of the altered rocks; and E. E. Wahlstrom kindly made available several geologic mine maps.

Many members of the Geological Survey gave advice and helpful criticism during various phases of the work. E. N. Goddard took part in mapping some of the mines of the eastern part of the district and furnished data on nearby areas. C. S. Ross aided greatly in the identification of clay minerals and the study of altered rocks. J. G. Fairchild made several chemical analyses of rocks; F. C. Calkins, W. S. Burbank, C. P. Ross, and A. H. Koschmann critically read parts of the manuscript; and D. M. and M. E. Lemmon read the entire report.

PREVIOUS WORK IN THE AREA

Many engineers and geologists have worked at times in the mines of the Boulder County tungsten district, and private reports have been made on several of the individual properties. One by O. H. Hershey, which was made available by Robert Sterling, of the Vanadium Corp. of America, contains valuable information on many of the mines as of 1914. The most complete account of the district that has previously been published is the Colorado Geological Survey report of George and Crawford, who studied the district in 1907 and 1908. This and other papers dealing with the district are noted in the list of references (pp. 192–196). Those of particular importance or interest are marked with an asterisk (*) and are described briefly.

REGIONAL GEOLOGIC SETTING

The Front Range, on whose east flank the tungsten district is situated, is the easternmost of the Rocky Mountain ranges in Colorado. It is 30 to 50 miles wide and about 200 miles long, extending northward from the Arkansas River, in south-central Colorado, to southern Wyoming. Pre-Cambrian rocks make up most of the Front Range area and comprise three main groups: (1) an early series of highly metamorphosed sedimentary rocks, represented by schists and gneisses, (2) a series of quartzites, phyllites, and slates lying unconformably on the older schists and gneisses, and (3) a series of intrusive granites and related rocks.

The early series of greatly metamorphosed rocks is made up principally of the biotitic schists and gneisses of the Idaho Springs formation. Bodies of hornblende gneiss occur with the biotitic rocks and are most abundant on the west side of the range.

The group of quartzites and phyllites is found in the central part of the Front Range only in a downfaulted synclinal area near Coal Creek, a few miles south of Boulder, where these rocks are approximately 14,000 ft thick. They are not known to occur in the tungsten district.

The pre-Cambrian intrusive rocks include several different types of granite, as well as related pegmatites, aplites, and mafic rocks. The granites may all be related genetically, and they all appear to belong to a single, long-continued period of batholithic invasion. Among them are the Boulder Creek, Pikes Peak, Sherman, and Silver Plume granites. The sequence of the principal granites has been fairly well established through the work of Ball (1908, pp. 49–60), M. F. and C. M. Boos (1934, pp. 304–307), Lovering (1935, pp. 11–14, 49–50), and Lovering and Goddard (1951, pp. 23–29).

The earliest of the granitic rocks is a quartz monzonite gneiss, much of which is probably of migmatitic rather than intrusive origin (Tweto, 1947c, and Snively, 1948, pp. 49–62). The gneiss occurs chiefly in lenticular masses and its contacts with the schists are gradational in most places. Snively believes that the migmatite is genetically related to the intrusive Boulder Creek granite.

The chief rock of the tungsten district is the Boulder Creek granite. It occurs in stocks and small batholiths around the border of the great batholith of coarse-grained, pinkish Pikes Peak granite which makes up most of the south half of the Front Range and forms small bodies in the central part of the range. Rock similar to the Pikes Peak granite in the northern part of the range, in Wyoming and northern Colorado, is called the Sherman granite. The satellitic distribution of the Boulder Creek granite suggests that it is a border facies slightly earlier than the main Pikes Peak batholith. Locally the two rocks grade into each other, although in most localities their contacts are sharp. A series of gneissic granites and aplites is genetically related to the Boulder Creek granite and is associated with it.

The Silver Plume granite, the youngest of the group of pre-Cambrian granites, forms widely distributed stocks and dikes in the central and northern parts of the Front Range. Several facies of this granite have been distinguished by Boos and Boos (1934, pp. 319–324) and by Boos and Aberdeen (1940).

The tungsten district is near the northeast end of the so-called mineral or porphyry belt, which cuts diagonally across the central part of the Front Range from Breckenridge to Lyons. Most of the early Tertiary intrusive rocks and mineral deposits in the Front Range are in this belt, which is less than 10 miles wide at most places. The northwest side of the porphyry belt is marked by a zone of stocks that range in composition from diorite to quartz monzonite (Lovering, 1933, pp. 301–397). Along the southeast side of this zone are many dikes and sills similar in composition to the stocks, and in this same terrane are most of the metalliferous deposits in the mineral belt. The zone of stocks lies about 3 miles west of the tungsten district, and all Tertiary intrusive bodies within the district are dikes.

PRINCIPAL ROCKS OF THE DISTRICT

PRE-CAMBRIAN ROCKS

IDAHO SPRINGS FORMATION

DISTRIBUTION

The only large mass of schist and gneiss of the Idaho Springs formation in the tungsten district is in the western part, west of the edge of a small batholith of Boulder Creek granite. The contact between the granite and the Idaho Springs rocks extends north-northwestward through Tungsten and Hurricane Hill; it turns east a mile or two north of the district (pl. 3) and skirts the north edge of the district north of Gordon Gulch, where a little schist is exposed within the area of the geologic map (pl. 1). Many small bodies of schist occur as inclusions in the Boulder Creek granite.

LITHOLOGY AND PETROGRAPHY

QUARTZ-BIOTITE SCHIST AND GNEISS

Quartz-biotite schists or gneisses are the principal rocks of the Idaho Springs formation in the tungsten district, but quartz-biotite-sillimanite schist is found north of Gordon Gulch and south of Nederland and several small lenticular bodies of schistose quartzite have been found on the surface and underground in the Beaver Creek area, in the southwestern part of the district.

Although the Idaho Springs formation seems homogeneous regionally, it is infinitely varied in detail. Gneiss and schist are closely seamed parallel to the schistosity by aplite and pegmatite, and they also are cut by innumerable small cross-breaking dikes and irregular masses of these rocks. Much of the gneiss is in reality schist so intimately mixed with granitic material that it has the composition and texture of a gneiss. Rock of this type is conspicuously banded and is made up of irregularly spaced layers of quartz-biotite schist alternating with seams of aplite and pegmatite 1 to 10 cm thick.

The quartz-biotite schist is medium-grained, dark gray, strongly foliated, and highly biotitic (fig. 2).

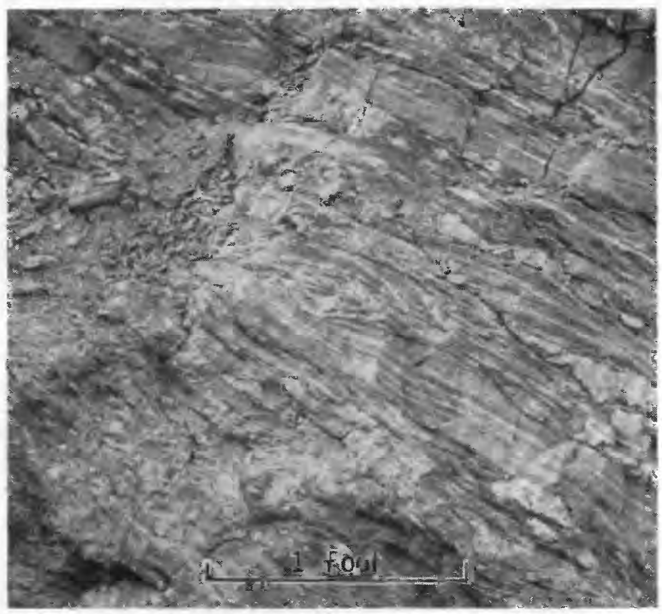

FIGURE 2.—Schist of the Idaho Springs formation in a road cut 4½ miles east of Idaho Springs, Colo.

Most of it is banded, although not so prominently as the gneisses; thin, black, relatively coarse grained layers of almost pure biotite alternate with gray, finer-grained layers that consist of quartz and feldspars and scattered small flakes of biotite. As shown by thin sections, the schist is made up principally of biotite and quartz, but most of it contains potash feldspar and oligoclase and some contains garnet and sillimanite (fig. 3).

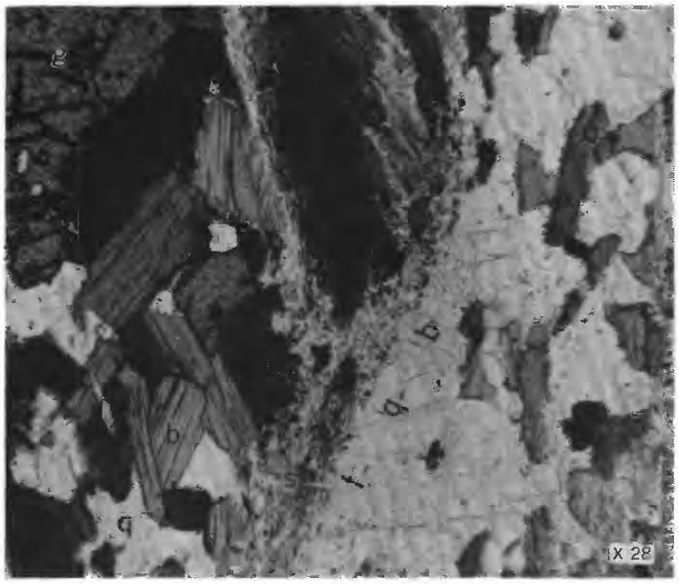

FIGURE 3.—Photomicrograph of quartz-biotite-sillimanite schist from the Idaho Springs formation at Nederland, Colo. The original bedding, which is nearly vertical in the photomicrograph, is cut by shear planes sloping down to the right at 45°, and these are cut in turn by later shear planes sloping to the left at 60°: *b*, biotite; *g*, garnet; *q*, quartz; *s*, sillimanite; *fqb*, feldspar-quartz-biotite seam. × 28

The schistose structure is produced primarily by the parallel orientation of the biotite flakes and, in sillimanite-bearing schists, of thin, platelike aggregates of sillimanite.

QUARTZITE

A northward-trending mass of sheared, schistose quartzite about 1,000 ft long and 300 ft wide is exposed at the surface south of the Sunday mine in the Beaver Creek district, about 1½ miles south of Nederland. Smaller lenses of massive quartzite are exposed underground in the nearby Tungsten, Mammoth, and Fitzimmons mines and the Windy tunnel. The quartzite ranges from fine- to coarse-grained and from granular to vitreous. The individual grains in the coarser facies are 1 to 3 mm in diameter. Some of the quartzite consists almost entirely of quartz, but much of it is flecked by biotite and some contains a little epidote and feldspar. The color ranges from greenish white or buff to medium gray. The quartzite is strongly sheared in most places and is cut by joints trending nearly at right angles to the shearing. Most of the joints contain thin seams of epidote. Cross-breaking seams of pegmatite and aplite are present in the rock but are much less abundant than in the surrounding schists. This probably reflects a difference in the ease of magmatic penetration rather than a difference in the age of the two types of rock.

COMPOSITION AND ORIGIN

The presence of garnet and sillimanite and the great differences in the proportions of the component minerals in different layers or laminae of the schist of the Idaho Springs formation strongly suggest a derivation from sedimentary rocks. This conclusion is supported further by the presence of quartzite and, in areas near the tungsten district, of impure limestone in lenses enclosed by schist. Moreover, as shown in table 1, the chemical composition of the schist is fairly similar to that of Paleozoic shale.

TABLE 1.—*Analyses of schist of the Idaho Springs formation and a composite analysis of Paleozoic shale*

	Idaho Springs formation			Paleozoic shale [4]
	Biotite schist [1]	Biotite sillimanite schist [2]	Quartz-biotite schist [3]	
SiO_2	62.04	42.20	64.23	60.15
Al_2O_3	17.43	35.45	16.45	16.45
Fe_2O_3	.95	1.70	2.40	4.04
FeO	7.12	8.18	4.31	2.90
MgO	2.07	2.80	1.68	2.32
CaO	.52	.18	3.11	1.41
Na_2O	.68	.62	3.75	1.01
K_2O	4.10	4.32	2.14	3.60
H_2O-	.12	.19	.02	.89
H_2O+	2.97	3.29	.89	3.82
TiO_2	1.16	1.25	.80	.76
CO_2	.88	Trace	None	1.46
P_2O_5	.05	.06	.10	.15
MnO	.06	.09	.08	Trace
BaO	.09	----	.02	.04
C	----	----	----	.88
S	----	----	.03	----
F	.17	----	----	----
SO_3	----	----	----	.58
Total	[5] 100.41	100.33	100.01	100.46

[1] Biotite schist from Idaho Springs formation half a mile south of Springdale, Jamestown district, Colo. Charles Milton, analyst. U. S. Geol. Survey Bull. 878, p. 23, 1937.
[2] Biotite-sillimanite schist from Idaho Springs formation 2½ miles S. 60° E. of Jamestown, Colo. R. E. Stevens, analyst. U. S. Geol. Survey Bull. 878, p. 18, 1937.
[3] Quartz-biotite schist of Idaho Springs formation obtained near Penn mill, just below Blackhawk, Colo. Specimen analyzed was probably a plagioclase-rich variety which is abundant locally in the Idaho Springs formation. George Steiger, analyst. U. S. Geol. Survey Prof. Paper 94, p. 27, 1917.
[4] Analysis of composite of 51 samples of Paleozoic shale. U. S. Geol. Survey Bull. 770, p. 552, 1924.
[5] Less 0.07 $O=F_2$, or 100.34 (corrected total).

STRUCTURE

The foliation in the schist of the Idaho Springs formation is in general parallel to the bedding planes of the original sedimentary rocks. This relation has been observed at several places in the Front Range and has been discussed in detail in the report on the Montezuma quadrangle (Lovering, 1935, pp. 8–10). At many places distinctive layers recognizable as original sedimentary zones can be seen in the schist, and the foliation is everywhere parallel to these layers except in parts of some sharp folds and in pre-Cambrian shear zones, where the schistosity conforms with the shear planes.

The rocks of the Idaho Springs formation are intricately folded. The larger folds are essentially isoclinal and have steeply dipping axial planes, but they are complicated by innumerable minor folds. The minor folds and crenulations give the schist a contorted appearance, and in the absence of any truly distinctive marker beds or layers they make it difficult or impossible to trace the details of structure except where the schist is very well exposed. However, as the general trend of the folds is parallel to the edge of the Boulder Creek batholith, and as the schistosity is in general parallel to the steeply dipping axial planes of the larger isoclinal folds, the apparent trend of the schistosity is remarkably uniform over wide areas, regardless of the minor folds and crenulations. Thus the schist throughout the western part of the tungsten district strikes, on the average, about north-northwest, and although the dip may differ widely within distances of only a few inches, the general dip is about 60° NE.

AGE

The Idaho Springs formation is one of the oldest geologic units known in Colorado. The high degree of metamorphism that characterizes the schist as contrasted with the phyllites and quartzites of the Coal Creek area suggests that the Idaho Springs rocks are much older than those of the Coal Creek area, but the rocks at Coal Creek are older than the Boulder Creek granite and are intruded by it. This granite in turn is older than the Pikes Peak granite, although the age difference may be slight. The Pikes Peak granite, as shown by the lead-uranium ratio in samarskite, is approximately one billion years old (Holmes, 1931, p. 338). Thus, although the length of time that elapsed between the deposition of the Idaho Springs sediments and the intrusion of the granites is not known, the Idaho Springs rocks would appear to have originated early in pre-Cambrian time.

BOULDER CREEK GRANITE AND RELATED ROCKS

DISTRIBUTION AND MODE OF OCCURRENCE

East of Hurricane Hill the country rock of the tungsten district is made up almost entirely of Boulder Creek granite and related rocks such as aplite and pegmatite. The granite is part of a small batholith that extends eastward to the mountain front, where it passes under Paleozoic sedimentary rocks. From the eastern part of the tungsten belt the batholith extends about 6 miles northward to the vicinity of Lefthand Creek and about 12 miles southward to the vicinity of Ralston Creek. Its location and shape are shown in figure 10. The granite is cut by many dikes of pegmatite and aplite; most of these are parallel to the platy structure of the granite, but a few of them cross the structure at high angles. Within the tungsten district the schist at the west edge of the batholith dips under the granite mass, but 2 miles to the north, where the contact turns east, the granite dips under the schist.

LITHOLOGY AND PETROGRAPHY

BIOTITE GRANITE AND QUARTZ MONZONITE

Although the rock of the Boulder Creek batholith is generally called "granite," most of it is technically quartz monzonite, and locally it is granodiorite. Strictly speaking, the only granite in the batholith is near Gold Hill, north of the tungsten district. The rock typical of the rest of the batholith is slightly porphyritic, dark-gray, coarse-grained granite (quartz monzonite) which has a primary gneissic structure made conspicuous by the subparallel arrangement of biotite flakes and packets (fig. 4). Near the margins of the

FIGURE 4.—Boulder Creek granite half a mile north of North Boulder Creek on the Ward-Nederland road, Boulder County, Colo. Note the coarse-grained and slightly gneissic texture characteristic of this granite. The ghost of a schist xenolith lies about a foot below the 6-in. scale, and a dike of pegmatite cuts the granite 2 ft above it.

batholith the granite is more gneissic, more uneven in grain, and more biotitic than elsewhere, and some border facies closely resemble the gneisses of the Idaho Springs formation. The granite disintegrates readily in the climate of the tungsten district and is not well exposed except on steep slopes. It weathers to a coarse, gritty, light-brown soil.

The Boulder Creek granite is easily distinguished from the Silver Plume granite by the larger size and rudely parallel orientation of its biotite flakes and by the absence of carlsbad twins of feldspar, which characterize the Silver Plume granite. It is distinguished from its own aplitic facies by its coarser grain and by its greater content of biotite.

As shown by thin sections, the Boulder Creek granite consists typically of 20 to 40 percent quartz, about 20 percent microline, 25 to 30 percent plagioclase, and 15 to 35 percent biotite (fig. 5). The plagioclase is calcic oligoclase or andesine. The biotite flakes are 2 to 3 mm in diameter, the quartz grains 2 to 5 mm long, and the plagioclase grains as much as 7 mm long. Microcline is the coarsest constituent of the rock, and in some localities where the granite is porphyritic it is in crystals up to 3½ cm long. The microcline phenocrysts are irregularly oriented, but grains of both biotite and plagioclase everywhere have a subparallel arrangement that constitutes a primary flow structure. Near the borders of the batholith the quartz and feldspar show a secondary granulation, but half a mile within the mass the minerals are little fractured.

At several localities in the tungsten district, the Boulder Creek granite contains hornblende rather than biotite. The larger masses of hornblende granite are distinguished on the map (pl. 1). Such masses are surrounded by transition zones in which both hornblende and biotite are present. As will be shown, the hornblendic facies of the granite is probably a product of reaction with hornblende gneiss.

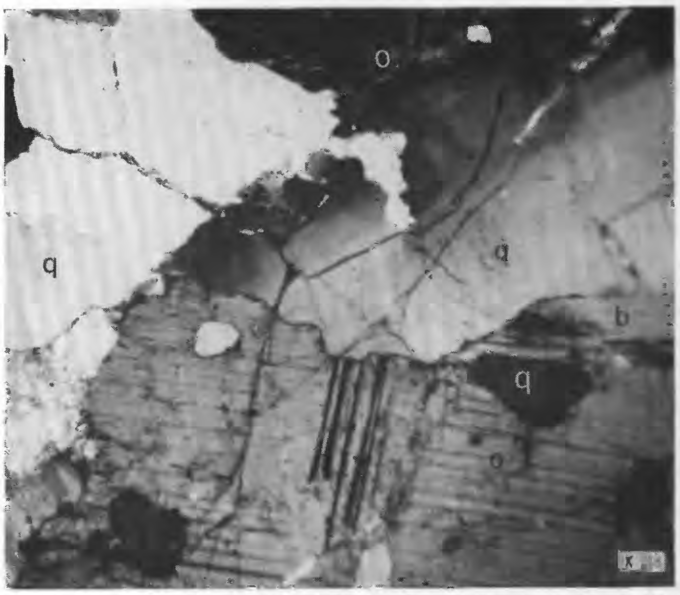

FIGURE 5.—Photomicrograph of fresh Boulder Creek granite from the sixth level of the Cold Spring mine, Boulder County, Colo. The primary gneissic structure is horizontal. Slight secondary shearing is shown by the undulatory extinction of the quartz in the upper right: *b*, biotite; *o*, oligoclase; *q*, quartz, × 28. Crossed nicols.

The chemical composition of the Boulder Creek granite and other granites of the Front Range is given in table 2.

TABLE 2.—*Analyses of pre-Cambrian granites from the Front Range, Colo.*

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	68.71	66.31	66.20	77.03	77.02	67.38	70.83	71.14	70.85	71.40	70.32
Al_2O_3	14.93	15.07	14.33	12.00	11.63	15.22	14.41	16.00	15.14	16.34	15.42
Fe_2O_3	1.02	1.35	2.09	.76	.32	1.49	.35	.00	.65	.15	.53
FeO	2.07	2.71	1.93	.86	1.09	2.58	2.94	.80	1.57	1.71	1.92
MgO	1.50	1.03	.89	.04	.14	1.12	.56	.13	.64	.31	.55
CaO	2.01	2.06	1.39	.80	1.24	2.12	.64	.94	.71	1.40	1.16
Na_2O	2.85	2.48	2.58	3.21	2.85	2.73	2.44	5.13	2.44	4.59	3.47
K_2O	5.14	5.96	7.31	4.92	5.21	5.41	6.21	3.74	6.09	3.24	4.49
H_2O-	.14	.06	.48	.14		.01	.04	.09	.06	.11	.06
H_2O+	.56	.90	.83	.30	.35	.39	1.34	.50	.77	.22	.64
TiO_2	.62	.66	.65	.13		.70	.24	.17	.31	.36	.36
CO_2	.46	.98	.36			.18		.03	.21	.09	.10
P_2O_5	.16	.32	.25	Trace		.32	.15	.19	.30	.36	.26
SO_3											
S (total)	Trace	.04				.06	.01				.03
ZrO_2			.02								
Cl			Trace				.04				.01
F			(?)	.36	.15						
FeS_2			.12								
MnO			.13	Trace		.04		.01	.02	.02	.02
BaO			.18	Trace		.14	.02		.06		.02
SrO			Trace								
Li_2O			Trace	Trace							
Total	100.17	99.93	99.74	100.55	99.85	99.82	100.22	98.90	99.98	100.30	99.36

1. Fresh Boulder Creek granite from New shaft, fifth level of Cold Spring mine, about 3 miles northeast of Nederland, Colo. J. G. Fairchild, analyst.
2. Relatively coarse grained aplite of Boulder Creek granite. Fresh specimen from Lily tunnel, about 2 miles north-northeast of Nederland, Colo. J. G. Fairchild, analyst.
3. Syenitic facies of Pikes Peak granite, similar in composition to Boulder Creek granite. Sixth level of Ajax mine, Cripple Creek, Colo. W. F. Hillebrand, analyst. U. S. Geol. Survey Prof. Paper 54, p. 45, 1906.
4. Pikes Peak granite from Sentinel Point, Pikes Peak, Colo. W. F. Hillebrand, analyst. U. S. Geol. Survey Geol. Atlas, Castle Rock folio (no. 198), p. 3, 1915.
5. Pikes Peak granite from Platte Canyon, Jefferson County, Colo. H. N. Stokes, analyst. U. S. Geol. Survey Geol. Atlas, Castle Rock folio (no. 198), p. 3, 1915.
6. Silver Plume granite, Silver Plume, Colo. R. B. Ellestad, analyst. Geol. Soc. America Bull., vol. 45, p. 320, 1934.
7. Fresh Silver Plume granite from Climax district, Colo. J. G. Fairchild, analyst. U. S. Geol. Survey Bull. 846–C, p. 225, 1933.
8. Granite from Longs Peak, Colo. D. F. Higgins, analyst. Geol. Soc. America Bull., vol. 45, p. 320, 1934.
9. Granite from South St. Vrain highway, near Estes Park, Colo. T. Kameda, analyst. Geol. Soc. America Bull., vol. 45, p. 320, 1934.
10. Mount Olympus granite, Glen Comfort, Colo. D. F. Higgins, analyst. Geol. Soc. America Bull., vol. 45, p. 320, 1934.
11. Average of analyses 6, 7, 8, 9, and 10. Silver Plume granite.

HORNBLENDE DIORITE

Slightly gneissoid hornblende diorite occurs in a northwestward-trending zone of dikes that passes just east of Nederland and in a few small dikes in the granite in the central part of the Boulder Creek batholith, in the region just west of Boulder Falls. The dikes and small irregular masses near Nederland are intimately associated with gneissic aplite and pegmatite. Most of the hornblende diorite dikes within the batholith occur in or close to the hornblendic facies of the Boulder Creek granite, and some of them contain small masses of hornblendite. The hornblende diorite is believed to be a local reaction product formed by the attack of late-stage hydrous magmatic fluids on inclusions of hornblendic rock in the granite.

The hornblende diorite is a massive, medium-grained, dark bluish- or greenish-gray rock. It shows a well-defined gneissic structure in most occurrences, but in a few of the larger masses gneissic structure is poorly developed. The rock is more resistant than the schist of the Idaho Springs formation, and the outcrops stand out in relief. Weathered outcrops have irregular pitted surfaces and tend to split into slabs parallel to the foliation (fig. 6).

FIGURE 6.—Hornblende diorite half a mile north of Nederland, Colo., near the center of a mass about 100 ft wide. The coarse-grained, slightly foliated structure shown in this outcrop is characteristic of the rock.

The diorite consists chiefly of hornblende and andesine, which together comprise 80 to 90 percent of the rock (fig. 7). All specimens contain several percent of augite, and most of them contain biotite and quartz as well. Magnetite is a relatively abundant accessory mineral and is visible to the naked eye in most specimens. The rock is granitoid in texture, and the mineral grains are mostly 1 to 2 mm in length.

APLITE, APLITIC GRANITE, AND GNEISSIC APLITE

There is apparently a continuous gradation from the earlier aplitic differentiates of the Boulder Creek granite into the late aplite, but the term "gneissic aplite" is used to distinguish as far as possible the earlier and more gneissic aplitic rocks. A gneissic structure can be seen in nearly all the aplitic masses of the tungsten belt, but it becomes more and more prominent outward from the interior of the Boulder Creek batholith through its margin into the Idaho Springs formation. The gneissic structure is in large part primary, but a secondary schistose structure has been superposed upon it in many of the bodies within the schist.

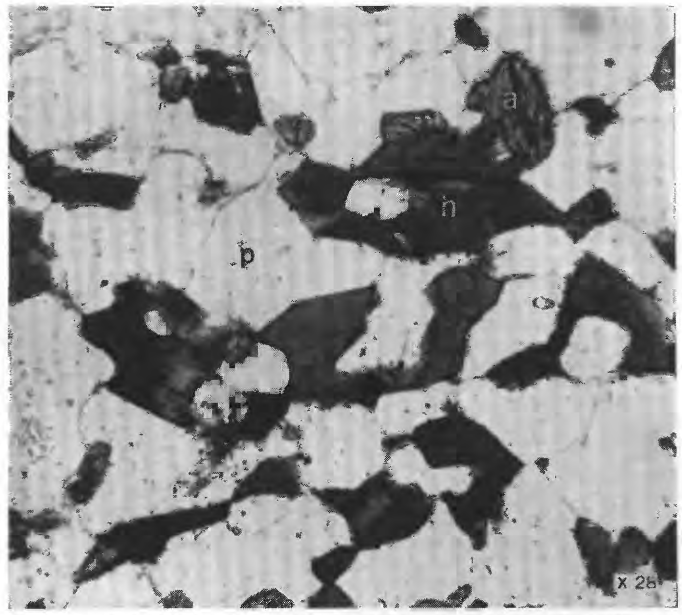

FIGURE 7.—Photomicrograph of gneissic hornblende diorite from a dike half a mile northwest of Nederland, Colo. The primary gneissic structure is nearly horizontal in the picture: *p*, plagioclase (andesine); *a*, augite; *h*, hornblende. × 28.

The various aplites are nearly everywhere associated with pegmatite. Many dikes of gneissic aplite grade, along their course, into a mixture of pegmatite and aplite and then into pegmatite. So far as practicable the aplite and pegmatite have been distinguished on the map, but many of the dikes have been designated according to their predominant rock. The aplitic rocks are in general earlier than the pegmatites, but some of the early gneissic aplites and pegmatites appear to have been contemporaneous.

The early aplitic fluids that emanated from the Boulder Creek granite and preceded it like an advance guard were extremely mobile and searching in their invasion of the Idaho Springs formation. With an increasing proportion of intrusive material, the schist of this formation grades through injection gneiss into gneissic aplite and pegmatite containing thin stringers and laminae of schist. Because of this intergradation, it is impracticable in many places to distinguish injection gneiss from gneissic aplite and pegmatite on the map. It is possible, however, and from the economic point of view desirable, to distinguish these gneissic rocks collectively from the enclosing schist, because the character of the wallrocks greatly influences the distribution of ore in the veins.

The aplitic rocks occur chiefly in dikes, but near the west border of the batholith they comprise moderately extensive irregular bodies such as those along Hurricane Hill (pl. 5). These bodies contain several intergrading types of aplite, although they consist largely of a relatively coarse grained, moderately gneissic variety that contains less biotite than most other types. This rock grades both into fine-grained aplite that shows only a faint gneissic structure and into strongly gneissic and biotitic aplite. Locally, it grades into fine-grained granite and alaskite.

The gneissic aplite weathers to buff or reddish brown but is grayish white or pinkish on fresh fractures. Where it is only slightly weathered, the rock has a sandy appearance and its surface is commonly mottled brownish red, buff, or gray. Where it is more deeply weathered, it breaks into thin slabs 1 to 2 in. long which cover the outcrop. The dikes are more resistant to weathering than the granite or the schist of the Idaho Springs formation and usually form ridges whose height above the surrounding surface is proportional to the width of the dike.

The aplite in the Idaho Springs formation occurs in well-defined sills and dikes and in poorly defined zones in which numerous aplite seams are interlayered with thin laminae of schist (fig. 8). The gneissic texture of the aplite is accentuated by a slight concentration of the biotite into layers and by the slabby weathering of the rock. In aplite of this type, the quartz grains are about half a millimeter long and form about 60 percent of the rock; the microcline grains are about the same size as the quartz and make up about one-third of the rock; the biotite crystals range from 0.25 to 0.75 mm in length and form 3 to 10 percent of the rock.

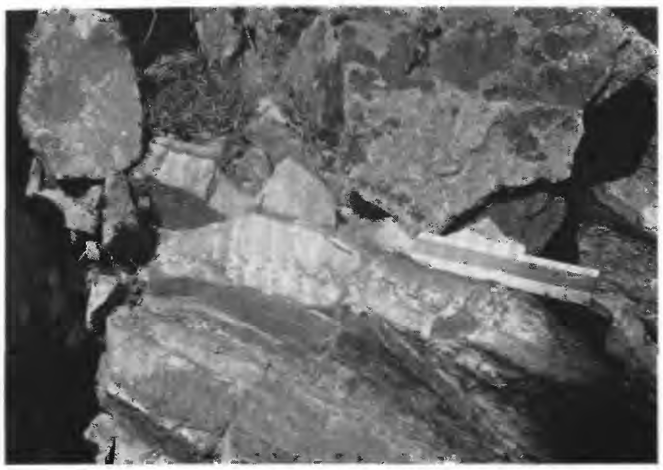

FIGURE 8.—Sill of gneissic aplite in schist of the Idaho Springs formation 0.7 mile north of Nederland, Colo. The gneissic aplite lies below the 6-in. scale and is bordered by a thin seam of pegmatite. It is interlayered with dark, strongly foliated schist.

The dikes in the Boulder Creek granite are generally coarser-grained than those in the schist, the individual grains of quartz and feldspar commonly ranging from 1 to 2 mm. and the biotite from 1 to 4 mm. in length. The appearance of aplite of this type under the microscope is shown in figure 9. Aplite in the relatively large body on the west flank of Hurricane Hill is relatively coarse grained. As shown by the analyses in table 2, its composition is very close to that of the Boulder Creek granite. Quartz, microcline, and oligoclase make up about 95 percent of the rock, and biotite constitutes only 5 percent or less.

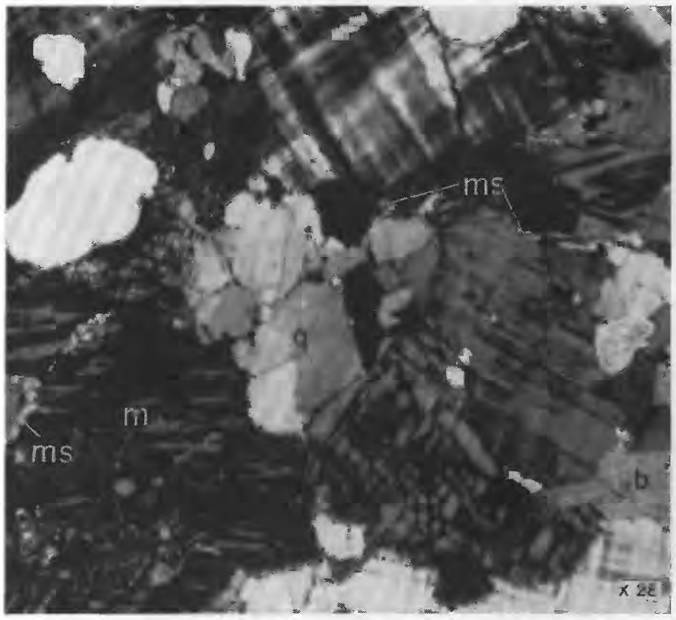

FIGURE 9.—Photomicrograph of gneissic aplite from a dike in the Boulder Creek granite near the Cold Spring mine, northeast of Nederland, Colo. The primary gneissic structure is shown by the elongation of the biotite and is nearly horizontal in the picture. Slight secondary granulation is shown by incipient mortar structure at the edges of some crystals: *b*, biotite; *m*, microcline; *q*, quartz; *ms*, mortar structure. × 28. Crossed nicols.

The linear structure (Balk, 1937, pp. 7–25, 45–54, 112–117) in the dikes of gneissic aplite within the Boulder Creek granite, except for a few that are flat, is nearly parallel to that of the enclosing granite, but the platy structure is everywhere parallel to the dike walls. These relations are well shown by a few dikes that follow the gneissic structure of the granite for some distance and then change direction abruptly and cut across the structure: The gneissic structure of the aplite remains parallel to the walls of the dike regardless of its course, whereas the linear structure remains essentially parallel to that of the enclosing granite. This concordance of linear structure, together with the regional distribution of the gneissic aplite, is strong evidence for the essential contemporaneity of the gneissic aplite with the granite and suggests that they were derived from the same magma.

Some of the gneissic aplite closely resembles fine-grained Silver Plume granite, which also is gneissic, but the two rocks differ in that all the minerals in the aplite are oriented approximately parallel, whereas only the tabular feldspar crystals in the Silver Plume granite tend to lie parallel.

ALASKITE

Many dikes and small irregular bodies of alaskite cut the granite and schist near the west border of the Boulder Creek batholith, and a few occur in the inner part of the batholith. The alaskite is closely associated with aplite and pegmatite, and it grades into both these rocks. Because of this association and the small size of the alaskite bodies, alaskite is not distinguished separately on the map but is shown as aplite or pegmatite, whichever is associated with it. Along the border of the main batholith, on the east flank of Hurricane Hill, the strongly gneissic and biotitic granite is cut by many irregular complex dikes consisting of intergrading aplite, alaskite, pegmatite, and a variety of granite that is richer in quartz than the normal granite. These dikes have irregular, ill-defined boundaries. Pegmatite and aplite within the dikes grade into alaskite, which grades into abnormally siliceous biotite granite, and this in turn grades into normal granite. Similar dikes occur near small granite masses in the schist. Farther within the main granite body, the alaskite dikes are more clearly defined and contain less aplite and pegmatite, but they are all very small. Most of them follow the gneissic structure of the granite, but some are at right angles to the gneissic structure and, like the aplite dikes, dip in the direction of plunge of the linear structure in the granite.

The alaskite is a gray to pinkish rock that is generally intermediate in grain size between the normal granite and aplite. It consists of quartz and pink microcline in about equal proportions, but a little biotite and magnetite may be present locally. With the appearance of biotite, the rock generally becomes finer-grained and grades into aplite. Most of the alaskite near the margin of the batholith is gneissic, but the alaskite farther within the granite mass shows only a faint gneissic structure or is massive.

Although much of the alaskite was apparently contemporaneous with aplite or pegmatite, some alaskite dikes cut the larger masses of aplite, and some are clearly cut by pegmatite. In a general way, the alaskite seems to be more closely associated with aplite than with pegmatite, and it probably represents a local differentiate of the aplitic magma.

PEGMATITE

Small dikes and irregular bodies of pegmatite are very numerous in the tungsten district, both in the granite of the Boulder Creek batholith and in the metamorphic rocks of the western part of the district. Most of them are parallel to the foliation of the schist or to the primary gneissic structure of the granite, but some cut across the structure. The pegmatite dikes are less uniform than the aplite dikes and are generally less persistent. A few dikes of early pegmatite have a gneissic structure caused by granulation of the original minerals, but most of the pegmatite is relatively undeformed. The pegmatite, like the aplite, is more resistant to weathering than the schist of the Idaho Springs formation and the Boulder Creek granite, and it weathers in relief, forming small knobs, ridges, or hills.

The pegmatites are grayish white to pinkish gray, depending on the predominant mineral. They are relatively simple and constant in their mineralogy, but the mineral proportions range widely. The major constituents are oligoclase, microcline, quartz, and biotite. In addition, most of the pegmatites contain minor magnetite, orthoclase, and muscovite, and some contain hornblende. Feldspar, chiefly microcline, constitutes 60 to 85 percent of the rock, and most of the remainder is quartz. In the pegmatites within the granite, the mica is almost invariably biotite, but the pegmatites in the Idaho Springs formation may contain either biotite or muscovite. Mica rarely comprises more than 10 percent of the rock and generally makes up less than 5 percent of it. Magnetite is locally as abundant as biotite. As a group, the pegmatites are not especially coarse textured. The quartz grains range from 3 to 10 mm in diameter, the feldspar crystals from 5 to 30 mm, and the mica books from 10 to 30 mm, but crystals of all these minerals locally attain diameters of as much as 10 cm.

The intimate association of pegmatite with aplite and the distribution of both these rocks with respect to the Boulder Creek batholith indicate that the pegmatite, aplite, and granite are all closely related genetically. The pegmatite is probably a residual differentiate of the Boulder Creek granite magma, and although it is later than the rocks previously discussed, much of it may be nearly contemporaneous with the emplacement of the Boulder Creek batholith.

STRUCTURE

The granite of the Boulder Creek batholith has a well-defined primary gneissic, or platy, structure and in addition consistently shows a preferred, or linear, orientation of elongated grains within the plane of foliation. As shown in figure 10, the platy structure

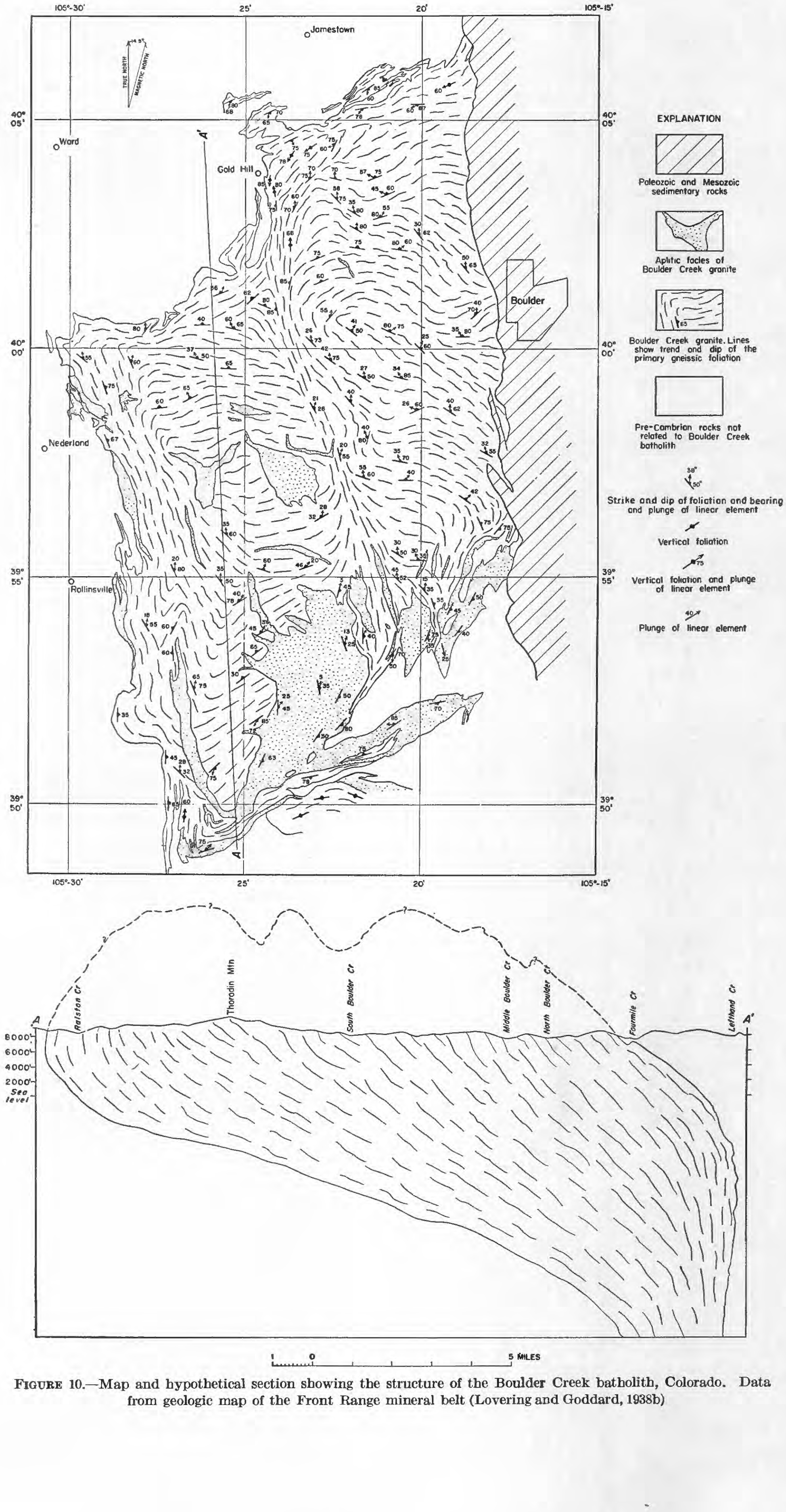

FIGURE 10.—Map and hypothetical section showing the structure of the Boulder Creek batholith, Colorado. Data from geologic map of the Front Range mineral belt (Lovering and Goddard, 1938b)

through most of the batholith strikes nearly east and dips 50°–70° N., but close to the west border of the batholith its strike changes abruptly and becomes parallel to the contact, and the dip there is about 60° E. The linear structure, which indicates the direction of intrusion of the magma (Balk, 1937, pp. 7–8), plunges 40°–60° N. throughout all but the northeastern and north-central parts of the batholith.

Near Gold Hill, 4 miles north of Sugar Loaf Post Office, both the platy and the linear structure are nearly vertical; farther north the dip of the platy structure and the plunge of the linear structure are to the south. East of Gold Hill the linear structure plunges to the west. The position of the steep structure at Gold Hill with respect to the linear and platy structures in the batholith as a whole suggests that this locality is close to the east edge of a deep-seated conduit through which the magma rose. The consistent northerly plunge of the linear structure in the granite southwest of Gold Hill suggests that this conduit is buried beneath schist in the triangular area between Nederland, Gold Hill, and Ward (fig. 10). If this interpretation is correct, the Boulder Creek granite spread southward from this deep-seated source, rising at an angle of 40° to 60° with the horizontal.

ASSIMILATION AND DIFFERENTIATION

The Boulder Creek granite shows evidence of reaction with both biotite and hornblende schists or gneisses along the contacts of the main batholith and in numerous inclusions. The mines at Tungsten afford good exposures of a granite-schist reaction zone that is several hundred feet wide. The zone is characterized by the presence of numerous compositional and textural varieties of rock intermediate between true granite and true schist. The various rocks occur in streaks a few inches to a few feet wide, and a pronounced streaky appearance is one of the most characteristic features of the reaction zone. There is, however, a gradual transition from schist to granite across the zone as a whole. Scattered small sill-like bodies of strongly gneissic granitic and aplitic material are found in increasing numbers in the schist or injection gneiss as the granite is approached. These show gradational contacts with the schist, and they contain included laminae of schist. The rocks contain much more biotite than the normal granite or aplite, and at least part of the biotite is in aggregates recognizable as fragments of highly biotitic schist. Closer to the main body of granite, the streaks of dark, gneissic, contaminated granite become larger and more frequent until they finally predominate, but they contain thin streaks of unassimilated schist and of relatively pure granite. Rock of this type is shown as biotite gneiss on the maps of the mines near Tungsten.

Eastward toward the batholith from the zone of biotite gneiss, the streaks of undigested schist disappear, the rock becomes somewhat less gneissic, and finally a dark granite rich in biotite and more or less uniform in composition and texture is reached. Much of the biotite in this rock is in clots or lenses about half an inch in diameter that appear similar to the fragments of thin, biotitic schist laminae, but the biotite flakes are much coarser. The biotite-rich granite grades into normal granite through a zone of a few hundred feet wide. The granite within this zone contains scattered masses of coarsely crystalline biotite. Most of these are only a few inches in diameter, but some are a few feet across. They were probably derived from streaks of highly biotitic schist which were recrystallized but not entirely assimilated.

Inclusions or xenoliths of biotite schist are fairly common in the granite batholith. They show a wide range in degree of metamorphism or reaction, depending on their location. Inclusions near the contacts apparently became incorporated in the granite late in the magmatic stage. They show very little reaction with the magma, and even sillimanite is unaltered in inclusions near the north edge of the batholith. This probably reflects a short period of immersion before the magma froze, as well as the low reactivity of the magma after it had cooled appreciably and lost both superheat and mineralizers. The inclusions a few thousand feet from the contact presumably were exposed to the granite magma longer than those near the contact, and most of them show some evidence of assimilation. Inclusions a mile or more from the contact show pronounced reaction effects. Fragments and larger masses of biotite schist are surrounded by biotitic aureoles in the granite, and there is a wide transition zone between the normal granite and the unaltered schist in the centers of the larger xenoliths.

Although the Boulder Creek batholith consists predominantly of biotite granite, it contains many masses of hornblende granite. These range from a few feet to 1¼ miles in length and from a few inches to 500 ft in width. Most of them are associated with inclusions of hornblende schist or gneiss. The pegmatite dikes, and some of the aplite dikes, contain hornblende where they cross hornblende granite or hornblende schist.

The transition from hornblende schist to hornblende granite is gradual in most places, but some inclusions are sharply defined, though recrystallized at the edges. Hornblende is most abundant in the granite close to inclusions of hornblende schist; with increasing distance from the inclusions, it becomes less abundant and finally disappears. The biotite content increases as the hornblende content decreases, and the hornblende granite facies grades into the normal biotite granite. The long dimensions of the inclusions of hornblende schist are parallel to the primary gneissic structure of the granite. The hornblende granite is generally more gneissic than the surrounding biotite granite and is most gneissic near the inclusions of hornblende schist.

The consistent association of hornblende granite with hornblende schist, the gradational contacts of most of the inclusions with the granite, the recrystallization of hornblende along the edges of some inclusions, and the presence of hornblende in the pegmatites and aplites where they cross the hornblende granite all indicate extensive reaction between the inclusions and the granite magma. The inclusions of hornblende schist are believed to have been interlayered originally with biotite schist, as is commonly observed throughout the Front Range. However, the central part of the batholith contains no large inclusions of biotite schist comparable to those of hornblende schist. The roof of the batholith may have consisted largely of hornblendic rocks, but nowhere in the Front Range are these rocks known to occur over so large an area without biotite schist. If the masses of hornblende schist represent roof pendants or great xenoliths, it is reasonable to assume that similar masses of biotite schist were completely detroyed by assimilation, whereas the hornblende schist reacted with the magma to form hornblende granite and, in accordance with Bowen's reaction principle, did not completely dissolve and disappear into the granite magma. The magma might, however convert hornblende to biotite, and evidence of this process is seen in the border or reaction zones in which hornblende granite grades into the normal biotite granite.

The close association of the dikes of hornblende diorite and accompanying hornblendite with hornblende granite suggests a genetic relation. The hornblende diorite is closely associated with the aplites and pegmatites and is presumably of late magmatic age. The presence of hornblende in the pegmatite dikes within areas of hornblende granite shows that the late-stage magmatic solutions were capable of dissolving and redepositing hornblende to a certain extent. Although it is unlikely that such fluids accomplished widespread transportation and concentration of hornblende, it seems probable that the hornblende diorite and hornblendite are local concentrations derived by this process from exotic hornblende distributed in the rocks nearby. They would thus be closely related to the pegmatites, and like the pegmatites, they formed dikes by filling fractures that resulted from continued movement of the hardening granite body.

The late magmatic solutions also redistributed the copper that occurs in minor quantity disseminated in the hornblende schist. Hornblende diorite and hornblendic pegmatite and aplite contain accessory chalcopyrite, but no copper minerals have been observed in the normal pegmatite, aplite, or granite.

Except for local facies that are ascribed to assimilation or reaction, the Boulder Creek granite is a comparatively uniform rock. This uniformity indicates that no important large-scale differentiation took place within the batholith except that a hyperfusible fraction was formed late in the period of consolidation and was probably "filter-pressed" from the crystal mesh. This fraction is represented by the late-stage dike rocks. The aplite, alaskite, and pegmatite seem to differ in composition from the Boulder Creek granite in proportion to the stage at which they were consolidated. The later the stage of consolidation, the more the composition differs. For example, the aplite is earlier than the alaskite and pegmatite, yet its composition, as shown by analysis 2, table 2, is not materially different from that of the normal biotite-rich granite.

In the vicinity of the conduit near Gold Hill, the normal gray biotite granite grades into a pinkish granite that is coarser in grain and less micaceous than the typical Boulder Creek granite. This rock resembles the Pikes Peak granite. Its occurrence in the conduit area may reflect differentiation in the deep-seated source magma from which the Boulder Creek batholith was derived, or it may be simply the pure form of Boulder Creek granite, uncontaminated by assimilation of schist from the Idaho Springs formation. However, its resemblance to the Pikes Peak granite and the gradations between the two granites that have been observed locally near the north end of the Pikes Peak batholith indicate that the Boulder Creek and Pikes Peak granites belong to the same batholithic cycle. The Pikes Peak granite, with its greater silica and smaller iron content (table 2), could have been derived from a parent magma with a composition like that of the Boulder Creek granite through crystal settling and normal differentiation, but abundant evidence of reaction and assimilation suggests that the Boulder Creek granite has been modified through the digestion of large amounts of the Idaho Springs formation.

The analyses in table 1 show that the schist of the Idaho Springs formation contains much more iron and alumina and considerably less silica than either the Pikes Peak or the Boulder Creek granite. Thus the uncontaminated parent magma of the Boulder Creek granite was probably somewhat closer in composition to that shown for the Pikes Peak granite in analyses 4 and 5, table 2, than analyses 1 to 3 would indicate. The two magmas were not identical, however, for even if the Boulder Creek granite assimilated 25 percent of its own weight of schist, the silica content of the original magma could not have been more than 70 percent, an amount much less than that characteristic of the Pikes Peak granite. Analyses 1 and 3, table 2, show a close similarity between the Boulder Creek granite and a local syenitic facies of the Pikes Peak granite in the Ajax mine at Cripple Creek, but the relation of this latter rock to the normal Pikes Peak granite is not known.

AGE

The Boulder Creek granite cuts the Idaho Springs formation and the quartzites at Coal Creek and is therefore clearly younger than both these groups of metamorphic rocks. It appears to be slightly older than the Pikes Peak granite, as granite of the Pikes Peak type occurs in the source conduit of the Boulder Creek granite near Gold Hill. In the Georgetown quadrangle, Ball (Spurr and Garrey, 1908, p. 58) found that the "Archean quartz monzonite," which is equivalent to the Boulder Creek granite, is cut by the "Rosalie granite," which is equivalent to the Pikes Peak granite. The lead-uranium ratio as determined in some samarskite from the Pikes Peak granite at Devils Head suggests an age of approximately a billion years for the Pikes Peak granite and according to Holmes (1931, pp. 338, 438), indicates that it dates from the middle part of the pre-Cambrian. The Boulder Creek granite belongs to the same general period of geologic time.

SILVER PLUME GRANITE

DISTRIBUTION AND MODE OF OCCURRENCE

Bodies of Silver Plume granite or its correlatives are scattered throughout the Front Range. The granite forms a few stocks and small batholiths, as well as numerous dikes. The south border of the Longs Peak-St. Vrain batholith (Boos and Boos, 1934, pp. 303–333), a body of granite of the Silver Plume type, lies about 5 miles north of the tungsten district, but within the district the Silver Plume granite is represented only by dikes and small irregular bodies not more than a few hundred feet in diameter. Most of these are near Gordon Gulch, in the north-central part of the district. They strike north to northeast, nearly parallel to the platy structure of the enclosing Boulder Creek granite.

LITHOLOGY AND PETROGRAPHY

The Silver Plume granite is pinkish gray and weathers buff or reddish brown. Some of it is medium-grained and nearly equigranular, but most of it is somewhat porphyritic. In the porphyritic varieties, most of the potash feldspar is in the form of prismatic crystals 1 to 2 cm long that show carlsbad twinning and have a conspicuous subparallel arrangement. On weathered surfaces the phenocrysts of feldspar stand out in relief, making the porphyritic texture and subparallel arrangement of the feldspar crystals conspicuous (fig. 11).

FIGURE 11. Silver Plume granite in a dike in Gordon Gulch, Boulder County, Colo., showing the characteristic subparallel arrangement of the potash feldspar crystals.

Silver Plume granite is readily distinguished from the Boulder Creek granite by its pinkish tinge and finer grain and by the parallel orientation of the potash feldspar crystals and the random orientation of the biotite. The finer-grained varieties resemble some of the aplites related to the Boulder Creek granite, but the random orientation of the biotite flakes in the Silver Plume granite is in contrast to the subparallel arrangement in the aplites and the rock is generally pinker where fresh, and much more reddish where weathered, than the aplites. The Silver Plume granite is more resistant to weathering than the Boulder Creek granite or the schist of the Idaho Springs formation, and the dikes stand out in blocky masses above the surrounding country.

As shown by thin sections (fig. 12), the Silver Plume granite is made up of about 40 percent orthoclase and microcline, 30 percent quartz, 15 percent oligoclase, and 15 percent biotite. Except for the large crystals of potash feldspar, most of the mineral grains are 1 to 5 mm in diameter.

RELATIONS AND AGE

The orientation of the feldspars and the lack of orientation of the biotite and quartz indicates that many of the feldspar crystals are of intratelluric

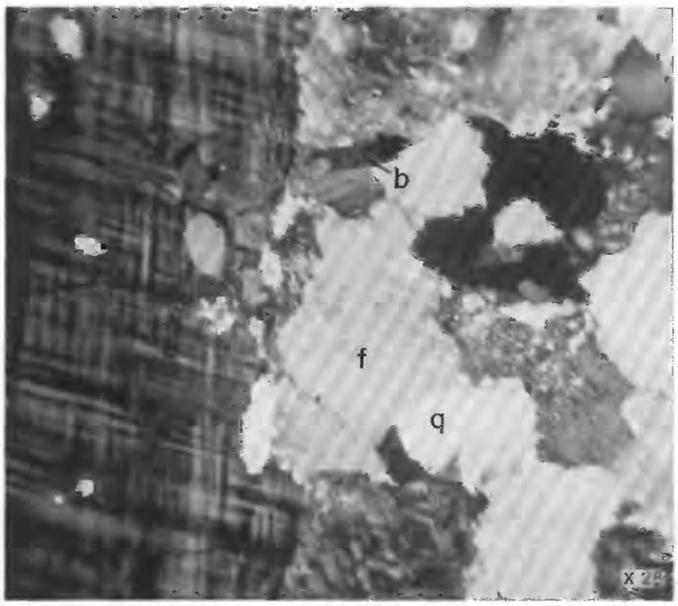

FIGURE 12.—Photomicrograph of Silver Plume granite from the outcrop shown in figure 11. The edge of one of the large microcline crystals that give the rock its gneissic appearance is shown on the left side of the picture: *b*, biotite; *f*, feldspar; *q*, quartz. × 28. Crossed nicols.

origin—that is, they were developed to a large extent in some deep magmatic chamber before intrusion—and that the fluid residuum in which the crystals were carried crystallized into biotite, quartz, and oligoclase after intrusion. The Silver Plume granite contains relatively few inclusions, and those that are found have sharp, angular outlines, indicating that the magma was not highly reactive. The analyses in table 2 show that the Silver Plume granite is closer in composition to the Boulder Creek granite than it is to the Pikes Peak granite.

The platy structure in the dikes in Gordon Gulch dips to the west or northwest, and the linear structures plunge about 45° N., suggesting that the dikes may have been derived from a deep part of the Silver Plume or Longs Peak-St. Vrain batholith lying to the north.

The Silver Plume granite cuts the Boulder Creek granite and related aplite in the tungsten district, and a few miles west-northwest of Jamestown it cuts the Pikes Peak granite. The age of the granite itself has not been determined, but a closely related cerite-bearing pegmatite in the Jamestown district is approximately 940 million years old (Goddard and Glass, 1940, p. 404). The Silver Plume granite probably represents the final major intrusive stage in the batholithic cycle that began with the quartz monzonite gneiss and reached a climax with the Pikes Peak granite.

EARLY TERTIARY IGNEOUS ROCKS

The Boulder County tungsten district lies in the so-called mineral or porphyry belt, a narrow zone, characterized by metalliferous deposits and small bodies of intrusive porphyry, that extends northeastward across the Front Range. The tungsten district occupies only the southeastern portion of that part of the belt lying in western Boulder County. A line of late Cretaceous and early Tertiary stocks marking the northwest edge of the belt lies about 3 miles northwest of the district. The porphyry bodies exposed within the district are all dikes and are probably all of early Tertiary age. The dikes show considerable divergence from the northeasterly trend of the porphyry belt as a whole, but their distribution conforms to that of a northeastward-trending belt. Most of the dikes in the west half of the district have an easterly trend. The few small dikes found in the central part of the district trend north to northeast. The most prominent dike in the eastern part of the district trends northwest, but several small ones trend northeast.

The dike rocks range in composition from silicic felsite to limburgite and include many different species. Monzonite and hornblende monzonite porphyries are the most abundant and are found chiefly in the western part of the district. Dikes of highly altered silicic felsite are found at the extreme east and west ends. Biotite latite porphyry and intrusion breccia occur in small dikes, chiefly in the central and eastern areas. Limburgite porphyry has been observed only in the east-central part of the district. Gabbro occurs in the large and persistent Iron dike in the eastern part of the district and in a few small dikes in the area north of Nederland.

A detailed study of the late Cretaceous and early Tertiary porphyries of the Front Range has been made by Lovering and Goddard (1938a), who concluded that a deep-lying magma which had a composition close to that of gabbro was the ultimate source of the porphyries on the east side of the range and that the various porphyritic rocks had formed through differentiation of this parent magma and masses of it that were withdrawn from time to time and introduced into shallower hearths. They concluded, moreover, that mineral deposits of various types could be correlated with certain rock series.

In the tungsten district Lovering and Goddard correlated the tungsten and associated gold telluride deposits with the biotite latite group of porphyries. The succession of late Cretaceous and early Tertiary igneous rocks in the Front Range and the position of the dike rocks of the tungsten district in the general sequence are shown in figure 2 of their paper (1938a). In the present report, which is based on more recent and detailed work, the nomenclature used for the porphyries and the sequence recognized differ somewhat from the earlier usage, but the general features remain the same. The nomenclature and sequence of the porphyries as recognized in the present report are shown in the left-hand column below, with the oldest at the bottom. The column at the right shows the sequence given for the tungsten district in the earlier paper by Lovering and Goddard (1938a), with the numbers in parentheses showing the equivalent rocks in the left-hand column.

Present report	*Lovering and Goddard (1938a)*
8. Latitic intrusion breccia.	8. Limburgite (6).
7. Biotite latite porphyry.	7. Intrusion breccia (8).
6. Limburgite porphyry.	6. Biotite monzonite (7).
5. Hornblende monzonite porphyry.	5. Hornblende monzonite (5).
4. Monzonite porphyry.	4. Felsite (1).
3. Hornblende latite porphyry.	3. Quartz monzonite (4).
2. Gabbro.	2. Andesite (3).
1. Felsite.	1. Diabase (2).

FELSITE DIKES

A light-gray to white, fine-grained, highly altered dike rock which is termed felsite has been observed at the extreme west and east ends of the district, in the Conger and the Yellow Pine mines. The composition and texture of the rocks have been changed greatly by hydrothermal action, but they are highly siliceous and may have been fine-grained rhyolite. The felsite of the Yellow Pine mine consists chiefly of fine-grained quartz, orthoclase, and carbonate that is close to dolomite in composition. It is definitely older than the biotite latite porphyry and the lead-zinc-silver mineralization. The felsite of the Conger mine is altered to clay minerals, sericite, and fine-grained quartz. It is older than the hornblende monzonite porphyry, but it was intruded after some of the movement along the premineral fissures had taken place.

GABBRO DIKES

OCCURRENCE AND GENERAL CHARACTER

The gabbro of the tungsten district is a black or greenish-black, medium-grained, slightly diabasic rock that weathers brown and is typically jointed much more severely than the adjacent rocks. To the naked eye it appears to be even-grained and to be made up principally of plagioclase and augite crystals. The gabbro forms a few small dikes in the western part of the district, but its chief occurrence is in the Iron dike, which trends northwest through Black Tiger Gulch and Sugar Loaf, in the eastern part of the district. The dike extends several miles southeastward from the tungsten district and has been traced northwestward for more than 25 miles (Boos and Boos, 1933). The main Iron dike ranges from 20 to 50 ft in width, and at many localities it is accompanied by similar but smaller parallel dikes in zones as much as 500 ft wide. The dike dips 65°–85° SW. It is somewhat more competent than the enclosing Boulder Creek granite, and some of the gold telluride veins in Black Tiger Gulch show a notable enrichment where they pass from granite into the gabbro.

PETROGRAPHY

Although most of the gabbro appears even-grained in hand specimens, the microscope shows that it is somewhat porphyritic. The plagioclase laths and augite crystals that make up most of the rock are embedded in a matrix consisting of minute subhedral feldspar and augite grains. Augite or its alteration products constitute about a third of the rock, and labradorite makes up a little less than 60 percent. Laths of ilmenite and octahedra of magnetite make up 5 to 10 percent of the rock. Accessory sphene and apatite are present, and in a few specimens small amounts of orthoclase and quartz were observed. The labradorite ($Ab_{40}An_{60}$) is an early mineral, and most of it occurs in subhedral crystals about a millimeter long and a third of a millimeter thick. The small labradorite grains in the groundmass are slightly less calcic than the larger crystals.

The augite crystals range from ½ to 2 mm in length, though most of them are less than 0.8 mm long. Most of the larger grains are nearly equidimensional, but the smaller ones are prismatic. Contact twins on the orthopinacoid are very common. The partial alteration of the augite to brown hornblende is probably deuteric.

Throughout most of its course in the tungsten district, the Iron dike is strongly albitized. Nearly all the labradorite of the groundmass and part of that in the coarser crystals has been altered to a low-index isotropic clay mineral (probably allophane) and to albite. The allophane, which is accompanied by a little white mica (paragonite?) and colorless chlorite, is the earlier of the two stages of alteration. The altered labradorite, turbid with minute blebs of allophane, was replaced irregularly by clear albite. Augite was not affected by the albitic alteration, but was partly replaced by brown hornblende, which was in turn replaced by a green variety of hornblende that is accompanied by both green and colorless chlorites. The albitic alteration is probably deuteric and later than the alteration of augite to hornblende.

In some places the gabbro contains small xenoliths of granite. These show two types of reaction. Some of them are partly assimilated, and the gabbro surrounding them contains orthoclase in the fine-grained groundmass. In other xenoliths, particularly those rich in quartz, quartz grains are surrounded by reaction halos consisting of an inner border of pyroxene and an outer rim of green hornblende. The solution of the quartz, an endothermic reaction, apparently occurred at a time when the magma was partly crystallized, and it probably accelerated the crystallization of augite, an exothermic reaction. The rim of hornblende around the augite is probably of deuteric origin, like the hornblende in the rest of the rock.

RELATIONS AND AGE

The Iron dike is the oldest Tertiary dike in the central part of the Front Range, with the possible exception of the felsite dikes, and is probably contemporaneous with the early stages of northwest folding that marked the beginning of the Laramide orogeny in the Front Range region (Lovering and Goddard, 1938a, p. 48). It is cut and displaced by the extension of the Maxwell breccia reef near Allens Park, several miles north of Ward, and it is sheared and silicified where it is in contact with the Livingston breccia reef in the Post Boy tunnel in Black Tiger Gulch. It is cut by hornblende diorite dikes in the Jamestown district and by rhyolite porphyry near Gold Hill (Lovering and Goddard, 1938a, p. 49). In the tungsten district it is cut by limburgite porphyry just north of the Bummers Gulch road. The dike is displaced by some of the east-west faults in Black Tiger Gulch, but at intersections with other east-west fractures in this area its thickness changes abruptly. These relations suggest that a system of eastward-trending fractures was present when the gabbro was intruded and that renewed faulting occurred along some of these fractures after the intrusion of the dike. The gabbro has not been observed to cut Tertiary dike rocks anywhere in the Front Range, but a gabbro dike east of Boulder cuts the late Upper Cretaceous sedimentary rocks. As indicated in table 3, the composition of the gabbro is very similar to that of the basalts at Table Mountain, which are of Paleocene age (Gazin, 1941, p. 289). Cumulative evidence thus indicates that the gabbro is of early Paleocene age.

HORNBLENDE LATITE PORPHYRY DIKES

OCCURRENCE AND GENERAL CHARACTER

Horneblende latite porphyry is found in the tungsten district only in a dike at the south edge of Nederland and in three small dikes in upper Sherwood Gulch. Similar rock occurs in several dikes in the area between Caribou and Eldora, just west of the tungsten district. This was called hornblende monzonite porphyry by Bastin and Hill (1917, p. 49), but as the fine-grained groundmass predominates over the phenocrysts, at least among the dikes in the tungsten district, the term "hornblende latite porphyry" is more appropriate. The rock is dark greenish gray and is conspicuously spotted with phenocrysts of greenish-black hornblende. On weathered surfaces the groundmass is gray and the hornblende phenocrysts are even more prominent than in the fresh rock. Feldspar phenocrysts are completely

TABLE 3.—*Analyses of early Tertiary igneous rocks, Colorado*

[Weight percent]

	Early basalt [1]	Basalt [2]	Gabbro [3]	Hornblende monzonite porphyry [4]	Limburgite porphyry [5]	Biotite latite porphyry [6]	Biotite latite intrusion breccia [7]
SiO_2	49.69	52.59	48.93	63.39	37.83	57.65	68.23
Al_2O_3	18.06	17.91	20.99	16.75	8.52	15.64	13.59
Fe_2O_3	2.64	3.81	2.02	1.83	6.48	3.08	1.95
FeO	6.19	5.18	9.36	3.05	5.52	2.78	.98
MgO	5.73	4.11	4.39	.90	11.44	1.17	1.39
CaO	8.24	7.24	8.03	3.85	13.80	4.33	1.11
Na_2O	2.99	2.94	3.06	4.26	2.82	3.80	.18
K_2O	3.90	3.83	1.80	3.61	1.15	4.28	3.74
H_2O	.91	1.24	1.18				
H_2O-				.13	1.24	1.44	3.59
H_2O+				.93	2.56	1.68	3.48
TiO_2	.85	.84		.35	1.35	.75	.43
CO_2				.09	6.08	3.31	1.20
P_2O_5	.81	.14	.15	.39	1.02	.45	.16
MnO	.13	Trace	.31	.14	.21	.11	.05
BaO						.11	.03
Cl	.13	.05					
Au					[8] .00	Trace	[8] .01
	100.27	99.88	100.22	99.67	100.02	100.58	100.11

[1] Early basalt at Table Mountain, Golden, Colo. U. S. Geol. Survey Mon. 27, p. 308, 1896.
[2] Basalt at Table Mountain, Golden, Colo. U. S. Geol. Survey Mon. 27, p. 306, 1896.
[3] Gabbro from Iron dike. Specimen taken just east of Sugar Loaf, Colo. U. S. Geol. Survey Bull. 228, p. 187, 1904.
[4] Hornblende monzonite porphyry, 1,700 ft west of Silver Queen mine near Tungsten, Colo. J. G. Fairchild, analyst.
[5] Limburgite porphyry, 0.9 mile southeast of Sugarloaf Mountain, Boulder County, Colo., near intersection with Iron dike. J. G. Fairchild, analyst.
[6] Biotite latite porphyry, fifth level, Yellow Pine mine, Boulder County, Colo. J. G. Fairchild, analyst.
[7] Biotite latite intrusion breccia, fifth level, Yellow Pine mine, Boulder County Colo. J. G. Fairchild, analyst.
[8] Ounces per ton.

lacking, a feature which immediately distinguishes the rock from the monzonite porphyry that makes up the persistent dikes north of Nederland.

PETROGRAPHY

The dark-green hornblende phenocrysts make up about 20 percent of the rock. They are cut by a few small veinlets of epidote, but in view of the strong alteration found in the groundmass, they are surprisingly fresh. Most of them are 2 to 5 mm long, though a few are as much as a centimeter in length. Many of the crystals show concentric dark-green and light-green zones. The hornblende encloses many small euhedral crystals of apatite, and some specimens contain a few anhedral grains of augite, which are rimmed with epidote and a little green hornblende. Feldspar phenocrysts are conspicuously absent.

The fine-grained groundmass is strongly altered and is so crowded with minute blebs of allophane and shreds of chlorite that determination of the relative indices of the host minerals is difficult. The groundmass is made up of tiny laths of plagioclase, measuring about 0.12 by 0.02 mm and lying with a somewhat trachytic arrangement in a microgranular aggregate that consists chiefly of untwinned feldspar of low index (probably orthoclase). A very small amount of quartz also is present. Some of the plagioclase laths seem to have an index of refraction above that of Canada balsam and are probably oligoclase, but others have an index definitely lower than that of balsam and are probably albite. The original constituents of the groundmass appear to have been oligoclase, orthoclase, and minor quartz, but much of the oligoclase has been albitized, probably deuterically. The groundmass of the latite porphyry is strikingly similar to that of the monzonite porphyry to be described, but the absence of plagioclase phenocrysts distinguishes the hornblende latite porphyry as a different though closely related rock.

RELATIONS AND AGE

The hornblende latite porphyry has not been found in contact with any other Tertiary intrusive rock, and its relative age must be inferred largely from its petrography. The hornblende phenocrysts, with their numerous euhedral inclusions of apatite, are identical in appearance with those found in the monzonite porphyry north of Nederland. As the plagioclase phenocrysts which distinguish the monzonite porphyry enclose euhedral crystals of hornblende, they obviously did not begin to grow until after crystallization of hornblende had started. It is possible that the hornblende latite and the monzonite porphyries were derived from the same source, but the latite may have been injected at an early stage when hornblende, but not plagioclase, had started to crystallize in the magma chamber.

MONZONITE AND HORNBLENDE MONZONITE PORPHYRY DIKES

OCCURRENCE AND GENERAL CHARACTER

Monzonite porphyry is the most common Tertiary dike rock in the tungsten district. Dikes of monzonite porphyry form two eastward-trending zones in the region north of Barker Reservoir, and small dikes are widely scattered over the western and central parts of the district. The individual dikes in the dike zones are all less than half a mile long, but the zones are persistent for several miles (pl. 1).

The typical monzonite porphyry is mottled light buff and gray and is made up of abundant phenocrysts of plagioclase and some hornblende in a gray, fine-grained groundmass. The plagioclase phenocrysts are nearly equidimensional and are 2 to 5 mm in length. Those of hornblende are mostly 2 or 3 mm long. Although all the monzonite porphyry contains hornblende, the amount is not the same in all the dikes. Some dikes in which hornblende is conspicuous are distinguished as hornblende monzonite porphyry on plates 1 and 5, and those in which the hornblende is inconspicuous are called simply monzonite porphyry. The hornblende crystals in most of the hornblende monzonite porphyry have a subparallel orientation, and the lineation thus defined consistently plunges about 60° W.

PETROGRAPHY

The plagioclase phenocrysts are calcic oligoclase in some dikes and sodic andesine in others, but at a few localities some of them are surrounded by narrow rims of albite. Most of them are subhedral, and a few enclose small euhedral crystals of hornblende. In nearly all specimens the plagioclase phenocrysts are largely altered to allophane, and in some localities sericite and calcite also are abundant.

Most of the hornblende is dark green, but some of it shows light- and dark-green concentric zones, and a few grains of brown hornblende are present in some specimens. The hornblende crystals show some alteration to epidote, light-green and colorless chlorite, and zoisite. Many of them contain inclusions of apatite, and a few enclose scraps of augite which appear to be relicts of crystals largely replaced by hornblende.

The groundmass consists chiefly of albite and orthoclase in proportions that range from about 1:2 to 2:1, but it also contains 10 to 20 percent quartz and a little accessory magnetite and apatite. The albite forms laths about 0.05 mm long, and they, together with small rhombs and laths of orthoclase, are poikilitically enclosed in irregular areas of quartz about 0.2 mm in diameter. The albite both in the groundmass and in the rims on the plagioclase phenocrysts may be a product of deuteric alteration. The groundmass is microgranular in texture, and it is everywhere clouded by blebs of allophane and small shreds of chlorite.

An analysis of a typical hornblende monzonite porphyry from the area northeast of Tungsten is given in table 3.

RELATIONS AND AGE

As already indicated, the monzonite porphyry is believed to have been derived from the same source magma as the hornblende latite porphyry but to be slightly younger. It cuts a felsite dike in the Conger mine, where it in turn is cut by the Conger vein. The monzonite porphyry dike is displaced along the vein for a shorter distance than the pegmatite dikes, indicating that intrusion occurred after faulting in a north-northeasterly direction had started.

LIMBURGITE PORPHYRY DIKES

OCCURRENCE AND GENERAL CHARACTER

Porphyritic lamprophyre classed as limburgite porphyry forms several short northeastward-trending dikes in the east-central part of the district (pl. 1). The rock is almost black on fresh fractures and weathers deep reddish brown. Weathering brings out a finely trachytic fabric of small calcite grains pseudomorphous after prisms of augite. The rock is moderately fine grained, and some of the dikes are finely vesicular or amygdaloidal. Most of the amygdules are less than 2 mm in diameter, and they are therefore inconspicuous in hand specimens.

PETROGRAPHY

The limburgite porphyry is made up of about two-thirds augite, olivine, and iron oxide minerals and one-third isotropic material, which resembles glass but is in large part analcite. The most conspicuous phenocrysts are subhedral crystals of olivine, about 4 mm in diameter, which make up 15 to 20 percent of the rock. They are more or less altered to carbonate and talc or to chlorite and iddingsite. As shown in figure 13, the

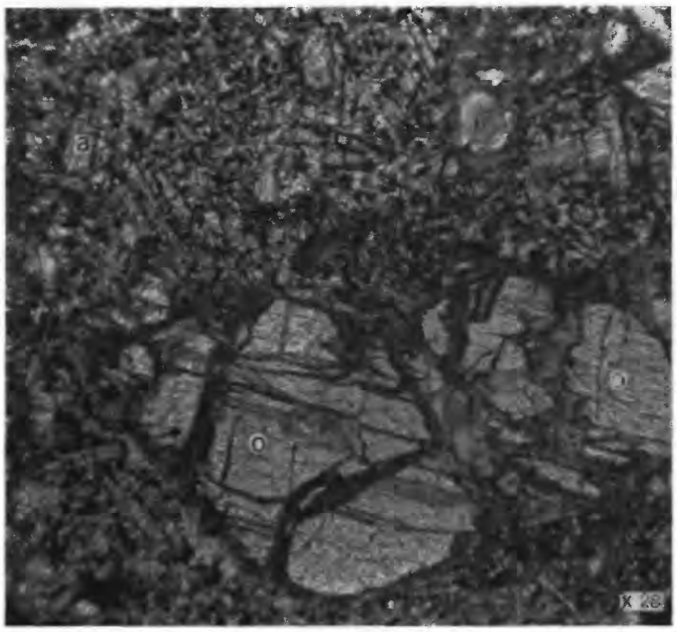

FIGURE 13.—Photomicrograph of limburgite porphyry from a dike just east of the Iron dike in Bummers Gulch, Boulder County, Colo. The corroded phenocryst of olivine lies in a groundmass of short, prismatic augite crystals and interstitial analcite: a, augite; o, olivine. × 28.

olivine phenocrysts lie in a matrix made up of augite crystals and interstitial isotropic material. The augite crystals are of two sizes; a few relatively large ones 0.5 to 0.75 mm long are scattered among small lath-like crystals, 0.05 to 0.08 mm long, which have a trachytic arrangement. The augite is colorless and fresh. It is accompanied by a small amount of brown biotite; magnetite and ilmenite, which make up as much as 10 percent of the rock; and a little apatite.

The interstitial isotropic material consists of two or three different substances, the most abundant of which is analcite. Some of the colorless isotropic material contains numerous tiny inclusions in a roughly zonal arrangement and is probably leucite. A greenish isotropic substance slightly above Canada balsam in index of refraction forms small, narrow, irregular areas between the analcite grains in both the amygdules and the groundmass and occurs, also, as interstitial material between closely spaced augite laths. The identity of this material is unknown; it looks like a glass, but its occurrence in the amygdules suggests that it is a mineral. All the isotropic materials are clear and relatively fresh, although they contain some allophane and a few small, irregular areas of carbonate.

The amygdaloidal cavities (fig. 14) may be as much as 5 mm in diameter, but most of them measure less than 2 mm. The filling in the cavities contains a core of calcite or dolomite (fig. 15) surrounded by a layer of

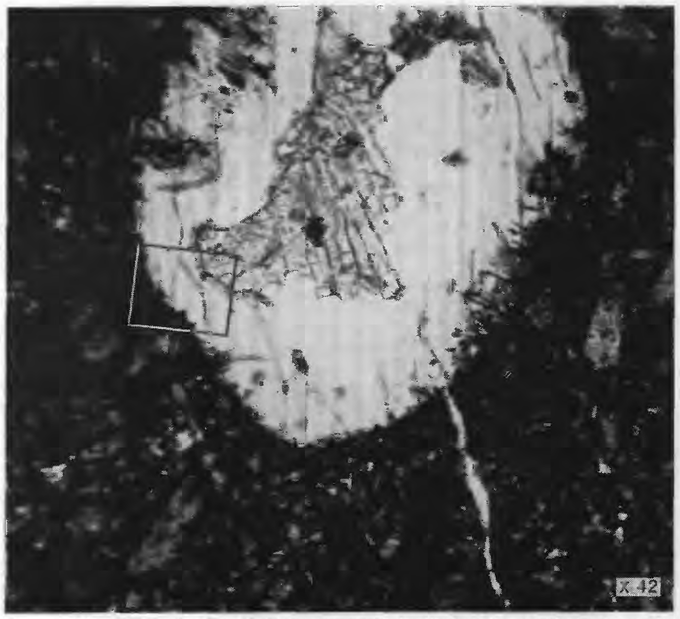

FIGURE 14.—Photomicrograph of an amygdule in limburgite porphyry from the Catastrophe mine, Boulder County, Colo. The area of figure 15 is outlined. × 42.

FIGURE 15.—Enlarged view of part of an amygdule (fig. 14). Well-formed crystals of biotite project into analcite, which forms a shell around a core of calcite; the analcite contains beidellite near the contact with the calcite: *ag*, augite and glass; *b*, biotite; *an*, analcite; *bd*, beidellite; *c*, calcite. × 315.

analcite. Near their outer borders, many of the analcite shells enclose crystals of green pyroxene, brown biotite, and minor pale-green chlorite. These mineral grains project from the rock matrix but are somewhat coarser than the grains in the rest of the matrix. The analcite in many of the amygdules contains fibrous beidellite in a narrow zone bordering the core of carbonate. The amygdules are believed to be of deuteric origin, but small veinlets of opal, quartz, and calcite cutting them are probably of supergene origin.

Limburgite porphyry from the Catastrophe mine contains inclusions of granite. These reacted with the magma and caused calcic plagioclase, rather than analcite, to form in the groundmass of the porphyry in narrow zones surrounding the fragments.

RELATIONS AND AGE

The limburgite porphyry is one of the youngest rocks known in the tungsten district and is contemporaneous with the early stages of vein formation. A dike of limburgite cuts the Iron dike near the head of Bummers Gulch. Very calcic hornblende and biotite diorites described by Bastin and Hill (1917, pl. 1 and pp. 50–51) from the area west of Nederland, where they cut rocks here classed as monzonite porphyries, have the composition and texture of porphyritic lamprophyre and are probably related to the limburgite porphyry. In the Catastrophe mine a small limburgite dike follows the vein, and a branch of the dike cuts gray horn quartz within the vein as shown in figure 16. The soft kaolinized granite bordering the vein is slightly hardened and is stained red by hematite for about 2 in. where it is in contact with the limburgite. Thus the limburgite is clearly later than the early gray horn quartz of the tungsten veins and the argillic alteration that preceded tungsten deposition. As the vein does not contain ferberite at this locality, the relative ages of the limburgite and ferberite are not proved, but the limburgite is probably the older. In a tight slip along the main branch of the limburgite dike, a little scheelite coats the wall of the limburgite dike, indicating that the scheelite is younger, but the scheelite is known to be later than the ferberite (Tweto, 1947a).

The amygdaloidal character of the limburgite and the presence of hydrous minerals such as biotite and analcite indicate a relatively high content of volatiles. This, with the late age of the limburgite, suggests a relation to the high-volatile biotite latite porphyry to be described.

An analysis of the limburgite porphyry from the dike that cuts the Iron dike north of Bummers Gulch is given in table 3.

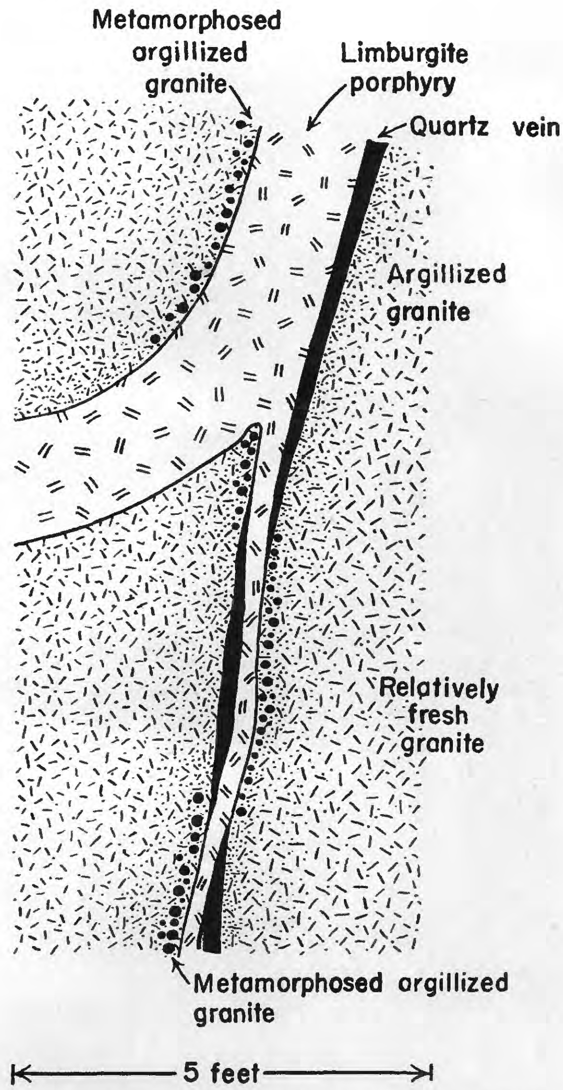

FIGURE 16.—Sketch showing limburgite porphyry cutting gray horn quartz in the lower tunnel of the Catastrophe mine, Boulder County, Colo.

BIOTITE LATITE PORPHYRY DIKES

OCCURRENCE AND GENERAL CHARACTER

Dikes of biotite latite porphyry and related latitic intrusion breccia are in general restricted to the east half of the tungsten district, where most of them follow or lie parallel to vein fissures, but small dikes have been noted in the Hugo and Vasco No. 6 mines in the western part of the district. The biotite latite porphyries are dark-gray, fine-grained rocks that contain abundant small phenocrysts of black biotite and light-gray feldspar in a dark, dense groundmass. The rock is moderately resistant to weathering, and most of it is quite fresh even where it adjoins veins, but a thin dike within the Hugo vein is intensely altered.

Many of the dikes of biotite latite porphyry exposed in mine workings can be seen to weaken or die out upward, suggesting that the zone of latite intrusions is only just reached by the present erosion surface.

Such relations have been observed in the Logan, Lou Dillon, Hugo, and Vasco No. 6 mines, and they suggest that the concentration of biotite latite dikes in the eastern part of the district is an expression of the greater depth of erosion there.

PETROGRAPHY

Phenocrysts of plagioclase, biotite, hornblende, and minor apatite constitutes one-third to two-thirds of the volume of the biotite latite porphyry. The plagioclase, which is most abundant, is primarily andesine, An_{35} to An_{45}, but some of the crystals have an outer rim of oligoclase. The crystals are euhedral or subhedral and are 1 to 2 mm long. Most of them are quite fresh. Biotite, most of which likewise is fresh, makes up 5 to 15 percent of the latite; it occurs in subhedral crystals and round flakes ½ to 1 mm in diameter, the flakes enclosing small crystals of apatite and andesine. Hornblende phenocrysts or their alteration products make up 5 to 10 percent of the porphyry. Unlike the biotite and plagioclase, the hornblende is everywhere strongly altered. Indeed, no hornblende remains in many of the rocks, and its former presence is indicated only by aggregates of secondary minerals pseudomorphous after hornblende. These aggregates are 1 to 2½ mm long. They consist principally of carbonate but contain some apatite and biotite, and those in hydrothermally altered specimens also contain chlorite. Alteration of the hornblende was probably deuteric, as it is characteristic of all the biotite latite porphyry of the tungsten district.

The groundmass is made up largely of feldspar laths 0.04 to 0.08 mm long and 0.01 to 0.02 mm thick

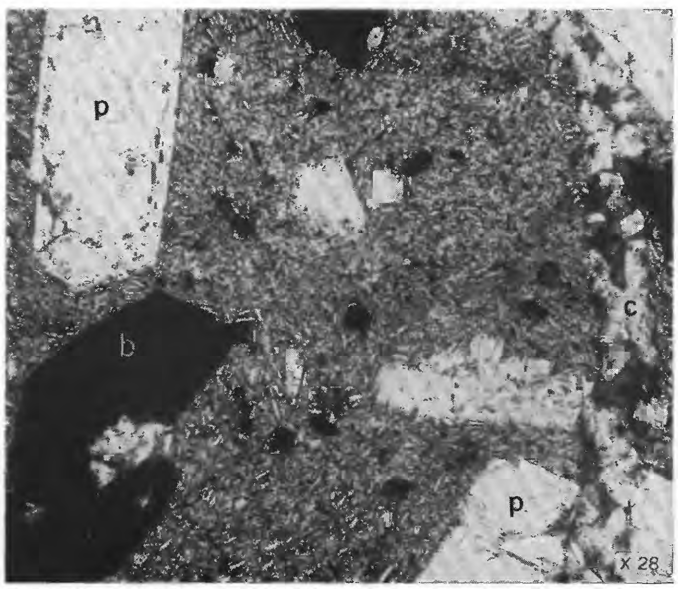

FIGURE 17.—Photomicrograph of biotite latite porphyry from the Eureka mine, Boulder County, Colo. Phenocrysts of plagioclase and biotite lie in a groundmas of fine-grained plagioclase and glass; a veinlet of calcite cuts the section at the right: *b*, biotite; *p*, plagioclase (andesine-oligoclase); *c*, calcite. × 28.

(fig. 17). Most of the laths are carlsbad twins that show very low extinction angles and indices well below that of canada balsam. These are orthoclase, probably somewhat sodic. A few of the laths show extinction angles of as much as 12° and have refractive indices very near that of canada balsam. These are oligoclase. Colorless, finely granular material between the feldspar laths appears to be intermediate in index between orthoclase and oligoclase, although the presence of numerous blebs of allophane makes the determination uncertain. This may be orthoclase more sodic than that in the carlsbad twins, formed perhaps by devitrification of glass. The groundmass also contains a little fine-grained quartz, apatite, and magnetite.

The groundmass of chilled biotite latite from narrow dikes and the borders of thicker dikes is essentially glassy but is dusted with finely divided carbonate and sericite(?).

Except in the Hugo mine, most biotite latite porphyry near veins was only moderately altered by the hydrothermal solutions. Alteration was confined chiefly to the andesine crystals, which were first replaced by beidellite and halloysite. At a later stage the altered material was partly replaced by carbonate, and still later it was cut by veinlets of carbonate.

The intensely altered biotite latite in the Hugo vein is made up in large part of a fine-grained mixture of quartz and carbonate. Sprinkled uniformly throughout this aggregate are limonite pseudomorphs after biotite. A few relatively large patches of carbonate appear to be pseudomorphic after hornblende. The original feldspar phenocrysts are marked by clusters of fine-grained quartz, most of which are partly bounded by irregular small patches of carbonate. The original groundmass has been altered to very fine grained quartz, interstitial carbonate grains and dust, and irregular small patches of isotropic material, possibly glass or an amorphous clay. Some of the carbonate and clay particles are concentrated in streaks that outline a whirly flow structure. As the altered biotite latite occurs in seams only 1 to 3 in. thick within the wide vein of horn quartz and silicified granite, the original rock was presumably chilled, and the groundmass was probably glassy. The porphyry occurs in two forms; one is fairly hard, greenish or purplish gray, and finely porphyritic in appearance. The other is soft, lighter in color, and almost indistinguishable from gouge except for observed transitions to recognizable porphyry. Thin sections of the two types are surprisingly similar, except that in the soft rock carbonate and isotropic particles are somewhat more abundant and more finely disseminated than in the hard rock, and the dark patches representing the original biotite appear to consist of iron-stained clay rather than iron oxide alone. The intense siliceous alteration of the biotite latite doubtless accompanied the quartz mineralization in the enclosing vein.

RELATIONS AND AGE

The biotite latite porphyry is of approximately the same age as the limburgite porphyry and is later than some of the vein quartz. The biotite latite of the tungsten district is similar in character, chemical composition, and geologic relations to the biotite latite porphyries of the Central City and Georgetown quadrangles and is correlated with them. Biotite latite porphyry near Idaho Springs is later than quartz monzonite, bostonite porphyry, and the pyritic gold ore of the Stanley mine (Bastin and Hill, 1917, pp. 56–57). In the tungsten district, a dike of biotite latite porphyry cuts through the Eureka vein and carries inclusions of the vein quartz and of granite containing clay minerals formed by hydrothermal alteration. Although the porphyry is altered slightly at places near the vein, most of it is fresh, and the presence of the inclusions of altered granite in it indicates that it was intruded during the period of mineralization, after most of the alteration to clay material had been accomplished.

Further evidence that the biotite latite porphyry was intruded during the period of vein formation was found in the Hugo mine. In a stope above the second level, the porphyry was observed to cut stringers and lenses of light-gray horn quartz, but it is cut by veinlets of medium-gray horn quartz and occurs as included fragments in a thick vein of this quartz. The next younger generation of horn quartz is dark gray, and following this came black, ferberite-bearing horn. All the biotite latite in the Hugo vein is seamed by veinlets of cream- or flesh-colored carbonate, and locally the latite contains a little disseminated pyrite.

In the Logan mine the biotite latite porphyry clearly cuts a vein of pyritic gold quartz, and in the Mayflower mine a gold telluride vein follows the contact of biotite latite porphyry and intrusion breccia. The biotite latite porphyry was evidently intruded during the period of gold telluride and tungsten mineralization and thus appears to be one of the latest of the Tertiary porphyries.

A chemical analysis of biotite latite porphyry from the Yellow Pine mine is shown in column 6, table 3. Spectroscopic analyses of biotite latite porphyry from the Logan mine and latitic intrusion breccia from the Yellow Pine mine are given in table 6, which shows that these two rocks are the only two among the 45 pre-Cambrian and Tertiary rocks tested that carry tungsten in detectable amounts (*See also* Bray, 1942).

BIOTITE LATITE INTRUSION BRECCIA DIKES

OCCURRENCE AND GENERAL CHARACTER

The biotite latite intrusion breccia consists of fragments of pre-Cambrian rocks and the older Tertiary porphyries in a matrix of fine-grained, highly altered biotite latite. The size and quantity of the rock fragments range widely. The breccia fragments in dikes in the Logan and Yellow Pine mines are only a fraction of an inch in diameter, whereas in a dike in the Good Friday mine the fragments are of boulder size. In some dikes the fragments constitute as much as 90 percent of the rock, and in others they make up as little as 20 percent. The biotite latite matrix is altered so intensely that it closely resembles gouge in most occurrences, but a characteristic purplish-gray color and the presence of numerous fine flakes of biotite distinguish it from gouge. The intrusion breccia occurs in irregular seams or thin dikes which locally make abrupt turns at minor intersecting fractures or fork into them.

In the Good Friday mine (pl. 23), dikes of biotite latite intrusion breccia intersect the vein about 150 ft east of the April Fool shaft on the lower tunnel level and on the next two levels above. As the dikes on each level dip 45°–50° W., they are evidently unconnected and lie in an echelon pattern. Intrusion breccia dikes on the trend of this zone are present, also, on both levels of the Little Lester mine, a few hundred feet south of the Good Friday. One of the dikes in the Good Friday is made up of well-rounded pebbles and boulders cemented by a fine-grained aggregate consisting chiefly of rock granules and sand grains. An abundance of tiny interstitial biotite flakes suggests that this fine-grained aggregate is cemented by latitic material. Some of the boulders in the breccia are as much as 15 in. in diameter; in addition to several varieties of granite, aplite, and pegmatite, they include biotite schist, monzonite porphyry, and a black lamprophyre that is probably either limburgite or a relatively fine-grained facies of the Iron dike gabbro. Located near the middle of the Boulder Creek batholith (pl. 3), this remarkable assemblage of rocks indicates that the fragmental material was transported a considerable distance horizontally or was carried up from great depth. As shown in the cross section of the Boulder Creek batholith in figure 10, the batholith is believed to be floored at relatively great depth in this area; this floor is believed to be the source of the schist boulders, inasmuch as schist inclusions are rare and small in the central part of the batholith. The nearest limburgite known is half a mile west, and the Iron dike, which dips steeply to the southwest, lies 4,000 ft to the northeast. No outcrops of monzonite porphyry are known within a mile of the Good Friday mine.

PETROGRAPHY

The biotite latite matrix of the intrusion breccia is so highly altered that traces of the original constituents have been found in only a few specimens, chiefly from the Yellow Pine mine. In thin section these specimens show microlites of oligoclase-andesine and small shreds of biotite surrounded by a rather dark, glassy groundmass containing some sericite and probably some feldspar. The microlites show a pronounced flow structure, but the pattern is one of whorls and snarls, rather than a unidirectional arrangement. The specimens from the Yellow Pine mine contain 20 to 50 percent matrix material of this type and 50 to 80 percent rock fragments. The fragments range from less than 0.01 mm to several centimeters in diameter and consist of granite, porphyry, and early vein quartz (fig. 18).

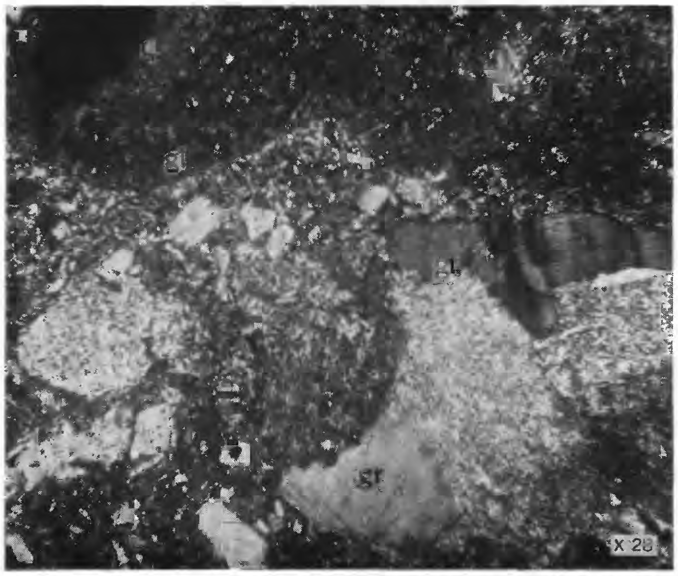

FIGURE 18.—Photomicrograph of biotite latite intrusion breccia from the Yellow Pine mine, Boulder County, Colo. Fragments of granite and early vein quartz lie in a groundmass that is made up of sericitized and partly silicified glassy material and fine flakes of biotite: *gl*, partly glassy groundmass; *gr*, granite fragment; *q*, early vein quartz. ×28. Crossed nicols.

RELATIONS AND AGE

The intrusion breccia is one of the latest of the Tertiary intrusive rocks. It cuts lead-zinc ore in the Little Eva tunnel in Perkins Gulch, and it cuts sharply across the Little Lester composite vein, which consists of early gold-bearing pyritic horn quartz and later ferberite and horn quartz. The tungsten ore mined from the Little Lester vein all came from the southwest side of the dike of intrusion breccia, and no trace of tungsten has been found in the vein in the short distance for which it has been explored northeast of the dike. In the Good Friday mine the vein narrows to a mere crack where it crosses the dikes, and the dike on the third level cuts a small vein of dark horn quartz that branches from the Good Friday vein. In the Yellow Pine and the Logan mines intrusion breccia cuts fault gouge and a felsite dike that was intruded along the same fault zone (fig. 19).

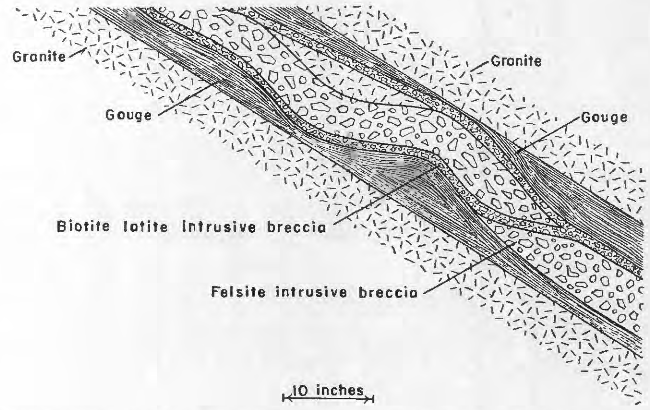

FIGURE 19.—Sketch of biotite latite intrusion breccia that cuts fault gouge and highly altered felsite in the Mud vein, sixth level of the Yellow Pine mine, Boulder County Colo., 225 ft west of the junction with the Hoosier breccia reef.

Relations shown in the Logan mine indicate that the latitic breccia was intruded at a late stage in the orogenic history of the region. At least five periods of fault movement preceded the introduction of the intrusion breccia, and only two followed, as shown in figure 20. Although the intrusion breccia is earlier

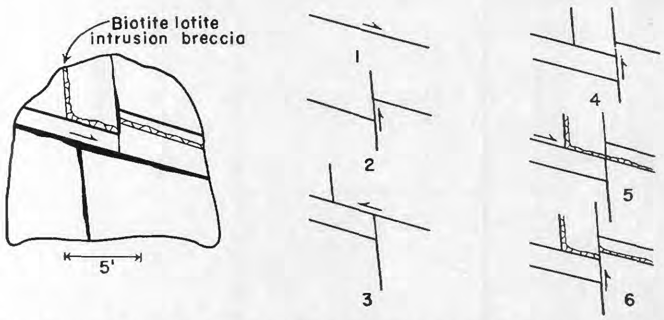

FIGURE 20.—At the left, a cross section showing alternation of movement on the Logan and Mud veins at their intersection on the third level of the Logan mine, Boulder County, Colo., and the relative age of the latitic intrusion breccia. At the right, the stages in the development of the present relations are shown diagrammatically.

than the gold telluride ore of the Logan mine, the relation of the shoots of high-grade telluride ore to the upward termination of the breccia suggests a genetic relation between the two (p. 73).

The intrusion breccia appears to be closely related to the biotite latite porphyry. Analyses of the two rocks are given in table 3. The sample of intrusion breccia analyzed was the purest that could be obtained, but it contained at least 20 percent foreign material, chiefly vein quartz and altered granite. If allowance is made for the higher silica content of the vein quartz and granite, comparison of columns 6 and 7 of table 3 shows that the biotite latite matrix of the intrusion breccia is very similar in composition to the biotite latite porphyry. This chemical similarity of the two rocks and their close association in several mines suggest that they were derived from the same source magma. They were probably almost contemporaneous, but indirect evidence suggests that the breccia may be slightly older than the biotite latite porphyry. The breccia is highly altered in almost all occurrences, whereas the porphyry is relatively fresh. The biotite latite porphyries in the Eureka and Hugo mines contain inclusions of hydrothermally altered granite from the walls of the veins, indicating that they were intruded after argillic alteration had occurred along the veins, but in the Good Friday mine both the dike of intrusion breccia and the enclosing granite are strongly altered on the footwall side of the vein and are relatively fresh on the hanging wall, showing that the breccia here was intruded before argillic alteration of the wall rocks occurred. Thus, if there is any appreciable difference in the ages of the latite and the intrusion breccia, it seems probable that the breccia is slightly the older.

TERTIARY OR QUATERNARY GRAVEL

Deposits of coarse gravel of undetermined age and origin cap Tungsten Mountain, 1½ miles southeast of Nederland, and high ridges and hills in a narrow belt that extends eastward for about 5 miles. Tungsten Mountain reaches an altitude of 8,922 ft and rises about 400 ft above the level of the surrounding upland area. The gravel deposit capping it is about 50 ft thick.

The gravel is made up chiefly of well-rounded pebbles and cobbles less than 4 in. in diameter, but it contains a few rounded to subangular boulders 2 to 15 ft in diameter. Some of the rounded pebbles have flat surfaces like glacially faceted pebbles. Many of the pebbles consist of coarsely porphyritic quartz monzonite similar to that in a stock at Ute Mountain, about 5 miles west of Tungsten Mountain. As no similar porphyry is known to occur for a long distance to the north and none has been found to the south, the quartz monzonite was probably derived from the Ute Mountain stock. The gravels contain pebbles of several other porphyries, also, and many of schist and granite.

The gravel is poorly sorted, and its origin is uncertain. It appears to be restricted to the narrow belt extending eastward from Tungsten Mountain, as no similar gravels have been found nearby. The trend of this belt and a progressive decrease in the size of the material toward the east suggest that the agent depositing the gravel moved east from the Ute Mountain region across what is now the top of Tungsten Mountain. The bedrock floor of the gravel falls 200 ft in the first mile east of Tungsten Mountain, but farther east the gradient is only 130 to 150 ft per mile. The character and occurrence of the gravel suggest a glacial origin or deposition by sheet wash on a late Tertiary pediment.

Wahlstrom (1947, pp. 563–565) has suggested that the gravel is an early Pleistocene drift. The large size of some of the boulders, the lack of sorting, and the presence of faceted pebbles all suggest glacial deposition. However, the gravel rests on a relatively smooth, deeply weathered bedrock surface east of Tungsten Mountain, which would be unlikely if the gravel were of glacial origin.

The gravel is similar to gravels that have been deposited by sheet wash, or in certain types of alluvial fans, or by streams with a high gradient, at many localities in Colorado and other Western states. Indeed, gravels of almost identical appearance are found in the coalescing Recent alluvial fans at the mountain front a few miles east of Tungsten Mountain. As indicated in the section on geomorphology, Tungsten Mountain is in the transition zone between the high crestal part of the Front Range and the dissected upland that lies between the high slopes and the mountain front. Coarse gravels might well be deposited by torrential streams of sheet wash in such a locality where the gradient changed suddenly.

The position of the gravel on ridges that are apparently unrelated to the valleys that developed during the earliest generally recognized glacial stage indicates that a large amount of material was removed prior to the late Pleistocene glaciation. The gravel is therefore believed to be not later than earliest Pleistocene, and if it is a fan or sheet-wash deposit, it is probably of Tertiary age, for it rests on remnants of erosion surfaces believed to be of late Oligocene age.

QUATERNARY DEPOSITS

The Quaternary deposits of the tungsten district comprise glacial moraine, glacial outwash gravels, and alluvium. The area west of the tungsten district is heavily glaciated, but glacial deposits within the district are restricted to the extreme western part, near Nederland. Two stages of Pleistocene glaciation are recognizable in most of the Front Range province. The morainal deposits shown near Nederland in plate 1 date from the early glacial stage; the outwash gravels are products of the late or Wisconsin glacial stage. The terminal moraine of the Wisconsin stage lies half a mile west of the town, just off the mapped area.

EARLY GLACIAL DEPOSITS

The early glacial drift within the tungsten district occurs in scattered remnants of moraines along the valley sides and in the valley bottom near Nederland (pl. 1). The drift extends to a height of about 100 ft above the valley north of the town and to about 150 ft south of the town. The thickness of the ground moraine in the valley is unknown, but the drift on the sides of the valley is a thin veneer only 10 to 15 ft thick. The drift consists of an unsorted mixture of boulders, pebbles, and clay. Most of the boulders are roughened by weathering, and in general the early drift is weathered conspicuously more than the late or Wisconsin drift. Most of the boulders are pre-Cambrian granite and schist, but some are Tertiary porphyry.

No outwash gravels of the early glacial stage have been recognized. Probably such gravels were in part removed from the valley by stream erosion between the the two glacial stages and in part covered by Wisconsin glacial deposits.

The glacier that deposited the early moraine at Nederland originated in a cirque at Yankee Doodle and Jenny Lakes, near the Continental Divide, and extended eastward down the valley of Jenny Creek to a point about a mile west of Buckeye Mountain, where it swung east-northeastward across the divide now occupied by Lake Eldora and into the valley of Middle Boulder Creek (pl. 3). The average gradient of this glacier in the lower part of its course, between Lake Eldora and Nederland, was approximately 300 ft per mile.

LATE GLACIAL (WISCONSIN) MORAINES

A heavily timbered ridge that crosses the valley of Middle Boulder Creek about a half mile west of Nederland is a terminal moraine of Wisconsin age. The till in it is fresh and shows a greater range in size of material and a much larger proportion of striated pebbles and boulders than the earlier drift. Its thickness is unknown, but the morainal ridge rises 50 to 75 ft above the present stream, which here is wholly in till.

The Wisconsin glacier followed the valley of Middle Boulder Creek and deposited the terminal moraine near Nederland at about the same altitude as the terminal moraine of the early glacier. Through the last few miles of its course, the Wisconsin glacier had a gradient of about 125 ft per mile, as contrasted with the 300 ft per mile of the early glacier. At the village of Eldora, 4 miles southwest of Nederland, the late glacial channel lies about 600 ft lower than the early glacial channel at Lake Eldora. The canyon at Eldora was probably deepened in large part by the Wisconsin glacier, but some of the deepening was probably caused by stream erosion between the two glacial stages.

OUTWASH AND ALLUVIUM

The town of Nederland is built on outwash gravels from the late, or Wisconsin, glacier. The gravels form a series of small terraces at Nederland, but a mile or two farther east these merge and lose their individuality. Similar coalescing outwash-gravel terraces occur in the valley of North Boulder Creek where it enters the tungsten district at Lakewood Reservoir (pl. 1). The Wisconsin moraine on North Boulder Creek is only a short distance west of the reservoir.

Many of the shallow valleys preserved on the upland between Middle and North Boulder Creeks are filled to a depth of 10 to 30 feet with alluvium and residual soil. This material probably accumulated slowly over a long period of time, and some of it may be as old as early Pleistocene or even late Tertiary.

GEOMORPHOLOGY

The Front Range displays two broad physiographic divisions: (1) the high, steep crestal portion of the range, including high spurs and shoulders extending out from the crest for several miles, and (2) a wide dissected upland reaching from the border of the crestal area, or "high country", as it is generally called, to the east edge of the crystalline rocks, where it descends abruptly to the level of the plains. Glaciation was in general confined to the first of these divisions, although the larger glaciers descended to the east edge of a narrow transitional zone between the two divisions, as at Nederland.

Sets of accordant surfaces in both the major physiographic divisions are conspicuous features of Front Range topography and reveal a complex erosional history. These surfaces have been widely studied and variously interpreted. They were recognized as a series of distinct erosion surfaces by Van Tuyl and Lovering (1935), in whose paper the conclusions of several earlier writers are summarized. More recently Rich (1935, pp. 2046–2051) and Wahlstrom (1947, pp. 566–567) have suggested that parts of once-continuous surfaces have been displaced differentially by faulting and warping, giving rise to several of the accordant surfaces.

Van Tuyl and Lovering recognize three erosion surfaces in the high country—the Flattop, Green Ridge, and Cheyenne Mountain surfaces, all probably of Eocene age. The highest and earliest erosion surface of the upland area is the upper Overland Mountain surface, probably of early Oligocene age. It is not preserved within the tungsten district, but the summits of Bald and Sugarloaf Mountains, just north of the district, are remnants of it. The next lowest and youngest surface, and the most conspicuous of the tungsten district, is the lower Overland Mountain surface, which is preserved on the upland north and south of Nederland at altitudes of 8,500 to 8,700 ft (fig. 21). A mile or two east of Nederland, well-defined benches occur at an altitude of 8,300 to 8,400 ft on the sides of the major interstream divides, and still farther east this bench surface extends across the divide between Middle and North Boulder Creeks. It is correlated with the upper

FIGURE 21.—View northwestward across Nederland, Colo., showing erosion surfaces. The Flattop (*F*), Cheyenne Mountain (*C*), and Overland Mountain (*Ov*) surfaces can be seen.

Bergen Park surface, which is believed to be of late Oligocene age. In the eastern part of the tungsten district, lower erosion surfaces appear as well-developed benches along the sides of the major stream valleys. The lower Bergen Park surface, probably of Miocene age, is prominent at an altitude of about 7,600 ft in the region east and north of Comforter Mountain, and a broad valley cut below the general level of this surface is preserved at an altitude of about 7,400 ft on the high spurs near Boulder Falls. This valley stage of erosion is correlated with the Flagstaff Hill surface near Boulder and is probably Pliocene in age. East of Boulder Falls remnants of benches corresponding to still younger erosion levels can be recognized at places along the valley of Middle Boulder Creek and in Bummers Gulch.

Several abrupt changes in the gradient of Middle Boulder Creek are probably expressions of the upstream migration of early and middle Pleistocene base levels established on the plains just east of the crystalline rocks. In the 5-mile stretch from Nederland eastward to the head of the Narrows, at an altitude of 7,500 ft in the valley bottom, the valley of Boulder Creek has a comparatively gentle gradient. East of the point where the 7,500-ft contour crosses the stream bed the valley deepens rapidly, but just east of the junction of Middle and North Boulder Creeks the gradient flattens again. Half a mile farther east it steepens and once more flattens near the east margin of the tungsten district. From this point to the plains the gradient is fairly uniform.

The mature valley west of the Narrows contrasts sharply with the steep-sided youthful canyon farther east. As this valley, near Nederland, contains deposits of both the early and late glacial stages, it is clearly preglacial and is probably of late Tertiary (Flagstaff Hill) age. The preservation of the valley since the late Tertiary is probably due to its location at the east edge of the high crestal part of the Front Range, where the gradient of Boulder Creek flattens abruptly. The reduction in gradient would cause the stream issuing from the higher country to the west to drop much of its burden at times when it was heavily loaded. Alternate filling and excavation due to climatic changes during the Pleistocene probably caused this part of the valley to remain stable.

STRUCTURE

PRE-CAMBRIAN STRUCTURE

The dominant structural feature of the tungsten district is the Boulder Creek batholith. Intrusion of the batholith closely influenced the structure of the surrounding schist and therefore that of many minor granitic bodies intrusive into the schist. Within the batholith itself, the grain or primary flow structure in the granite controlled many later intrusions and fractures, both pre-Cambrian and younger.

The schist of the Idaho Springs formation is intricately folded and is extensively seamed and intruded by granitic materials. As explained on page 7, the foliation is parallel to the bedding planes of the original sedimentary rocks and to the fold axes. The folds and foliation are approximately parallel to the edge of the Boulder Creek batholith (pl. 3), indicating that any earlier folds were modified by the batholith as it made room for itself by crowding aside the rocks of the Idaho Springs formation. The folds in the schist range in size from minute plications to regional folds several miles across, and the general pattern of folding is isoclinal. The schist of the tungsten district is on the east flank of a northward-trending regional anticline, the axis of which lies a few miles west of Nederland. Moderately large isoclinal folds subordinate to this major fold are evident at places in the tungsten district, as in Sherwood Gulch and on the north side of Gordon Gulch, but no attempt has been made to map in detail the folds in the Idaho Springs formation. However, the axes of many minor folds are marked by bodies of aplite and pegmatite.

Most of the intrusive bodies in the schist are concordant or partly concordant. The smallest of these are of aplite, pegmatite, and alaskite and take the form of thin sill-like seams which are interlayered with the schist and follow even the tiniest crenulations in the contorted rock. Countless thin seams of this type have been introduced into the schist at places, particularly near the edge of the batholith, forming the injection gneiss facies of the Idaho Springs formation.

In general the intrusive bodies that are larger than the thin seams just described have both sill-like and dikelike characteristics. They are a few inches to several hundred feet wide and consist of aplite, pegmatite, alaskite, diorite, or granite. They resemble sills in that they trend parallel to the regional strike of the schist and thus form long, narrow outcrops that accentuate the "grain" of the schist (pl. 5). Many of them follow the general trend of the axial planes of tight isoclinal folds and thus are parallel to the schistosity or the flanks of the folds. However, they resemble dikes in that they transect many of the minor crenulations in the schist and cut across the schistosity in the crests and troughs of the tight folds. Some of the larger pegmatite masses are made up of concordant pods connected by cross-breaking dikes or necks, and some pegmatite bodies are entirely cross breaking. Aplite shows cross-breaking relations much less frequently than pegmatite, but near the edge of the granite batholith the larger bodies of aplite are cross breaking in part, and many have gently sloping floors that cut sharply across the schistosity of the underlying Idaho Springs formation. A few bodies of aplite have both horizontal and vertical discordant contacts with the schists. Movement occurred on many such contacts during the Laramide revolution, opening a way for mineralizing solutions.

As shown in the discussion of the Boulder Creek granite and related rocks, the Boulder Creek batholith, as well as many of the dikes within it, has a well-defined internal, or primary, flow structure. The orientation of the gneissic and linear elements of this structure in the batholith as a whole indicates that the center of intrusion was in the vicinity of Gold Hill, near the north end of the batholith, and that the batholith has the shape of a tilted, wedge-shaped block, thick at the north end and thinning to the south above a floor that slopes northward (fig. 10). The gneissic structure of the granite controlled the form and orientation of many bodies of the later intrusive rocks. Thus the aplite and pegmatite within the batholith occur mainly in sill-like bodies essentially parallel to the foliation of the granite, although there are many cross-breaking dikes and irregular bodies.

No pre-Cambrian faults were identified with certainty in the tungsten district, although many doubtless exist. Some are probably followed by cross-breaking dikes of aplite and pegmatite, but displacement of the contorted schist or the uniform granite is hard to prove. Dikes or sills of hornblende diorite and aplite appear to be offset along an east-west line a mile north of Nederland, but as the later pegmatites do not seem to be affected, the fault—if one exists—must be nearly contemporaneous with the intrusion of the aplite and pegmatite. The discontinuous dikes of the Tertiary monzonite porphyry strung out along an east-west line a short distance farther north mark a zone of weakness which might be of pre-Cambrian age, but it might also be of any age between pre-Cambrian and Tertiary.

LARAMIDE STRUCTURE

Most of the structural features that define the Front Range were formed during the Laramide revolution, although the range coincides approximately with an area that was elevated most of the time during the Paleozoic and Mesozoic eras. From the regional point of view the range is essentially anticlinal in structure, but in detail the sides are folded and faulted and the interior is a complex fault mosaic. The most prominent faults in the eastern part of the range have a northwesterly trend and extend diagonally from the border toward the middle, where some of them swing to a more westerly strike. Near the west edge of the range, in contrast, the main faults strike northeast.

The northwestward-trending faults of the eastern part of the range are persistent for many miles in the pre-Cambrian terrane and are exposed prominently in many places. The areas between the major faults are broken by many minor faults and vein fissures, most of which strike northeast, nearly at right angles to the major, northwestward-trending faults. The fractures of this group are younger and far more numerous than the northwest faults but much less persistent.

BRECCIA REEFS

The so-called breccia "reefs" of the Front Range area—or "dikes," as they were known to the early miners—are silicified fault zones. In general they mark the major faults of the early northwestward-trending fracture system; numerous minor faults and fractures of the same system are unsilicified and inconspicuous. The major faults, or reefs, were recognized and named by the earliest miners in Boulder County because ore on many of the northeastward-trending veins is localized near the intersections of the veins with the reefs. In the tungsten district the reefs are spaced 2 to 3 miles apart across the entire length of the district, as shown in plate 3. From east to west they are known as the Hoosier reef, which marks the east end of the tungsten district; the Livingston reef; the Rogers reef; the Hurricane Hill reef; and the Maine-Cross reef, which marks the west end of the district.

Displacement on the breccia-reef faults is best seen at the mountain front, where the faults displace the sedimentary rocks as much as several hundred feet, with the southwest side downthrown. The total displacement cannot be determined with certainty in the crystalline rocks of the tungsten district, but various types of movement and directions of displacement recorded by individual fractures within the reefs attest to a long and complex fault history. Nearly all the reefs contain fractures that show a minor, nearly horizontal movement, in which the northeast walls moved southeast and rose slightly, and a major movement in which these same walls dropped and moved southeast at an angle of 20° to 50°, but numerous other, less readily correlated movements occurred. The first movement on the breccia-reef faults took place before the Paleocene Iron dike gabbro was intruded in the eastern part of the district, and movement was repeated intermittently at various times during the Laramide revolution.

The northwestward-trending fractures of the breccia-reef system are the oldest Laramide fractures recognized in the tungsten district and surrounding region. They are followed by the earliest dikes, such as the Iron dike, and they are cut and displaced by the northeastward-trending veins. Many of the fractures were mineralized with quartz and hematite before the tungsten vein fissures were formed. The minor fractures between the main reefs are marked only by a little hematite, either specular or earthy, or are merely slips marked by gouge, but the major faults or reefs are characterized at most places by dikelike masses of silicified fault breccia or silicified sheared rock as much as 50 ft wide. These masses are colored purplish by disseminated hematite and are seamed by veins of quartz and hematite. The hematite in the veins or veinlets is nearly all fine-grained, but the quartz with which it is associated is in part coarse-grained, white, and glassy and in part fine-grained and horny. In places hematite is absent, and there the fissures may be filled with a nearly solid vein of coarse-grained quartz 2 to 15 ft wide, or the outcrops may be marked by a wall of silicified granite standing in strong relief above the surrounding rock (fig. 22). Although the north-

FIGURE 22.—View southeastward along the outcrop of the Livingston breccia reef near the head of Black Tiger Gulch, Boulder County, Colo.

westward-trending faults are conspicuous where they cut across the pre-Cambrian structure and contain a breccia cemented by quartz and hematite, they are commonly much less prominent where they follow northwestward-trending aplite dikes as do the Hoosier and Hurricane Hill reefs at Arkansas Mountain and Hurricane Hill, or where favorable structure in the granite allowed them to widen out into broad, sheeted zones. At some places the reefs are broad, chloritized shear zones, and at others they are simply wide gougy zones.

Both the Hoosier reef and the Livingston reef are strongly silicified throughout their course in the tungsten

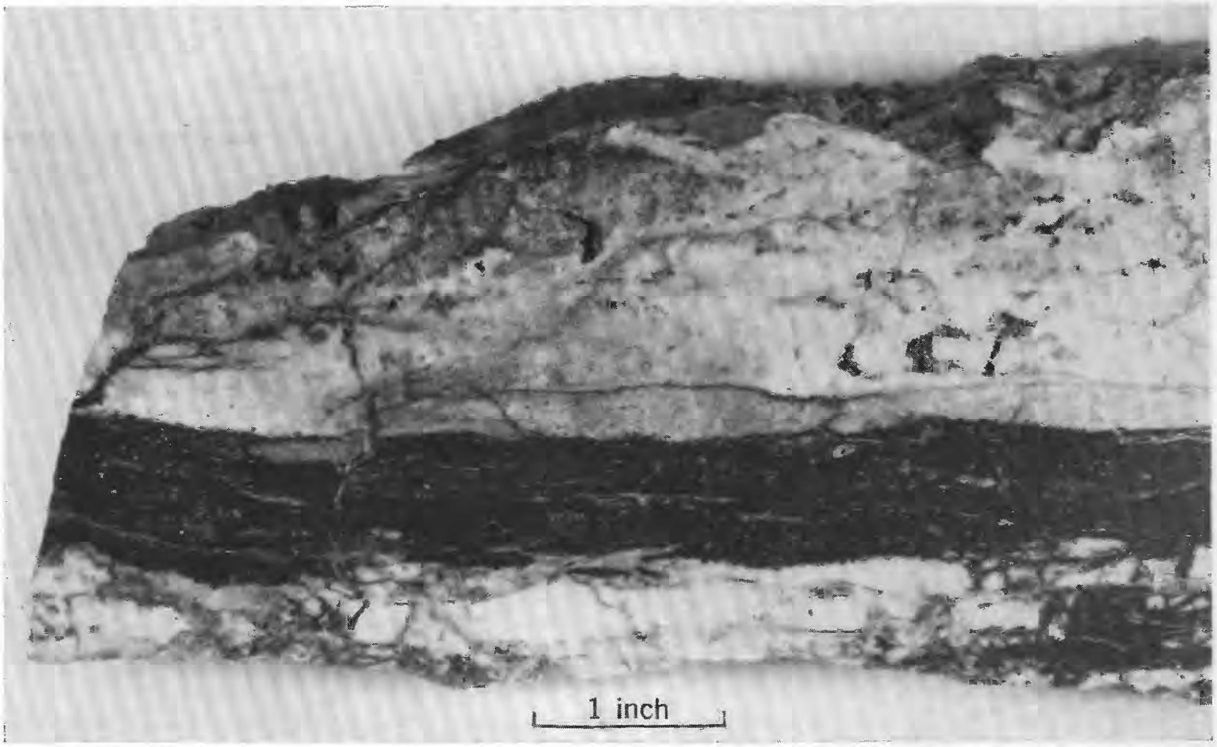

FIGURE 23.—Polished slab from the Rogers breccia reef, Boulder County, Colo., showing a vein of hematite cutting coarse, sugary quartz. Natural size.

district, and they contain less hematite than the breccia reefs to the west. The Rogers reef, where it crosses the ridge between North and Middle Boulder Creeks, carries abundant hematite and quartz in a zone 20 to 30 ft wide. It contains as much as 0.03 oz of gold to the ton, and a little lead-silver ore is said to have been found on it in several prospect pits on the crest of the ridge. A polished slab from this reef is shown in figure 23. The Hurricane Hill reef, which crosses the tungsten district near the west margin of the Boulder Creek batholith, ranges from a wide, gougy, unmineralized fault zone to a strongly silicified shear zone with or without hematite. A little late sphalerite and galena have been found in it near Sherwood Gulch. It is relatively obscure at the surface between Tungsten and North Boulder Creek, where it follows the gneissic structure of the aplite that borders the granite; but it is well exposed in the workings of the Clark tunnel. As the reef is essentially parallel to the foliation, the fault movement was largely interlaminal and thus diffused, and in few places was the resulting shear zone sufficiently permeable to carry the quartz-hematite solutions that mineralized the reefs elsewhere. In the Clark tunnel, however, a small body of high-grade hematite was mined from it (p. 129).

Numerous minor breccia reefs have been found in the Beaver Creek district, south of Nederland, and a strong but relatively narrow quartz-hematite reef that cuts diagonally through the Cross and Maine claims marks the western limit of tungsten ore in this part of the district. The Maine-Cross reef can be traced for only about a mile northwest of the Maine claim. It probably continues to the northwest, and it may connect with a zone of hematite-bearing, northward-trending shear planes in the Illinois mine, about a mile northwest of Nederland, but it is parallel to the schistosity of the Idaho Springs formation in most of the intervening area and thus is inconspicuous.

In a few places eastward-trending breccia reefs branch from, or cross, the northwestward-trending faults. Of these the Poorman reef, which extends from the Maxwell to the Hoosier reef, is the most conspicuous in the tungsten district, though it barely extends into the northeast corner of the area shown in plate 1, near the Logan mine. The Copeland reef, which is about 5½ miles farther south, near South Boulder Creek, extends westward from the Livingston reef to the Rogers reef; it contains tungsten at the Copeland mine and at places is slightly mineralized with gold. Many of the veins with an easterly strike in the eastern part of the district show characteristics of the breccia reefs and are believed to be reef fractures that were partly reopened and mineralized during tungsten deposition. The zone of eastward-trending veins that crosses Black Tiger Gulch is an example of this group. The Black Prince vein, on the southwest side of the gulch, comprises narrow, discontinuous streaks of late horn quartz and ferberite in a wide shear zone that contains veins of horn quartz of the breccia-reef type and many strong gougy slips. The granite in and along the shear zone is stained red by hematite through widths of as much as 100 ft, but along the tungsten veins within the shear zone the iron-stained granite is bleached and chloritized. Where the Black Prince and other east-west veins of Black Tiger Gulch intersect the Iron dike, the width of the dike changes abruptly, indicating that the veins were in existence at the time that the dike was intruded.

Although many important bodies of ore have been found in northeastward-striking veins near their intersection with the reefs, the breccia reefs themselves in general are barren, except that at a few places, particularly near the margins of the district, the reefs were reopened at the time of vein formation and were mineralized with tungsten and gold (pp. 55–57). At a few places, also, breccia reefs served as the loci of intrusion for biotite latite porphyry and latitic intrusion breccia, and there is some suggestion that the intrusions were the cause of the late movement on the reefs and thus a factor in the subsequent mineralization. In the Yellow Pine and Logan mines, at the northeast edge of the district, the Hoosier reef is a wide, silicified shear zone whose middle portion has risen in a horstlike movement. The reef is locally bounded and cut by dikes of biotite latite porphyry and intrusion breccia (pl. 27), and it seems possible that the horstlike movement of the reef and some of the brecciation along the reef walls were caused by the upward push of an underlying biotite latite magma and that the reef was silicified partly by solutions from the biotite latite magma. Somewhat similar relations were observed in one of the group of short adits that comprise the Rogers No. 17 mine (fig. 24*B*), where intrusion breccia bordering a small dike of biotite latite porphyry grades almost imperceptibly into the silicified breccia of a minor breccia reef and a narrow streak of the breccia is partly filled with later ferberite. Thus it appears that at some places the breccia reefs were loci of later intrusion and that the attendant fracturing allowed the mineralizing solutions that followed to gain access to the reefs.

VEIN FISSURES

All the veins in the tungsten district follow premineral fault fissures, most of which are later than the early movement on the breccia reefs and in large part later than the mineralization of the reefs. Nearly all the veins strike either about north-northeast or about east-northeast, but some persistent veins in the Beaver Creek area, south of Nederland, strike nearly due east.

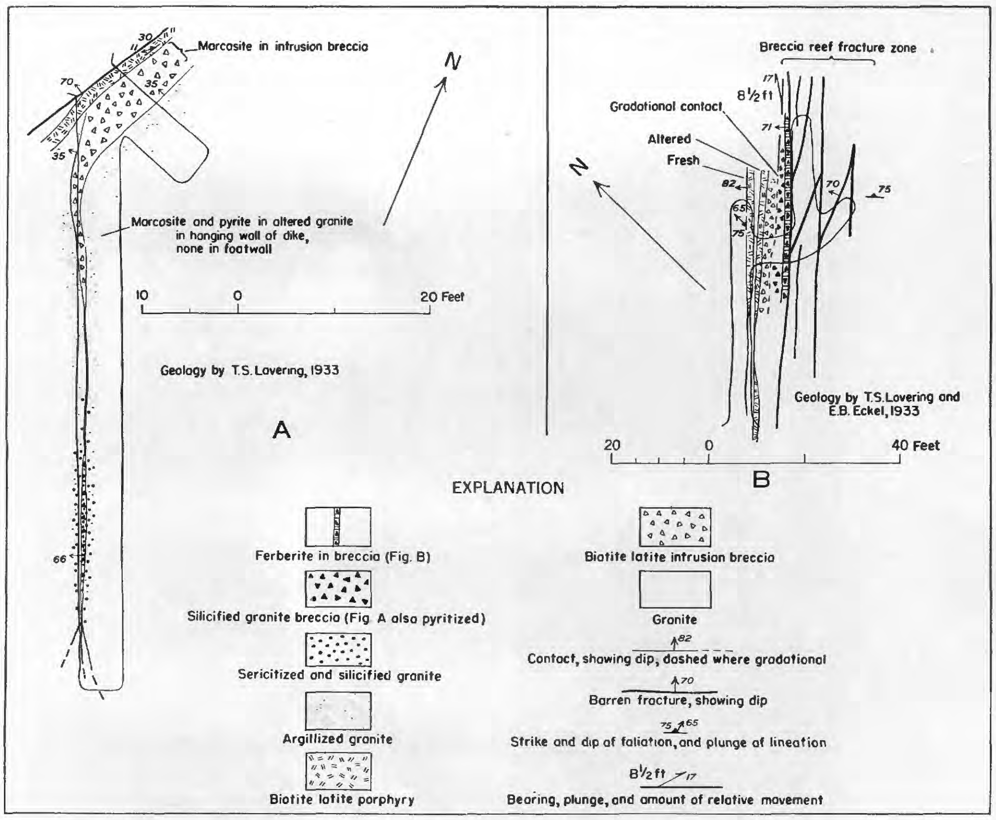

FIGURE 24 *A*, Geologic plan of the prospect tunnel on the Lou Dillon claim, Boulder County, Colo., showing the relations of biotite latite intrusion breccia, altered wallrocks, and fracturing. *B*, Geologic plan of the Rogers No. 17 prospect tunnel, Boulder County, Colo., showing the relation of biotite latite intrusion breccia to silicified breccia of a minor breccia reef. The breccia in a narrow streak within the reef is partly filled with late ferberite.

The fissures with an east-northeasterly trend are grouped in three zones (pl. 3). The strongest of these extends eastward from Hurricane Hill through the so-called Dry Lake district to Comforter Mountain and thence eastward along the north slope of the valley of Middle Boulder Creek to the east edge of the district. There is a zone of less persistent intersecting eastward- and northeastward-trending fissures near Gordon Gulch and North Boulder Creek, ½ to 1 mile north of the Dry Lake-Comforter Mountain zone, and a third zone is situated just north of Beaver Creek in the southwestern part of the district. The Gordon Gulch and the Dry Lake-Comforter Mountain zones converge southwestward toward the north end of Hurricane Hill, and nearly all the ore mined farther west has come from a narrow zone which extends west-southwestward along Sherwood Gulch from the north end of Hurricane Hill to Sherwood Flats. Most of the veins within this zone strike obliquely across it in a north-northeasterly direction. Although they are not very persistent individually, these veins have yielded a substantial part of the output of the district. Comparatively little tungsten has been found in a belt about a mile wide lying between the west flank of Hurricane Hill and the Conger-Illinois group of mines and extending from Sherwood Gulch southward 2½ miles through Nederland to the Beaver Creek district.

Fault movement along the vein fissures took place in spasms over a considerable length of time. Movement on some of the fissures occurred prior to the intrusion of the porphyries, as shown by the fact that pre-Cambrian rocks are displaced farther than the porphyry dikes. Movement obviously continued during the period of porphyry intrusion, because the earlier porphyry dikes are displaced farther than the later dikes along some veins, and finally, the brecciation of successive generations of horn quartz and even of ferberite in the veins indicates repeated movement during the period of vein formation. The individual movements appear to have been fairly small, rarely amounting to more than a few feet, and most of them were in the same general direction, but along some veins the pattern of movement was complex, as shown in the detailed descriptions of the mines, and the observed displacements are the result of several movements in diverse directions. The net displacement ranges from a few inches along some of the minor and in general younger fissures, to as much as 50 ft along some of the major, more persistent, and in general older vein fissures.

The most persistent veins in the tungsten district are those with an easterly strike in the Dry Lake-Comforter Mountain zone, but this zone also contains many nonpersistent fissures that diverge to the northeast from it. On both the eastward- and northeastward-striking fault fissures, the main component of movement was horizontal; the north walls of most of the eastward-striking fissures moved down and west at low angles, whereas on the fissures that strike northeast or north-northeast the southeast walls moved down and southwest at low angles. Similar relations prevail among the relatively short intersecting fissures with an easterly and northeasterly trend in the Gordon Gulch zone, and in general it can be said that along the northeastward- and north-northeastward-trending fissures the left-hand wall moved forward and that on the eastward- and east-northeastward-trending fissures the right-hand wall moved forward. Under such conditions, the westward-pointing wedge-shaped blocks formed by the intersecting veins tended to move down and southwest at a low angle, and eastward-pointing wedges, considerably fewer in number, moved up and northeast at a low angle. Thus the general effect is one of crustal shortening in the northeast-southwest direction and of lengthening in the northwest-southeast direction.

In many places the movement along the northeastward- and eastward-trending fissures was apparently simultaneous, and the points of the wedge-shaped blocks formed by the intersection of the fissures were driven along the through-going fissures—generally those with easterly trend—with the result that these fissures were opened near the points of the wedges and thus made receptive to vein filling. However, during the many stages of movement recorded by the complex brecciation of the vein filling, some of the fissures remained dormant while others were active, and the movement was shunted along first one and then another of the intersecting fractures. This is especially true of the intersection of northeast and northwest fractures and is well illustrated in the Logan and the Rogers No. 1 mines (fig. 20; pl. 22).

POSTMINERAL FAULTS

Only a few postmineral faults have been observed in the district, and they are all small. Most of the postmineral movement took place along the earlier-formed veins and resulted only in reopening the old fractures and brecciating the ferberite ore; there is no evidence of regional postmineral fault systems. In a few places the veins have been offset a foot or so by late movement on either gently dipping or steep cross fractures, but most of these cross fractures were premineral faults reactivated by late movement, and some of them were the controlling features in the localization of the ore. Such conditions are well illustrated in the Clyde mine and the Rogers No. 1 mine (pls. 12, 22).

STRUCTURAL RELATIONS OF THE TERTIARY DIKES

The earliest of the Laramide intrusions in the district is the Iron dike, consisting of gabbro and extending northwestward across the eastern part of the district near Black Tiger Gulch and Sugar Loaf. Its tendency to pinch at some of the minor east-west breccia-reef fractures and the fact that it follows the Livingston breccia reef for some little distance near the mouth of Black Tiger Gulch indicate that it is later than the early movement on the breccia-reef fissures. However, it is earlier than the quartz-hematite mineralization of the reefs, for in the Post Boy tunnel (fig. 132), in Black Tiger Gulch, the dike is altered and is cut by quartz veins where it is in contact with the Livingston breccia reef. The Iron dike is cut also by tungsten and gold veins, and just north of Bummers Gulch it is crossed by a limburgite dike. Elsewhere in the mineral belt it is seen to be earlier than rhyolite porphyry and hornblende diorite (Lovering and Goddard, 1938, pp. 48–49), and near the Copper King mine, a few miles north of the tungsten district and just west of Gold Hill village, it is cut by a dike of biotite monzonite porphyry. The linear structure in the Iron dike is steep everywhere within the tungsten district, and the dike itself dips 65°–85° W.

The felsite and gabbro in the western part of the tungsten district may be related to the Caribou Hill stock (Smith, 1938, pp. 168–196) a few miles west of Nederland. The monzonite porphyry dikes in the two zones with an easterly trend in the area north of Nederland and Tungsten were intruded somewhat later than the gabbro and felsite, but their linear structure plunges 50°–80° W. and indicates that their source was probably west of the tungsten district. They are later than some of the movement on fractures that trend northeast and east-northeast and, as would be expected with a source to the west, the dikes commonly swell on the west side of the cross fractures and pinch just east of them.

Except for the Iron dike, the porphyries found in the central and eastern parts of the district are chiefly biotite latite and limburgite. The biotite latite porphyry occurs chiefly in short dikes which trend north-northeast. Dikes of limburgite porphyry are found in a zone extending east-northeastward from Comforter Mountain to Arkansas Mountain. The limburgite porphyry was probably almost contemporaneous with the biotite latite prophyry, for it was intruded after early gray horn quartz was deposited in the Catastrophe vein (fig. 16), and the biotite latite also was intruded during horn quartz deposition (p. 24). All these dikes are clearly later than much of the movement on the premineral vein fissures. Many of the dikes are displaced only a few inches, or even only a fraction of an inch, by veins that have displaced the pre-Cambrian rocks many feet, and some dikes, upon reaching a vein, turn and follow the vein fissure for a short distance before breaking through the other wall. The linear structure of the porphyry dikes in the eastern part of the district plunges west.

The biotite latite intrusion breccia is closely associated with biotite latite porphyry dikes in the Yellow Pine, Logan, Franklin, and Lou Dillon mines, and both rocks commonly follow premineral fault fissures. Both are found underground in several veins where no trace of either rock is to be seen along the outcrop. Although linear structure was not observed in the intrusion breccia, the breccia presumably rose from the west like the biotite latite prophyry with which it is associated. In the Yellow Pine and Logan veins the intrusion of the breccia occurred after nearly all the movement on the east and northeast fissures had taken place, and it immediately preceded the introduction of gold (fig. 20).

ORE DEPOSITS

GENERAL FEATURES

The total output of tungsten from the Boulder district to the end of 1946 considerably exceeded that from any other district in the United States, even though the annual output was small for many years prior to this time.

Although tungsten ore has been mined throughout the Boulder County district, the principal production has come from veins close to the northwestward-trending breccia reefs (pl. 3). The ore occurs almost solely as fissure filling in veins whose mineralogy is relatively simple, and most of the ore shoots are small. Ferberite ($FeWO_4$) is the principal ore mineral, but in a few localities it contains enough manganese to be classed as low-manganese wolframite. Scheelite is found as a late mineral in many of the veins; it is only an accessory in most ore shoots, but it is sufficiently abundant in a few mines to affect the grade of ore substantially. The predominant gangue mineral is fine-grained quartz known locally as horn quartz or simply as "horn." The quartz is accompanied by sulfides, carbonates, and clays in small amounts.

A late lead-zinc-silver mineralization occurred at places in the outer fringe of ferberite ore, but so far as known, it did not produce ores that could be exploited commercially. Silver ore formed during a period of mineralization earlier than the one in which the tungsten deposits were formed has been mined from several veins near the Hoosier breccia reef, in the northeastern part of the district. Gold telluride ores are found in the central and northeastern part of the district. They are probably earlier than the main ferberite mineralization, but a small amount of ferberite was deposited before the gold in some of the telluride veins. Pyritic quartz veins found at several placed in the district are essentially barren and seem to be the earliest veins in the area.

The structure, associations, mineralogy, and texture of the tungsten deposits indicate that they were formed under a relatively light load at moderate temperatures by hypogene solutions and that they should be classed as epithermal deposits formed near the magmatic source.

MINERALOGY

The alphabetical list of minerals here given includes only those in the veins or in the hydrothermally altered wall rocks. Details of occurrence are given on succeeding pages, where the minerals are arranged in chemical groups according to Dana's system of mineralogy.

	Composition
Adularia (silicate)	$KAlSi_3O_8$
Alabandite (sulfide)	MnS
Allophane (silicate)	$Al_2SiO_5 \cdot nH_2O$
Altaite (telluride)	PbTe
Alunite. *See* Goyazite.	
Ankerite (carbonate)	$(Ca,Mg,Fe)CO_3$
Apatite (phosphate)	$(Ca,F)Ca_4(PO_4)_3$
Arsenopyrite (sulfide)	FeAsS
Azurite (carbonate)	$2CuCO_3 \cdot Cu(OH)_2$
Barite (sulfate)	$BaSO_4$
Beidellite (silicate)	$Al_{2.17}\left[\begin{matrix}Na_{.33}\\ \uparrow \\ Al_{.83}Si_{3.17}\end{matrix}\right]O_{10}(OH)_2 \cdot nH_2O$
Bornite (sulfide)	Cu_5FeS_4
Calaverite (telluride)	$AuTe_2$
Calcite (carbonate)	$CaCO_3$
Chalcedony (oxide)	SiO_2
Chalcocite (sulfide)	Cu_2S
Chalcopyrite (sulfide)	$CuFeS_2$
Chlorite (silicate)	Complex hydrous silicate of Fe, Mg, and Al
Cimolite (silicate)	$2Al_2O_3 \cdot 9SiO_2 \cdot 6H_2O$
Clay. *See* Allophane, Beidellite, Cimolite, Dickite, Halloysite, Hydrous mica, *and* Montmorillonite.	
Coloradoite (telluride)	HgTe
Covellite (sulfide)	CuS
Cuprite (oxide)	Cu_2O
Dickite (silicate)	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
Dolomite (carbonate)	$CaMg(CO_3)_2$
Epidote (silicate)	$HCa_2(Al,Fe)_3Si_3O_{13}$
Ferberite (tungstate)	$FeWO_4$
Fluorite (haloid)	CaF_2
Freibergite (sulfosalt)	$5(Cu,Ag)_2S \cdot 2(Cu,Fe)S \cdot 2Sb_2S_3$
Galena (sulfide)	PbS
Goethite (oxide)	$Fe_2O_3 \cdot 3H_2O$
Gold (native element)	Au
Goyazite (phosphate)	$2SrO \cdot 3Al_2O_3 \cdot 2P_2O_5 \cdot 7H_2O$
Graphite (Native element)	C
"Gray copper" (sulfosalt)	$(Cu,Fe,Zn,Ag)_{12}(Sb,As)_4S_{13}$
Halloysite (silicate)	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
Hamlinite. *See* Goyazite.	
Hematite (oxide)	Fe_2O_3
Hessite (telluride)	Ag_2Te
Huebnerite (tungstate)	$MnWO_4$
Hydrous mica (silicate)	$K_{<1}Al_2(AlSi_3)O_{10}(OH)_{>2}$
"Illite." *See* Hydrous mica.	
Iron hydroxide (oxide)	$Fe_2O_3 \cdot nH_2O$
Kaolin. *See* Dickite.	
Leucoxene. (*See* Sphene.	
"Limonite" [1] (oxide)	$Fe_2O_3 \cdot nH_2O$
Magnetite (oxide)	Fe_3O_4
Malachite (carbonate)	$CuCO_3 \cdot Cu(OH)_2$
Manganite (oxide)	MnO(OH)
Marcasite (sulfide)	FeS_2
Marmatite. *See* Sphalerite.	
Mercury (native element)	Hg
Miargyrite (sulfosalt)	$Ag_2S \cdot Sb_2S_3$
Molybdenite (sulfide)	MoS_2
Montmorillonite (silicate)	$\left[\begin{matrix}Na_{.33}\\ \uparrow \\ Al_{1.67}Mg_{.33}\end{matrix}\right]Si_4O_{10}(OH)_2 \cdot nH_2O$
Nontronite (silicate)	$Fe_{2.17}\left[\begin{matrix}Na_{.33}\\ \uparrow \\ Al_{.83}Si_{3.17}\end{matrix}\right]O_{10}(OH)_2 \cdot nH_2O$
Opal (oxide)	$SiO_2 \cdot nH_2O$
Petzite (telluride)	Ag_3AuTe_2
Pearceite (sulfosalt)	$8Ag_2S \cdot As_2S_3$
Polybasite (sulfosalt)	$8Ag_2S \cdot Sb_2S_3$
Proustite (sulfosalt)	$3Ag_2S \cdot As_2S_3$
Psilomelane (oxide)	$MnO_2 \cdot nH_2O$
Pyrargyrite (sulfosalt)	$3Ag_2S \cdot Sb_2S_3$
Pyrolusite (oxide)	MnO_2
Pyrite (sulfide)	FeS_2
Quartz (oxide)	SiO_2
Ruby silver. *See* Proustite and Pyrargyrite.	
Scheelite (tungstate)	$CaWO_4$
Sericite (silicate)	$KH_2Al_3(SiO_4)_3$
Siderite (carbonate)	$FeCO_3$
Sphalerite (sulfide)	ZnS
Sphene (titanosilicate)	$CaTiSiO_5$
Stephanite (sulfosalt)	$5Ag_2S \cdot Sb_2S_3$
Stromeyerite (sulfide)	$(Ag, Cu)_2S$
Sylvanite (telluride)	$(Ag,Au)Te_2$
Tetrahedrite (sulfosalt)	$5Cu_2S \cdot 2(Cu, Fe)S \cdot 2Sb_2S_3$
Tungstite (oxide)	$WO_3 \cdot H_2O$
Wad (oxide)	Hydrous manganese oxide
Wolframite (tungstate)	$(Fe,Mn)WO_4$

[1] See also Goethite, Hematite, and Iron hydroxide.

NATIVE ELEMENTS

Gold.—Most of the native gold found in the district is in the oxidized zones of the gold telluride veins, and most of it is in the form of "rusty gold" associated with limonite. Such gold is largely supergene; that is, it was derived from gold-silver tellurides which were broken down by oxidation. The gold telluride veins contain a little native gold of primary origin, but this makes up only a small part of the total gold mined. Primary gold is a late mineral, and most of it occurs as a replacement of the gold-silver tellurides (fig. 25). As gold occurring in this way is found far below the oxidized zone in the deeper mines, it is evidently of hypogene origin.

Graphite.—A strong sulfide-bearing shear zone that lies east and southeast of the Conger mine contains abundant graphite, as shown by several diamond-drill cores. The graphite occurs with molybdenite and other sulfides in schist, where it is closely associated with, and replaces, biotite. The graphite appears to be genetically related to the sulfide minerals; it does not appear to be a metamorphic component of the schist. The graphite- and sulfide-bearing schist in the shear zone is cut by veins of dark horn quartz that contains finely disseminated ferberite. The graphite and sulfides thus seem to be older than the tungsten mineralization, and they are tentatively correlated with the early pyritic quartz veins.

Mercury.—Native mercury was seen in strongly oxidized vein matter in the Franklin mine, 60 ft below the surface. The vein quartz contains coloradoite,

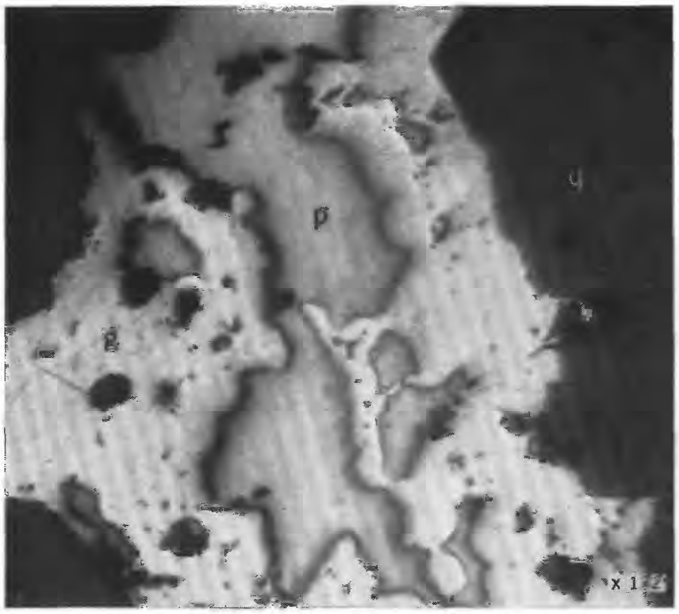

FIGURE 25.—Photomicrograph of high-grade ore from the Logan mine, Boulder County, Colo., showing petzite partly replaced by gold: *g*, gold; *p*, petzite; *q*, quartz. × 132.

and the mercury was undoubtedly formed by the decomposition of this mercury telluride. Several miners have reported the presence of mercury in the outcrops of gold telluride veins. Mercury is not ordinarily visible in the hand specimen until the rock has been pounded gently; then the mercury appears at the surface in tiny droplets which ooze out of minute cracks. According to Henry Lawerence, who did some of the earliest work on the Good Friday tungsten vein, mercury was found in the oxidized ore at the surface. This strongly suggests the presence of a telluride in the upper part of the vein, but so far as known, none of the ore was tested for gold.

SULFIDES

Alabandite.—Alabandite, the manganese sulfide, has been identified only in ore from the Forest Home mine, where it occurs as a very thin powdery coating on ferberite crystals in small vugs. The powder is made up of minute greenish-black crystals which show triangular faces under high magnification. The ferberite coated by alabandite has a dark-greenish velvety sheen, and the crystals are slightly rounded at the edges and corners, as if they had been slightly corroded by the alabandite-depositing solutions. Crusts of manganese oxides found on ferberite ore in a vein southeast of the Forest Home shaft on the first level were probably derived from the oxidation of alabandite.

Arsenopyrite.—Arsenopyrite has been found in small amounts in the ferberite ores of the Beddig and Grand Republic mines. In both places it is associated with marcasite and ferberite. It is definitely later than some of the ferberite and appears to be contemporaneous with the latest ferberite.

Bornite.—A little bornite is present as a primary mineral in the silver-bearing gray copper ores. It is relatively early in the paragenetic sequence and precedes galena and chalcopyrite. A small amount of supergene bornite was observed in the silver ore associated with ferberite in the Illinois mine above the 100-ft level. It forms small blebs and veinlets that cut or have replaced chalcopyrite, galena, and miargyrite.

Chalcocite.—Chalcocite is found only in meager amounts and is chiefly supergene. Some may be hypogene in the silver-bearing gray copper ores. (See "Stephanite.")

Chalcopyrite.—Chalcopyrite, the copper-iron sulfide, is a minor constituent of both the silver ores and the gold telluride ores and is present also in a few tungsten veins. Much of the chalcopyrite in the gold and silver ores is primary and is relatively late. In the silver ores it occurs chiefly in tiny branching replacement veinlets that interlace through the gray copper, but it also forms small irregular masses associated with galena and sphalerite. Chalcopyrite of supergene origin is present in minor quantity in most ores from the zone of secondary sulfide enrichment. In the tungsten veins, chalcopyrite occurs as pseudotetrahedral crystals in openings or embedded in late horn quartz. In the Vasco No. 6 mine, chalcopyrite crystals rest on ferberite in vugs and are scattered through late white horn quartz that rests on ferberite; in the Oregon vein open fractures adjacent to the quartz-ferberite vein bear a dustlike coating of tiny pyrite and chalcopyrite crystals; in the Sunday mine small chalcopyrite crystals were found on coarsely crystalline ferberite in a body of vuggy, disseminated tungsten ore.

Covellite.—Covellite is rare and is associated with supergene chalcocite.

Galena.—Galena, the lead sulfide, is most abundant in the silver ores, but it occurs in small amounts in the gold telluride ores and in some tungsten veins. In the silver veins, it is later than gray copper but earlier than the silver minerals. In the gold veins, it is later than sphalerite but earlier than the gold tellurides. In most of the tungsten veins that contain galena, it is present in minute well-formed crystals associated with sphalerite and barite in vugs in the ferberite ore. It therefore is distinctly later than the ferberite in most veins, but in the Illinois and Galenite veins, some of the galena is intergrown with ferberite in a manner that suggests contemporaneous deposition (fig. 26). The early galena in the Illinois vein is cut by freibergite, but galena of a later stage in the same vein is later than both freibergite and sphalerite. Most of the galena in the Galenite vein also is later than sphalerite and gray copper. In the Quaker City vein in the Oregon mine, galena is later than fluorite and pyrite, which are later than ferberite, but it is earlier than sphalerite, gray copper, and ruby silver.

Marcasite and pyrite.—Marcasite and pyrite are widely distributed though minor constituents of the tungsten veins. They occur chiefly in microscopic grains disseminated in the black, ferberite-bearing horn quartz that marks the beginning of the ore stage, but coarser grains, lumps, and veinlets also can be found in most veins. In the black horn quartz, pyrite is much more abundant than marcasite, but many of the pyrite grains have small cores of marcasite.

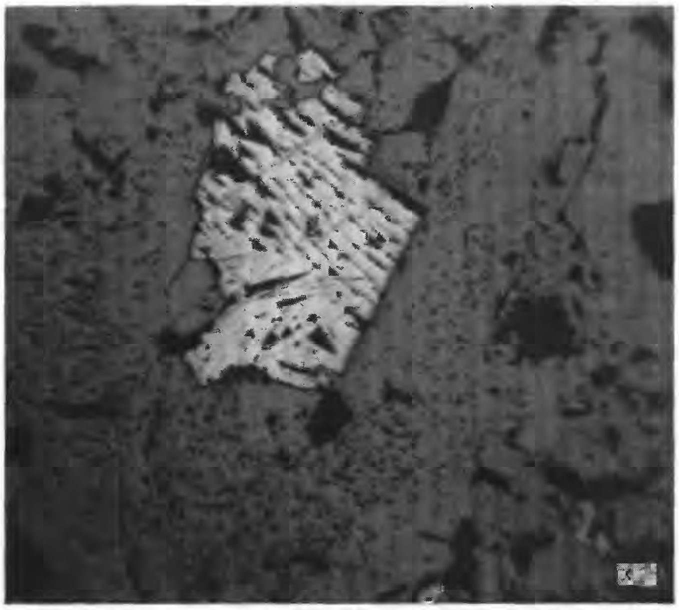

FIGURE 26.—Photomicrograph showing galena, contemporaneous with or slightly earlier than ferberite, in ore from the Illinois mine, Boulder County, Colo.: *g*, galena; *f*, ferberite. × 28.

Marcasite is the earliest sulfide in the veins and in general is earlier than ferberite, but in a few places it is contemporaneous with ferberite and in others it is intergrown with pyrite that is later than ferberite (fig. 27). In tungsten ore from the third level of the Grand Republic mine, at the northeast corner of the district, marcasite was deposited before the ferberite, and both these minerals are earlier than pyrite (figs. 28, 29). Late marcasite is rare and occurs far less commonly then pyrite as the form of iron sulfide postdating the ferberite, but in an ore body in the Pennsylvania mine late marcasite was present to the exclusion of pyrite. The marcasite lined vugs in coarsely crystalline ferberite ore and was coated in turn with crystals of scheelite and galena.

In the typical banded quartz-ferberite veins, the amount of marcasite decreases, and that of pyrite increases, as the ferberite-bearing layers are ap-

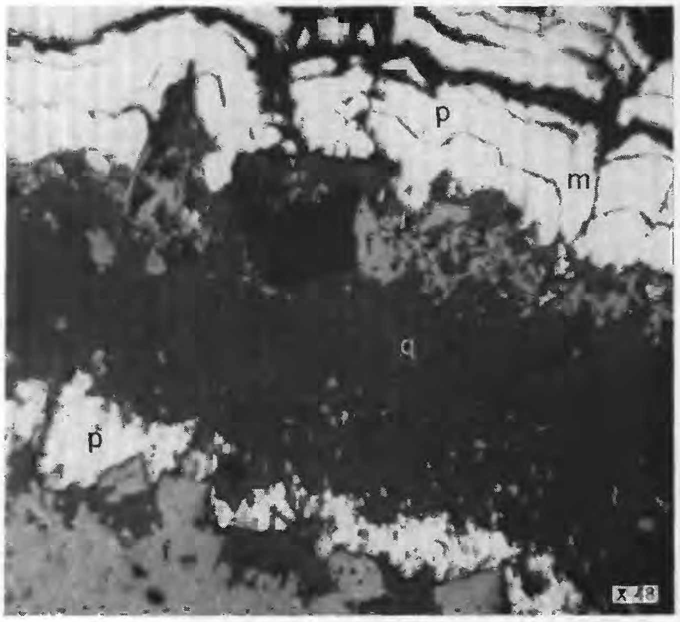

FIGURE 27.—Photomicrograph showing late pyritic layers in ore adjacent to a vug, fifth level of the Beddig mine; some marcasite may be seen intergrown with the late pyrite near the top of the picture: *f*, ferberite; *m*, marcasite; *p*, pyrite; *q*, quartz. × 48.

proached; and where pyrite and other sulfides are found intergrown with ferberite, marcasite is rarely present. In some places the pyrite also stops abruptly at the ore seam, but locally it forms minute cores in the ferberite. In a few places, the amount of pyrite present in the barren quartz and in the ferberite is nearly the same. In general pyrite is contemporaneous with or later than ferberite and earlier than the other sulfides.

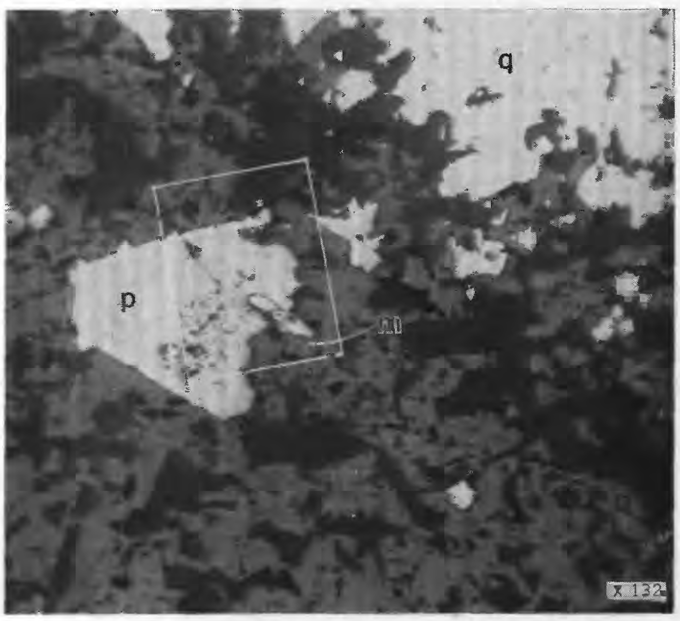

FIGURE 28.—Photomicrograph showing pyrite which is later than ferberite and marcasite, third level of the Grand Republic mine, Boulder County, Colo.: *f*, ferberite; *p*, pyrite; *m*, marcasite. × 132. Outlined area shown in figure 29.

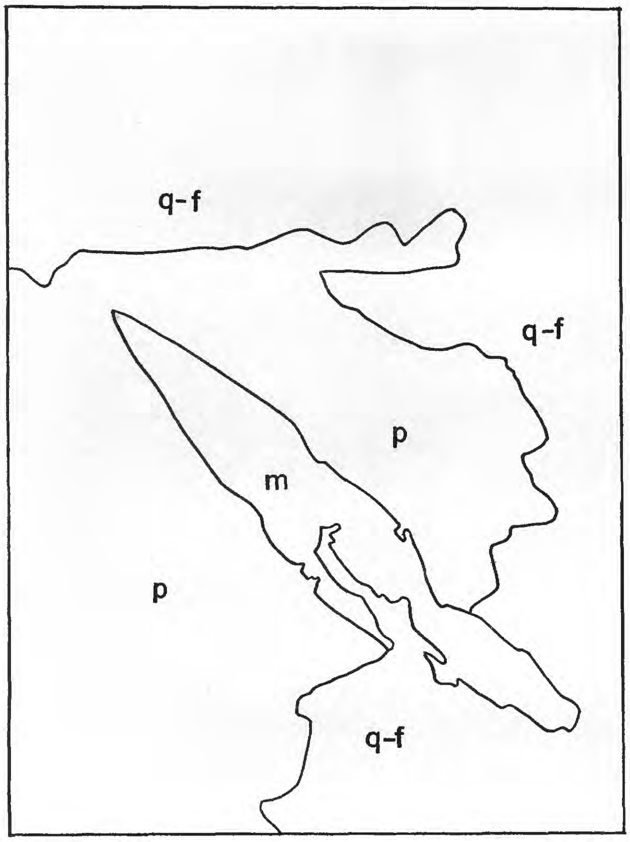

FIGURE 29.—Tracing from a photomicrograph of part of the area included in figure 28. The marcasite is enclosed by later pyrite: *m*, marcasite; *p*, pyrite; *q-f*, quartz and ferberite. × 600.

Pyrite is widely distributed in the other classes of veins in the district as well as in the tungsten veins, but marcasite is rare outside the tungsten veins. A little marcasite has been found in some of the breccia reefs, and traces of it have been observed in some of the biotite latite intrusion breccia. None has been found in the gold telluride or silver veins except those that contain some tungsten ore, such as the Grand Republic and Logan. In the Grand Republic mine the marcasite accompanies ferberite that seems to be earlier than the gold telluride ore, and in the Logan mine it occurs in quartz veinlets that cut silver-lead-zinc ore near a small body of tungsten ore.

Pyrite is the chief metallic constituent of most of the gold telluride and silver veins, and at places it is also prominent in the wall rocks, where it has replaced ilmenite particularly. Most of the pyrite in the veins is earlier than the other sulfides, but some veins contain later generations of pyrite younger than the other sulfides. Pyrite also occurs in a group of early barren quartz veins, most of which have heavily pyritized walls. The pyrite in these veins is coarser than most of that in the later veins, and much of it is in well-formed cubes and pyritohedrons. Fragments of pyritic quartz of this type have been found in several of the later tungsten and gold telluride veins.

Pyrite is present at places in several of the breccia reefs, but it is a late constituent introduced after the quartz-hematite mineralization, and most of the pyrite in the reefs has replaced hematite.

Molybdenite.—According to George (1909, p. 75), "molybdenite in minute flakes is found very sparingly in the gneissoid granite but is exceedingly rare. A specimen of ore from the Clyde mine shows a small flake or two." The writers have not seen molybdenite in association with ferberite but have noted it in a few veins in the district. Seams of molybdenite were found just above an ore shoot in the Footwall vein in the Clyde mine. Drill cores from the Sunday vein east of the Sunday mine, in the Beaver Creek district, contain a little molybdenite accompanied by pyrite and chalcopyrite and a trace of scheelite. Drill cores from the sulfide-bearing shear zone near the Conger and Greyback mines contain considerable molybdenite in veinlets and disseminated flakes in schist and pegmatite.

Sphalerite.—Sphalerite, the zinc sulfide, is abundant in the early silver veins and is found in small quantities in the gold telluride veins and in the late tungsten-silver ore. The sphalerite associated with the early silver ores is of the dark-colored ferriferous variety known as marmatite. It formed early in the ore sequence, being earlier than galena, tetrahedrite, and the silver minerals (fig. 30), though later than pyrite. In the gold veins, also, sphalerite is ordinarily an early mineral, having preceded galena, tetrahedrite, and the tellurides; but

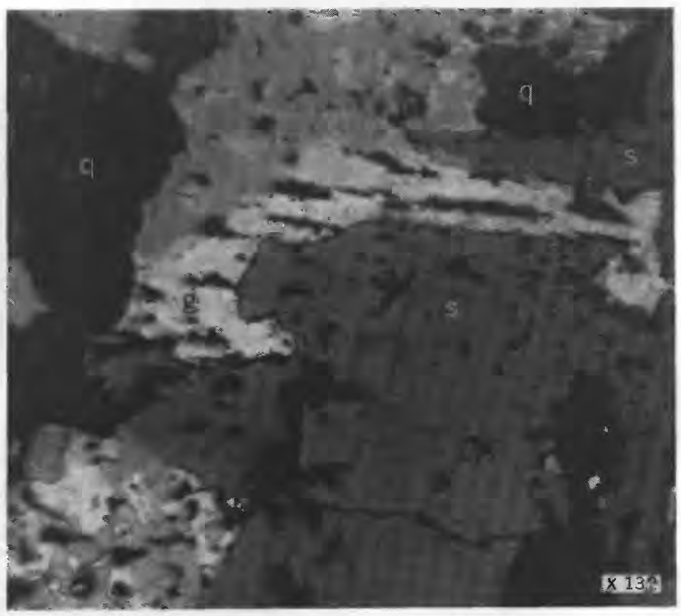

FIGURE 30.—Photomicrograph of ore from the Silver vein near the Mud vein on the second level of the Logan mine, Boulder County, Colo. Galena cuts sphalerite and is replaced by tetrahedrite: *g*, galena; *s*, sphalerite; *t*, tetrahedrite; *q*, quartz. × 132.

in the Herald mine a few well-shaped crystals of light-colored sphalerite, found in crevices and on faces of the ore, seem to be later than the tellurides. In the tungsten ores, the sphalerite forms light-colored euhedral crystals in vugs, where it is associated with barite and galena and is, like them, later than the ferberite and earlier than the clay mineral beidellite (fig. 41). A few minute specks of sphalerite are found interzoned with ferberite in ores from the Galenite vein in Gordon Gulch, but most of the sphalerite in this vein and in similar veins in the Illinois mine is later than the ferberite and earlier than chalcopyrite, galena, freibergite, and miargyrite.

TELLURIDES

The gold and silver telluride minerals, sylvanite, petzite, hessite, and calaverite, as well as the rare mercury telluride (coloradoite) and lead telluride (altaite) accompanying them, are so intimately associated that they can best be treated as a group. They occur as well-developed blade-like crystals and in small, irregular masses in fine-grained vuggy quartz. They have been found only in the east half of the tungsten district. Most of the telluride ore bodies are distinct from those of tungsten, although the two types are both present in some veins, but ferberite and tellurides occur together in the Wheelman tunnel and the Herald, Red Signe, Grand Republic, and Logan mines, as well as in a few mines just outside the district. In the Herald mine, the ferberite is definitely earlier than the gold tellurides. In the Grand Republic, the paragenesis is not so clear, but pyritic quartz that is later than the ferberite is identical in appearance with some that has been observed elsewhere to enclose tellurides, suggesting that here too the ferberite is the earlier mineral. In the Grand View mine, 2 miles north of the northeast end of the tungsten district, vugs in ferberite are filled with sylvanite, hessite, petzite, calaverite, and other tellurides (fig. 31). In specimens of ore from the Red Signe mine, however, the ferberite is later than the gold tellurides (fig. 32), and according to the late Fred Fair, brecciated fragments of gold-bearing ore were cemented by ferberite where a ferberite vein cut through gold ore in the Red Signe vein. Similarly, in the Magnolia district, a few miles southeast of the Red Signe mine, George (1909, p. 76) found ferberite crystals resting upon sylvanite in vugs in the Graphic mine. In the Kekionga mine, ferberite is also in large part later than sylvanite, although some is contemporaneous.

The paragenetic relations in the Herald, Grand Republic, and Grand View mines suggest that minor ferberite deposited during the telluride mineralization was earlier than the tellurides, but the relations in the Red Signe mine, and to a lesser extent those in the Magnolia district, suggest that the commercially important ferberite ore of Boulder County was deposited during an epoch of mineralization distinctly later than that in which the gold telluride ores formed.

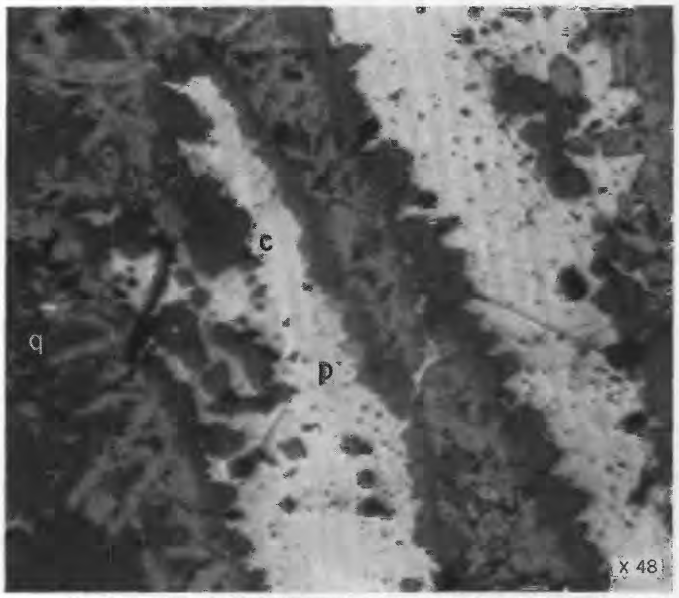

FIGURE 31.—Photomicrograph of high-grade ore from the Grand View mine, Boulder County, Colo. Quartz and ferberite line vugs which are filled with later petzite and calaverite: *f*, ferberite; *p*, petzite; *q*, quartz; *c*, calaverite. × 48.

The telluride veins in the tungsten district are similar in all respects to those in the adjoining Gold Hill and Jamestown districts, and the reader is referred to reports on these districts by Goddard (1940, pp. 125–126; also manuscript report) and by Lovering and Goddard (1951, pp. 234, 264) for details of mineralogy of the tellurides.

SULFOSALTS

Gray copper (*tetrahedrite, tennantite, and freibergite*).—Most of the gray copper in the tungsten district is tetrahedrite or freibergite, the silver-bearing variety of tetrahedrite, but tennantite is present in the Yellow Pine vein. Tetrahedrite is later than sphalerite and earlier than galena in most of the early silver veins, but in a silver vein in the Logan mine, it cuts galena and is replaced by freibergite, and in the Quaker City vein it is clearly later than galena. It is peculiarly susceptible to replacement by later minerals, and in many of the ores it is host to the ruby silver minerals, late chalcopyrite, and the supergene copper sulfides. No supergene gray copper mineral has been recognized in the tungsten district.

The gray copper mineral of the late silver phase of the tungsten mineralization is freibergite. In all specimens studied, the freibergite has been replaced to a large extent by miargyrite or chalcopyrite (fig. 33). Like the tetrahedrite of the early silver deposits, the freibergite of the Illinois mine is mostly later than sphalerite and pyrite and earlier than galena and the ruby silver minerals, but a little freibergite or tetrahe-

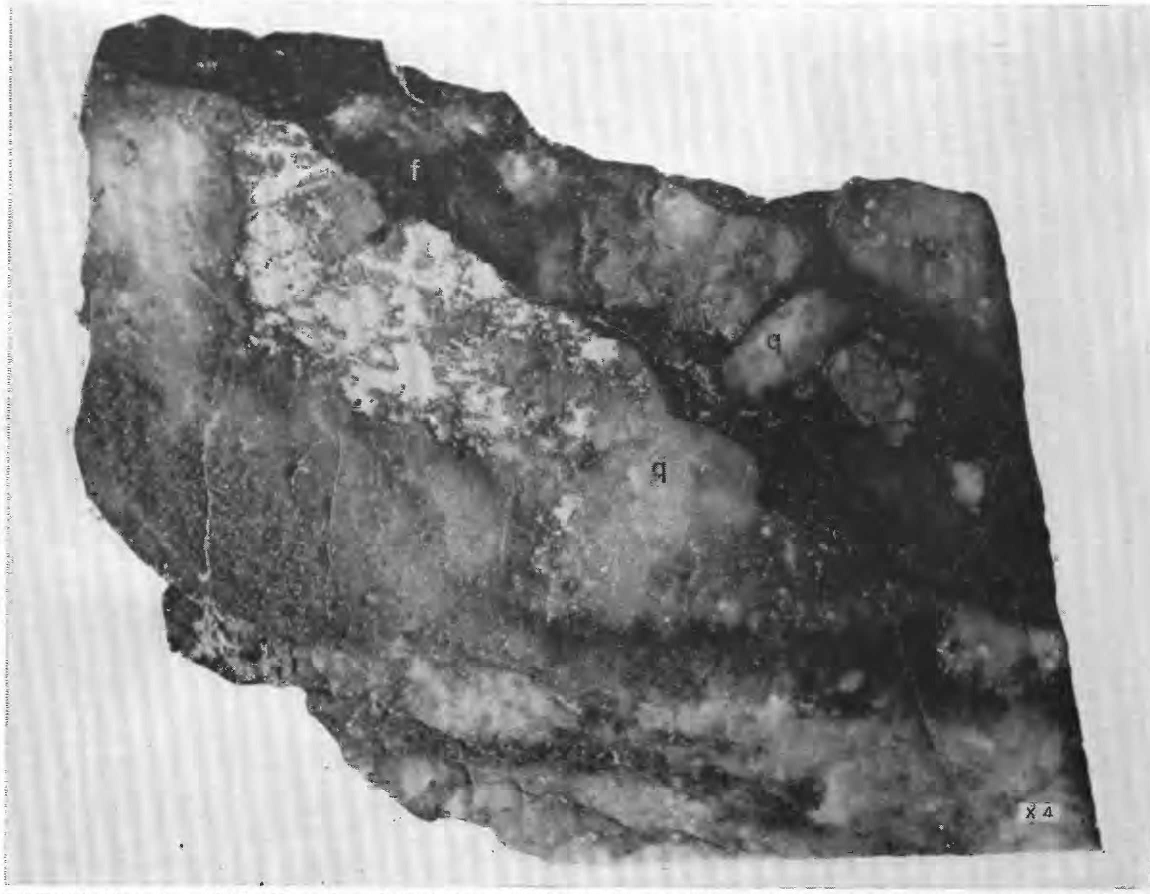

FIGURE 32.—Tungsten-gold telluride ore from the Red Signe mine, Boulder County, Colo. Dark-colored ferberite and quartz cut the early gold telluride-bearing quartz: *f*, ferberite; *t*, gold telluride; *q*, quartz. X 4.

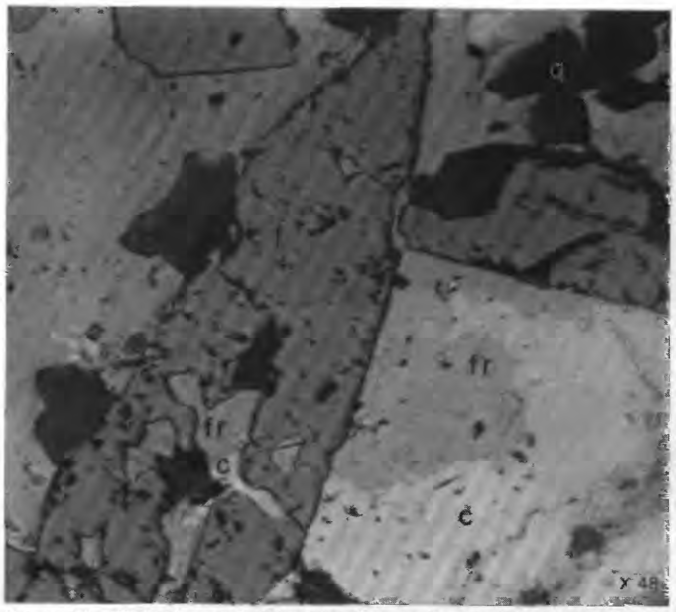

FIGURE 33.—Photomicrograph of tungsten-silver ore from the Illinois mine, Boulder County, Colo. Ferberite is replaced by freibergite, and both these minerals are replaced by chalcopyrite: *f*, ferberite; *fr*, freibergite; *q*, quartz; *c*, chalcopyrite. X 48.

drite occurs in small grains that have partly replaced galena intergrown with ferberite. Tetrahedrite in the Quaker City vein is likewise later than galena.

Massive tennantite occurs in the early silver ores at the Yellow Pine mine, where it is intergrown with silver minerals and copper sulfides in narrow veins.

Miargyrite.—Miargyrite, one of the silver sulfantimonides, is one of the chief ore minerals in the early silver ores of the district. It is one of the latest minerals to form, but most of it is probably primary. It is intergrown with polybasite, and both minerals have replaced tetrahedrite. It is commonly cut by supergene replacement veinlets of chalcopyrite and pearceite or proustite. Miargyrite is also abundant in the late silver ores associated with the tungsten deposits. Late silver ore from the Illinois vein shows two generations of miargyrite, one earlier than galena and one later. Very little polybasite was found in this ore, in contrast to the general association of the two minerals in the early silver veins. Most of the miargyrite has developed by replacement of earlier tetrahedrite, freibergite, or stromeyerite (fig. 34).

Polybasite.—Polybasite intergrown with miargyrite contributes much to the richness of the early copper-silver ores. (See "Miargyrite.")

Pearceite.—Pearceite was found as a supergene mineral in ores from a small prospect on the Hurricane Hill breccia reef just north of Sherwood Gulch. It

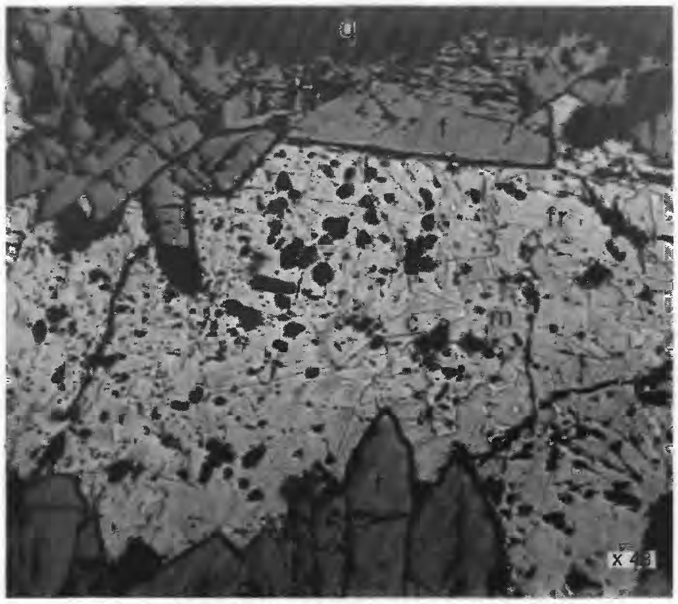

FIGURE 34.—Photomicrograph of silver-tungsten ore from the Illinois mine, Boulder County, Colo. Miargyrite has replaced chalcopyrite and freibergite in a vein bordered by corroded ferberite: *c*, chalcopyrite; *fr*, freibergite; *f*, ferberite; *m*, miargyrite; *q*, quartz. × 48.

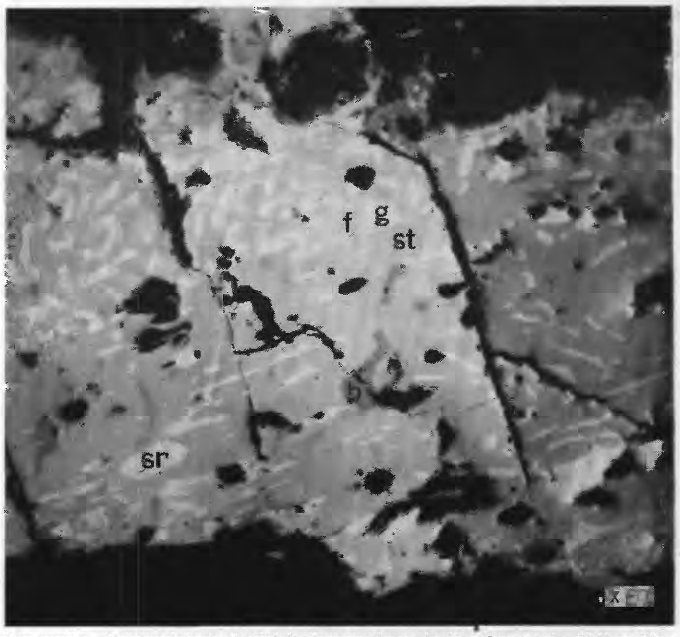

FIGURE 35.—Photomicrograph of rich silver ore from the Vaucleuse vein, Yellow Pine mine, Boulder County, Colo. An intergrowth of stromeyerite and stephanite cuts freibergite and galena; the galena is replaced by freibergite, and bornite is later than all four minerals: *b*, bornite; *f*, freibergite; *g*, galena; *sr*, stromeyerite; *st*, stephanite. × 80.

replaces hypogene bornite in ore found close to the surface.

Ruby silver (proustite and pyrargyrite).—In the Quaker City and Hugo veins, which are quite similar mineralogically, a little ruby silver was found in small drusy masses in vugs. The material from both localities is silvery red and has a bright red streak. The ruby silver seen in the Hugo vein was in a vug that was partly filled by several late minerals in horizontal bands. It formed a thin coating on the upper surfaces of a layer of tertahedrite crystals. The sequence of layers from the bottom upward was (1) black horn quartz, (2) crystalline ferberite, (3) banded light-gray and white horn quartz, (4) tetrahedrite, (5) ruby silver, (6) banded white horn and possibly some opal, (7) scheelite, and (8) calcite. In the Quaker City vein small patches of drusy ruby silver occur with tetrahedrite crystals and octahedrons of amber sphalerite sprinkled over the walls of vugs in galena ore. Thin barite crystals rest on these minerals at places, and a film of powdery scheelite coats the faces of all of them.

Stromeyerite and stephanite.—An intergrowth of stromeyerite and stephanite was found in early gray copper ore from the Vaucleuse vein just below the Mud vein on the fifth level of the Yellow Pine mine (fig. 35). Freibergite and galena are both cut by this intergrowth, and the intergrowth is cut in turn by veinlets of late bornite. The stromeyerite and stephanite are believed to be hypogene, but the bornite, which replaces all the other sulfides and is associated with late quartz in ramifying veinlets, is probably supergene.

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HALIDE

Fluorite, the calcium fluoride, has been found in a few veins, but on the whole it is a rare constituent of the tungsten veins. It is present in only minor amounts in all the known occurrences except in the Quaker City vein in the Oregon mine. At places in the Quaker City vein, purple fluorite cements breccia in a streak 1 to 3 ft wide within the vein, which is 4 to 12 ft wide. The breccia consists chiefly of gray horn quartz and altered granite, but it contains some fragments of black ferberite-bearing horn. Small cubes of pale-violet fluorspar rest on ferberite in vugs, and veinlets of fluorite cut seams of horny ferberite; the fluorite thus is clearly later than the ferberite. It is earlier than galena, sphalerite, tetrahedrite, and ruby silver but is apparently contemporaneous with pyrite, inasmuch as most of the granular fluorite contains small grains of pyrite. Elsewhere in the Oregon mine, fluorite was observed with specular hematite pyrite, chalcopyrite, and calcite in a small vein in the footwall of the Oregon vein. This occurrence is believed to represent an early mineralization unrelated to the tungsten, and it may be as old as the breccia-reef mineralization. Fluorite in association with specular hematite was noted on the dump of the Lower Rambler mine, near the Maine-Cross breccia reef, at the west edge of the Beaver Creek district, although none was found underground, and a trace of fluorite with specular hematite was found in small prospects along the reef a short distance to the west.

A little fluorite is associated with ferberite on the second level of the Logan mine at the junction of the main vein with a small eastward-trending branch, about 640 ft from the portal. The fluorite is clearly later than pyrite, but its relation to the ferberite is uncertain. A few crystals of fluorite were noted in the gold telluride and tungsten ore from the 300-ft level of the Grand Republic mine. In the Vasco No. 10 mine, a vein of banded gray and black horn quartz that branches from the main vein on the fourth level contains a quarter-inch streak of pale-pink to lavender fluorite.

OXIDES

Chalcedony.—Although the horn quartz of the telluride and tungsten veins has often been described as chalcedonic quartz, chalcedony is a rare mineral in the district. In the few places where it has been observed, it occurs as fine crusts grading outward into opal in the drusy openings of quartz that is later than the ferberite.

Cuprite.—Cuprite, the copper oxide, is present in the oxidized parts of many of the early silver veins. In the specimens studied, cuprite has directly replaced chalcopyrite and tetrahedrite and is cut in turn by replacement veinlets of malachite and azurite. Cuprite also is found in the oxidized parts of some of the telluride veins that contain copper minerals. In the strongly oxidized outcrops of these veins, it has replaced chalcopyrite and tetrahedrite and is generally accompanied by malachite, azurite, and limonite.

Goethite.—Goethite, the hydrated iron oxide, is probably the chief constituent of the "limonite" formed by supergene alteration. It shows no recognizable crystal structure in most of the oxidized ores, but in a few of the tungsten veins crystalline goethite can be seen grading into amorphous material. Most of the goethite occurring in this way has been formed from pyrite or marcasite associated with the ferberite, rather than from the ferberite itself. In the few places where ferberite has yielded to oxidation, it shows a peculiar grain-by-grain replacement by goethite. Most of the individual grains are either entirely fresh or completely altered, and the few grains that are only partly oxidized generally show a uniform advance of the limonitic alteration along a smooth front (fig. 36). Rarely, and only in coarsely crystalline and porous tungsten ore, limonitic material has replaced the ferberite irregularly, as illustrated in the report by Hess and Schaller (1914, pl. 4*A*). Goethite that has replaced ferberite contrasts sharply in habit with goethite that has replaced the sulfide minerals, whose individual grains when in process of replacement are usually broken up into many small residual islands which are enmeshed in a pervasive network of limonite veinlets (fig. 37). These veinlets extend from the more altered grains into the adjacent ones long before the replacement of the grain previously attacked is complete.

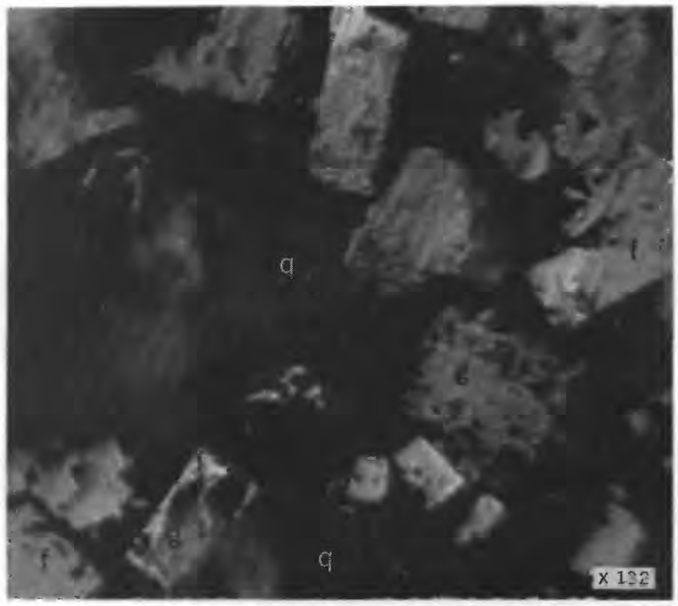


FIGURE 36.—Photomicrograph of oxidized ore from the Cold Spring mine, Boulder County, Colo., showing the typical grain-at-a-time replacement of ferberite by goethite: *f*, ferberite; *g*, goethite; *q*, quartz. × 132.

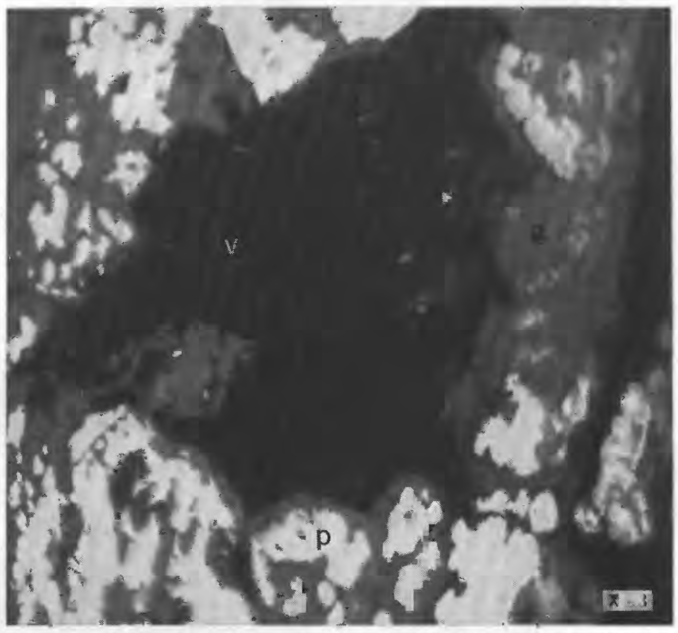


FIGURE 37.—Oxidized pyrite lining a vug in ore from the Catastrophe mine, Boulder County, Colo. Note the irregular replacement of the pyrite by goethite: *g*, goethite; *p*, pyrite; *v*, vug. × 48.

Hematite.—Hematite, the ferric iron oxide, occurs chiefly in the breccia reefs and in the hydrothermally altered wall rocks of the tungsten veins. Some of the so-called "limonite" of the oxidized veins probably contains fine-grained hematite, but, as indicated, most of the "limonite" is probably goethite. A little hematite is disseminated in the biotite latite intrusion breccia on the Lou Dillon claim (p. 64), where it is associated with marcasite.

In the breccia reefs hematite occurs disseminated in quartz, giving it a purple color, and in veinlets ranging from less than a millimeter to several centimeters in width. The veinlets form interlacing networks in the quartz and silicified rock through widths of as much as several yards. Most of them are more or less siliceous, but some are almost pure, and one mass of hematite found in the Hurricane Hill breccia reef in the Clark tunnel was sufficiently large and pure to be mined for chemical purposes during World War I.

Hematite has replaced much of the ilmenite in the wall rocks of the tungsten veins. The replacement is most complete in the strongly argillized rock near the veins, where dickite is abundant, and as the outer fringe of the zone of hydrothermal alteration is approached, progressively smaller amounts of the ilmenite are altered to hematite. In the zone of sericitic alteration, immediately adjacent to the veins, the hematite is converted to magnetite or pyrite.

Hematite seems to have been stable in the presence of the solutions that deposited ferberite but unstable in the presence of the later, alkaline, solutions. Hematite is absent from the normally hematitic breccia reefs where they are crossed by tungsten veins, and its place is taken by chlorite, but ferberite itself is found in close association with specular hematite in several minor veins and in association with earthy red hematite at many places in the district. Along a few of the smaller hematite-bearing breccia-reef fractures in the Beaver Creek district, thin seams of ferberite cut sheared granite that contains abuntant hematite. This relationship is well shown at the intersection of the Sunday vein with a small hematitic shear zone in the bed of the creek about 2,000 ft east of the Sunday shaft. Hess reports that at the south end of the Black Hawk No. 1 vein, about a quarter of a mile northwest of the Sunday shaft, ferberite gives way to specular hematite in a short vein which is nowhere more than a few inches thick (Hess and Schaller, 1914, p. 15), and this relationship was also noted by the writers. Veins of black siliceous hematite near the Greyback shaft, north of Nederland, contain a little ferberite which is disseminated in the dense hematite, as well as abundant pyrite which has replaced the hematite. The wall rocks of veins that contain ferberite in association with either specular or earthy red hematite are typically fresh or only slightly altered.

Iron hydroxide.—Very fine grained flecks of brown iron hydroxide are locally disseminated through fine-grained quartz which was deposited during a late stage of the vein-forming period. Although the color and composition of this seal-brown horn quartz suggest that it might be a product of supergene alteration of pyritic quartz, its occurrence clearly shows that it is of hypogene origin. At many places the brown horn is interlayered with gray pyritic quartz, and in some places both types are brecciated and cemented by later, white, quartz. Under the microscope the brown quartz is found to contain extremely minute, disseminated, dust-like particles of iron hydroxide and also a small amount of disseminated pyrite showing no sign of oxidation. Fragments of earlier, marcasite-bearing, quartz embedded in the brown quartz also are free from oxidation. In most places the brown horn is later than ferberite (fig. 41), but in a minor vein that branches southwestward from the Clyde vein on the 200-ft level, gradation from ferberite-bearing quartz to the brown horn quartz was found. The earliest quartz in the thin branch vein is a gray band carrying ferberite, some of which is poikilitically enclosed by marcasite. The gray quartz grades into a band of seal-brown quartz through alternating layers of light-brown quartz, gray ferberite-bearing quartz, clear quartz, brown-gray ferberite-bearing quartz, light-brown quartz, and dark-brown quartz. The earliest ferberite is associated with marcasite, and the succeeding layers contain less and less marcasite and more and more pyrite. The brown horn quartz itself contains disseminated pyrite but no marcasite apart from that in the enclosed fragments of gray ferberite- and marcasite-bearing horn quartz. The ferberite, pyrite, and marcasite are entirely unoxidized. The brown horn quartz is accompanied by later seams of fine-grained, light brownish-gray horn quartz and of clear quartz and barite.

Supergene iron hydroxide is found in many mine workings into which ground water has been flowing from crevices. Black or orange-brown crusts of "limonite" several inches thick have been built up on the walls and floors of drifts near some of the water-bearing crevices, but at others no deposits have formed. Some of the deposits in the Cold Spring mine were tested for tungsten by W. Y. Bleakley, of Boulder, with the following results: orange-colored deposits of the Footwall vein, seventh level, Cold Spring mine, 30 ft east of 1929 ore shoot, 0.39 percent WO_3; black deposit, Footwall vein, seventh level, Cold Spring mine, 50 ft east of winze, 0.40 percent WO_3; brown deposit, seventh level, Cold Spring mine, Sharkey vein in main crosscut, 0.13 percent WO_3; orange-colored deposit, Sharkey vein, seventh level, Cold Spring mine, in crosscut, 0.20 percent WO_3.

"Limonite."—See "Goethite," "Hematite," and "Iron hydroxide."

Magnetite.—In the sericitic zone adjacent to the veins, most of the hematite pseudomorphous after ilmenite has been converted to either magnetite or pyrite. Where the tungsten ore contains pyrite or other sulfides in appreciable amounts, pyrite has formed at the expense of hematite, but adjacent to ore shoots free of pyrite, magnetite has formed. As pyritic ferberite ore is uncommon, it is safe to assume that magnetite has developed along most veins.

Magnetite is rare within the veins, but it is known in a few localities. Ferberite ore mined from a branch vein on the 100-ft level of the Red Signe mine in 1944 contained so much magnetite and pyrite that the best concentrate that could be made from it contained only 30 percent WO_3. A specimen consists of finely crystalline black ore cementing a breccia of sericitized and silicified granite fragments. It looks similar to the typical ore of the eastern part of the district except that it contains considerable pyrite, which is largely concentrated in or adjacent to the granite fragments. The black ore is an intimate mixture of fine-grained magnetite and ferberite. When this is powdered, 10 to 20 percent of it can be separated with a hand magnet, but mill tests made on the ore proved magnetic separation impractical because too much tungsten was lost to the magnetic concentrate, even after fine grinding.

Hess (Hess and Schaller, 1914, p. 17) reports a small quantity of magnetic material from the Eagle Rock mine, near the Red Signe, and believes that it is probably magnetite. George (1909, p. 75) states that magnetite is present in the tungsten ores, but his description suggests that he crushed ore and then tested it with a magnet, and as fragments of wall rock are present in nearly all the ore it seems probable that the magnetic concentrate obtained was magnetite from the wall rock and not a hydrothermal vein mineral.

In addition to the hydrothermal magnetite described, primary magnetite is common in the Boulder Creek granite and in the pre-Cambrian pegmatite and aplite, although the principal iron-ore mineral in these rocks is ilmenite.

Manganese oxides (psilomelane, pyrolusite, and manganite).—Except for the fine-grained manganiferous alteration products of siderite and ankerite described as wad, the only occurrence of manganese oxides known in the tungsten district is in the Forest Home mine. In a vein southeast of the shaft on the first level, manganese oxides occur as botryoidal crusts on ferberite wherever the vein is open and vuggy. The manganese crusts are made up chiefly of psilomelane, but some pyrolusite is present, and possibly a little manganite. These minerals are believed to be supergene and to have been derived from the oxidation of alabandite, which is present in small amounts in some of the Forest Home ore.

Opal.—Opaline silica is very common in the tungsten veins and is one of the latest minerals. It is generally associated with beidellite and montmorillonite or allophane in vuggy openings. The opaline crusts generally show gravitational control of deposition and tend to lie on the upper surfaces of crystals and fragments to a much greater degree than on the lower surfaces. Although this may be interpreted as indicating deposition from descending waters, the writers believe that it has resulted from the precipitation of colloidal silica in nearly stagnant solutions.

In ore from the Clyde mine, crusts of opaline silica and beidellite form casts of coarse crystals of ferberite. The casts, thousands of which were found, consist of a thin shell of beidellite, opal, horn quartz, and barite. This material was originally deposited on coarse ferberite crystals and has preserved their form perfectly, although in the hundreds examined only a few ferberite crystals still remained as cores of the siliceous shells. Barite is abundant in well-formed crystals resting on these shells and suggests that the opal is hypogene.

Quartz.—Quartz is the most abundant vein mineral in the district. The early barren quartz of the breccia reefs is commonly coarse-grained and in places has an almost pegmatitic appearance. This is the typical "bull quartz" of the miners. In vuggy parts of the reefs, crystals as much as 2 cm in length have been observed. The quartz in the later veins is much finer grained, and most of that accompanying hematite also is fine-grained. The quartz of the early silver veins is sugary and granular and distinctly coarser than that of the telluride veins and the tungsten veins. The so-called horn quartz or "horn" of the telluride and tungsten veins is made up of grains 0.001 to 0.05 mm in diameter. Some of this fine-grained quartz is dense and impervious, and some is open and vuggy. Most of it is well banded, and in places small, clear, subhedral crystals of quartz deposited during the closing stages of mineralization give it a crustified appearance.

The quartz of the silver and gold veins is grayish and owes its color to disseminated pyrite. Fragments of pyritic vein quartz are found locally in the tungsten veins, but they represent an earlier period of mineralization unrelated to the tungsten.

Many generations of different-colored quartz occur in the tungsten veins (fig. 38). Much of the vein filling is medium to light-gray or milky-white horn quartz, the color of which is due to a porous texture and finely disseminated clay minerals or, locally, sericite. Where sericite is present, the clay mineral is generally allophane; elsewhere beidellite and dickite are disseminated in the gray horn quartz. In general the beidellite-, sericite-, and allophane-bearing horn quartz is light gray, whereas the dickite-bearing horn is somewhat darker and might be called simply gray or medium-gray. Both beidellite and dickite are much less common in the vein quartz than might be expected from their abundance in the altered wall rock. They

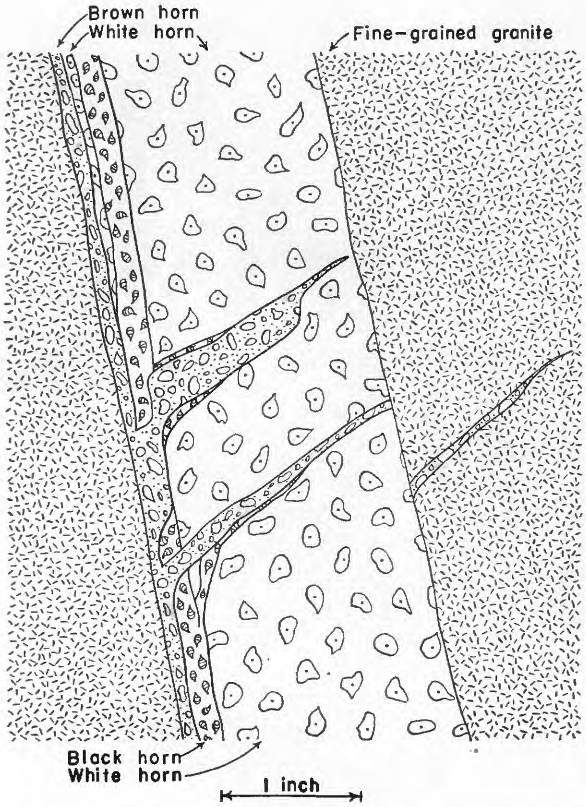


FIGURE 38.—Sketch showing the relative ages of different types of horn quartz cn a branch of the Footwall vein of the Clyde mine, Boulder County, Colo., 50 ft. southwest of the winze on the tunnel level.

are generally accompanied by a potash-bearing goyazite of the alunite family. Goyazite is also found, together with fluorite, in some of the early sericitic white quartz, but only in or near vuggy openings.

A fine-grained red quartz that owes its color to disseminated hematite is later than some of the light-gray quartz but earlier than the gray, dickite-bearing, quartz, which in turn is earlier than a light-green horn quartz. The green horn, which is relatively rare, is found chiefly in the barren parts of veins near ore shoots, and its color is probably caused by a high concentration of minute crystals of goyazite. This quartz contains a small amount of sericite and allophane and an occasional tiny crystal of ferberite. Locally the green quartz is brecciated and is cemented with a blue-gray horn quartz which grades into black horn. The black horn owes its color to disseminated ferberite crystals (fig. 39) and is the quartz of the ferberite stage of mineralization.

Most of the quartz younger than the black horn and ferberite is gray and owes its color to finely disseminated pyrite. Some red horn is later than the ferberite and almost everywhere contains disseminated pyrite. Relatively rare tan and flesh-colored varieties of horn are later than the ferberite and are believed to be variants of the brown horn formed after the ore deposits and

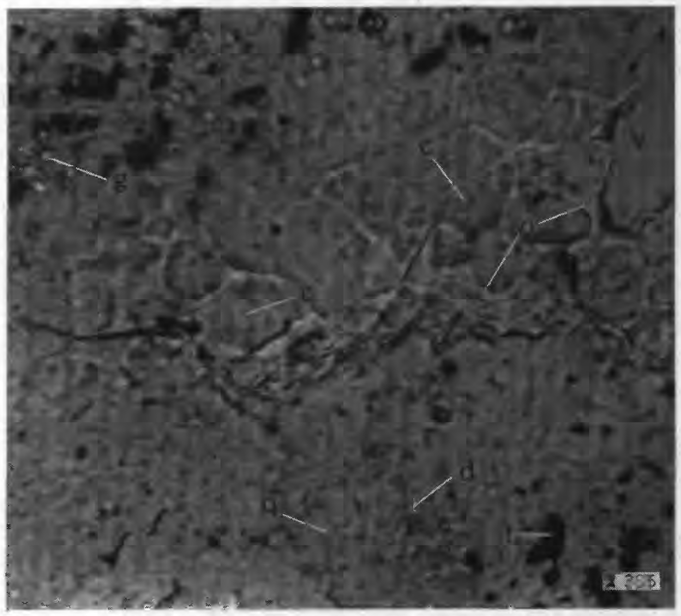


FIGURE 39.—Photomicrograph of black horn quartz from the Cold Spring mine, Boulder County, Colo. The dark color is due to the fine-grained ferberite disseminated through the quartz. The ferberite is associated with goyazite and dickite; the black horn quartz is cut by a late seam of clear, vuggy quartz which locally carries opal and chalcedony: *q*, quartz; *c*, chalcedony; *o*, opal; *v*, vug; *d*, dickite; *f*, ferberite; *g*, goyazite. × 385.

described under "Iron hydroxide." The latest variety of horn quartz is white and is commonly found interbanded with clear quartz or accompanied by opal.

By far the largest part of the horn quartz was deposited in open fissures, but a little of the quartz replaced the wall rocks. Aplite appears to have been more susceptible to replacement by horn quartz than any of the other types of wall rocks. Replacement of aplite by horn quartz is particularly well shown in the Vasco No. 6, Hoosier, and Phillip Extension mines (fig. 40).

Tungstite.—Tungstite was seen by the writers only at the Roderick shaft on the Brace tract, in the Beaver Creek district. The shaft was sunk in 1942 on a seam of coarsely crystalline ferberite that cropped out at the surface. At a depth of a few feet, vugs in the ferberite vein were found filled with soft, curdlike, bright-yellow tungstite. The larger pockets may have contained as much as a pound of this material. As the coarse ferberite crystals surrounding the pockets were shiny black and uncorroded, the tungstite was evidently derived from ferberite weathered higher in the vein. George (1909 [ed. of 1916], p. 98) says that "several specimens of ferberite showing considerable coatings, and in one or two instances vug fillings, of tungstite have been found," but he does not give the localities.

Wad.—The term "wad" is here applied to fine-grained mixtures of manganese oxides which probably consist largely of pyrolusite with subordinate psilome-

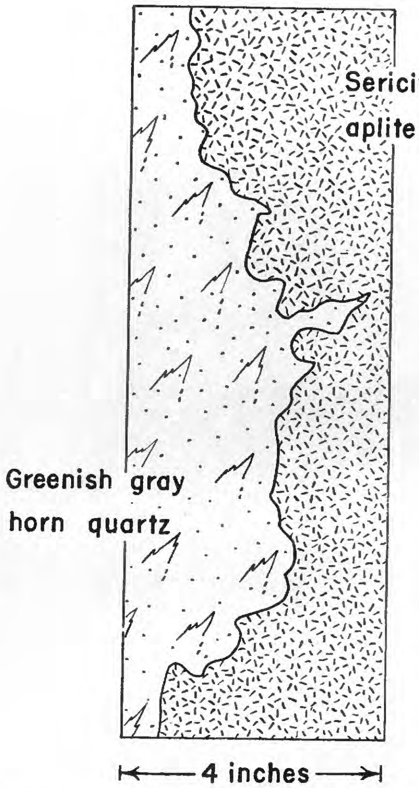


FIGURE 40.—Sketch of the contact between horn quartz and sericitized aplite, showing the replacement of aplite by horn quartz. Eighth level of the Vasco No. 6 mine, Boulder County, Colo.

lane and manganite. Such material is not abundant in the tungsten district but has been observed in a few places as crusts on siderite and ankerite in the oxidized zone.

CARBONATES

Ankerite.—Manganiferous ankerite is a minor gangue mineral of the early silver veins. It is found cutting the vein quartz and the ore in moderately coarse grained late veinlets and is present as well-formed crystals in vugs. Some early ankerite has been found in the tungsten veins, but most of the early carbonate associated with ferberite is siderite carrying only a small amount of manganese. Ankerite is not abundant.

Calcite.—Small veinlets of calcite are found near the surface in many veins. This calcite is probably of supergene origin, but calcite occurs also as one of the latest hypogene minerals. The carbonate found in vugs associated with beidellite and allophane is calcite. Both ferberite and quartz are commonly corroded where they are in contact with calcite. Well-formed crystals of calcite are especially common in the upper parts of ore shoots and are generally intergrown with barite. The crystal forms include well-developed scalenohedrons and bipyramids terminated by flat rhombohedrons.

Dolomite.—Small streaks of white or cream- or flesh-colored carbonate that is later than the ferberite are found at places in many of the tungsten mines. Although some of the carbonate of this type may be ankerite, much of it is known to be fairly pure dolomite, which in general is later than the ankerite. In the Vasco No. 7 mine, a breccia of dark horn quartz and crystalline ferberite is cemented by coarsely crystalline, vuggy, pure-white dolomite, which nearby is interbanded with pyritic red horn quartz. A vein of flesh-colored dolomite 4 to 8 in. wide is present on the eighth level of the Vasco No. 6 mine, a short distance below the bottom of the main ore shoot.

Siderite.—Siderite, the iron carbonate, is the typical early carbonate mineral of the tungsten veins. It is contemporaneous with the early stages of ferberite deposition in most places, and well-shaped but small rhombohedrons of siderite are visible in many thin sections that contain black horn quartz and early ferberite. Siderite is rarely visible in hand specimens, but some unusually coarse crystals were found in the ore from the Sunday mine in the Beaver Creek district, where a vein of siderite about 2 in. thick showed individual cleavage faces extending across the width of the vein. The siderite vein was very close to the bottom of a shoot of coarse-grained ferberite ore. At a few places in the Quaker City vein, coarse lens-shaped crystals of manganosiderite rest on crystalline ferberite in vugs.

SILICATES

Adularia.—Adularia is relatively rare in the district but has been found in small veinlets seaming ferberite ore and the adjacent wall rocks. It occurs also as small crystals resting on ferberite or sulfide minerals in vugs. It is later than barite and later than the sericitic phase of wall-rock alteration.

Chlorite.—Chlorite is not abundant, but along the barren parts of many of the tungsten veins the ferromagnesian minerals of the wall rocks have been converted to a low-iron chlorite whose composition is near that of penninite. In the sericitized wall rocks of the veins, chlorite has developed from biotite, and its relatively high birefringence suggests that it has a composition near that of antigorite. The hematite in breccia-reef fractures is typically altered to green chlorite near the tungsten veins. Chlorite has not been found as a vein mineral.

Clay minerals (dickite, beidellite, cimolite, allophane, and others).—Except in a few local areas, the clay minerals in the tungsten veins and their altered wall rocks fall in one of four groups. Arranged according to decreasing indices, these are distinguished as dickite ($n=1.56$), beidellite ($n=1.54\pm$), cimolite ($n=1.505$), and allophane ($n=1.48$).

Dickite is abundant in the altered wall rocks of the tungsten veins, just outside the sericitic sheath that adjoins the vein. It developed chiefly in oligoclase, but it also replaced biotite to a minor extent and much of it has formed by replacement of earlier beidellite, halloysite, and allophane. Within the veins, dickite is disseminated through the gray horn quartz that predates the ferberite, and it occurs also in small masses associated with ferberite. Much of the vein dickite is earlier than the ferberite, but locally, as in the Conger mine, dickite forms thin seams separating successive layers of ferberite, and in several veins it has been found filling openings in coarse vuggy ferberite, particularly near the bottoms of ore shoots.

Beidellite is probably the most abundant clay mineral in the tungsten veins. It occurs in plates which show refractive indices close to 1.54 when lying flat, and between 1.530 and 1.547 when standing on edge. Wherever beidellite has been found as a vein mineral it is later than ferberite, but in the Grand Republic mine, at the east end of the district, fragments of altered wall rock consisting largely of beidellite are surrounded by concentric rings of marcasite, pyrite, and ferberite. Beidellite is also the commonest clay mineral in the late silver ores representing the end phase of tungsten deposition. In the tungsten veins, beidellite occurs chiefly in the vuggy openings near the tops of the ore shoots, where it rests on the ferberite. Although later, as a vein mineral, than ferberite, sulfides, and barite (fig. 41), it is earlier than the late, fine-grained, quartz and opal or is contemporaneous with them.

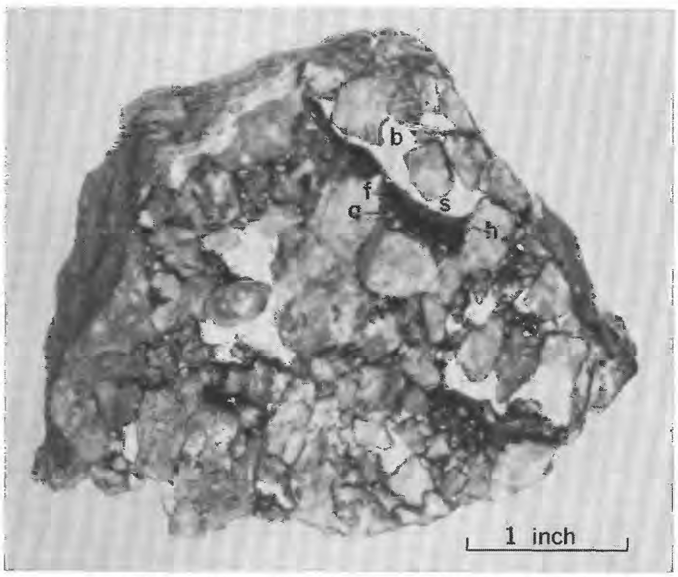


FIGURE 41.—Polished specimen of ore from the Quaker City mine showing the sequence from early quartz through ferberite, brown iron hydroxide, and sphalerite to beidellite; gravitational control of deposition is shown at this locality: *q*, quartz; *f*, ferberite; *h*, brown iron hydroxide; *s*, sphalerite (a minute single crystal); *b*, beidellite. Natural size.

Beidellite has formed extensively by replacement of oligoclase in the altered wall rocks of the tungsten veins, and it is especially abundant between the zone of dickite and the outer fringe of the argillized zone. The rock that contains much beidellite is soft and bleached and sloughs readily on exposure to the air.

A clay mineral having an index of 1.505 is tentatively referred to as cimolite, which is listed as a doubtful species by Larsen and Berman (1934, pp. 50, 257). The cimolite is almost as abundant as beidellite. It is always accompanied by beidellite, but not all beidellite is accompanied by cimolite. Cimolite forms aggregates of nearly isotropic irregular scales in which the beidellite is embedded. The proportion of cimolite to beidellite varies greatly in different specimens. Cimolite probably has about the same composition as beidellite and may have the same relationship to it that halloysite has to dickite.

Allophane in minute blebs and irregular scales is intergrown with the other clay minerals and is almost everywhere a minor constituent of the clay assemblage. In the Vasco No. 10 mine, a clay that seems to have consisted originally of pure allophane but which is now partly replaced by beidellite fills a few of the crevices in open horn quartz breccia. Some of the breccia fragments are dusted with tiny crystals of sulfide minerals and adularia, and these materials, as well as the allophane clay, are believed to have been deposited from a stagnant solution that filled the open breccia. In a vug in the Beddig mine, a shell of nearly pure allophane was found between scheelite, which had filled the center of the vug, and an earlier rim of pyrite crystals which rested on ferberite. In appearance, refractive index, and size of grain, this vein mineral is strikingly similar to the early low-index clay found in the altered wall rock near the outer edge of the zone of alteration.

In addition to the minerals already described, which are found throughout the district, other clay minerals have been found in certain localities. A clay mineral with an index between 1.525 and 1.53 has been noted in a few specimens, mostly from the Beaver Creek part of the district. It is probably related to montmorillonite and, like the beidellite, is later than the ferberite. A beidellite-cimolite clay, later than the ferberite, found in the Vasco No. 2 mine contains a few flakes of brownish clay that has an index near 1.60 and is believed to be nontronite. Another clay mineral that is later than the ferberite, with a refractive index of about 1.55, was found in the Cold Spring mine. It is probably a member of the montmorillonite-nontronite series. Also, an amorphous substance which had replaced beidellite, and in which dickite seemed to be crystallizing, was noted in the altered wall rocks of the Cold Spring. This is probably halloysite, as the refractive index is greater than that of canada balsam and less than n_ϵ of quartz and is very close to 1.55. The occurrence and paragenetic relations of the various clay minerals are described on pages 59–60.

Epidote.—Epidote is found along many joint cracks in the Boulder Creek granite, but it seems unrelated to Tertiary mineralization and much of it dates from pre-Cambrian time. Epidote is associated with garnet in some of the pegmatites in the Boulder Creek granite, and most of the epidote is genetically related to pegmatites. An occasional grain of epidote is present where the wall rocks of the veins are chloritized, but this type of alteration is uncommon.

Hydrous mica.—Hydrous mica is abundant in the sericitized wall rocks of the tungsten veins and in rock fragments enclosed by ferberite and quartz in the veins. Its average refractive index is between those of dickite and of sericite, and its birefringence, though strong, is less than that of sericite. In the sericitic zone, the hydrous mica developed largely by the replacement of dickite and the other clay minerals and to a lesser extent by the replacement of oligoclase and biotite. The mineral is identical in appearance with the muscovite-like mineral described by Ross and Kerr (1931, p. 172).

Sericite.—Sericite is the predominant mineral in the altered wall rocks immediately adjacent to the ore bodies in the tungsten veins, the silver veins, and the gold telluride veins. It has replaced oligoclase, biotite, and the clay minerals; it is seldom found in apatite, quartz, and the potash feldspars. It is almost invariably associated with hydrous mica, a mineral very similar in appearance but slightly lower in birefringence and refractive index. The occurrence of sericite and its paragenetic relations with respect to the clay minerals are described on pages 60–61.

TITANOSILICATES

In the altered wall rocks of the tungsten veins, the accessory ilmenite has broken down to leucoxene and hematite. The leucoxene, a fine-grained, white, amorphous (?) material, forms veins in the ilmenite grains and thin crusts around them. It is of relatively late origin, and veinlets of it cut the clay minerals and sericite in both the outer argillized zone and the inner sericitized sheath of rock next to the tungsten vein. Close to the vein fissure, the leucoxene is in part finely crystalline, and adjacent to some of the larger veins it grades into recognizable crystals of secondary sphene as much as 0.02 mm in diameter. It is extremely rare within the vein filling. In a few thin sections of the early ferberite-bearing horn quartz, minute, highly birefringent crystals showing strong relief and believed to be sphene were found in veinlets containing quartz, goyazite, opal, and chalcedony that are later than the ferberite-bearing horn quartz.

PHOSPHATES

Apatite.—In a few places the altered wall rocks of the tungsten veins contain minute crystals of apatite which appears to be of hydrothermal origin. Sericitized aplite adjoining an ore body on the third level of the Dorothy mine contains as much as 5 percent apatite by volume. At least a part of this apatite was introduced during the period of wall-rock alteration. Most of the apatite found in the district is of igneous origin, however, and it shows little solution or corrosion in either the sericitic or argillic zones of alteration.

Goyazite.—An alunitelike mineral is abundantly disseminated through the early barren vein quartz in many places and is associated with the early stages of ferberite deposition. It was first identified as "hamlinite" by Schaller (Hess and Schaller, 1914, p. 14). The optical character of the mineral indicates that it is very close to goyazite, the hydrous strontium aluminum phosphate, and the presence of a small amount of sulfate in the material identified by Schaller shows that it is intermediate between goyazite ($2SrO{\cdot}3Al_2O_3{\cdot}2P_2O_5{\cdot}7H_2O$) and svanbergite ($2SrO{\cdot}3Al_2O_3{\cdot}P_2O_5{\cdot}2SO_3{\cdot}6H_2O$), both members of the alunite group. Schaller later (1917) established the identity of this mineral with goyazite and advocated this name as preferable to "hamlinite."

Goyazite is present in most of the fine-grained quartz intergrown with ferberite, but the greatest concentrations have been observed in the green horn quartz that shortly preceded the deposition of ferberite ore. The goyazite is the cause of the light-green color of the quartz. It occurs as very small, nearly euhedral crystals disseminated through the quartz, and in places it forms 10 to 25 percent of the green horn veinlets.

On the Rogers tract, near the center of the tungsten belt, specular hematite and "hamlinite" (goyazite) are reported in ferberite ore, and according to Hess (1921a, p. 941), the goyazite is probably more closely associated with hematite than with ferberite. This occurrence is unusual, and hematite is lacking in most rocks that contain goyazite.

Goyazite in its few other recorded occurrences seems to be associated with relatively high temperature assemblages in pegmatite. Similarly, svanbergite is commonly found in crystalline schists and gneisses, being associated with hematite, lazulite, pyrophyllite, damourite, and cyanite near Lake Wenner in southern Sweden and also in the iron mine of Westanå, Scania, Sweden, where the mineralogy is similar (Dana, 1898, p. 855, 868).

SULFATE

Barite, the barium sulfate, is widely distributed in the tungsten district but is nowhere abundant. It forms white-crested, divergent groups of thin wedge-shaped blades in the vuggy openings of the ferberite ore in several mines. Most of it is associated with relatively late minerals in the upper parts of ore shoots. In the Quaker City vein, some barite is intergrown with galena and sphalerite, which are later than ferberite, and some is later than the sulfides, gray copper, and ruby silver but earlier than scheelite. In the Clyde mine, in an open vuggy part of the vein between two large ore shoots on the 200-ft level, fine-grained barite, quartz, and opal form shells around a rubble of earlier vein fragments (fig. 51). Well-shaped barite crystals as much as a centimeter in height are conspicuous on the barite-silica crusts and are partly coated with beidellite and other clay minerals. Barite in a vug at the top of one of the adjacent ore shoots is earlier than associated tetrahedrite, and most of it is later than ferberite, but a small amount is enclosed in quartz that immediately preceded ferberite deposition. Barite that is contemporaneous with ferberite has been observed in a few places (fig. 42).

Barite is also a constituent of the gangue of the early lead-silver veins. In ore from the Logan mine, white wedge-shaped crystals of barite are intergrown with quartz that was deposited before sphalerite, galena, and the silver minerals.

In the Herald mine, fine-grained barite occurs in the quartz accompanying the gold and tellurides. The paragenetic relations indicate that the barite is essentially contemporaneous with free gold and marks the close of the gold mineralization.

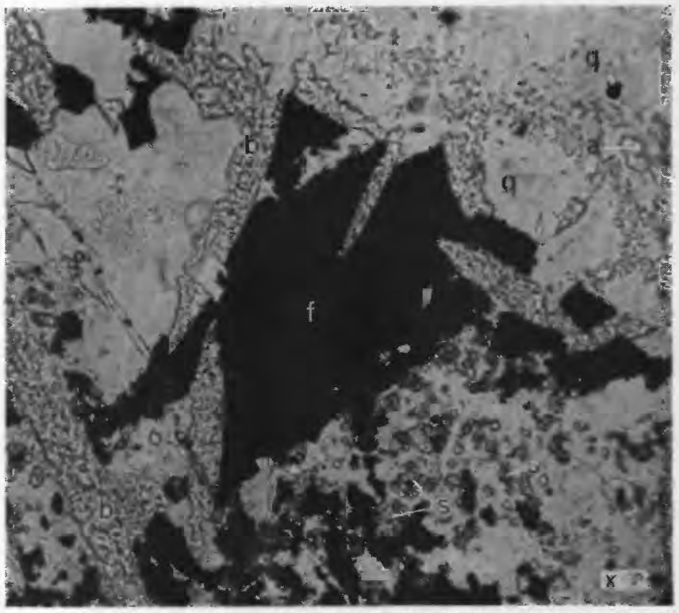


FIGURE 42.—Ferberite contemporaneous with barite, siderite, and quartz. Tunnel level of the Clyde mine, Boulder County, Colo. The ore-bearing seam is covered with a layer of late quartz and adularia which shows in the upper right-hand corner: *q*, quartz; *b*, barite; *f*, ferberite; *a*, adularia; *s*, siderite. × 88.

TUNGSTATES

Ferberite.—Ferberite, the iron tungstate, is the only abundant tungsten mineral in the district. It occurs almost universally as small, well-formed, chisel-shaped-crystals. Even seams of apparently massive ferberite ore such as that shown in figure 43 are found, when

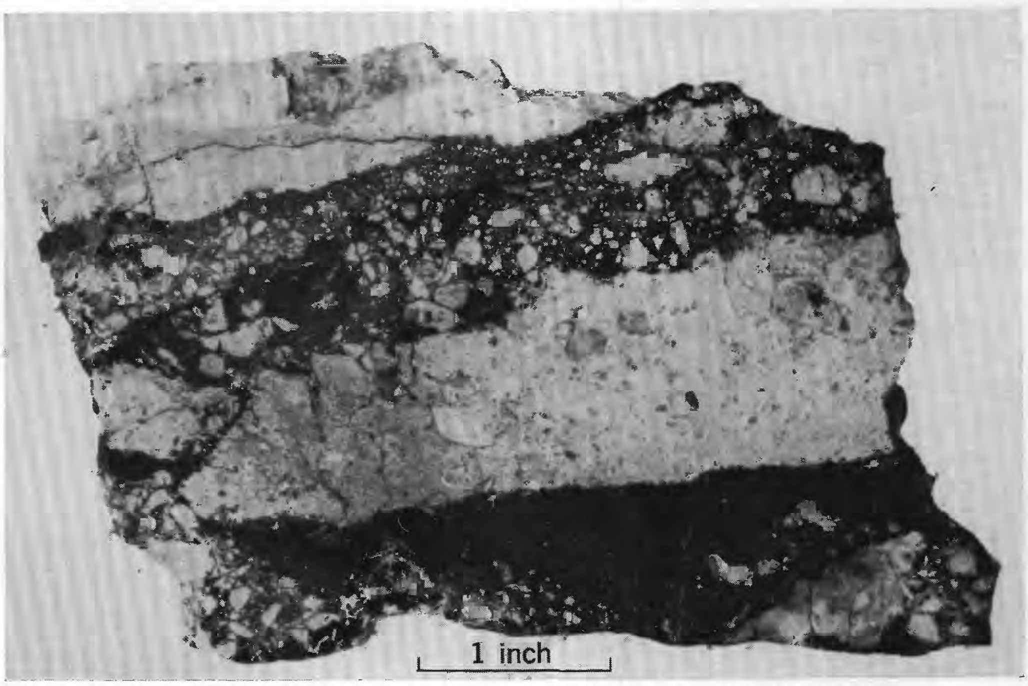


FIGURE 43.—Polished specimen of typical fine-grained ferberite ore from the Cold Spring mine, Boulder County, Colo. Natural size.

FIGURE 44.—Specimen of typical coarse crystalline ferberite ore from the Sunday mine, Boulder County, Colo. × 1½.

examined under the microscope, to consist of aggregates of tiny interlocking euhedral crystals. The grain size of the ferberite ores ranges from about a tenth of a millimeter in some dense ores to as much as a centimeter in the coarse ores. The miners generally class ore containing crystals about a tenth of an inch long or larger as "coarse crystal ore" (fig. 44). Coarse crystalline ferberite is found most abundantly in the Beaver Creek section at the southwest edge of the district. In contrast, some of the ore in Millionaire Gulch, at the east edge of the tungsten area, is so fine grained that it is known as "steel ferberite" (fig. 45). In some ore shoots, the coarsest ferberite is found along the edge nearest the source and occurs in vuggy seams that cut through earlier, fine-grained, ferberite. The fine-grained ore was probably formed by rapid precipitation from a solution that was far from equilibrium, whereas the coarse ore was formed by slow crystallization from solutions that were only slightly supersaturated.

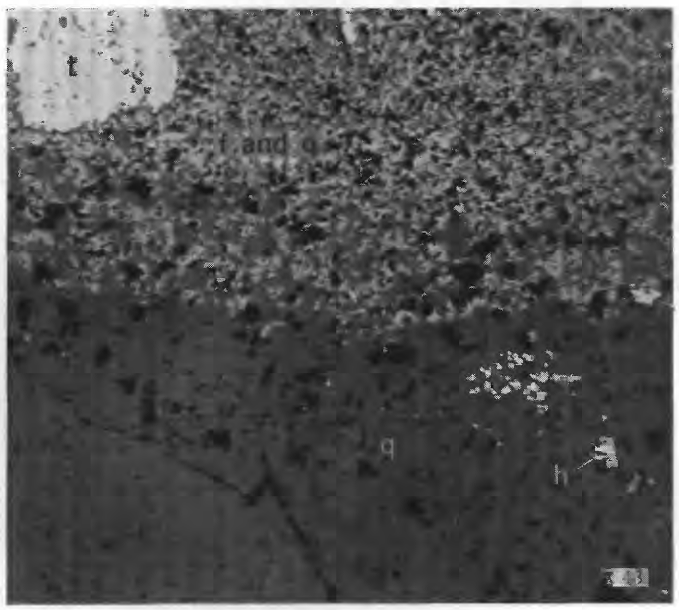


FIGURE 45.—Photomicrograph of "steel ferberite" ore from the Dorothy mine, Millionaire Gulch, Boulder County, Colo. Corroded fragment of early tetrahedrite embedded in a matrix of fine-grained ferberite and quartz which is perched upon early quartz-carrying hematite: *f*, ferberite; *t*, tetrahedrite; *q*, quartz; *h*, hematite. × 48.

Although the long, narrow, wedge-shaped crystal is by far the most common form, Schaller noted four other crystal habits in the district (Hess and Schaller, 1914, p. 56). A rhombic habit is often seen, as is a short, prismatic form somewhat flattened parallel to the orthopinacoid. Cubic crystals are rare, and so are simple individual crystals tabular parallel to (100), although this is the common habit of the individual crystals in contact twins.

Results of spectroscopic examination of ferberite,

TABLE 4.—*Analyses of Boulder County tungsten ores*

	Source of ore	WO_3	FeO	Fe_2O_3	MnO	CaO	SiO_2	MgO	Al_2O_3	S	P	Total
1	Gordon Gulch	60.84	18.36		4.73		16.28			0.20	0.05	100.46
2	Do	61.80	16.36		3.12	0.35	15.93	1.71	1.06			100.33
3	Beaver Creek	66.41	24.31		3.25		6.00			.02	Tr	99.99
4	Last Chance mine	62.30	19.90		.69	.79	14.68		1.34			99.70
5	Clyde mine	61.15	19.33		.51	.38	16.10	.39	2.49			100.35
6	Elsie mine	73.52	22.65		.60	.42	1.81		.75			99.75
7	Barker mine	65.88	20.44	4.11	.37	.35	6.45	.50	2.19			100.29
8	Conger mine	60.98	19.13		.08	.44	15.94	.59	3.10			100.26
9	Manchester Lake	74.13	23.15		.56	1.28	.71		.46			100.29

1, 3. From Greenawalt, W. E., The tungsten deposits of Boulder County, Colo.: Eng. and Min. Jour., vol. 83, p. 951, 1907. Analysis 1 includes Au, trace; Ag, 3.1 oz per ton. Analysis 3 includes Au, trace; Ag, 1.2 oz per ton.
2, 4, 6, 9. From George, R. D., The main tungsten area of Boulder County, Colo.: Colorado Geol. Survey 1st Rept. [1908], pp. 42–43, 1909. Manchester Lake the source of the ore in analysis 9, is about a mile south of the Beaver Creek district.
5, 7, 8. From Kendall, G. D., Jr., One hundred percent analyses of some Nederland tungsten minerals (Univ. of Colorado thesis), p. 7, 1908.

made by Professor G. Eberhard, of Potsdam, Germany, are given by Hess and Schaller (1914, p. 18). Lines for W, Si, and Fe are strong; those for Mg and Al, moderate; those for Ca, Cb, Cu, Mn, Sc, Sr, Ti, and V, weak; and these for Cr and Mo, doubtful. Lines for Ba, Gl (Be), Pb, Ga, K, Li, Na, Ni, Ag, Sn, Bi, Zn, Zr, and Y are absent.

Most of the ore taken from the district carries too little manganese to be classed as wolframite (table 4).

The ore from Gordon Gulch has a higher ratio of manganese to iron than the other ores of the district, and some of it is properly classed as wolframite, although a low-manganese variety. The appearance and mode of occurrence of the high-manganese ferberite and the low-manganese wolframite are identical with those of ordinary ferberite.

Ferberite is everywhere intergrown with more or less fine grained quartz and seldom makes up as much as 20 percent of the vein matter mined. Most of the quartz was deposited before the period of ferberite deposition, but some accompanied the ferberite and some followed it. The quartz is chiefly well-defined veinlets or bands within the veins, but some is closely intergrown with the ferberite itself, even in the purest-looking crystalline ores, as shown by the analyses in table 4. Pure ferberite ($FeWO_4$) contains 76.64 percent WO_3; most of the so-called "pure" ferberite of the Boulder district contains substantially less than this because of the intergrown horn quartz. The quartz fills the interstices between the ferberite crystals and, in some ores at least, forms minute lamellar plates on parting or cleavage surfaces within the ferberite crystals.

Ferberite is earlier than most of the clay minerals except dickite.

Many of the vugs in the tungsten ore are filled with clean white clay which is generally beidellite (fig. 46), cimolite, or allophane; rarely it is dickite. In many veins, ferberite is accompanied by minor quantities of sulfide minerals, particularly marcasite and pyrite. The marcasite is mostly earlier than the ferberite, although some is later; most of the pyrite is contemporaneous with, or later than, the ferberite (fig. 47).

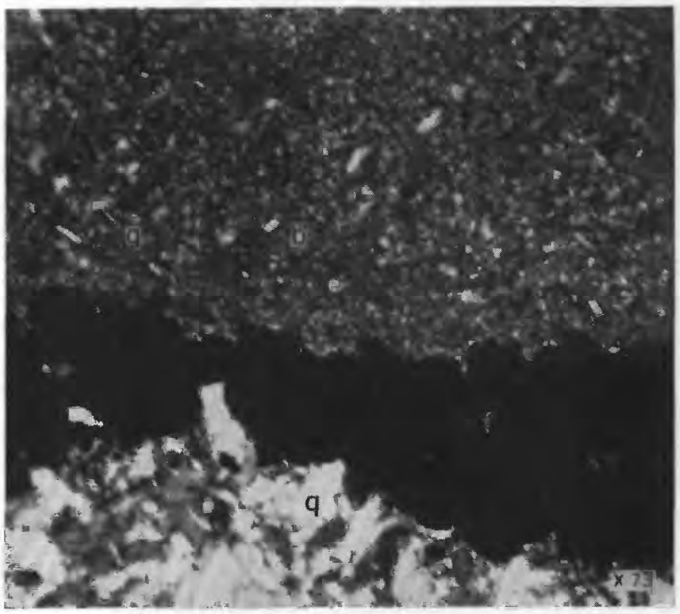


FIGURE 46.—Photomicrograph showing ferberite lying on early quartz and surmounted by beidellite with a small amount of hydrous mica and quartz: *q*, quartz; *f*, ferberite; *b*, beidellite. X 73. Crossed nicols.

Other sulfides are relatively rare in association with ferberite, but in the Illinois, Clyde, Quaker City, and Galenite veins, and in several of the veins on the Rogers tract, sulfides of lead, zinc, copper, and silver are present in minor quantity with the ferberite. These apparently represent a late and relatively cool phase of the tungsten mineralization. Except for a little of the sphalerite and galena, these sulfides are all later than the ferberite.

Huebnerite.—Some of the ore from a vein southeast of the shaft on the first level of the Forest Home mine has the reddish-yellow, resinous appearance characteristic of huebnerite, the manganese tungstate. It is coated by crusts of manganese oxides which were evidently derived from alabandite, which also is present in the ore at this locality. The concentration of manganese-bearing minerals in this one restricted locality is believed to have resulted from reaction between the ore-bearing solutions and some local source of manganese. Elsewhere in the district, the

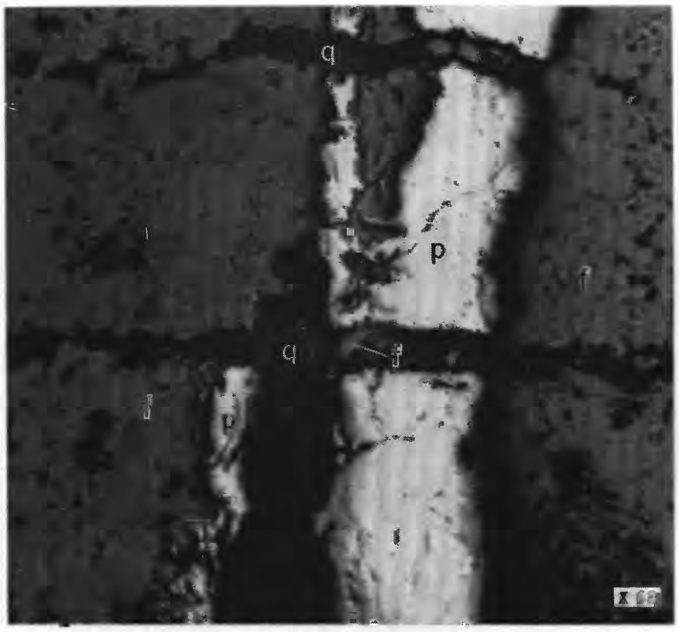


FIGURE 47.—Photomicrograph showing two generations of ferberite, fifth level of the Beddig mine, Boulder County, Colo. Early massive ferberite is cut by a pyrite vein, and both are cut by a later vein of quartz and ferberite: *f*, ferberite; *p*, pyrite; *q*, quartz. × 68.

ore mineral contains so little manganese that very little of it ranks even as a low-manganese wolframite.

Scheelite.—The occurrence of scheelite in the district has been described in detail elsewhere (Tweto, 1947a). Scheelite, the calcium tungstate, accompanies ferberite in many of the veins, but it is only an accessory mineral in most places. In a few mines along the north edge of the district, however, it is abundant enough locally to increase the grade of the ore substantially. It occurs in small veins, in vugs, disseminated in sericitized rock (fig. 48*A*), and in the gouge and minute fractures of shear zones (fig. 48*B*, *C*). Locally scheelite has replaced ferberite (fig. 48*D*). Scheelite is later than all the minerals of the tungsten veins except calcite and some late dolomite.

Wolframite.—Except for the low-manganese wolframite found locally in Gordon Gulch, there is no true wolframite (the iron-manganese tungstate) in the main tungsten district. North of the district, however, wolframite that is presumably related to the minor tungsten mineralization at Ward is found in scattered localities. This mineralization is older than the ferberite mineralization in the tungsten district (p. 70), and there is no direct relation between the wolframite and the ferberite. A little wolframite has been found in float ore only a short distance north of the main tungsten belt near the Nederland-Ward road.

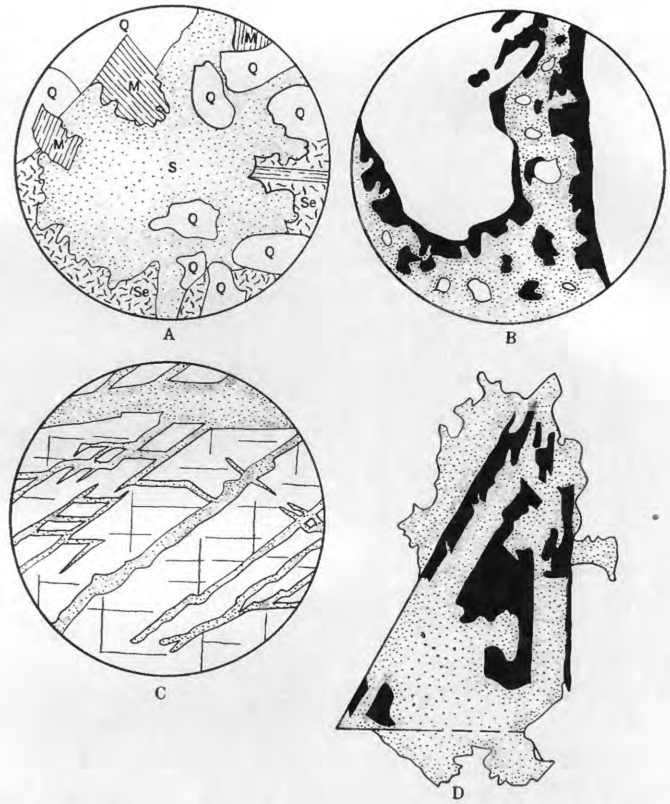


FIGURE 48.—*A*, Scheelite that has partly replaced a sericitic aggregate and microcline in sericitized aplite; quartz is little affected: *s*, scheelite; *se*, sericitic aggregate; *m*, microcline; *q*, quartz. Crow No. 18 mine, Boulder County, Colo. × 60. *B*, Scheelite (stippled) that has partly replaced ferruginous gouge (black) between rock fragments (blank). Ohio mine, Boulder County, Colo. × 8. *C*, Scheelite veinlets (stippled) along cleavages and microscopic sheeting in microcline. Ohio mine. × 12. *D*, Scheelite (stippled) that has largely replaced a ferberite crystal and part of the adjacent sericitic matrix. Crow No. 18 mine. × 40.

VEINS

EARLY SILVER VEINS

Veins that have been mined chiefly for silver are of commercial importance only in the eastern part of the district, where a substantial production of silver-bearing gray copper ore has been made from the Yellow Pine and Logan mines. No direct evidence as to the relative age of the gold telluride veins and the early silver veins is found in the tungsten district, but in the Jamestown district Goddard (manuscript report) found that the galena-gray copper veins are earlier than the gold telluride veins. Galena, sphalerite, gray copper, and the silver sulfantimonides and sulfarsenides are the principal ore minerals of the early silver veins. The chief gangue mineral is quartz, but some barite and ankerite are present locally. The paragenesis of the minerals is shown in figure 49. Near the intersection with the Mud vein (fig. 123), the early silver veins of both the Yellow Pine and the Logan mines are strongly sheared, and the sulfides are reduced to a fine-grained gouge. In the Logan mine the early silver vein is cut by veinlets of marcasite, pyrite, and quartz that probably belong to the later period of tungsten mineralization. For further discussion of the silver veins, see the descriptions of the Logan and Yellow Pine mines.

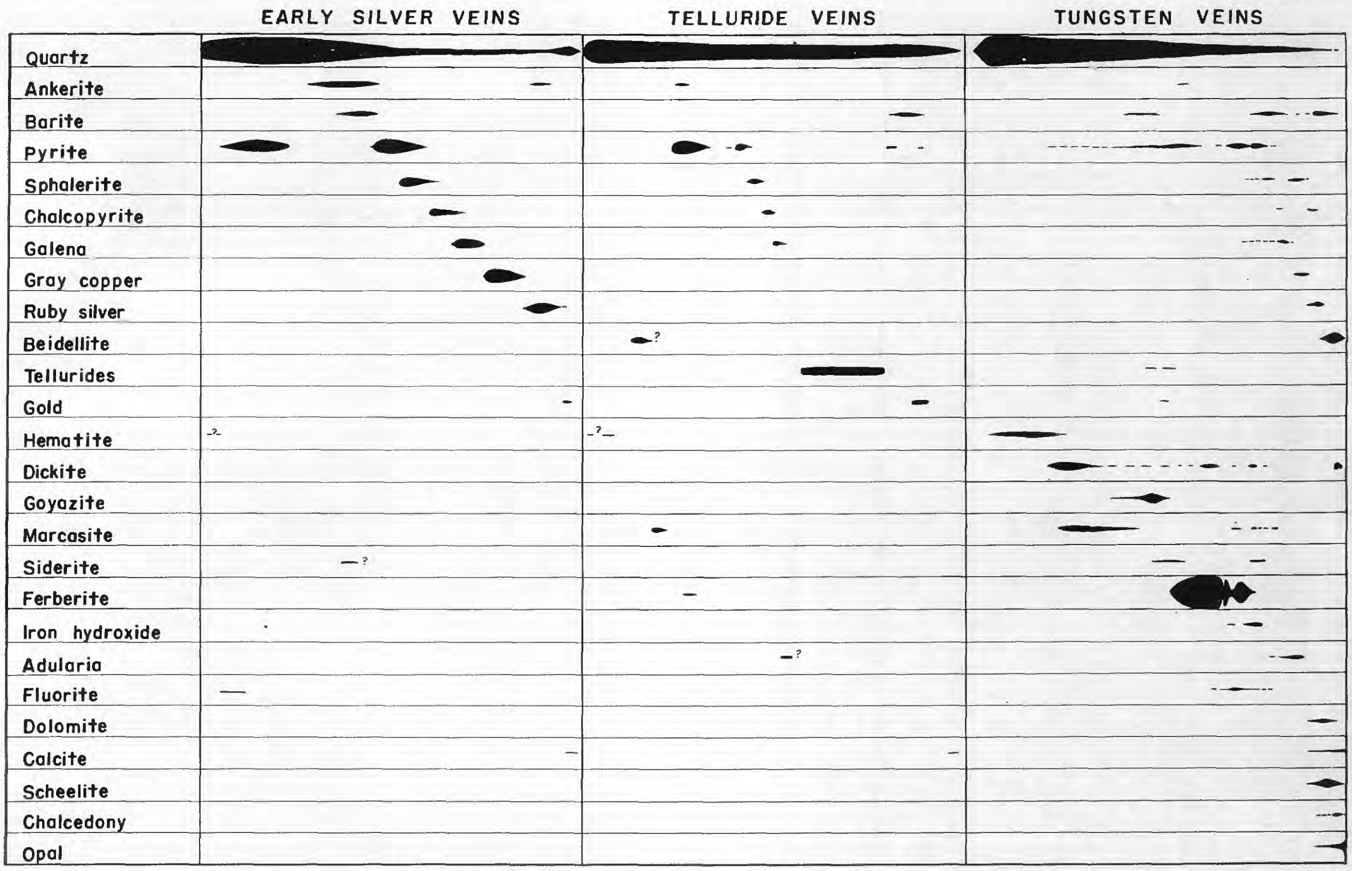


FIGURE 49.—Chart showing the paragenesis of the vein minerals of the Boulder County tungsten district.

EARLY PYRITIC VEINS

Pyritic quartz veins that are older than the tungsten ores are found in the eastern part of the district as well as at several localities adjoining the district. These veins contain some gold, and a few of them outside the tungsten district have been productive, but the gold content of most of the veins within the district is too low to be of economic interest. In the Gold Hill district, which adjoins the tungsten district on the northeast, Goddard (1940, p. 125) found some pyritic veins that are later than the gold telluride ores, but in most of the eastern part of the Front Range mineral belt, the pyritic veins are relatively early. Many of the early pyritic quartz veins in the tungsten district were later reopened and partly mineralized with tungsten, but some were not. The Pleasant Dream vein in the Good Friday mine is a strong vein of pyritic horn quartz which can be traced at the surface for more than a mile. It contains a trace of gold, but to the writers' knowledge, no gold ore has been mined from it. Near the Good Friday shaft on the lower tunnel level, it is joined from the northeast by the tungsten-bearing Good Friday vein, and for several hundred feet to the west the composite Pleasant Dream-Good Friday vein was stoped for tungsten. The Pleasant Dream vein was also mineralized with tungsten at places east of the junction, and a moderate amount of tungsten was recovered from a branch of it in the Little Lester mine.

Mineralization in the strong shear zone east of the Conger mine (p. 110) may be related to the early pyritic veins or it may be older. The shear zone is cut by horn quartz veins that contain a little tungsten, and along numerous postmineral fractures, the sulfide-bearing rock has been finely brecciated or reduced to gouge and later silicified. Strong alteration along these younger fractures is similar to the argillic alteration along the tungsten veins. The shear zone contains abundant pyrite, which occurs as disseminated grains in strongly fractured schist, aplite, and pegmatite, as larger irregular masses replacing biotite in schist, and as small veinlets. Locally, veinlets that appear to be marcasite cut the pyritic rock. At places in the shear zone, galena, sphalerite, gray copper, and chalcopyrite are fairly abundant, occurring both in small veinlets and disseminated in schist and injection gneiss. The shear zone contains, also, both molybdenite and graphite. The molybdenite occurs in small veinlets and disseminated flakes in schist, aplite, and pegmatite. The graphite is confined largely to the schist, where it is associated with and in part replaces biotite, but it is also found in minor quantity in the granitic rocks.

The graphite is probably of hydrothermal origin and not a metamorphic constituent of the schist, for it occurs in granite as well as schist, is closely associated with sulfides, and is absent from the schist outside the shear zone. The origin of the graphite is not understood, but there may be some relation between the graphite and an undentified gas present under relatively high pressure in the schist of the shear zone. At a depth of 250 ft in a flat hole drilled N. 13° E. from the north breast of the 200-ft level of the Greyback mine, drillers for the Vanadium Corp. of America encountered a pocket of foul-smelling gas that was under pressure high enough to blow several 10-ft sections of the string of drill rods from the hole. The drillers suffered no ill effects, but they did not linger when the blast of foul gas blew their lights out. The gas pocket was several hundred feet from the Conger workings, and as it was well above the water level in any neighboring mines, there is little likelihood that it was "timber gas" or any other gas concentrated in mine workings and trapped in a crevice under a hydrostatic head. The sulfide minerals in the drill cores show no trace of oxidation; so it is unlikely that the gas was an oxidation product.

GOLD TELLURIDE VEINS

Gold telluride veins are limited to the east half of the district and are most abundant close to the Hoosier and the Livingston breccia reefs. The gangue of the gold telluride veins is a fine-grained horn quartz or fine-grained sugary quartz carrying only a small percentage of other minerals, chiefly pyrite. The pyrite is disseminated in the quartz, and because of its fineness of grain and relative abundance it colors the quartz light gray to nearly black. Thin seams of carbonate and a small amount of barite are present locally. The ore minerals are chiefly the gold and silver tellurides, but free gold also is present. Accessory sphalerite, galena, pyrite, and gray copper accompany the ore minerals, but in such small amounts that they are of little commercial importance. The age relations of the minerals are shown in figure 49.

At the Herald mine, in the east-central part of the tungsten district, ferberite and gold tellurides occur in the same vein. The ferberite is present in very meager amounts and is doubtless a product of the gold telluride mineralization. It is definitely earlier than the gold telluride and free gold.

The texture of the gold telluride deposits is fairly open, but drusy openings are not as common as in the tungsten veins. The different generations of quartz are marked by well-defined bands or seams that pinch and swell with the variations in width between the walls of the fissures. The quartz seams that contain the high-grade telluride ores are narrow, and much of the production has come from veins only a few inches wide. The telluride minerals occur in blades and irregular masses that have filled small openings in the quartz, but coarse, well-formed telluride crystals are rare in the vugs, which are fairly common in these veins. An unusual type of gold telluride vein is exploited at the Recluse mine, about 1½ miles southwest of Sugar Loaf Post Office. There the telluride minerals are disseminated through a strongly banded vein of fine-grained pyrite that carries very little quartz and only a few scattered grains of sphalerite and galena.

The localization of ore in the telluride veins is apparently caused by the same features as in the tungsten veins; it is discussed in the section on ore shoots. There is a pronounced difference in the habit of the two types of veins in the Iron dike, however. The Iron dike seems to have had some special affinity for gold telluride, and the ore in many gold mines along the dike is almost entirely restricted to the dike. In some of these mines the telluride minerals are plastered like foil on the walls of fractures that are little larger than joints, and no trace of them is found outside the dike. Many of the tungsten veins, on the contrary, weaken markedly in the Iron dike, and none of them are known to contain ore within the dike.

TUNGSTEN VEINS

The mineralogy of most of the tungsten veins appears very simple; in most of the ore only horn quartz and ferberite are visible. A few minute grains of pyrite can be found in most specimens of ferberite when examined with a microscope, and pyrite and marcasite are locally abundant enough to be seen in hand specimens. The color of the successive generations of horn quartz that preceded and followed the deposition of the ferberite ranges from white through gray, green, and brown to black and depends upon the presence of various finely disseminated accessory minerals (pp. 44–45). At many places the various types of horn quartz occur in parallel veinlets and in streaks of breccia which give the vein a strongly banded arrangement (fig. 50). Some

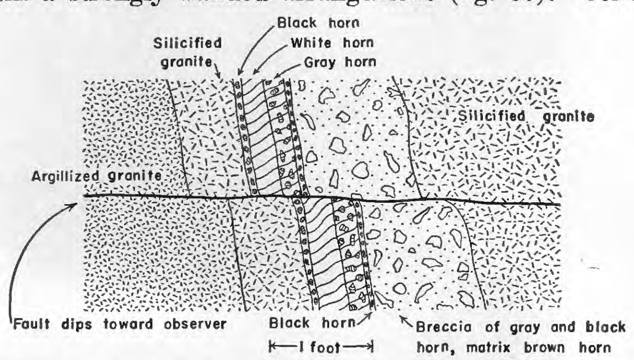


FIGURE 50.—Sketch showing the banding of horn quartz in the Clyde vein, Boulder County, Colo., 5 ft from the Clyde shaft and 50 ft above the tunnel level.

early siderite is locally associated with the horn quartz, and a little of it was deposited with the early ferberite. Calcite, barite, white horn quartz, opal, and the clay minerals occur in vugs in the early horn quartz and ferberite ore, and chalcedony and scheelite are found locally. The quartz is generally vuggy, brecciated, and porous near the ore bodies but may be tight and dense in the barren segments of the veins; as a result the ore shoots are usually wet and the barren portions of the vein are mostly dry. However, open, dry, vuggy quartz is present beneath many of the ore shoots, and large unfilled vugs are often found in or adjacent to excellent ore (fig. 51).

FIGURE 51.—A barren silicified portion of the Clyde vein, Boulder County, Colo., on the tunnel level. The white seams outlining the fragments in the vuggy opening to the left and above the hammer consist chiefly of beidellite and barite with some dickite. The cavity to the right and above the hammer is a natural vug and contains no ore, though the vein was rich in ferberite less than 20 ft away.

In most of the tungsten ore, the ferberite forms the matrix of a breccia of horn quartz or country rock, but solid seams of high-grade ferberite ore free from fragments of country rock or quartz are found in some veins, and in a few the ferberite is in brecciated fragments cemented by later quartz. Practically all the ferberite is intergrown with some horn quartz, but the amount of quartz varies widely. Pure-looking, coarsely crystalline ferberite from the Beaver Creek district contains as little as 1 or 2 percent silica, but the high-grade ferberite from most other localities contains several percent (table 4). From this type of high-grade ore there is a complete gradation through horny ferberite (fig. 45) to low-grade black horn that consists essentially of quartz colored by finely disseminated ferberite. Nearly all the ferberite ore mined shows alternate generations of rich and lean ferberite-bearing quartz. Specimens of the common types of ore are shown in figures 41, 43, 44, 45.

The width of the ferberite-bearing veins ranges widely. The average width of most of the veins mined is 6 to 12 in. (figs. 52, 53), but seams of high-grade ferberite only an inch wide have at times been mined as commercial ore, and shoots of high-grade ore 2, 3, or even 5 ft wide have been found locally in a few veins. Locally the ferberite is in veinlets in broad sheared or sheeted zones, or in wide shattered zones near vein intersections. Ore bodies of this type reach widths of as much as 20 ft, but they are exceptional.

FIGURE 52.—A tungsten vein typical of the Boulder County district. Photograph taken 80 ft above the fourth level of the Cold Spring mine. The high-grade ferberite ore shows as narrow, black, irregular areas in the vein.

The tungsten ore is notably spotty in its occurrence. A wide shoot of high-grade ore may give way abruptly along strike or dip to barren quartz or gouge (fig. 54), and conversely, an apparently barren, unmineralized fracture may, after blasting, show a highly profitable ore body.

MINERALIZATION IN BRECCIA REEFS

Sometime after the breccia-reef fracture zones were formed, and after the Iron dike was intruded but before any of the veins described were formed, the breccia reefs were mineralized with quartz and hematite as described on p. 30. This mineralization was essentially barren of precious or base metals, but most of the reef quartz assays a trace of gold, and the Rogers

FIGURE 53.—Vein of high-grade tungsten ore, fourth level of the Cold Spring mine, Boulder County, Colo. The ore is wider than the average of the vein. The black material assays 40 to 60 percent WO_3.

FIGURE 54.—A barren portion of the Tungsten vein, Boulder County tungsten district. Photograph taken a short distance north of the main ore shoot in the Tungsten (Chance) mine.

reef assays as high as 0.03 oz of gold per ton in places. The quartz-hematite mineralization appears to have sealed the reef-fracture zones, for in general these remained unaffected during the later periods of mineralization. They were remineralized in a few isolated localities, however, and the several types of mineralization found in such deposits testify to the early age of the reefs. In the Yellow Pine mine early silver ore is closely associated with the Hoosier breccia reef (see description of the Yellow Pine mine). The Hurricane Hill breccia reef contains sulfides of iron, copper, lead, and zinc with some silver, and similar ore is found at places in the Rogers reef. These occurrences are probably related to the early silver veins. Breccia reefs in the area adjoining the northeast end of the district have been mineralized at places by pyritic gold ore and by gold telluride ore (Goddard, 1940, pp. 119–121, 125–126, fig. 2), and the Copeland reef south of Magnolia contains gold telluride (Wilkerson, 1939b, p. 95).

The breccia reefs contain tungsten at several localities, particularly near the margins of the district and in outlying areas. On the Great Sphinx claim, on the east slope of Arkansas Mountain (pl. 2), tungsten occurs in several closely spaced seams of sheared and silicified rock in the footwall fracture zone of the main Poorman breccia reef. Finely crystalline ferberite and black, tungsten-bearing horn quartz cement a breccia of silicified rock and occur as small pockets and veinlets in moderately persistent minor veins of gray horn quartz within the crushed and silicified rock. The nearby Little Wallace K. mine, on the northeast branch of the Hoosier breccia reef at the foot of the Yellow Pine dump, is said to have produced tungsten ore valued at $60,000 during World War I.

The Ohio mine (fig. 135), on the ridge south of Bummers Gulch about 3,500 ft east of Millionaire Gulch, is on a wide east-west breccia-reef fracture zone that branches from the main Hoosier reef a short distance east of the mine. Crushed or sheared rock, some of it hematite-stained, occurs in several streaks, each several feet wide, in a zone 50 to 75 ft wide. Veinlets of late ferberite and scheelite ramify through these streaks and the intervening shattered pegmatite, making a large body of fairly low grade ore that was mined chiefly by glory-holing.

The Copeland breccia reef is tungsten bearing at the Copeland mine, near South Boulder Creek about 2½ miles south of Magnolia. This occurrence is described in connection with the Copeland mine.

A northwestward-trending reef that is part of the Rogers breccia-reef system is mineralized with tungsten on the Walker ranch, about half a mile west of Crescent station on the Denver & Rio Grande Railway and about 5 miles south of the main tungsten district. Small veins of high grade, coarsely crystalline ferberite occupy late fractures within or alongside the reef; finely crystalline ferberite occurs in places on joint faces and in small spots or bunches in reef breccia, mostly in close association with reef hematite; and tungsten-bearing black horn quartz of low grade seams the sheared reef rock or cements a breccia of sheared and silicified rock in places, particularly near the intersection of the northwestward-trending reef with one that trends N. 80° E. The granite along east-northeastward-trending veins that branch from the northeast side of the reef is intensely altered and shows both the argillic and the sericitic alteration characteristic of the veins in the main tungsten district. These veins contain a little gray and greenish-gray horn quartz, but no ferberite has been found in them.

Fairly high grade ferberite ore occurs in northwestward-trending fractures of the Hurricane Hill breccia reef and in intersecting northeastward-trending fractures about 1½ miles east-southeast of Tungsten Mountain.

SUPERGENE ALTERATION

GENERAL CHEMISTRY

Certain agents of supergene alteration, such as oxygen, carbon dioxide, and the organic acids derived from decaying vegetation, are nearly everywhere present in the ground water above the water table. The more active agents, such as sulfuric acid and ferric sulfate, are confined to the places where pyrite or marcasite is decaying. The susceptibility of the vein minerals and the country rock to attack varies greatly in different deposits, but the relative solubility of the minerals in the oxidized zone is of less importance in secondary enrichment than the readiness with which they may be precipitated in the reducing environment that exists below the water table. With those compounds that are sensitive to a change from an oxidizing to a reducing environment, the speed with which precipitation takes place, and consequently the depth and richness of the secondary sulfide zone, depend upon the rate of change in the acidity of the solution. In veins containing large proportions of primary minerals that react readily with acid solutions and would therefore rapidly neutralize them, the change from oxidizing to reducing solutions is rapid, and a marked zone of secondary sulfide enrichment would be expected. Carbonate gangue, galena, and sphalerite react rapidly with acid sulfate solutions, and the veins containing noteworthy amounts of these minerals may be expected to show a definite zone of supergene sulfide enrichment. In pyritic quartz veins the effect would be the reverse.

Both residual enrichment and supergene sulfide enrichment are determined by the composition of the vein, the former upward extent of the ore deposit above the present erosion surface, and the past and present position of the ground-water table. Because of the last-mentioned factor, the distribution of supergene ore is closely related to the physiography of the area, and veins are much more extensively enriched on the gently rolling upland surfaces than on the steep sides of the major stream valleys.

SULFIDE AND TELLURIDE VEINS

In the silver veins of the tungsten district there is usually a greater concentration of gold in the outcrop than in the primary ore, but silver is leached out of the uppermost part of a vein. In the oxidized zone a short distance below the outcrop more gold and silver are present than in the primary ore, but the richest ore may be expected in the zone of supergene enrichment at and below the water table. Nearly all the highest-grade ore is found at depths of less than 300 ft from the surface, and most of it at depths of less than 150 ft. The transition from the zone of sulfide enrichment to primary ore is gradual in most deposits, and the lower limit of the secondary sulfides is a very irregular zone rather than a sharp line.

The thoroughly oxidized parts of the sulfide veins consist chiefly of brown claylike material that is rich in both silver and gold. Residual masses of oxidized galena ore which contain much gold and silver are irregularly distributed throughout the oxidized zone in these veins. Sooty masses of secondary copper minerals rich in silver are scattered through the secondary sulfide zone, and some of the fractures in the primary ore contain well-crystallized secondary sulfarsenides of silver.

The small content of reactive minerals in the gold telluride deposits and the insolubility of the gold and gold telluride are unfavorable to secondary enrichment but favorable to residual enrichment. The outcrop and the oxidized zone of most of the telluride veins are distinctly richer in gold than the primary ore, but only very rarely can any secondary sulfide be recognized. In the upper part of the oxidized zone, gold telluride decomposes to fine-grained, semicolloidal gold associated with limonite. This is the "rusty gold" so eagerly sought by the prospector. In some places droplets of native mercury can be made to exude from the surface of limonite-stained horn quartz by hammering; the mercury indicates the former presence of coloradoite, the mercury telluride.

TUNGSTEN VEINS

Ferberite is very resistant to weathering and, as a rule, weathers more slowly than the country rock, particularly if it is not accompanied by pyrite or marcasite. There is practically no enrichment of the tungsten ores except for the residual concentration of ferberite near the outcrops of the veins. Much of the tungsten ore first mined in Boulder County was the so-called "float ore" or "potato ore" picked off the surface. The ferberite is brittle and will withstand transportation by streams for only a short distance. Placer tungsten is consequently confined to the gulches close to the outcrops of tungsten veins.

Even where ferberite is accompanied by relatively abundant pyrite and marcasite and abundant limonite forms in the zone of oxidation, the ferberite changes very slowly to the iron oxides, and most of it is bright and fresh at the vein outcrops. Most of the limonite found in the upper part of the ferberite ore bodies is transported limonite derived from the oxidation of sulfides rather than ferberite, and in the few places where ferberite has changed to limonite, it shows the grain-at-a-time replacement described on page 42 rather than the anastomosing network of replacement veinlets characteristic of partly oxidized pyrite.

Where the vein or the wall rock contains disseminated pyrite, the lack of activity of the associated minerals results in more extensive transportation of limonite than in most veins. Limonite-stained walls may be seen as much as 150 ft below the surface, and local oxidation effects are perceptible along open channels at even greater depths. The presence of small amounts of marcasite in the veins, and the ease with which it oxidizes, cause the mine waters to be acid, and deposits of black ferrous sulfide and brown iron hydroxide have formed at many places where water issues from the veins into mine openings. Although these deposits contain a little tungsten (p. 43), the amount is small, and the leaching of tungsten has been negligible in most veins.

The small amount of tungstite that is found in the upper parts of some veins in the district was probably transported by the tungsten-bearing ferric sulfate solutions of the type just described. Experiment has shown that following decomposition of ferberite by acid, the iron is much more readily precipitated than the tungsten trioxide upon neutralization of the solution (Lovering, 1941, pp. 269–270). Tungsten and iron might therefore become separated, the tungsten being carried deeper in the vein and deposited as the hydrated oxide tungstite, but the rarity of tungstite indicates that, once dissolved, very little tungsten was reprecipitated.

HYDROTHERMAL ALTERATION

GENERAL FEATURES

Although some of the ferberite ore is found in veins between nearly fresh walls, the wall rock of most of the veins is hydrothermally altered. The zone of alteration is generally 5 to 20 times the width of the vein. One of the most striking features of the tungsten veins is the almost universal presence of two sharply defined divisions in the envelope of altered rock adjacent to the vein (fig. 55). Most of the productive veins have a narrow casing or sheath of silicified and sericitized rock which is ordinarily thinner than the veins themselves. This sheath gives way abruptly to a zone where the dickite and beidellite are abundant; this argillized zone is very indefinitely bounded on its outer side. The chalky complexion of the soft, clay-bearing rock contrasts much more sharply with the fresh granite than the silky sheen and the yellowish or greenish appearance of the sericitized zone, with the rather surprizing result that as a vein is approached the rock first appears more and more bleached but then seems to give way abruptly to a rock that is almost normal in appearance except for the absence of fresh biotite. The general effect is that of a narrow bar of moderately fresh granite separating the vein from a wide zone of strongly altered granite, which in turn grades gradually into fresh rock some distance away. Although this type of alteration is characteristic of the

FIGURE 55.—Altered wall rock adjacent to the Cold Spring vein, fifth level of the Cold Spring mine, Boulder County, Colo. The inner edge of the sericitized casing is at the edge of the vein, at the point of the hammer, and the outer edge is about 2 in. to the right of the end of the hammer handle. The clay-bearing rock farther to the right contrasts decidedly with the fresher-appearing sericitized casing.

tungsten veins, the two divisions are seldom discernible in the gold telluride and early silver veins of the district. In most places where these latter ores occur, the wall rocks are sericitized, silicified, and pyritized, but they rarely contain a zone characterized by clay minerals.

ARGILLIC ALTERATION

The term "argillic alteration" was first used in 1941 (Lovering, 1941, p. 236) to describe that type of hydrothermal alteration that has resulted in the prominent development of clay minerals. Studies in many districts in the ensuing decade have shown that argillic alteration is not uncommon but heretofore has rarely been recognized as hydrothermal alteration.

In the Boulder County district the wall rocks of most of the tungsten veins are more or less argillized, but the alteration is most prominent near the larger veins and next to some of the barren premineral faults. Along most of the veins the wall rock is altered for a distance of less than 30 ft on either side of the vein, but in places along the barren Madeline vein and along a vein in the Illinois mine the alteration extends to a distance of more than 50 ft.

The minerals of the Boulder Creek granite were attacked selectively by processes of alteration that formed several clay minerals. Oligoclase and ilmenite were by far the most susceptible to attack. Biotite was moderately stable, and orthoclase, quartz, and microcline remained fresh even in the zone of most intense alteration.

In the outermost zone of alteration, veinlets of leucoxene and carbonate appear in the ilmenite, and oligoclase is replaced along crystallographic directions by sericite and low-index isotropic clay minerals, which probably include both allophane and cimolite. The clay is disseminated through irregular areas in very fine blebs and shreds; the sericite, in contrast, cuts sharply through the oligoclase in stringers parallel or, more rarely, almost perpendicular to the twin lamellae. The clay tends to orient itself perpendicular to the twin lines (figs. 56, 57). Somewhat closer to the vein, where the rock begins to show strongly bleached plagioclase crystals, beidellite appears. Beidellite extensively replaced the allophane and the fresh oligoclase, but it did not affect the sericite. The replacement veinlets of beidellite wind and branch through the oligoclase with little regard for crystallographic direction, in contrast to the definite pattern of the sericite (fig. 58). Beidellite reaches its maximum development in a zone about halfway between the vein and the outer fringe of altered rock.

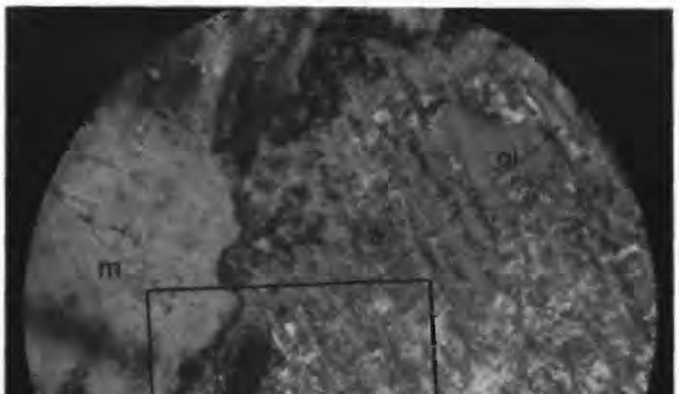


FIGURE 56.—Photomicrograph showing hydrous mica, sericite, and allophane replacing oligoclase along crystallographic directions. Boulder Creek granite 25 ft from the Cold Spring vein, Boulder County, Colo. Note the preferential replacement of oligoclase, right, in contrast to microcline, left: *m*, microcline; *ol*, oligoclase; *hs*, hydrous mica and sericite; *a*, allophane. ×165. Crossed nicols. (See figure 57 for enlargement of area within box.)

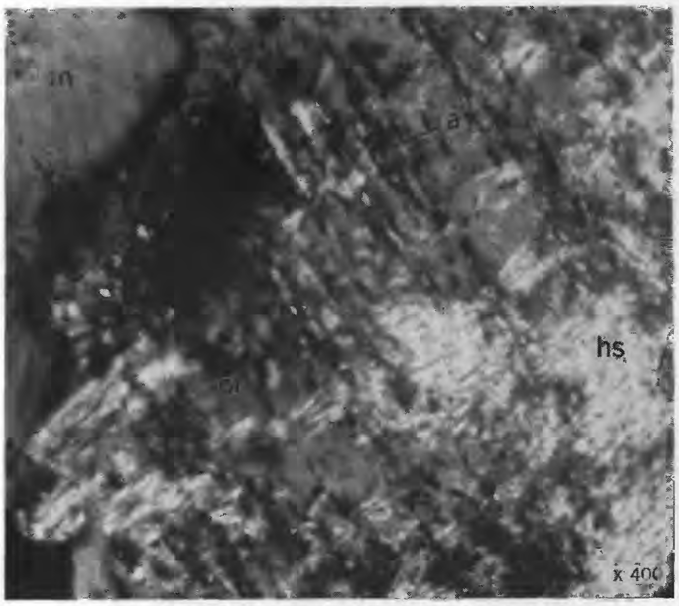


FIGURE 57.—Part of the field shown in figure 56: *ol*, oligoclase; *hs*, hydrous mica and sericite; *a*, allophane; *m*, microcline. ×400. Crossed nicols.

Intimately associated with the beidellite is a sericite-like mineral here termed hydrous mica, which is optically identical with a mineral from the Franklin, N. C., kaolin deposits described by Ross and Kerr (1931, p. 172). Most of the hydrous mica occurs in mattelike areas rather than in veinlets. The beidellite and associated hydrous mica are almost entirely confined to oligoclase; the microcline, orthoclase, quartz, and sericite are not attacked. Some of the beidellite-hydrous mica mattes alter in irregular spots and veinlets to halloysite, which encloses recognizable crystals of dickite in various stages of development.

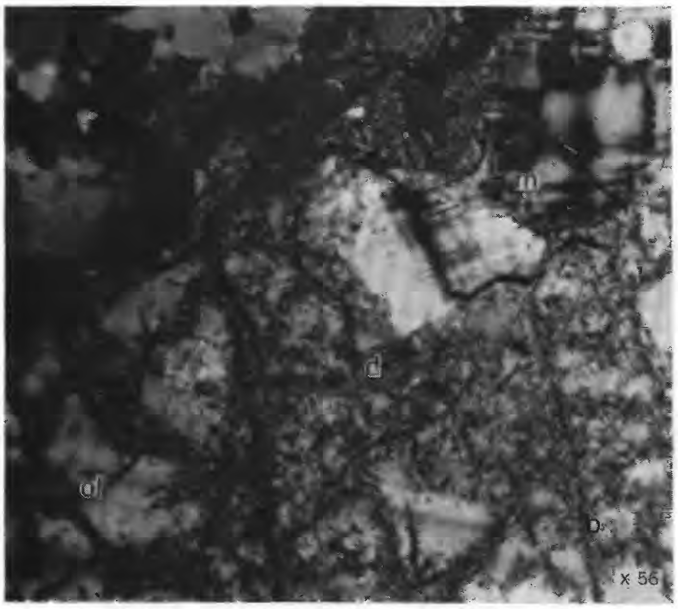


FIGURE 58.—Photomicrograph showing beidellite and dickite replacing oligoclase but leaving microcline and orthoclase unattacked. Boulder Creek granite 10 ft from the Cold Spring vein, fifth level of the Cold Spring mine, Boulder County, Colo.: *ol*, oligoclase; *m*, microcline; *b*, beidellite; *d*, dickite. × 56. Crossed nicols.

Dickite first appears in the central part of the beidellite zone, and veinlets of beidellite quite commonly have central seams of dickite (fig. 59). Veinlets of this type become smaller in strongly sericitized areas, where the beidellite is replaced by sericite, and only the dickite portion remains as relict veins within the sericite. Dickite veinlets in the inner part of the dickite zone are unaccompanied by a border fringe of beidellite. Such veinlets are coarser-grained and somewhat later than the beidellite-dickite veinlets. The amount of dickite present increases steadily as the vein is approached until the sericitic sheath is reached, where it drops sharply.

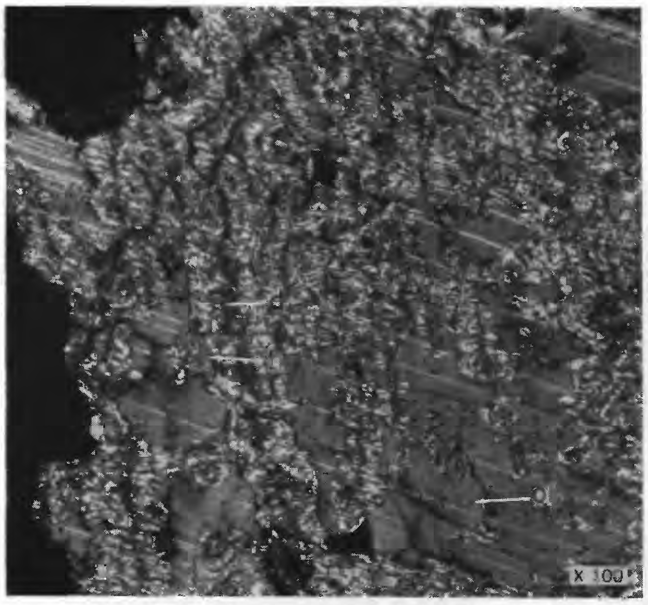


FIGURE 59.—Photomicrograph showing dickite following the center of beidellite replacement veins in oligoclase. Boulder Creek granite 10 ft from the Cold Spring vein, fifth level of the Cold Spring mine, Boulder County, Colo.: *ol*, oligoclase; *d*, dickite; *b*, beidellite. × 100. Crossed nicols.

In the zone where beidellite is the dominant clay mineral, nearly all the biotite is fresh, but as dickite becomes more abundant, the biotite becomes altered. In the first stage of alteration, the biotite is cut by veinlets of carbonate and leucoxene parallel to the cleavage. In the second stage the biotite becomes decolorized in irregular areas, taking on the general appearance of some strongly birefringent chlorite, but it is probably a hydrous biotite. In a still more advanced stage of alteration, dickite appears and replaces the decolorized biotite and, to a lesser extent, the brown biotite itself. Orthoclase, microcline, and quartz remain almost unaffected even in the zone of most intense alteration to dickite, but a few grains are cut by veinlets of dickite or quartz formed by the filling of fractures. Where the sericitized sheath is lacking, dickite increases in abundance up to the vein itself, which, under these conditions, is unlikely to be sufficiently mineralized that the deposit will be commercially important. Ilmenite shows some oxidation to hematite in the beidellite zone, and it is completely converted to hematite and leucoxene in the zone where dickite is abundant.

The chemical changes involved in argillic alteration are shown in figures 61 and 62 and are discussed on pages 61–63.

SERICITIZATION AND RELATED ALTERATION

Sericitization was most extensive along the gold telluride veins, but it occurred also along most of the tungsten veins, and some of the larger tungsten veins are encased in sericitized shells several feet thick. As mentioned, a little sericite is also found in the outer part of the argillized zone, throughout the beidellite zone, and even in the zone where dickite is the dominant clay mineral, but most of the sericite is in the casings adjacent to the veins. There it is associated with relatively coarse grained hydrous mica that may easily be mistaken for the sericite itself. The hydrous mica has replaced dickite and biotite and was in turn replaced by sericite. In the outer part of the casing, hydrous mica is relatively fine grained and is intergrown with fine-grained dickite. Nearer the vein it is coarser and is intergrown with coarse sericite. Both quartz and coarse sericite cut and replace the fine-grained hydrous mica-dickite masses. (See fig. 60.) Some of the quartz is probably contemporaneous with the coarse sericite, but some is distinctly later.

Near some of the veins much of the rock has been converted to fine-grained quartz, but in most places silicification is of minor importance. However, most

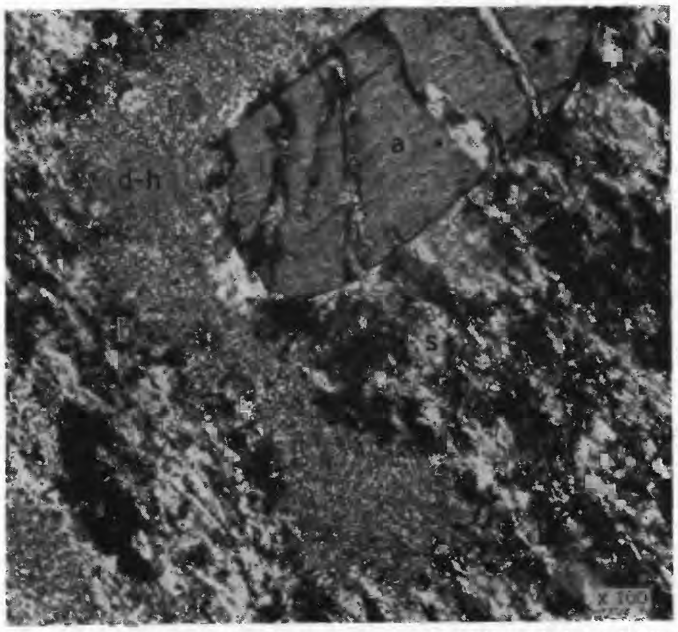


FIGURE 60.—Photomicrograph showing quartz and sericite replacing a dickite-hydrous mica intergrowth in Boulder Creek granite adjacent to the Cold Spring vein, fifth level of the Cold Spring mine, Boulder County, Colo.: *q*, quartz; *s*, sericite; *d-h*, dickite-hydrous mica intergrowth; *a*, apatite. × 100. Crossed nicols.

of the breccia fragments within the quartz veins are silicified, whether the original material was fresh granite or rock that had been largely replaced by clay or sericite.

In the sericitized casing nearly all the biotite is converted to sericite, hydrous mica, or chlorite, but a few relatively fresh biotite crystals may persist even in this zone where the oligoclase was completely destroyed. Orthoclase, microcline, quartz, and apatite show little or no replacement but are cut by fracture veinlets of secondary quartz, sericite, or siderite.

The ilmenite, which was completely changed to hematite in the dickite zone, is altered to magnetite or pyrite in the sericitized casing. These minerals are associated with leucoxene and secondary sphene, and veinlets of these latter two minerals also traverse all the other minerals and alteration products. Although leucoxene has been found throughout the altered wall rock, even to the outer fringe of the zone of clay minerals, secondary sphene is confined to the sericitic casing close to the vein. Crystals of goyazite are not uncommon in the altered wall close to the vein and are commonly associated with small areas of carbonate, probably siderite. Adularia has been found as a late mineral close to some of the large tungsten veins, where it occurs chiefly as a fracture filling.

CHEMICAL CHANGES IN THE ALTERED ROCKS

As shown in table 5 and by figures 61 and 62, analyses of specimens ranging from fresh to thoroughly altered rock show a consistent progressive change in composition from the outermost zone to the edge of the sericitized casing, where a sharp reversal in the chemical trend takes place. A plot of the molecular percentages of the constituents contained in the same volume of rock shows a continuous decrease in the proportion of silica through the zone of argillic alteration and an abrupt increase in the sericitized zone next to the vein (fig. 61). The alumina and total iron remain nearly constant, but the proportion of ferrous oxide to ferric oxide reaches a maximum in the dickite subzone (rock 3 ft from vein, fig. 61). Magnesia decreases in the clay zone and increases very slightly in the sericite zone. Lime decreases through both zones. Potash decreases in the outer part of the argillized zone and increases through the area of more intense alteration, both in the dickite

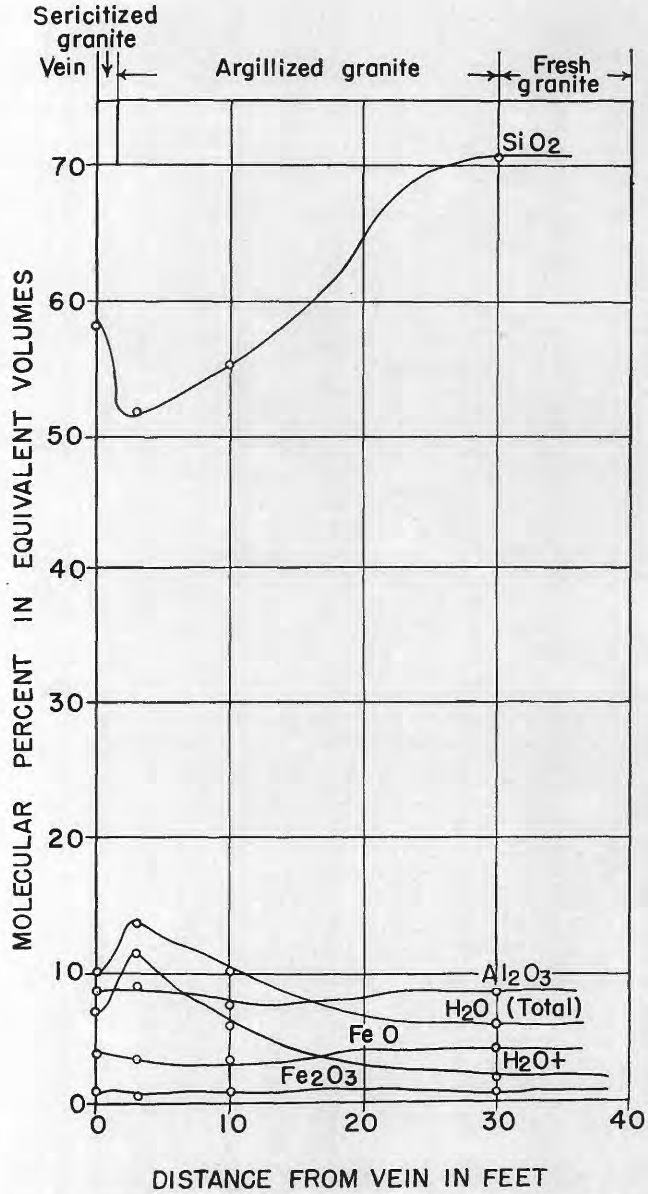


FIGURE 61.—Changes in the molecular proportion of SiO_2, Al_2O_3, H_2O, FeO, and Fe_2O_3 in equivalent volumes of altered Boulder Creek granite adjacent to the vein, fifth level of the Cold Spring mine, Boulder County, Colo.

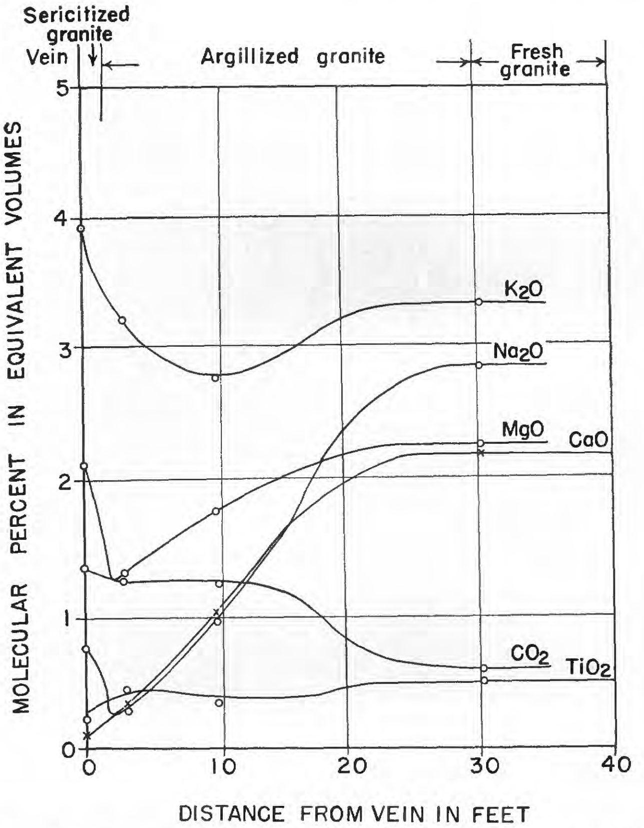


FIGURE 62.—Changes in the molecular proportion of K_2O, Na_2O, MgO, CaO, TiO_2, and CO_2 in equivalent volumes of altered Boulder Creek granite adjacent to the vein, fifth level of the Cold Spring mine, Boulder County, Colo.

subzone and in the sericite casing. Soda decreases sharply through the argillized zone and shows a marked increase in the zone of sericitization. Total water reaches its maximum just outside the sericite casing, and where dickite is most abundant the water driven off above 100 C is much in excess of water lost below this temperature. Farther away from the vein, where beidellite is abundant, the H_2O+ diminishes in amount and the H_2O- increases. These relations are in harmony with the dehydration curves of the two clays.

TABLE 5.—*Analyses of altered wall rocks, Boulder County tungsten district*

[J. G. Fairchild, analyst]

	1 (fresh)	2 (altered)	3 (altered)	4 (altered)	5 (fresh)	6 (altered)
SiO_2	68.71	66.61	63.34	65.67	66.31	65.08
Al_2O_3	14.93	15.13	18.21	16.52	15.07	15.26
Fe_2O_3	1.02	1.40	.79	1.21	1.35	1.30
FeO	2.07	2.26	2.44	2.53	2.71	2.90
MgO	1.50	1.45	1.08	1.00	1.03	.93
CaO	2.01	1.23	.40	.08	2.06	.43
Na_2O	2.85	1.20	.41	.81	2.48	.94
K_2O	5.14	5.02	6.11	6.70	5.96	8.63
H_2O-	.14	1.45	.71	.94	.06	.17
H_2O+	.56	2.08	4.07	2.34	.90	1.38
TiO_2	.62	.54	.75	.33	.66	.75
CO_2	.46	1.09	1.16	1.70	.98	1.75
P_2O^5	.16	.19	.24	.22	.32	.31
SO_3	N. d.	N. d.	N. d.	N. d.	N. d.	.64
S (total)	Trace(?)	.02	.04	.02	.04	N. d.
	100.17	99.67	99.75	100.07	99.93	100.47
Powder density	2.671	2.625	2.642	2.673	2.710	2.688
Bulk density	2.631	2.173	2.177	2.283	2.700	2.461

1–4. Samples of Boulder Creek granite from the fifth level of the Cold Spring mine collected at distances of 35 ft., 10 ft., 3 ft., and ½ in. from the vein.
5. Fresh aplite, related to the Boulder Creek granite, from the Lily tunnel, 6 ft. from a barren part of the Rake-off vein.
6. Sericitized aplite adjacent to the Rake-off vein, Lily tunnel.

The inflection points of most of the curves shown in figures 61 and 62, at the contact of the zone of sericitic and argillic alteration, are noteworthy in that they are quite unlike graphs that represent alteration in most mining districts. The paragenesis of the alteration minerals and the chemical changes in the wall rock indicate that sericitic alteration was superposed on an earlier, argillic, type, and they suggest a radical change in the nature of the altering solutions at a late stage in the period of mineralization.

CHARACTER OF THE SOLUTIONS CAUSING ALTERATION

In their study of the hot springs of Lassen Peak, Day and Allen (1925, p. 141) state that the kaolin minerals are the product of hot or cold acid waters, in contrast to sericite, which presumably forms from alkaline solutions. Lindgren voiced his complete agreement with this view (1933, p. 457), and it is further supported by the experimental work of Noll (1936). The latter found that the formation of montmorillonite, a clay almost indistinguishable from beidellite, depends on the cation concentration and that this mineral, in contrast to "kaolin," forms best in solutions of definitely alkaline character. Kaolin formed instead of montmorillonite in solutions of bicarbonates, chlorides, and sulfates, especially if they were acid. Noll concluded that dilute solutions, active circulation, and the presence of carbonic acid or hydrochloric acid caused kaolin to form and that the converse of these conditions resulted in montmorillonite. As the potash concentration increased, sericite formed instead of montmorillonite and was the usual end product of dilute solutions containing potassium hydroxide.

In recent experiments by Lindner and Gruner, a kaolin mineral was formed through the action of hydrosulfuric acid on orthoclase at 300 C (Lindner and Gruner, 1939). In contrast, a sodium sulfide solution attacked orthoclase and formed acicular crystals of mica—either sericite or paragonite.

More recent work by Gruner (1944) showed that sericite forms rapidly above 320 C in acid or neutral solutions that contain a marked excess of potash over silica; below 320 C kaolin or pyrophyllite formed in the neutral or acid solutions. Sericite seemed to have a rather narrow stability range below 320 C and was synthesized only in mildly alkaline solutions; from moderately alkaline solutions orthoclase or kaliophyllite formed and sericite did not. The potash-silica ratio of the solutions also was a vital factor. At a given temperature and at a relatively low pH, sericite, pyrophyllite, or kaolinite could be formed successively by decreasing the proportion of potash to silica. Similarly, at a higher pH, orthoclase could be formed if the concentration of potash was low and sericite formed at a higher concentration.

Although the stability ranges of the minerals overlap, the generalization seems warranted that below 300 C kaolin minerals reflect acid solutions; beidellite, neutral or slightly alkaline solutions poor in potash; sericite, neutral or slightly alkaline solutions rich in potash; and orthoclase, more alkaline or less potassic solutions.

The behavior of iron in the oxidized zone of ore deposits, as well as the chemistry of the element as known in the laboratory, indicates that oxidation from the ferrous to the ferric state is characteristic of acid solutions or neutral ones carrying free oxygen. Only free oxygen and a very few powerful and unusual oxidizing agents are known to be capable of oxidizing ferrous to ferric iron in alkaline solution, and it is unlikely that such solutions exist in nature. Grunner (1930, pp. 704, 715) reported that, with constant displacement of equilibrium, it is possible to oxidize ferrous iron appreciably at high temperatures by using steam only, but the effectiveness of pure steam was very small as compared to that of steam containing a minute amount of hydrochloric acid.

More recently, Lindner and Gruner (1939, pp. 554–555) reported that they produced hematite by treating fayalite (Fe_2SiO_4) and magnetite with an alkaline solution of sodium sulfide, which they suggest is to some extent an oxidizing agent at high temperatures. Most of the material formed by reaction with fayalite is said to have been acmite and ferrous sulfide, but some small crystals of hematite were intergrown with the acmite. Reaction between sodium sulfide and ferrous silicate, however, would be expected to produce ferrous sulfide and sodium silicate, so that the few small crystals of hematite seem incongruous and suggest that the oxidizing agent must be sought elsewhere, presumably in air which may have been accidentally trapped in the apparatus. The fact that free sulfur formed during the attack of sodium sulfide solutions on orthoclase definitely shows that oxidation took place, as the authors point out, but because there is no oxidizing agent in orthoclase, the presence of a contaminant such as air seems clearly indicated. The only experiment noted in which hematite formed abundantly was one involving the derivation of hematite from magnetite. In this experiment, however, ferrous sulfide, as well as hematite, was a reaction product. No iron was oxidized; instead the ferrous oxide in magnetite was converted to ferrous sulfide by the following reaction:

$$Fe_2O_3.FeO+Na_2S+H_2O \rightleftarrows Fe_2O_3+FeS+2NaOH$$

It therefore seems that these experiments, far from proving that ferrous iron can be oxidized in alkaline *oxygen-free* solutions, suggest that the presence of free oxygen is essential to produce oxidation in other than acid solutions.

Although free oxygen is a common constituent of fumarolic gases, its association with nitrogen in about the proportion of 1 to 4 has led investigators to ascribe it to contamination with air or meteoric water (Clarke, 1924, pp. 262–272). The possibility that alkaline or neutral oxygen-rich hypogene solutions altered ilmenite to hematite in the zone where dickite is abundant seems remote. It is much more likely that the oxidation from ferrous to ferric iron took place in hot acid solutions and that solutions of this character were instrumental in changing oligoclase and the other aluminum silicate minerals to dickite.

Beidellite probably formed under approximately neutral conditions while allophane and sericite were developing in the outer fringe of the altered zones, where the spent solutions had become slightly alkaline. The presence of adularia, carbonate, sericite, magnetite, and pyrite in the narrow zone of sericitic alteration bordering the veins indicates that at a late stage the solutions changed from acid to neutral or alkaline and became reducing in character. The abundance of hydrous mica in this zone indicates that its development was furthered by such solutions.

ORIGIN OF THE ORES

MAGMATIC SOURCE

Approximate contemporaneity of igneous rocks and ores does not necessarily mean a common magmatic source. Nevertheless, *if* the igneous rock genetically related to the tungsten ores is exposed, it is likely to be the one most nearly contemporaneous with them. The biotite latite porphyry and intrusion breccia fulfill this qualification and show several other features that suggest that the tungsten and gold telluride ores were derived from the biotite latite magma.

The hornblende monzonite porphyry dikes in the western part of the district are displaced by about half the total movement along premineral faults that contain unbrecciated ferberite ore. In contrast, a biotite latite dike cuts across the Eureka tungsten vein (fig. 113) and contains inclusions of granite that show alteration effects characteristic of the tungsten mineralization. The dike itself is slightly altered where it crosses the vein, but to a much smaller extent than the granite wall rock.

In the Yellow Pine and Logan mines definite evidence was found that biotite latite and latitic intrusion breccia were intruded during one of the last of the movements that affected the veins (fig. 20). The dikes are apparently earlier than the gold telluride ores but contain fragments of early pyritic vein quartz. The biotite latite dikes and gold telluride veins in the mineral belt of the Front Range are spotty in distribution but are strikingly coextensive. This areal coincidence, together with other factors, led Lovering and Goddard (1938a, pp. 64–65) to conclude that the telluride ores were derived from the latitic magma, and as the gold telluride and tungsten stages of mineralization were nearly contemporaneous, the possibility that the latites are genetically related to the tungsten ore immediately suggests itself.

A suggestion that the latitic magma was the source of mineralizing solutions is also found in the character of the wall-rock alteration associated with latite dikes. The fresh biotite latite contains a remarkably high concentration of volatiles, as much as 4.06 percent H_2O+ and 4.60 percent H_2O-. The explosive violence with which thin persistent seams of breccia-charged latite must have been emplaced indicates a magmatic reservoir in which a tremenduous vapor pressure had been generated. It is not surprising that these rocks are commonly altered and are generally associated with mineralized fissures.

A short tunnel on the Lou Dillon claim, just east of Switzerland Park, exposes a small dike of biotite latite porphyry and associated intrusion breccia and also altered rock that seems genetically related to the intrusions (fig. 24*A*). The porphyry, which shows only at the portal of the tunnel, was intruded along a strong fault zone that strikes N. 30° E. and dips 70° NW. It is not found elsewhere in this fracture zone and seems to represent the top of a dike. The linear structure within the dike plunges southwest at a low angle. The porphyry is moderately fresh and forms the hanging wall of a nearly parallel seam of latitic intrusion breccia. To the south the breccia swings south and southeast from the porphyry dike along a branch fracture that dips 35°–65° W. This fracture rapidly weakens toward the south and disappears near the breast of the drift, a short distance south of the point where the intrusion breccia itself pinches out, which suggests that the fracture formed as a result of intrusion.

The latitic breccia contains disseminated marcasite and hematite and a minor amount of pyrite. The walls of the dike of intrusion breccia are strongly altered; for a distance of about 15 ft from the point where the breccia branches from the main dike, the granite wall rock is partly argillized and contains some marcasite. Coarse dickite is present close to the dike, but farther away the dickite gives way to beidellite, and this in turn to hydrous mica and sericite. Near the south end of the intrusion breccia the argillic alteration gives way to the sericitic type characteristic of the tungsten veins. Pyrite accompanies the sericite, but no ferberite was introduced. The relations seem to indicate that the alteration was caused primarily by solutions coming from the intrusion breccia or rising through it from the same source magma soon after its emplacement. The rock alteration is more intense close to the intrusion breccia than at a distance, and the argillic alteration occurs closer to the breccia than the sericitic type. The presence of marcasite and hematite in the argillized zone points to initially acid solutions, but the change in mineralogy in the outer fringe of the altered zone suggests that the solutions became alkaline as they soaked through the granite and reacted with it.

Field evidence therefore supports the theory that the biotite latite porphyry represents the source magma of the tungsten and gold telluride deposits. Additional evidence is supplied by spectroscopic tests made by R. F. Jarrell and J. M. Bray on samples of 45 rocks from the district.

In these tests, unseparated samples and magnetic concentrates of the following rocks were tested for tungsten with negative results:

Boulder Creek granite. Two specimens, one fresh, one argillized.
Gneissic aplite, fresh. Four specimens.
Relatively coarse grained massive aplite from Sherwood Gulch. Two specimens.
Hornblende pegmatite and garnet-epidote pegmatite. One specimen each.
Gabbro. Two specimens.
Hornblende monzonite porphyry. Two specimens.
Limburgite. Two specimens.
Quartz-hematite rock from the Rogers breccia reef.

One specimen of gneissic aplite taken 35 ft north of the main ore shoot on the tunnel level of the Clyde mine showed a "small" amount of tungsten.

Table 6 gives detailed analyses by Jarrell and Bray of three rock samples from the district.

As, Be, Bi, Cd, In, Pd, Pt, and Ir were absent in all three specimens analyzed in table 6. Sb, B, Li, P, Sr, and Te were not determined.

Thus fresh specimens of all the pre-Cambrian and Tertiary rocks described in this report were tested for tungsten, and all gave negative results except the biotite latite and the latitic intrusion breccia. Moreover, the altered wall rocks of the veins show no trace of tungsten even within a few feet of large ore shoots. It therefore appears that tungsten was not deposited by the solutions while they were causing argillic alteration and that the tungsten was not derived by the leaching of material disseminated in the pre-Cambrian rocks. The latitic intrusion breccia contains much more tungsten than the massive dike rock. Both rocks differ from all the others in containing Cr, Co, and Ni; and the intrusion breccia also contains Rh and Mo. The Yellow Pine mine, from which the freshest breccia came, was exploited for silver-bearing gray

TABLE 6.—*Spectroscopic determinations of elements in rocks from the Boulder County tungsten district*

J. M. Bray and R. F. Jarrell, analysts. A, Absent; St, small trace; T, trace; S, small amount; M, medium amount; L, large amount; VL, very large amount.]

	1	2	3
Ba	VL	VL	VL
Cr	S	M	L
Co	A	T	S
Pb	ST	A	ST
Mo	A	A	ST
Ni	A	ST(?)	S
Nb	T	S	T
Sc	A	S	S
Ag	A	A	A
Sn	A	A	T
Ti	S	L	L
W	A	ST(?)	S
Y	A	S	T
La	A	M	M
V	L	VL	VL
Rh	A	A	ST
Andesine concentrate:			
Ag	----------	T	T
W	----------	A	A
Magnetic concentrate:			
Ag	----------	A	A
W	----------	T	S

1. Hornblende monzonite porphyry from Sugarloaf Mountain.
2. Biotite latite porphyry from the Logan gold mine.
3. Latitic intrusion breccia from the Yellow Pine silver mine.

copper, but no silver or arsenic were detected in a bulk sample of this breccia. The possibility of contamination by vein solutions appears to be small, for glass is still recognizable in the breccia under the microscope. Tungsten, but no silver, was found in a magnetic concentrate from the breccia, and silver, but no tungsten, was present in the feldspar concentrate.

It is especially interesting to note that the intrusion breccia is richer than the massive dike rock in the elements characteristic of deep-seated magmatic deposits. Although these elements were present in the latite porphyry magma in small amounts, they were apparently concentrated in the volatile-rich fraction represented by the intrusion breccia. The presence of these elements is perhaps comparable to the occurrence of Mo, Sn, Cu, Pb, Zn, Cd, As, Sb, and Tl in the rhyolitic glass of Nova Rupta in the Valley of Ten Thousand Smokes (Zies, 1929, p. 58). In both places the metals were disseminated in a magma in which the vapor pressure built up until it was released explosively.

Cumulative evidence points to the biotite latite magma as the source of the tungsten and gold.

CHARACTER OF THE SOLUTIONS

The chemistry of the mineralizing fluids must be inferred largely from the minerals precipitated, certain of which are much more significant than others. The clay minerals have already been discussed, and of the other minerals found as vein filling, marcasite and pyrite are most diagnostic of the solutions.

The work of Allen, Crenshaw, and Johnston (1912) on the iron sulfides established the fact that at a given temperature the proportion of iron sulfide precipitated as marcasite instead of pyrite is almost a linear function of the final acidity of the solution. Marcasite is deposited from a cold solution that is sufficiently acid, but as the temperature of the solution is progressively increased, a greater and greater proportion of pyrite is precipitated. Neutral or alkaline solutions yield pyrite alone, whether cool or hot. The chemical relations between pyrite and marcasite have been discussed at greater length elsewhere (Lovering, 1941, pp. 263–265).

Alunite has been generally accepted as proof of acid solutions because of its known origin at Tolfa, where it is formed by the action of sulfuric acid solutions on trachyte (De Launay, 1907). Ransome's assignment (1907, pp. 687, 692) of the alunite of Goldfield to acid sulfate solutions has not been questioned, although the origin of the solutions may still be debated. Lovering's studies of alteration in the Tintic district (Lovering and others, 1949; Lovering, 1950) have led him to conclude that solutions from which alunite normally forms in nature are only faintly acid, probably corresponding to a pH between 4 and 5. Goyazite is associated with hematite in the horn quartz of some of the tungsten deposits, but in others the goyazite is found with siderite. These relations and the affiliation of goyazite with the alunite group suggest that the goyazite may form from faintly acid solutions, but its common association with siderite and the fact that it is most abundant in the late green horn quartz that immediately preceded the tungsten deposition suggest that it is formed most abundantly from nearly neutral solutions.

The marcasite and dickite of the tungsten veins may be taken as sufficient evidence to establish the acid character of the solutions that preceded the ferberite mineralization, and the abundance of sulfate-bearing goyazite and the widespread but sparse hematite furnish corroborative evidence.

The paragenetic relations of ferberite to marcasite, pyrite, and brown iron hydroxide (pp. 37 and 43) are interpreted to mean that the precipitation of ferberite was inhibited when the solutions became sufficiently alkaline to precipitate iron hydroxide. The increasing alkalinity of the mineralizing solutions after ferberite was deposited is shown by the presence of adularia and calcite. The evidence of both the wall-rock alteration and the vein filling thus harmonizes and leaves little doubt that initially acid hypogene solutions became neutral and eventually alkaline and that the ferberite ores themselves were deposited by neutral or slightly acid solutions. Deductions concerning the chemistry of the ore solutions, as well as experiments in the precipitation of tungsten, are discussed in greater detail in a paper by Lovering (1941, pp. 266–271).

The chemical changes in the wall rock shown in figures 61 and 62, and the differing readiness with which different minerals of the wall rock succumbed to the attack of the hydrothermal solutions, give evidence regarding the relative abundance of certain constituents in the solutions. The resistance of quartz, orthoclase, and apatite to alteration, the relative stability of biotite, and the introduction of minerals containing the sulfate and phosphate radicals suggest that the early solutions were rich in silica, potash, and acids of sulfur and phosphorus, that they carried iron in moderate amounts, and that they contained a little strontium, barium, fluorine, and carbon dioxide. In the later phases of mineralization the solutions carried tungsten and traces of lead, copper, silver, antimony, and zinc. The early acid solutions, in acting on the country rock, must have taken up much silica, soda, and lime, as well as some magnesium. The addition of these oxides would inevitably decrease the acidity of acid solutions and eventually make them alkaline.

MINERALIZATION

In the preceding pages it has been shown that the wall rocks were subjected first to acid attack by potash-deficient solutions, with the resulting formation of dickite, and that following this stage they were attacked by neutral to slightly alkaline potassic solutions that caused sericite to form in part of the rock previously altered to dickite and the accompanying clay minerals. The relatively narrow width of the sericitized zones as compared with the zones of clay alteration indicates that the alkaline attack either was shorter-lived than the acid attack or was accomplished by much less reactive solutions. A parallel change is recorded in the vein fillings. Such acid-solution products as marcasite, dickite, hematite, and goyazite were in general deposited before ferberite, although minor quantities of these minerals were contemporaneous with ferberite. During the stage when ferberite was precipitated, pyrite, which is deposited from less acid solutions than marcasite, first began to form in the veins, and is correlated with the beginning of sericitic alteration in the rocks adjoining the veins. With or following the pyrite came brown iron hydroxide and minor barite. At a later stage the common sulfide minerals, clays of the montmorillonite group, adularia, carbonates, and scheelite formed, all of which suggest alkaline solutions. The iron hydroxide precipitated during the pyrite stage seems to have signaled the end of ferberite deposition. In acid solutions ferric salts start to hydrolize to the insoluble hydroxide at a pH of about 2.5. (Britton, 1942, pp. 44–45).

As noted, reaction between the early acid solutions and the alkaline wall rocks liberated soda, lime, and magnesia, which would tend to neutralize the acid solutions and finally make them alkaline. The question remains whether this reaction was alone responsible for the change in character of the solutions or whether there was also a change in the character of the solutions supplied to the veins. In earlier papers, the present writers have presented the arguments for change by reaction (Lovering, 1941) and for change at the source (Tweto, 1947a, pp. 53–55), but they are fully agreed that both types of change were effective.

The great quantities of rock altered along the hundreds of miles of veins and fractures in the district would most certainly affect the composition of solutions supplied even in great volume. Moreover, the mineralogic subzones in the zone of argillic alteration, showing dickite, beidellite, and allophane with sericite, successively, from the vein outward, are regarded as proof of change in composition through reaction. If the early solutions were tungsten bearing, they should have deposited ferberite in the upper parts of the veins after having been made less acid by reaction at lower levels. However, such a mechanism of precipitation should have been effective to a certain extent as a result of horizontal movement through the wall rocks, and some trace of tungsten should then be present in some of the rocks showing argillic alteration. Spectroscopic analyses have shown no trace of tungsten in such rocks, however, and it is concluded that tungsten was not present in the solutions that accomplished the early wall-rock alteration and therefore that the precipitation of ferberite was not achieved entirely by a simple reduction in the acidity of solutions that were initially constant in composition.

On the other hand, much of the quartz in the veins was probably precipitated under just such conditions. As shown in figure 61, the acid solutions removed substantial amounts of silica from the granite. Silica may be deposited from acid solutions of almost any strength simply by cooling or by changing the pH (Lovering, 1950, p. 234); thus it is reasonable to suppose that much of the silica found in the veins was derived from the wall rock altered at greater depth by hot rising solutions that cooled as they rose. The constant shifting of the major channels of circulation caused by recurrent movement on faults during mineralization, so plainly recorded in the repeated brecciation, was probably an important factor in this precipitation, for it would allow the alternate cooling and heating of different parts of a vein. The quartz may therefore be pictured as deposited in a shifting but generally descending zone of precipitation along intermittently active fault zones. Although it is known that many silicates are readily soluble in acid solutions, quartz, once it is deposited as such, is much more stable

(Lovering, 1923, p. 530). Thus, after the leaching of silica from the wall rocks and its redeposition along intermittently cooler or less acid places in the vein, quartz might remain unattacked, even though the solutions became either hotter or more acid temporarily.

If tungsten was absent or was present only in very small amounts in the solutions that caused the early wall-rock alteration, its presence in the solutions at a slightly later stage implies a change in the character of the raw solutions themselves. The distribution and paragenesis of the minerals in the altered wall rocks and the veins furnish other evidence of such a change.

If an acid solution rising in a vein reacted with the alkaline wall rocks, the rock adjoining the vein up to a certain level where the solution became neutral and then alkaline would show acid (argillic) alteration; the rock above the neutral level would show alkaline (sericitic or orthoclasic) alteration reflecting the higher content of bases—especially potash. Below the neutral level, some sericitic alteration would also occur at the outer edges of the argillized zone, as has been observed (p. 59), owing to the reduction in acidity of solutions diffusing outward through the wall rocks. At a later stage, if the composition of the solution remained constant at the source, and if the flow did not decrease to a mere trickle, the lower part of the vein would have been chemically insulated by a zone of argillic alteration, so that the solution would rise higher in the vein before reaching neutrality. Both the acid and alkaline zones of alteration should thus migrate upward, and the zone of acid alteration would reach rock that had been sericitized at a slightly earlier stage. Sericite should then be replaced by clay in a shell immediately adjacent to the vein, and the sequence from the vein outward should be (1) clay minerals and (2) sericite. However, the actual sequence is (1) sericite, (2) clay minerals, and (3) sericite, the sericite in the inner zone (1) having replaced clay minerals of zone 2.

If the mineralization were short-lived and occurred with explosive rapidity, as its apparent relation to the biotite latite intrusion breccia suggests, the insulating effects of the walls would be at a minimum. Under these conditions migration of alteration zones might be slight, but sericitic alteration should then become stronger upward and should have been present alone at some unknown upper level. Similarly, argillic alteration should increase downward and should exist alone at depth. Although the mines of the district afford only a relatively small vertical exposure, there is indication of an increase in argillic alteration with depth in some mines, particularly the Cold Spring and others nearby. However, in other mines argillic alteration seems to decrease with depth and sericitic alteration to increase. This is true of the relatively deep Vasco No. 6 and Illinois mines and to a lesser extent of the Conger and Dorothy mines, all of which are near the edges of the district.

Change in the character of the solutions through reaction alone thus seems incompatible with certain features of the wall-rock alteration. On the other hand, these same features would be expected if there was a gradual change in the composition of the solutions leaving the magmatic source.

The distribution of different minerals within the veins also is more readily accounted for by deposition from solutions changing at the source than from solutions changing entirely by reaction. If the change were by reaction alone, there should be a general zoning in the veins; minerals deposited by the more alkaline solutions should in general be concentrated higher in the veins than minerals deposited from neutral or acid solutions, like ferberite and marcasite. Although local factors, such as the changes in temperature, pressure, and circulation routes caused by intermittent fault movement along the veins, would doubtless result in some intermingling of acid- and alkaline-zone minerals, the observed association of the two types throughout the known vertical extent of the ore deposits is hardly to be expected. On the other hand, if the solutions became progressively less acid at the source, alkaline-solution minerals such as many of the sulfides, as well as carbonates, clays, scheelite, and adularia, might be deposited, as observed, on and below the tungsten ores.

The writers' concept of the tungsten mineralization may be summarized as follows: The pressure of pent-up vapors concentrated in a shallow biotite latite magma by differentiation was released suddenly if not explosively. Acid gaseous solutions (Lovering, 1941, pp. 274–278) rose through preexisting fractures, condensed, and reacted with the alkaline wall rocks. The earliest solutions leached much silica from the vein walls through the destruction of plagioclase and redeposited it higher in the veins as early vein quartz. Although little tungsten appears to have been transported during this earliest stage, the solutions supplied at a slightly later stage carried considerable tungsten. These were probably somewhat less acid at the source then those preceding them. The first surge of mineralizing solutions was the strongest, and although it was relatively short lived, most of the mineralization observed in the veins was accomplished by it. Ferberite was deposited during the latter part of this first major stage, but by the end of ferberite deposition the flow had ebbed greatly. By this time, also, much less acid solutions were being supplied to the veins. These were potash-bearing and became neutral and then alkaline by reaction relatively near the source; because of their potash content they sericitized part of the rock that had undergone argillic alteration earlier, forming relatively thin sheaths of sericitic rock adjacent to the veins. They also contained small amounts of iron, copper, lead, and zinc and some silver, which were deposited as sulfides. With continued decrease in the flow, the solutions became spent in large part in the lower parts of the veins, and even within the vertical limits visible, sericitic alteration is observed to increase in strength with depth along some veins near the edges of the district, where the early argillic alteration may have been less intense and more easily obliterated. By the last stages of mineralization, when minor amounts of scheelite, calcite, dolomite, opal, barite, and beidellite were deposited, the flow of solutions had almost ceased, and in many places these minerals show indications of deposition from solutions that were essentially stagnant.

ENVIRONMENT OF DEPOSITION

The relation of the tungsten deposits to the biotite latite magma, and the absence in the tungsten district of post-Eocene extrusive rocks such as are found elsewhere in the Front Range, may be taken as evidence that the tungsten deposits formed during Paleocene or early Eocene time. Physiographic evidence, based on the probable position of the Flattop peneplain over the tungsten district, suggests that the position of the surface in Eocene time was some 3,000 ft or more above the present one. Pressures in gougy fissures at such a depth may have been relatively high, but the sensitivity of the ore shoots to the presence of gouge in the veins indicates that relatively open channels were available and that the pressure driving the solutions upward was not much greater than the hydrostatic pressure that might be expected at such a depth. Relatively low pressures are also indicated by the lack of fluid inclusions in the quartz and by the mineral assemblage.

According to the work of Allen and others, marcasite changes to pyrite at 450 C, and its presence fixes an upper limit for the temperature at which the ores formed. The presence of dickite indicates temperatures too cool for the formation of nacrite, but too hot for kaolinite. The associated sphalerite, galena, freibergite, miargyrite, and tetrahedrite suggest the deposits were formed under epithermal conditions but from solutions that were distinctly cooler than at the time of ferberite deposition. Judging by the gage pressure of staurated steam (Hodgman, 1934, p. 1273), the maximum temperature of a hot dilute aqueous solution with a uniform thermal gradient under a hydrostatic pressure of 3,000 ft would be approximately 290 C. Such a solution would be under a pressure of about 75 atm. It is concluded that the tungsten ore was precipitated at temperatures between 200 and 300 C.

DISTRIBUTION OF TUNGSTEN

DEPOSITS WITHIN THE DISTRICT

Although ferberite is found scattered throughout the Boulder County district, almost all the production has come from a few small areas that together comprise only a fraction of the total area of the district. As shown in plate 3, all these areas are near breccia reefs except one near Boulder Falls, between the Rogers and Livingston reefs, and as was noted in the discussion of the breccia reefs, many of the east-west veins in this area are believed to be original reef cross fractures that were later mineralized by tungsten. More than half the total output from the district has come from two small areas covering no more than a square mile, one in the vicinity of the Conger mine, about a mile northwest of Nederland, and the other along the east flank of Hurricane Hill, north of Tungsten. In addition to the Conger mine, which has had an output of at least 400,000 units of WO_3 and is by far the most productive mine of the district, the small productive area northwest of Nederland includes such important mines as the Beddig, Oregon, Quay, Illinois, and Crow No. 4. The area north of Tungsten has been almost as productive as the Conger area, although the output is distributed among many more mines. The Cold Spring, the chief mine of this area, has had an output of more than 100,000 units of WO_3 and is the second most productive mine of the district. Other large producers in the vicinity are the Cross, the Western Star, the Forest Home, and the several Vasco mines, of which No. 1 and No. 6 have been particularly productive. In addition to these major mines, the area includes many smaller mines which together have made a fairly large output.

The productive area along the Rogers breccia reef in Gordon Gulch and near North Boulder Creek ranks third among the important producing localities in the district. The mines of Gordon Gulch are also among the oldest in the district. They were, with the Conger, the chief source of ore during the early years of tungsten mining in the district. The important mines in this area are the Quaker City, Ophir, Misers Hoard, Misers Pride, Oregon, and Pennsylvania, in Gordon Gulch, and the Rogers No. 1 mine near North Boulder Creek.

In the area just west of the Hurricane Hill reef, along the flank of the hill and in Sherwood Gulch, the Lone Tree, Clyde, Rake-off, Phillip Extension, Crow No. 18, and Hoosier mines were important producers, and rich ore was obtained from many small pockets on the north side of Sherwood Gulch.

In the Beaver Creek area, southeast of Nederland, the output came chiefly from the Mammoth and Tungsten (Chance) mines, but a substantial amount of ore was produced by the Sunday, Rambler, Elsie, and

Fitzsimmons mines, and a moderately large total output was contributed by many small mines.

According to the incomplete records available, the area around Boulder Falls, east of Comforter Mountain, would rank next in total output. The chief mines are the Good Friday, Eureka, Luckie 2, and Lookout.

The easternmost productive area is centered in Millionaire Gulch, a tributary of Bummers Gulch, where the Dorothy and Katie mines were the chief producers. The Ohio mine, a short distance to the east, also had a substantial output.

In the productive area along the Livingston reef in Black Tiger Gulch, the Pueblo Belle, Black Prince, and Roosevelt are the best-known tungsten mines.

OUTLYING OCCURRENCES

The limits of the main tungsten district as generally recognized correspond approximately with the boundaries of the topographic map of the district (pls. 1, 2), but some ferberite is found in sparsely scattered localities from the Nederland area southward to Central City (11 miles) and northeastward to Jamestown (12 miles). The scattered ferberite occurrences north of the main district are intersprinkled with sporadic small deposits of wolframite ore related to an older mineralization centered at Ward, 8 miles north of Nederland. Several of the outlying deposits have been productive, but none of them except the Copeland has had a large output.

Tungsten also occurs in minor quantity in a belt that extends from the southeastern part of the main tungsten district into the adjoining Magnolia district, which is important chiefly for its gold telluride ores. Most of the tungsten ore at Magnolia is fine-grained and horny, and much of it is rather highly pyritic, but small bodies of coarsely crystalline ferberite also are found, as at the Graphic mine. The Tungsten King and Kekionga mines were worked for tungsten during World War II, and small lots of tungsten ore have been shipped at times in the past from several of the mines at Magnolia. Wilkerson (1939 a, b), who has described the deposits briefly, distinguishes the tungsten veins from gold telluride veins on the map accompanying his report. The Copeland tungsten mine, on the Copeland breccia reef, is about 2½ miles south of Magnolia; 2 miles farther south are the prospects variously known as the Walker ranch, Sallee, or M & P workings on the Rogers reef (pp. 56–57).

A few minor occurrences of ferberite are known in widely scattered localities along South Boulder Creek from the Walker ranch area westward to Pinecliffe. In Gilpin County, southwest of Pinecliffe and about 4 miles southeast of Nederland, very pure and coarsely crystalline ferberite has been mined at the Manchester, Campania, and one or two other mines which are clustered together in a small area. A substantial production was obtained from the Manchester. The ore is similar in character and occurrence to the ore of the Beaver Creek district, a mile or two farther north.

Some high-grade crystalline ferberite ore has been mined in Moon Gulch, southwest of Rollinsville and about 5 miles south-southwest of Nederland. Farther south, ferberite occurrences are reported near Gilpin and Apex, and a little ore has been mined on Dory Hill, north of Blackhawk. Ferberite is reported to be present in the Chihuahua mine in Hardmoney Gulch, just southwest of Dory Hill, and small amounts have also been reported from some of the mines at Blackhawk and Central City.

From the vicinity of the Logan and Yellow Pine mines on Arkansas Mountain the tungsten mineralization tails out northeastward into the Gold Hill district. Tungsten ore has been produced at times from pockets found in the Grand View mine on the ridge between the hamlets of Salina and Sunshine. Small veins of good-quality ferberite ore are reported from the vicinity of Sunshine, and Hess (1921a, p. 942), noted scheelite in a ferberite prospect on Lee Hill, a mile northeast of Sunshine. At Jamestown, 7 miles north of the east end of the main tungsten district, pockets of ferberite have been found in the gold telluride veins; one discovered in the Wano mine in 1942 yielded several hundred pounds of high-grade ferberite ore, according to E. N. Goddard, of the Geological Survey. Some tungsten ore was shipped from the Longfellow mine at Jamestown during World War I, but, according to Goddard, this may have been wolframite ore.

A group of tungsten veins on what is known as the Manion property, in Spring Gulch, about 5 miles southwest of Jamestown, 3 miles east of Ward, and 5 miles north of the main tungsten district, was worked during World War I and has been worked in a small way at several times since then. Tungsten occurs in a strong vein with a northerly trend, the Jumbo, and in at least four veins that branch southwestward from it. The veins contain 1 to 5 ft of gray and buff horn quartz and as much as 1 ft of black horn quartz. "Steel ferberite" and dense, horny ferberite occur in pockets in the black horn quartz and in places cement brecciated light-gray horn, forming characteristic "peanut ore." Some of the buff quartz contains a few flakes of molybdenite. The granite wall rocks show the greenish sericitic alteration characteristic of the ferberite veins, and along the Jumbo vein they are strongly silicified. A stope in the main adit, which follows the northernmost vein northeastward to the Jumbo vein, is about 100 ft long and in one place reached the surface. There are several tungsten prospects on wolframite veins at Gold Lake, about half a mile northeast of the Manion property.

The Hallie A. tungsten mine, near Glacier Lake, about 4 miles north of Nederland, was worked for a time during World War II and at various times earlier.

Wolframite was recognized as early as 1899 in the pyritic quartz veins at Ward, 8 miles north of Nederland, and during World War II the presence of appreciable amounts of scheelite was discovered. Some tungsten ore has been mined at times at Ward and shipped to the mills at Nederland, but the production has not been large. Most of the wolframite seen in the area is along the Columbia vein zone, which is the master vein of the district. The tungsten minerals occur in small pockets in the quartz veins and are generally associated with pyrite and chalcopyrite. Accessory gray copper and molybdenite are present at places. Except for a few of the larger lenses of pyritic wolframite ore, the veins contain too little tungsten to be mined on a large scale for tungsten alone. Moreover, in most places where tungsten is present, the veins contain sulfides and their gold and copper content is more valuable than the tungsten. Much of the gold-copper ore is sorted, however, and some tungsten ore can be separated at the same time. The relation of the wolframite ore to porphyry dikes, as contrasted with that of the ferberite ore of the Nederland area, indicates that the wolframite mineralization is earlier than the ferberite mineralization. In the Utica mine of the Ward United group, the tungsten-bearing pyritic quartz vein is cut out at places by a dike of monzonite porphyry, whereas dikes of similar porphyry a few miles farther south are earlier than the ferberite ores. The Utica vein is cut and displaced 65 ft by an eastward-trending fault that is younger than the ore but older than the dike.

ORE SHOOTS

SIZE AND VERTICAL EXTENT

The following discussion relates primarily to shoots of tungsten ores. The shoots of the early lead-silver ores and the gold telluride ores resemble the tungsten shoots in their general features, but as a group they extend somewhat farther along strike and dip.

The tungsten ore is almost entirely a fissure filling and occurs in irregular shoots in the veins, most of which are vertical or dip steeply. Most of the tungsten veins are 6 in. to 3 ft wide, but some of the ore bodies are 12 to 16 ft wide, and during periods of high tungsten prices veins as little as 1 in. wide have been mined. The ore occurs in distinct shoots separated by barren stretches where the vein contains only horn quartz or gouge or is simply a narrow shear zone (fig. 54). The ore shoots differ greatly in size, but most of the more productive shoots have stope lengths of 50 to 100 ft and pitch lengths of 100 to 200 ft. The largest ore body found in the district—in the Conger mine—had an average stope length of about 400 ft and a pitch length of 625 ft (pl. 9*B*). The single large ore body in the Good Friday mine covered a larger area, being as much as 1,000 ft long and 400 ft high (pl. 23), but the ore was thinner and lower in grade than that in the Conger mine.

The shape of the ore shoots depends almost entirely on the shape of the open spaces available within the veins at the time of the tungsten mineralization. As shown by the longitudinal section of the Cold Spring mine (pl. 18*B*), ore shoots in the same vein and only short distances apart may be chimneylike, elliptical, or highly irregular. Some of the ore bodies are so irregular that no definite elongation can be discerned, but most of them are elongated vertically. Some of these stand about vertically in the plane of the vein; that is, they plunge straight down the dip, but many have a pronounced rake. The rake is almost invariably toward the northeast quadrant. Only a few ore shoots are known that rake toward the southwest quadrant. It may also be noted that, with the exception of veins in the Conger area that trend only a few degrees east of north, by far the greatest number of the productive veins have a northerly component of dip, although northerly and southerly dips are about equally divided among the veins of the district as a whole.

The dip and plunge of the 163 ore shoots for which the writers could obtain data are as follows:

Veins trending N.–N. 30° E.:
- Westerly dip:
  - 11 ore shoots plunge north.
  - 2 ore shoots plunge vertically.
  - 5 ore shoots plunge south.
- Easterly dip:
  - 22 ore shoots plunge north.
  - 8 ore shoots plunge vertically.
  - 8 ore shoots plunge south.

Veins trending N. 30–60° E.:
- Northwesterly dip:
  - 26 ore shoots plunge approximately north.
  - 8 ore shoots plunge vertically.
  - 4 ore shoots plunge approximately south.
- Southeasterly dip:
  - 9 ore shoots plunge approximately north.
  - 2 ore shoots plunge vertically.
  - 0 ore shoots plunge approximately south.

Veins trending N. 60–90° E.:
- Northerly dip:
  - 16 ore shoots plunge east.
  - 24 ore shoots plunge vertically.
  - 8 ore shoots plunge west.
- Southerly dip:
  - 5 ore shoots plunge east.
  - 4 ore shoots plunge vertically.
  - 1 ore shoot plunges west.

In the southwestern part of the district, ore has been mined between altitudes of 8,200 and 8,800 ft. In the northwestern part, ore crops out at the surface at an altitude of 8,700 ft. and has been mined to a vertical depth of about 600 ft. At the extreme east edge of the district, tungsten ore has been mined between altitudes of 6,400 and 7,100 ft. The greatest vertical range of ore on a single vein known in the district is 900 ft., on the Eureka vein in the south-central part of the district. Most of the total vertical exposure on this vein is due to surface relief, however, and the bottom level of the Eureka mine is only slightly lower than the canyon bottom nearby. In general it may be said that at most localities in the district the maximum vertical range within which ore has been found is approximately 700 ft., and this depth corresponds rather closely to the topographic relief. The small size of most of the individual ore shoots, and the fact that by far the greatest number of ore bodies mined cropped out at the surface, suggest that the correspondence between the known depth range of the ores and the topographic relief largely reflects the ease with which ore bodies can be discovered rather than the thickness of the zone of ferberite deposition.

The majority of the individual ore shoots extend to depths of little more than 100 ft., although the shoots in all the more productive mines extend deeper. The deepest continuous ore shoot is that of the Conger mine, very close to the west edge of the district, where commercial ore was found to a depth of 575 ft. A winze was sunk 320 ft. deeper, but only a moderate amount of drifting was done, and no pay ore was found on the deep levels. The average depth of the 30 most productive mines of the district is about 350 ft., but in several of these the depth is due to the presence of blind ore bodies.

Blind ore shoots that overlap or lie completely below the shoots exposed at the surface have been found in several mines. The relatively large output from a few of the mines is a direct reflection of the number of blind ore shoots found in addition to shoots followed down from the surface. There can be little doubt that many blind shoots remain in the district, but the cost of finding them is high.

TENOR AND CHANGES WITH DEPTH

Many veins are mined selectively, and ore is commonly sorted both in the stopes and at the surface (see discussion of mining practice, pp. 83–85). As a consequence, it is difficult to give figures for ore tenor without explanation or qualification, but in general within the ore shoots the veins contain 1 to 20 percent tungsten trioxide. Practically all the ore must be milled, and it is hard to obtain a high recovery because of the strong tendency of ferberite to slime when the ore is crushed. For this reason, ore in which the ferberite is coarsely crystalline is more valuable than ore of the same grade in which the ferberite is fine-grained and intergrown with horn quartz, and the cut-off grade for ore thus depends on physical characteristics as well as tungsten content. The fine-grained ores in the eastern part of the district are not nearly so easily concentrated as the coarser-grained variety farther west. In parts of some of the veins ferberite is very finely disseminated in the horn quartz that makes up the bulk of the vein, and although this material may assay 0.5 to 2 percent WO_3, the difficulties of milling have generally prevented its use (fig. 39). Bodies of this type of ore are not abundant, however, and most of them are small. In the Copeland mine, 2½ miles south of Magnolia, a moderately large deposit of fine-grained ferberite-bearing quartz has been worked from time to time, but most of it is too refractory to be worked profitably. Deposits in which ferberite has replaced the country rock or impregnated broad shattered zones are rare, and no extensive bodies of low-grade ore have been discovered. The only replacement ore body known in the district is in the Sunday mine (p. 93), where coarsely crystalline ferberite replaced sericitized injection gneiss through widths of several feet on each side of the vein, which itself was barren, but this ore body was not large. Bodies of ferberite ore consisting of veinlets in relatively wide shattered zones have been mined in the Peewink and Ohio mines, but these bodies, too, were not large even in comparison with the ordinary vein ore bodies.

In any mining district the terms "large" and "small" as applied to ore shoots are relative and require interpretation. In the Boulder tungsten district many shoots have been completely mined out, and the tonnage and grade of these exhausted ore bodies help to evaluate the terms "large," "small," "low grade," or "high grade" as used in this district.

Fortunately, some excellent production figures have been made available by the Wolf Tongue Mining Co., which has been one of the leading operators in the district since 1905. From some of these figures an idea may be had as to the size and grade of the ore bodies mined in the past. In the Cold Spring mine, the second most productive in the district, the ore was found in four separate shoots, all of which have been mined out. The largest of these contained approximately 4,500 tons of ore that averaged 8½ to 10 percent WO_3. Two other shoots each produced approximately 3,000 tons which averaged 6 to 7 percent WO_3. The fourth shoot produced 1,120 tons of ore averaging 7.60 percent WO_3. For the Boulder district, these shoots were both large and moderately high in grade. The production from more than 50 other ore shoots averaged a little more than 350 tons each, assaying approximately 8 percent WO_3, or about 2,800 units of WO_3 per ore shoot. This seems to be a reasonable figure for the tungsten content of the average commercially valuable ore shoot in the district.

The lower limit of commercially valuable ore, at a price of approximately $20 per unit, is probably about 1½ percent WO_3, but it would be higher for fine-grained ores because of the difficulties in milling already noted.

No progressive change in the ore with depth has been noted. The ore near the bottom of many ore shoots is somewhat more dense and horny than the ore higher in the shoot, but ore found in other shoots at greater depths on some of the same veins is as good in quality as the ore in the upper shoots. However, there may be a change through a depth range greater than that of any individual mine, as the ore in the eastern part of the district, which is 1,000 to 2,000 ft lower than the west end, is distinctly finer-grained and on the whole more siliceous than the ore of the western part.

The gangue minerals, the vein structure, and the wall-rock alteration differ slightly above and below ore shoots in some veins, but no clear-cut criterion that is generally applicable to all veins has been recognized. Some blind ore shoots give way near their upper limit to a coarse, friable, loosely cemented breccia of country rock coated with siliceous crusts thickly sprinkled with barite, but most shoots give way to gouge at their upper margins. Although generalization is hardly warranted, it might be said that ore shoots most commonly end above against gouge and below against horn quartz. Certain minerals, such as opal, chalcedony, barite, calcite, and dolomite, are more abundant near the tops of ore shoots or above them than at greater depths, but the carbonates also occur below ore shoots. Some of the quartz below ore shoots is more open and vuggy and somewhat coarser in grain than the quartz above shoots. Pockets of clay below ore shoots are mostly dickite, and clay above ore shoots is mostly beidellite, but both beidellite and allophane have also been found below ore shoots and dickite has been found above. Pyrite and other sulfides are perhaps a little more abundant in the upper than the lower parts of ore shoots, but the distribution of sulfides in individual shoots is erratic. Spots, or lenses, of ferberite only a few inches long are irregularly distributed in the horn quartz, in the breccia, or in the gouge below many ore shoots. Similar spots are found above ore shoots, but they are less abundant, and there is a greater tendency for the little ferberite present to be distributed as thin veinlets of black horn or as ferberite in banded veins of horn. Many of the ore shoots, as well as bodies of horn quartz, terminate abruptly upward, downward, or along the strike against gouge. Little ore is found, as a rule, in gougy parts of the veins.

FACTORS CONTROLLING LOCALIZATION

The movement of the mineralizing solutions and the localization of ore were controlled primarily by the relative permeability of different parts of the fissures, and this depended upon the displacement of the irregular walls of the vein fissures and on the character of the wall rock. Altered granite readily broke down to impermeable gouge, whereas silicified rock, horn quartz, and fresh granite, aplite, and pegmatite formed an open rubble. In the metamorphic rocks west of Hurricane Hill, the tungsten ores are rarely found between schist walls but are localized where the veins cut ribs of pegmatite or aplite in the schist. The Boulder Creek granite is more extensively altered than the aplite and pegmatite that cut it, and fissures contain more gouge where their walls are granite than where the walls are aplite or pegmatite; ore shoots are therefore more likely to occur in these dike rocks than in the granite.

Nearly all the ore bodies are structurally controlled by the relation between the direction of movement of the fissure walls and the course of the fissure. In most of the tungsten veins there was a strong horizontal component of movement, and in those veins in which the right-hand wall moved forward there is a marked tendency for ore to occur where the vein's course swings to the left (pls. 9*A*, 18*A*). Similarly, ore may be localized in the steeper parts of a vein in a normal fault fissure, and in numerous mines ore shoots are thus correlated with a steepening of dip (pl. 12). In a reverse fault fissure, ore would be expected in the flatter parts. Reverse faults are rare in the district, but the important Beddig vein follows one, and the best ore was in the flattest parts of the vein.

The intersections and junctions of veins were loci of brecciation, and many of them therefore are especially permeable. Many ore shoots are localized at such places, but the frequency of ore occurrences at all the junctions known in the district is fairly low. In the Rake-off mine (fig. 77), ore shoots occur at the intersection of two veins that meet at a low angle. In the Vasco No. 6 mine (pl. 13*B*), an ore shoot is localized at the intersection of two veins that meet at a high angle. At many intersections and junctions, ore occurs on only one of the two veins near the intersection or junction. In several mines in the district, branch veins or minor veins die out a few feet short of an actual junction with the major vein. The movement that caused the minor vein to form was presumably taken up by slight movement on shattered or strongly jointed rock in the wall of the stronger vein, but such minor fracturing is not always noticeable, and occurrences of this type should thus offer some incentive for exploration of the walls of major veins, even though no veins or only very small ones are seen branching from them. In the Forest Home, Quay, Oregon, and several other mines, ore shoots were found within a few feet of the main veins on branch veins that were almost imperceptible in the wall of the main vein.

Where repeated movements occurred on intersecting fractures, wide brecciated zones developed, such as that found in the Grand Republic vein—mainly a gold telluride vein but with a little ferberite—near its junction with the Hoosier breccia reef. About 500 ft west of the reef the vein is a gougy sheeted zone about 5 ft wide, but nearer to the breccia reef it is an intensely shattered zone 25 to 75 ft wide.

In the Logan mine the pyritic gold ore shoots are apparently controlled by the intersection of branch veins and by changes in the strike and dip of the fissures, but the distribution of the gold telluride ore also shows a relation to the biotite latite intrusion breccia. Biotite latite porphyry and intrusion breccia follow the Logan and Teller veins in the lower part of the mine (pl. 26). The porphyry is found only in the two lower levels, but the intrusion breccia extends upward to the third level. At the intersection of the Logan and Mud veins on the third level, where recurrent movement on both fissures is well shown, it is evident that the intrusion breccia dates from a late stage in the faulting and is approximately contemporaneous with the mineralization, as it is slightly mineralized and is involved in only the latest of several premineral faults (fig. 20). The ore shoot roughly parallels the course of the intrusion breccia between the second and third levels just over the upper termination of the intrusion breccia. The ore shoot was comparatively poor in gold on the third level, but the gold content was better on the second and still better on the first level. Thus it seems that the ore is genetically related to the intrusion breccia itself or that the solutions which deposited the ore may have followed through the same channel as that penetrated by the intrusion breccia while the breccia was still hot enough to keep the temperature of the solution too high for deposition. Above the hot intrusion breccia steep precipitation gradients would exist, and ore shoots might be localized in the vein above the breccia for this reason.

SUGGESTIONS FOR PROSPECTING

The general areas regarded as most favorable to prospecting, which are shown on the map in plate 3, are close to the major breccia reefs. The largest part of the production has come from these areas, but commercially valuable ore bodies are known to lie between them and others will doubtless be found outside them in the future. However, it would seem that the best chance of reward is to be had in exploring the areas where tungsten mineralization is known to be pervasive.

The generalizations made in the discussion of ore shoots should be kept in mind in prospecting. Experience through the district shows that different types of country rock are favorable to the ferberite ore shoots in different degrees. Within the metamorphic area aplite, pegmatite, and granite all make excellent hosts, but within the batholith of Boulder Creek granite, ore bodies, especially the smaller shoots, are likely to expand between walls of pegmatite and aplite and to contract where granite forms both walls.

The character of the wall-rock alteration along the vein is significant. Strongly argillized wall rocks are unfavorable unless there is a well-developed silicified or sericitized casing along the vein itself. Branch veins in an argillized hanging wall are very likely places for ore if their walls are sericitized or fresh—away from the argillized zone—but are unfavorable otherwise. Mineralization of the type found near the tops of ore shoots should be sought. The presence of minor quantities of lead, zinc, and silver sulfides, or of a small amount of barite, pyrite, or opal, suggests the possibility of ore nearby in the vein. Mineralization of this type has been noted at the top of Hurricane Hill in the Hurricane Hill breccia reef, and future work may prove the presence of ferberite ore bodies in branch veins beneath the heavy soil cover of this locality. If the direction of relative movement of the fissure walls is known, and changes in the strike and dip of veins can be determined in advance of exploration, the most favorable localities for exploration can be forecast, but such facts are difficult to ascertain. It is much easier to locate the intersections of veins.

Specific suggestions for prospecting are included in many of the mine descriptions, and the methods and problems of exploration are discussed on pages 88–89.

HISTORY AND PRODUCTION

MINING IN THE DISTRICT

DEVELOPMENT PRIOR TO WORLD WAR I

In the seventies, especially in the years 1876 and 1877, most of the region west of Boulder Falls was homesteaded by a group of French settlers, chiefly for the sake of its timber. After the valuable timber had been cut, much of the land was allowed to revert to the State for taxes, and prior to the discovery of tungsten, large areas now included in the Boulder tungsten district could be obtained by payment of the back taxes. After the discovery in the early seventies of the silver and lead-silver deposits at Caribou and Cardinal, a few miles west of Nederland, the region was thoroughly prospected. Black ferberite float found abundantly in the Nederland area was assayed repeatedly for gold and silver but always proved barren, and it became known by such names as "heavy iron," "barren silver," and "black iron." In 1899 somewhat similar black float found in relatively minor quantity in the Ward district, 8 miles north of the main tungsten district, was identified as wolframite by John H. Knight, and in 1900 the ferberite float in the main tungsten district was recognized as a tungsten mineral by W. H. Wanamaker, who had seen the tungsten ore of the Dragoon Mountains of Arizona.

Wanamaker and his partner, S. T. Conger, began negotiations at once to secure a lease on a part of the Boulder County Ranch, about a mile northwest of Nederland, where the float was abundant. In August 1900 a lease was obtained on a parcel of land which had been bought for tax title in 1898 by a Mr. Sherrill, and shortly thereafter some 40 tons of high-grade ore was picked from the surface. This was the earliest known tungsten production from Boulder County. The ore was shipped to Denver, where half of it was sold at $1.60 per unit and the other half at $1 per unit. In 1900, also, Conger discovered the Conger vein on the land leased from Sherrill, and soon afterward Conger and Wanamaker discovered the Oregon, Denver, Illinois, Charley, Lone Jack, Hoosier, and Last Chance veins on Government land and took them up as mining claims.

After the discovery of tungsten, prospectors flocked to the region, and during the next few years many discoveries were made. In 1900 tungsten ore was exposed in mine workings driven in search of silver on the Miser claims in Gordon Gulch, in the north-central part of the district, and by the end of the year Morris Jones, of the Great Western Exploration & Reduction Co., had begun mining and milling this ore. The mill stood at the foot of the hill where the Sugar Loaf road enters Gordon Gulch, and the first ore came from the nearby Misers Hoard and Ophir mines. In 1901 a Mr. Yates discovered the nearby Quaker City vein, and mining was also started on the Misers Pride vein. This group of mines supplied about half the district output through 1904. Much of the ore handled in the mill was float ore, for which the Great Western Co. paid $10 per ton if it assayed 30 to 60 percent WO_3.

In 1901 Conger and Wanamaker sank a shaft 80 ft deep on the Conger vein. The sump was then in a barren part of the vein, and the operators stopped sinking under the impression that tungsten ore did not extend to greater depth. In the same year tungsten was discovered by Henry Loughlin on Tungsten Mountain in the Beaver Creek district, although so far as known, he made no shipments. Ore was also discovered in the Bummers Gulch area and near Boulder Falls at about this time.

In 1902 the tungsten produced in Boulder County found little market, and much of it was sold for $2 to $2.25 per unit (1 percent of a short ton, or 20 pounds, of contained WO_3). The district was beginning to become widely known for its tungsten, however, and during this year the Krupp steel interests in Germany began negotiating for Boulder tungsten. By 1903 several ore buyers had entered the district, facilities for removing tungsten ore became adequate, and the development of the district was greatly stimulated. In this year A. J. McKenna came to Boulder County and began acquiring property for the Firth-Sterling Steel Co. The Copeland mine, 3½ miles south of the tungsten district, was leased but proved unprofitable because the horny ore was too refractory; only 600 pounds of 33-percent concentrates was obtained from 65 tons of ore. This property was soon abandoned, and several claims in the western part of the district were obtained from C. W. Bell, of Denver. This property was shortly transferred to a subsidiary, the Wolf Tongue Mining Co., which was organized in 1904. This company soon began working the Oregon mine, on the southern continuation of the Conger vein. At first the ore was concentrated in the Black Swan gold mill at Salina, but in 1905 the Midget mill, an old silver mill at Nederland, was acquired and revamped to treat tungsten ore.

By 1904 several large corporations had acquired property in the district, and from this time on, the production was dominated by the larger companies, such as the Wolf Tongue Mining Co.; the Primos Chemical Co. or its subsidiaries, of Primos, Pa.; the Crucible Steel Mining Co.; the Colorado Tungsten Corp.; and later, the Vasco Mining Co., a subsidiary of the Vanadium Alloy Steel Co.; and the Vanadium Corp. of America. Most of the ore produced prior to 1904 was purchased by the Primos Chemical Co., but after 1904 the Wolf Tongue Mining Co. was very active both in buying and in mining ore. The Henry E. Wood Ore Testing Works, of Denver, also was an active buyer at this time and handled much of the ore from the Rogers tract. In 1904 mining and development were centered in the vicinity of Nederland and in Gordon Gulch, and these localities produced by far the greater part of the tungsten mined in the United States at this time. The discovery of high-grade ore in the Oregon mine below the supposed barren zone 80 ft from the surface encouraged the owners of the Conger mine to continue sinking their shaft, and they soon reached a large body of high-grade ore. This work was done by Messrs. Lake and Barnsdall, who had become owners of the Boulder County Ranch. They treated their ore in the stamp mill at the Boulder County gold mine at Cardinal, about 2 miles west of Nederland.

Although the demand for tungsten rose, if somewhat irregularly, the price for concentrates containing 60 percent WO_3 had increased only to $5 per unit in 1904 and to $6 per unit in 1905. As a result, deep mining was not attempted until most of the float had been picked from the surface, and in 1905 the deepest shaft was only 200 ft deep. The Stein & Boericke Mining & Milling Co., a subsidiary of the Primos Chemical Co., acquired the property of the Great Western Exploration & Reduction Co. in 1905 and continued to operate the mines and mill in Gordon Gulch. During the same year, a syndicate from Pittsburgh organized the Colorado Tungsten Corp. and took over a large tract, known as the Crow patent, in the northwestern part of the district. This company operated the Boyd mill in Boulder, treating custom ore as well as ore from its own mines.

The increasing use of tungsten tool steel was reflected by higher prices during the first 9 months of 1907, when ore sold for as much as $14 per unit, but with the deep business depression that occurred in the fall of that year the price fell to less than $5 per unit and demand was slow even at that price. During this year the Phillip Bauer Co., of Hamburg, Germany, took over the Rogers tract, in the central part of the district, and built the Clarasdorf mill on Boulder Creek about a mile above the Narrows. This company operated several mines until 1909 and shipped its concentrates to Germany. The district output reached 1,146 tons of 60-percent concentrates in 1907. The principal mines of the district at this time were the Conger, Oregon, and Beddig northwest of Nederland; the Crow No. 4, Lone Tree, and Clyde in Sherwood Gulch; the Townlot, "1½, ""1¾," and Hoosier north of Nederland; the Mammoth, Elsie, and Tungsten (Chance) in the Beaver Creek district south of Nederland; the Western Star, Pansy Blossom, Bonanza, Philadelphia, and Rogers Upper Tract No. 1 (later the Vasco No. 1) north of Tungsten Post Office; the Quaker, Oregon, Ophir, Misers Hoard, and Misers Pride in Gordon Gulch; the Rogers No. 1 on North Boulder Creek; the Good Friday, Lookout, Luckie 2, and Eureka near Boulder Falls; and the Ohio in Bummers Gulch at the east edge of the district.

In 1908 the price for tungsten remained so low that production was less than half as large as in the previous year. Most of the output was made by lessees of the Wolf Tongue Mining Co., but the larger companies continued to develop their mines. In this year the holdings of the Stein & Boericke Co. in Gordon Gulch and those of Lake and Barnsdall in the western part of the district were combined as the Primos Mining & Milling Co., a subsidiary of the Primos Chemical Co., with C. F. Lake as general manager. This company was then the largest tungsten mining company in the world. In 1909 the Stein & Boericke mill in Gordon Gulch was dismantled and construction was started on the Primos mill at Lakewood, at the junction of Sherwood Gulch and North Boulder Creek. The Primos output in this year came chiefly from the Lone Tree and Conger mines and was milled at Cardinal. The lowest level of the Conger was 350 ft from the surface at this time. Practically all the ore mined in the district was sold either to the Wolf Tongue Co. or to the Primos Co. and concentrated in their mills. These mills probably did not recover more than 80 percent of the tungsten contained in the ores, though an effort was made to save the slimes by straining them through canvas.

In 1910 the demand for tungsten was good, and the output rose to a new record: 1,221 tons of concentrates containing 60 percent WO_3. According to the ore schedule in general effect, the price paid in the district ranged from $1 per unit of WO_3 in 1-percent ore to $7 per unit for 60-percent ore, delivered at the mills. The increased demand for tungsten stimulated the building of new mills, and several were erected at about this time. The Primos Mining & Milling Co. completed its new mill at Lakewood, and the Wolf Tongue Mining Co. rebuilt its mill at Nederland. Many improvements, such as the extensive use of Frue vanners and "rag plants," were incorporated in these mills in an effort to save the ferberite slimes. Two mills were built on Beaver Creek 2 miles south of Nederland, and another mill was built in Boulder. The Primos Co. continued to operate the Conger mine, but most of the other companies operated their properties through lessees.

During 1911 the demand for tungsten fell off, with the result that many of the mines closed for a large part of the year, and the output of the district was reduced to 730 tons of concentrates. The Primos Co. closed down all its mines and both its mills, but the Wolf Tongue Mining Co. built a new reinforced concrete mill to replace its old one. Some of the smaller mills, such as the Ardourel & Smith mill on Beaver Creek and the Tungsten Mountain Mines Co. mill, reworked old dumps and tailings. Considerable mining was done even in this lean year on the Rogers tract under the supervision of Eugene Stevens.

In 1912 the price of tungsten ore continued low and the output was about the same as in 1911. The Primos Mining & Milling Co. completed an electric tramway from the Conger mine to the Lakewood mill, and the vertical shaft at the Conger mine was deepened, cutting an excellent ore body. New mills were built by the Tungsten Mines Co. at Switzerland Park and by the Colorado Tungsten Corp. in Carrie Nation Park. Six mills were operated in the district, including those of the Primos Co., the Wolf Tongue Co., Ardourel & Smith, the Colorado Tungsten Corp., the Eureka Mill at Boulder, and the Tungsten Mountain Mines Co. mill on Beaver Creek. The Tungsten Production Co., under the direction of J. G. Clark, began its long period of activity in the district in 1912, when it acquired extensive holdings northeast of Nederland.

In 1913 the production of the district, responding to a slightly better price, amounted to 953 tons. The Primos and Wolf Tongue Companies were the largest producers. In this year the Primos Mining & Milling Co. deepened its inclined shaft on the Conger vein, stopped its work at the Lone Tree mine, and worked on the Quaker City vein until July. In the eastern part of the district the principal production came from the Lord Byron claim, near Sugar Loaf. A little ore was produced by the Manchester Mining Co. south of the main district. Early in 1914 the price of tungsten was as low as $6 per unit. Immediately after the outbreak of the European war the demand for tungsten ceased entirely for a short time, but it soon quickened, and toward the end of the year ore was selling at $9 per unit. The production in Boulder County during 1914 amounted to only 467 tons and consisted chiefly of small lots mined by lessees.

BOOM YEARS, 1915–18

The war-caused demand for high-speed steels did not appear until the summer of 1915. Some tungsten was sold in the early part of the year for as little as $5.60 per unit, and much ore was contracted for in the spring at low prices. In the fall, however, the unparalleled demand for tungsten all over the world became effective; the price of ore rose to $45 per unit; the tungsten district was overrun with prospectors searching for new deposits; and every effort was made to increase production from the properties already known. Unfortunately, the policy of working mines through lessees had resulted in the removal of ore as fast as it was found, and the known reserves were very small. As a consequence, the output did not increase very rapidly, but the larger active companies acquired or leased additional property and began extensive development work. The Primos Co. leased all the Colorado Tungsten Corp. ground and reopened many of the mines. The Tungsten Production Co. acquired the Barker tract between Nederland and Tungsten and continued to drive the Clark tunnel beneath the tract. The Vasco Mining Co., a subsidiary of the Vanadium Alloy Steel Co., of Latrobe, Pa., entered the field during this year and purchased the highly productive upper tract of the Rogers patent near Tungsten Post Office. The company built a large mill at Tungsten and began immediately to operate the 10 mines on the tract and to buy custom ore on a large scale. The lower tract of the Rogers patent was intensively developed under the direction of Eugene Stevens in 1915.

The price of tungsten continued to increase in the early part of 1916, reaching $60 per unit in February and $90 in March, and although the published schedules did not exceed $90, some ore is said to have changed hands at as much as $106 per unit, a price equal to about $3.50 per pound of ferberite. The population of Nederland increased to more than 3,000; towns containing several hundred people sprang up at Lakewood, 2 miles north of Nederland, and along Boulder Creek east of Nederland at Ferberite and Stevens camp (later Tungsten Post Office) and small tent settlements dotted the district. The old dumps were resorted, and the ground near veins was carefully worked over for float, much of which was jigged at the scene of the operation. All the mines were worked to the utmost, and an output of 2,401 tons of 60-percent concentrates was achieved that year. The Primos Co. built a large mill at the Copeland mine near South Boulder Creek, a mile and a half north of the Crescent station of the Denver & Rio Grande Railroad, and began operating the mine and mill early in 1917.

Although the price of tungsten fell rapidly from a peak of $90 per unit in March 1916 to a low of $10 in August of that year, the boom prices had stimulated development, with the result that a high rate of output continued during the next 2 years. Thus, in 1917, the production rose in spite of the decrease in price, and the output from the district reached an all-time peak of 2,707 tons of 60-percent concentrates. The local price of tungsten was $15 per unit on a 60-percent basis during most of 1917, but it rose to $18 near the end of the year. The Wolf Tongue Mining Co. was the leading producer. Most of the output of its many properties was obtained from lessees, and this ore, together with a considerable amount of custom ore from other producers, was concentrated at its mill in Nederland. The Primos Mining & Milling Co., the second-largest producer, continued to operate some mines itself and to work numerous deposits near Nederland through lessees. The Vasco Mining Co. worked its property at Tungsten and also purchased custom ore. In the Vasco No. 10 mine the company found one piece of high-grade ore weighing more than a ton—probably the largest piece of ferberite ever mined—which is now in the United States National Museum.

Many mines, as well as hundreds of shallow prospects and float "beds," contributed to the record output achieved during the so-called tungsten boom of 1915–18. The Cross, Clyde, Cold Spring, Western Star, Bonanza, Kicker, and Hoosier mines were major sources of ore for the Wolf Tongue Co. The Primos Co. obtained ore from the Conger, Beddig, and Rake-off mines and from several of the Crow mines in the western part of the district; from the Oregon and Quaker mines in Gordon Gulch, and from the Copeland mine on South Boulder Creek. The Vasco Co. operated all 10 Vasco mines. The Tungsten Production Co. worked the Barker, Nancy Henderson, and Forest Home mines near Tungsten and took rich ore from the Luckie 2, Eureka, and Lookout mines near Boulder Falls. The Rogers No. 1 was the largest producer on the Rogers tract, but many smaller mines also were active. Rich ore was mined in the Philadelphia, just west of the Rogers tract. The Good Friday, near Boulder Falls, was a large producer, and the nearby Catastrophe mine was active. The Pueblo Belle and other mines in Black Tiger Gulch, in the eastern part of the district, were worked intensively. In the Dorothy and Katie mines, in Millionaire Gulch, the Tungsten Metals Corp. mined high-grade ore as much as 3 ft. thick. In the Beaver Creek district the Elsie, Mammoth, and Tungsten or Chance mines produced heavily, and a considerable output came from several smaller mines, such as the Black Rover, Fitzsimmons, Sunday, Blackhawk, Rambler, Missing Link, Cross No. 2, and Brace tract.

In 1918 the Wolf Tongue Mining Co. found bonanza ore in the Cold Spring mine and was again the largest producer in the district. The other large mines continued to produce at a high rate during the first part of the year, but the great fall in price after the 1916 peak had an adverse effect on development. This began to affect production in 1918, even though the price of tungsten was higher than in 1917. The output decreased rapidly during the last few months of 1918, and the output for the year fell to 1,910 tons of 60-percent concentrates. In December 1918 the local price of tungsten dropped from $20 to $12 per unit, partly because of the flow of tungsten into world markets from the newly discovered Chinese deposits. The following statement was made in 1918 by some of the producers to the United States Tariff Commission (Hess, 1921b, pp. 981–983):

> It may be stated that practically all the cheaply mined ore was extracted during the boom of 1915–1916, and it will be clearly shown in the perusal of the questionnaire submitted herewith that practically all of the production of the county is coming from below the surface, and it will also be clearly shown in the questionnaire that the cost of such mining is from 3 to 7 times the cost of mining at the surface. It is evident from information obtained that many of the operators are uncertain as to whether they will be able to continue operations at the present prices of from $20 to $22 and a great many will have to shut down unless better prices than the present ones are obtained. The committee may state from its own knowledge that very little development work compared to the amount of ore produced has been done at the present time and it is believed that the production will materially decrease unless present prices are stabilized or increased * * *. Answers made by the majority of producers to the subject proposed in the questionnaire indicate that most of these producers feel that they must have a price of from $30 to $40 per unit in order to obtain a reasonable profit in operation.

In 1919 the price of tungsten fell from $12 per unit at the beginning of the year to $6 at the end of the year; the production of the Boulder district reached a lower figure than at any time since 1901, and only 130 tons of concentrate were sold. The production would have been even lower if it had not been that some ore was still being sold on unexpired contracts at higher prices than those prevailing in the world market. Most of this ore was produced by the Vasco, Wolf Tongue, and Long Chance Mining Companies, and much of this was ore previously extracted. The Wolf Tongue Co. completed its new shaft in the Cold Spring mine to a depth of 440 ft, and the high-grade ore discovered in 1918 was mined throughout 1919 and made up a considerable part of the production for that year. The Primos Mining & Milling Co. closed the Conger, the last of its mines to remain in operation, in January 1919.

PERIOD BETWEEN THE WARS

In 1920 the Wolf Tongue Mining Co. and the Vasco Mining Co. were the only producers in the United States, and even they might not have mined any ore had they not been subsidiaries of companies manufacturing high-speed steels. The Vanadium Corp. of America acquired all the holdings of the Primos Co. in the Boulder district in 1920, but it did not work any of the mines, except for minor operations by lessees, until 1938. In 1921 and 1922 no tungsten ore was produced in the United States, but the Wolf Tongue Mining Co. did a small amount of development work in the Cold Spring mine. Chinese ore continued to flood the market, and much wolframite was sold in New York at $1.80 to $2 per unit in 1922. The distress of the domestic producers was so acute and so vocal that a tariff of $7.14 per unit was placed in effect on September 22, 1922. This encouraged a few companies to resume operations, and in 1923 the Vasco Mining Co. and the Wolf Tongue Co. again produced ore in about the same quantity as they had 3 years previously. At this time William Loach, general manager of the Wolf Tongue Co., estimated that tungsten could not be mined in Boulder County for a cost of less than $12 a unit, and according to Hess (1927, p. 242), there were few deposits in the United States that could be operated profitably at $12 a unit. Chinese ores could be landed in New York and London for $2.75 per unit, and the $7.14 tariff was not sufficient to stimulate mining in the United States.

In 1924 and 1925 the Wolf Tongue Mining Co. continued to operate the Cold Spring mine and sold all concentrates to the Firth-Sterling Steel Co. The Tungsten Production Co. acquired the holdings of the Vasco Mining Co. about 1924 and began operation of the mines in 1925. Its production in that year came chiefly from a body of bonanza ore found in sinking the Vasco No. 6 shaft. In 1926 and 1927, when the price of tungsten was about $11 per unit, most of the district output came from the Cold Spring and Vasco No. 6 mines. During 1928, 1929, and 1930 the Cold Spring was the chief producer in the district, but some ore came from the Vasco mines and from lessees of the Wolf Tongue Mining Co. In 1928 the Wolf Tongue Co. built a new and improved mill at Nederland to replace its old mill, which burned in 1927. In 1930 and 1931 the production of the district was less than 100 tons, and in 1932 no ore was sold.

Better prices in the summer of 1934 stimulated activity in the district. Many lessees sold small quantities of ore to the Wolf Tongue Co. and to the Tungsten Production Co., and the district output rose to 342 tons of concentrates for the year, the largest output since 1918. In 1935 the output rose to 390 tons. A large part of the output came from the Beaver Creek area, where Messrs. Henderson, Walsh, and McKenzie were operating the Mammoth mine. The Cold Spring mine was abandoned in 1935 and ore was sought in other Wolf Tongue properties with some success. During 1936, 1937, and 1938 some ore was produced from operations scattered through the district, but the yearly output averaged only about half that of 1935. The price of tungsten rose from $12 to $20 in 1937, however, and this rise stimulated development that was to affect the district output markedly in 1939, when the price of tungsten had again fallen to $12.

The Vanadium Corp. of America, with Robert Sterling in charge, reopened the Conger mine in 1938 and built a new mill there. The company's Rake-off property was operated in 1939 and 1940, and the Spider Leg mine was operated in 1941 and 1942. The Quay and Phillip Extension mines, two essentially new mines on the property of the Colorado Tungsten Corp., which was held under lease by the Wolf Tongue Mining Co. after 1935, began producing in the late thirties and were highly productive for a few years. The Wolf Tongue Mining Co. sank the shaft of the shallow Illinois mine and found rich ore. In the Beaver Creek district Tom Walsh operated the Sunday and Tungsten mines alternately and achieved a substantial output, and the Mammoth mine of the Tanner group continued to be productive. Operation of the Luckie 2, Eureka, and Good Friday mines near Boulder Falls was resumed about 1936, and production continued through the war years with only minor interruptions. Mills of the Wolf Tongue Mining Co., the Vanadium Corp. of America, and Gold, Silver & Tungsten, Inc., the successor to the Tungsten Production Co., operated on ore from company mines and from lessees. Smaller mills were operated by Walsh and by the Tanner group on Beaver Creek, and by Ray Betasso in Black Tiger Gulch.

As a result of the new activity, the district output rose from 240 tons of 60-percent concentrates in 1938 to 479 tons in 1939 and to 693 tons in 1940.

ACTIVITY DURING WORLD WAR II

After the start of hostilities in Europe in September 1939, the local price of tungsten rose from $12 per unit to $15, and in 1940 it rose to $18. This rise in price and the increasing demand for tungsten for rearmament led to the reopening of several mines. In 1941 the district output was 646 tons of 60-percent concentrates. The Wolf Tongue Mining Co. and the Conger mine of the Vanadium Corp. were by far the largest producers from 1939 through 1941, but important contributions were made by Gold, Silver & Tungsten, Inc., by the Fortuna Mining & Milling Co., which worked the Good Friday mine, and by the Chance and Mammoth mines in the Beaver Creek area. In 1942 the output dropped to 376 tons, even though the price rose to $26 during the year. This decrease represented the cumulative effect of a marked decrease in the output from almost every mine in the group that had started production in the late thirties. The output from the Illinois, Quay, Phillip Extension, and Conger mines and the group near Boulder Falls, including the Good Friday, Luckie 2, and Eureka, fell off markedly in 1942. Although some mines had come into production, including the Dorothy, Pueblo Belle, Sunday, Rogers Nos. 1 and 11, Spider Leg, Cross, and Western Star, they could compensate only in part for the loss in output from the more productive mines.

In 1943 the 100-ton gravity-flotation mill of the Boulder Tungsten Mills, Inc., was completed; the Government-owned Metals Reserve Company established a local stockpile and began buying ore at premium prices; several mines were opened with the aid of Government loans; and some ore was found by drilling done by the Bureau of Mines in cooperation with the Geological Survey. By the end of the year about 50 mines were in operation, and the district output rose to the equivalent of 660 tons of 60-percent concentrates, including stockpiled ore and low-grade concentrates sent to the chemical plant of the Metals Reserve Company in Salt Lake City. In addition to the larger mills operated by the Wolf Tongue Co. and the Vanadium Corp., George Teal's Marine mill handled considerable custom ore; H. M. Gregory operated the mill owned by Gold, Silver & Tungsten, Inc.; the Sunnyside mill was operated on Pueblo Belle ore for the Southwest Shattuck Chemical Co.; and small mills were operated during the year at the Good Friday, Eureka, Oregon, Quaker, Phillip Extension, Quay, Sunday, and Mammoth mines. The Boulder Tungsten Mills, Inc., was operated chiefly on mill tailings during 1943 and the first part of 1944. A low-grade concentrate suitable for feed for the Salt Lake City tungsten plant of the Metals Reserve Company was made, and this production contributed substantially to the district output.

The Metals Reserve Company established a stockpile at the Boulder Tungsten mill and began buying ore on July 1, 1943. It paid \$30 per unit for ore containing 60 percent WO_3, and although this price was far lower than the peak price during World War I, production was greatly stimulated because higher prices were paid for tungsten in low-grade ore than at any time in the history of the district. Prior to 1942, ore containing 1 percent WO_3, or one unit per ton, was generally quoted at \$1 to \$3 per ton, or 10 to 20 percent of theoretical value, and earlier in the history of the district quotations were not customarily given for ore containing less than 3 percent WO_3. In 1942 Boulder Tungsten Mills, Inc., buying on a \$23 schedule for 60-percent ore, offered \$7 per ton for 1-percent ore—that is, \$7 per unit of WO_3 in ore containing 1 percent WO_3. When the Government-owned Metals Reserve Company entered the market in 1943, it paid an unprecedented \$20.50 per ton for ore containing 1 percent WO_3; for a time it accepted ore running as low as 0.50 percent WO_3, but the minimum was later changed to 0.80 percent.

The Wolf Tongue and Conger mills continued to operate during the time the Metals Reserve Company was buying ore, but ore from most of the mines was shipped to the stockpile. Among the more important producers at this time were the Crow No. 18, Hugo, Forest Home, Vasco No. 7, Vasco No. 2, Eureka, Good Friday, Oregon, Quaker, Pennsylvania, Dorothy, Ohio, Red Signe, Pueblo Belle, Rogers No. 5, Roosevelt, Fitzsimmons No. 1, and Copeland mines. Ore from the Quay and Phillip Extension mines was milled in part in small mills at the mines and in part at the Wolf Tongue mill, and the Conger ore was milled at the Conger mill.

During three exploration programs conducted by the Bureau of Mines in cooperation with the Geological Survey in 1942 and 1943, 145 diamond-drill holes totaling 12,385 ft were drilled on 24 different properties, and 30 bulldozer trenches were dug. Ore was found in 26 drill holes and one trench on 12 different properties.

At the end of February 1944, the Metals Reserve Company announced that it would stop buying at the \$30 price at the end of March, but as one alternative in the settlement of contracts, it offered to pay \$24 per unit until July 1. The local price fell to \$20 for ore containing 60 percent WO_3 and to a much lower level for tungsten in low-grade ore after the Metals Reserve Company withdrew from the market. As costs had increased greatly during the war, most of the mines closed in the summer of 1944. By the end of the year only the Conger and the Forest Home mines were in operation. The district output fell to an estimated 445 tons of concentrates (including 75 percent of the assay value of ore stockpiled in 1944). At the close of buying in July 1944, the Metals Reserve stockpile contained 15,949 tons of ore containing 23,632 units of WO_3. In 1944 the properties and functions of the Wolf Tongue Mining Co. were taken over by the mining department of the Firth-Sterling Steel Co., the parent organization, but William Loach continued to direct the activities of the company in the Boulder district.

The Conger mine closed in May 1945, and the Forest Home mine, operated by Elmer Hetzer, was left as the only producing mine in the district, although the Firth-Sterling Co. continued to do development work in the Hoosier mine. Hetzer milled his ore at the Phillip Extension mill, and in September he closed the Forest Home and began mining at the Phillip Extension. Late in the year the Metals Reserve Company sold the Boulder stockpile after competitive bidding to Boulder Tungsten Mills, Inc., which began milling the stockpile immediately. The output for 1945 was estimated as about 75 tons of 60-percent concentrates, not including concentrates produced from the stockpile, which was included in the estimates for 1943 and 1944. Most of this output came from the Forest Home and Phillip Extension mines, and most of the remainder came from the Conger mine in the early part of the year.

Early in 1946 the Phillip Extension was the only mine in operation, producing 3 to 5 tons of concentrates per month; the Firth-Sterling Co. was driving a long exploratory tunnel southeastward under Hurricane Hill from the vicinity of the Clyde mine in Sherwood Gulch; and the Conger mill of the Vanadium Corp. of America was being dismantled.

SUMMARY OF PRODUCTION

The yearly output of the Boulder tungsten district is given in table 7, and the annual and cumulative production is shown graphically in figure 63. The figures given for the various years are not all of the same degree of accuracy. Exact figures are not available for the years 1900–1906, inclusive, and for some of these years as many as three different sets of production figures have been found in various reports. In general the figures given by George (1909, p. 86) are the most conservative, and these have been used in the present compilation. They should be regarded as minimum estimates, however. The figures for the years after

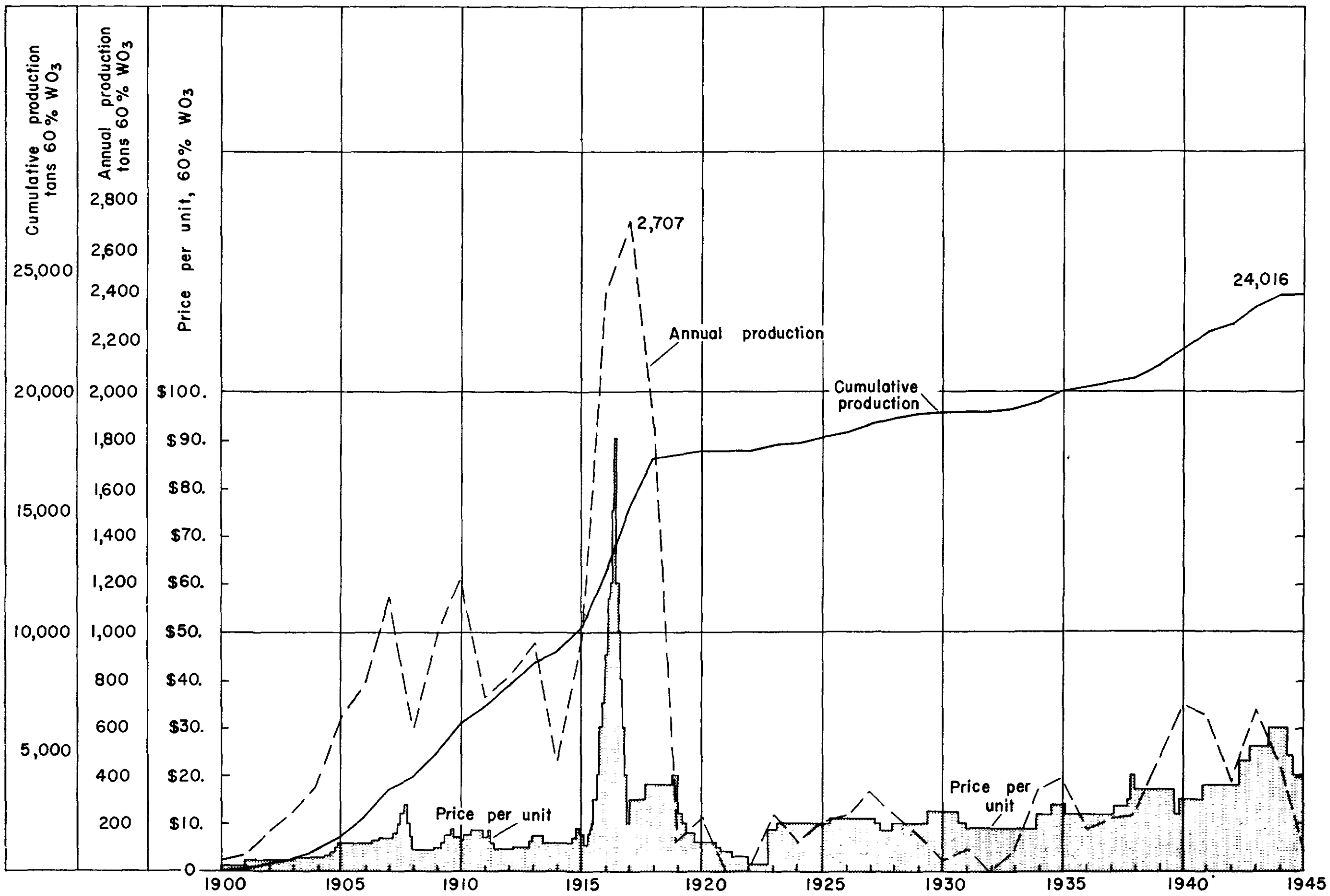


FIGURE 63.—Annual and cumulative production of tungsten, in tons of ferberite concentrates (reduced to the equivalent of 60 percent WO_3), and local price per unit of WO_3 (in ore, based on a content of 60 percent WO_3) in Boulder County, Colo., during the years 1900–1945.

1906 are taken from Mineral Resources of the United States and from Minerals Yearbook or were supplied by C. W. Henderson and R. H. Ridgway, of the Bureau of Mines, to cover years for which exact figures for Boulder County were not included in the statistical publications. The production figures for 1943–45 are estimates that include the probable concentrate recovery from stockpiled ore. For this purpose 75 percent of the assay value of ore stockpiled in 1943 and 1944 was included in the estimates for those years. Inasmuch as they include the probable recovery from some unmilled ore, the figures given for these 2 years will be higher than the figures appearing in Minerals Yearbook. On the other hand, Minerals Yearbook will show a considerable output for 1945, 1946, and 1947, when the stockpile was milled and low-grade concentrates shipped to Salt Lake City were treated, although there was practically no mining in the district at this time. The total output for the years 1943–47 should of course be the same by both methods of accounting, except that one is an advance estimate.

The value of the annual output is given by George (1909) for the years 1900–1906 and by Hess (1921a, p. 942) for the years 1907–17. Exact figures are not available for most of the years after 1917; for these years the value has been computed from the price averages, which are given for most years in Mineral Resources and Minerals Yearbook, or from local ore schedules or local sale prices of concentrates. The values quoted for many of the years are therefore only approximate, making the total value an approximation also, but the error in total value is believed to be considerably less than a million dollars. It should be noted that George (1909 [1916], p. 105) gives considerably higher values for most of the years between 1909 and 1915 than Mineral Resources.

According to the available figures, the total output from the Boulder tungsten district through 1945 was about 24,000 tons of concentrates containing 60 percent WO_3 and valued at about $23,000,000. If these figures are correct, the average value of concentrates, in terms of a 60-percent product, produced in Boulder County from 1900 through 1945 is about $960 per ton. This is equivalent to $16 per unit of WO_3 in concentrates sold. The average value per unit of WO_3 in ore would be considerably less than $16.

The 24,000 tons of 60-percent concentrates produced from the Boulder district through 1945 is equal to

TABLE 7.—*Production of tungsten ore (reduced to equivalent of 60 percent WO_3) in the Boulder County district, 1900-1945, in short tons*

Year	Tons of ore containing 60 percent WO_3	Value	Year	Tons of ore containing 60 percent WO_3	Value
1900	42	$3,216	1924	123	$62,509
1901	70	8,775	1925	201	127,474
1902	165	24,900	1926	232	148,206
1903	240	36,317	1927	332	209,007
1904	360	125,000	1928	229	142,896
1905	640	231,120	1929	152	104,880
1906	780	309,603	1930	47	34,094
1907	1,146	573,643	1931	98	64,798
1908	584	204,465	1932	0	0
1909	993	391,160	1933	86	49,433
1910	1,221	535,567	1934	342	298,976
1911	730	234,513	1935	390	312,858
1912	812	297,533	1936	180	160,164
1913	953	428,760	1937	219	256,230
1914 [1]	467	182,013	1938	240	259,200
1915	963	2,311,200	1939	479	503,595
1916	2,401	4,666,301	1940	693	711,480
1917	2,707	2,994,000	1941	646	928,279
1918	1,910	2,595,800	1942	376	540,763
1919	130	78,334	1943	660	934,196
1920	216	101,800	1944	[2] 445	[2] 587,400
1921	0	0	1945	[2] 75	[2] 94,500
1922	0	0			
1923	241	144,600	Total	24,016	$23,009,438

[1] According to George (1909 [1916], p. 105), Boulder County produced 630 tons valued at $252,000 in 1914.
[2] Estimate.

1,440,000 units of WO_3. This is almost 50 percent greater than the output from any other district in the United States according to the following data, which were supplied by D. M. Lemmon, of the Geological Survey:

	Period	*Units WO_3*
Mill City, Nev	1917–45	986,842
Atolia, Calif	1906–45	986,179
Bishop, Calif	1916–45	889,744
Yellow Pine, Idaho	1941–45	810,837

Thus the Boulder district has held first place in total output among the tungsten districts in the United States since shortly after 1900. At the end of 1945 it still led all other districts in the country by a substantial margin, but its annual output had become almost insignificant in comparison to the high rate of output from the scheelite deposits of Mill City, Nev., and Bishop, Calif.

The output from the Boulder district rose rapidly from 1900 to 1907, when 1,146 tons of concentrates containing 60 percent WO_3 was produced. From 1907 to 1915 the output fluctuated widely, climbing as high as 1,221 tons in 1910 and falling as low as 467 tons in 1914. In 1916 the output jumped to 2,401 tons, and in 1917 it reached an all-time peak of 2,707 tons. It fell to 1,910 tons in 1918, and from this year until 1938 the average output was less than 200 tons a year. Production began to increase in 1939, and the yearly output for the 6 years 1939–44 averaged about 550 tons. Of the total output from the district, more than 17,000 tons, or about 70 percent, had been produced by the end of 1918, and 29 percent was produced in the 3 years 1916, 1917, and 1918.

As the average mill recovery in the Boulder district has probably been about 75 percent, the 24,000 tons of 60-percent concentrates indicates a gross mine production equivalent to about 32,000 tons of material containing 60 percent WO_3, or nearly 2 million units of WO_3. Although accurate figures are not available, it seems probable that the Conger mine supplied 20 to 25 percent of this total. The 25 largest mines of the district have supplied about 75 percent of the output, and the remaining 25 percent was supplied by about 200 small mines and several hundred surface workings and float beds.

ECONOMIC FACTORS AFFECTING PRODUCTION

PRICE

As noted earlier, the price of tungsten ore and concentrates is quoted in terms of the unit. Weight in tons multiplied by the WO_3 content in percent gives the WO_3 content in units; thus 1 ton of ore containing 1 percent WO_3 contains 1 unit, and 1 ton of ore containing 60 percent WO_3 contains 60 units. Price quotations are based on a content of 60 percent WO_3, and the price per unit is lower if the tungsten is contained in material assaying less than 60 percent. For example, according to one schedule, the 60 units in a ton of ore containing 60 percent WO_3 would be worth $20 each, or a total of $1,200, but the 60 units in 2 tons of ore containing 30 percent WO_3 would be worth only $14.52 each, or a total of $871.20.

Tungsten is consumed, as in making ferrotungsten, in the form of concentrates having a tungsten trioxide content of approximately 60 percent, and tungsten ore must eventually be put in this form before it can be finally marketed. Ore assaying less than 60 percent WO_3 must therefore be beneficiated to increase the WO_3 content. Because the mill recovery decreases with decreasing grade and the milling cost per unit increases, the per-unit value of tungsten decreases rapidly with decreasing grade. The value of a unit of tungsten trioxide in crude ore therefore depends more on the grade of the ore in which it is contained than on the market price of the 60-percent product. Thus, according to the schedule given in table 8, the value per unit in ore containing 10 percent WO_3 is 5.9 times as great as the value per unit in 1-percent ore. As this is a "$10 schedule" ($10 per unit for 60-percent ore), the price for 60-percent ore would have to increase from $10 to $59 in order to have as great an effect on the per-unit value as the increase from 1 to 10 percent in the grade of the ore. The difference between $10 and $59 is far greater than the normal range in tungsten prices.

A $10 schedule of the Wolf Tongue Mining Co. is given in table 8. In order to illustrate relative values in terms of units, price per unit has been added to the original schedule, which shows only price per pound of WO_3 and price per ton of ore. This is a standard schedule for this company, and it can be converted to any other base price by simple multiplication. For a $20 schedule, all prices would be multiplied by 2; for $12 they would be multiplied by 1.2.

TABLE 8.—*Schedule of prices paid for crude ferberite ores, based on a price of $10 per unit WO_3 in ore containing 60 percent WO_3*

Percent WO_3	Price per pound WO_3	Price per unit WO_3	Price per ton ore	Percent WO_3	Price per pound WO_3	Price per unit WO_3	Price per ton ore
1	$0.05	$1.00	$1.00	31	$0.363	$7.26	$225.06
2	.06	1.20	2.40	32	.368	7.36	235.52
3	.09	1.80	5.40	33	.374	7.48	246.84
4	.18	3.60	14.40	34	.379	7.58	257.72
5	.22	4.40	22.00	35	.385	7.70	269.50
6	.245	4.90	29.40	36	.39	7.80	280.80
7	.27	5.40	37.80	37	.396	7.92	293.04
8	.275	5.50	44.00	38	.401	8.02	304.76
9	.285	5.70	51.30	39	.407	8.14	317.46
10	.295	5.90	59.00	40	.412	8.24	329.60
11	.315	6.30	69.30	41	.418	8.36	342.76
12	.32	6.40	76.80	42	.423	8.46	355.32
13	.325	6.50	84.50	43	.429	8.58	368.94
14	.33	6.60	92.40	44	.434	8.68	381.92
15	.335	6.70	100.50	45	.44	8.80	396.00
16	.34	6.80	108.80	46	.44	8.80	404.80
17	.345	6.90	117.30	47	.44	8.80	413.60
18	.35	7.00	126.00	48	.44	8.80	422.40
19	.35	7.00	133.00	49	.44	8.80	431.20
20	.355	7.10	142.00	50	.44	8.80	440.00
21	.355	7.10	149.10	51	.44	8.80	448.80
22	.355	7.10	156.20	52	.44	8.80	457.60
23	.355	7.10	163.60	53	.445	8.90	471.70
24	.355	7.10	170.40	54	.455	9.10	491.40
25	.357	7.14	178.50	55	.46	9.20	506.00
26	.358	7.16	186.16	56	.47	9.40	526.40
27	.358	7.16	193.32	57	.475	9.50	541.50
28	.36	7.20	201.60	58	.485	9.70	562.60
29	.36	7.20	208.80	59	.49	9.80	578.20
30	.363	7.26	217.80	60	.50	10.00	600.00

The schedules of the various mills differ somewhat, depending upon the type of ore best suited to the mill, the type of ore most commonly available to the mill, and the nature of the market outlets. Differences in price at different grade levels are illustrated by the figures here given which were selected from $12 schedules effective at the same time at three different mills:

Grade (percent)	*Price per unit*		
	Mill A	*Mill B*	*Mill C*
1	Refused	$1.20	Refused
5	$6.00	5.28	$5.50
10	8.00	7.08	8.00
20	8.00	8.52	8.00
40	10.00	9.88	8.00
50	11.00	10.56	10.00
55	11.50	11.04	11.00
59	11.90	11.70	11.80
60	12.00	12.00	12.00

The price of tungsten in the Boulder district is generally $2 to $4 lower than the New York quotations.

During the history of the Boulder district the price of tungsten has ranged from $1 to $90 per unit according to the published schedules, and some ore is said to have sold for as much as $106 per unit during the boom. The local price per unit, in ore containing 60 percent WO_3, from 1900 to 1945 is shown graphically in figure 63. This chart was compiled from a large collection of ore schedules, but as there is no way of knowing whether the collection is complete, the chart may not show every change that has occurred. Paradoxically, more data are available for the period before 1920 than that which followed, and the chart may therefore be less accurate for the period 1920–40 than for the period 1900–1920. In general, the price of tungsten rose slowly from $1 per unit in 1900 to $5 late in 1904. From 1904 to 1915 the price fluctuated between $4.50 and $9.00 per unit except for a brief period in 1907, when it rose to $14. The tungsten boom began late in 1915, and by March 1916 the price had reached $90, but it fell more rapidly than it had risen and by August 1916 it had dropped to $10. Although the rise in price reflected a wartime increase in demand, it was apparently exaggerated by speculation, as shown by the abruptness and brevity of the boom as a whole and by the great changes in price and the brief duration of each price level. The history of the boom is recorded by the following price changes, based on published ore schedules:

1915	*Price per unit*	*1916*	*Price per unit*
Feb. 7	$5.60	Feb. 7	$57.00
May 10	8.00	Feb. 22	60.00
June 1	9.00	Mar. 13	75.00
June 21	10.00	Mar. 17	90.00
July 10	15.00	Mar. 28	60.00
Sept. 28	20.00	May 12	50.00
Oct. 30	30.00	May 19	40.00
Nov. 18	35.00	May 27	30.00
Dec. 20	45.00	June 13	20.00
		Aug. 2	15.00
		Aug. 30	10.00

The price rose to $18 in 1917 and to $20 for a short time in 1918. It fell to $12 at the end of 1918 and continued to decline during 1919, 1920, and 1921, finally dropping to $1.50 in 1922. The tariff of $7.14 per unit imposed in September 1922 raised the price to $10 in 1923, and quotations remained at about this level until 1934, when they rose to $14. The price fell to $12 in 1935, rose as high as $20 in 1937, fell to $17 in 1938, and fell to $12 in 1939. It rose to $15 late in 1939, to $18 in 1940, and to $23 and then $26 in 1942. In 1943 it finally rose to $30, which was a premium price paid by the Metals Reserve Company. When this Government-owned company withdrew from the market early in 1944, the price fell to about $20 and remained at about that level through 1945.

Because of the high cost of finding and mining small bodies of rich ore, the district has always been remarkably sensitive to changes in price. The small size and erratic distribution of the ore bodies, together with the long-established practice of working the mines through lessees, precludes the possibility of blocking out extensive reserves in advance of mining, and as there is little ore in sight at any one time, production falls with a fall in price simply because the process of hunting for ore stops. Similarly, a rise in price stimulates exploration and development and leads to increased output. As might be expected, however, with increasing depletion of the district, the time lag between an increase in price and an actual increase in output has gradually become greater. In 1907, when the first peak in production was reached (figure 63), the output increased greatly owing to a rise in price during that year. In 1909 and 1910 the output rose in response to fairly good prices during those years. The rise in price late in 1915 and early in 1916 caused a great increase in production in 1916, but the peak production was not reached until 1917. A rise in price late in 1933 and in 1934 caused the output to increase in 1934 and to reach a minor peak in 1935, almost 2 years after the price impetus was received. A rise from $12 to $20 in 1937 stimulated development, but output was not greatly affected until 2 years later, in 1939, and the peak was not reached until 1940. A price rise that began late in 1939 and continued to 1943 caused a minor peak in output in 1943, but in a sense the peak came in 1944. The output in 1944 fell below the 1943 level, but most of the year's output was achieved during the first few months of the year, when the rate of production was above the 1943 level, and production dropped suddenly when the price began to fall in April 1944.

The reaction of the production curve to a price change depends greatly on the character of the ore bodies in the mines that happen to be in production. The output that caused the 1940 peak came largely from a group of mines capable of producing a substantial quantity of fairly high grade ore, and the output from these mines was barely affected by the decrease in price in 1939. The 1943–44 output, on the other hand, came from a large number of mines that were producing relatively low grade ore. They were therefore much more sensitive to price changes than the mines that were operating a few years earlier, and when the price dropped the output dropped almost simultaneously.

MINING

The small bodies of high-grade ore typical of the Boulder district can be worked most efficiently by small-scale operations, and this has led to the development of the district through a large number of small mines. There are about 225 mines in the district, and in addition, several hundred minor shafts, prospects, trenches, and float "beds" have been more or less productive. Most of these workings were started where there was some trace of ore showing, and most of them were abandoned when ferberite could no longer be seen in the vein. The small size and erratic distribution of the ore bodies make more systematic exploration economically hazardous, and the fluctuating price of tungsten adds a further element of risk.

In most of the mines only one ore shoot was found, and in many of the small mines and surface workings the ore constituted no more than a pocket in the vein. Although such pockets and small ore bodies may contain rich ore, their total value, considering their small size and the high mining costs, is not enough to pay the costs of the exploration necessary to find a second ore pocket. As a result, most of the mines and diggings in the district are small and have had only a small output. In the larger mines, where larger ore bodies are found, exploration has been more extensive, and many of the larger mines owe their productivity in part to the discovery of blind ore shoots. However, even in these mines the actual tonnage of ore handled is relatively small, and the productive periods are generally short.

The bottoms of most of the mines are at or just below the bottoms of ore shoots followed either down from the surface or from a point near it, and as the individual ore shoots have a relatively short vertical range, the mines are shallow. The average depth of the 30 most productive mines in the district is only about 350 ft, and the average depth of the total of more than 200 mines probably is not more than 100 ft. The Conger mine is the deepest in the district and has a maximum depth of just under 1,000 ft. Other relatively deep mines are the Vasco No. 6 (618 ft), Illinois (505 ft), Clyde (503 ft), and Cold Spring (480 ft). These mines yielded ore to a somewhat greater depth than the average, but they owe their depth in part to exploration below the ore shoots. Practically all the ore recovered from the Conger mine was found within 600 ft of the surface, and the lower 400 ft of the mine was essentially barren.

Most of the productive area in the Boulder district has been controlled by four or five major owners through most of the life of the district. As shown on the claim map (pl. 2), much of the district is covered by agricultural patents. These are homestead entries made for the most part in the 1870's and 1880's, and they carry mineral rights. A very few companies and estates own almost all these homestead tracts. Certain holdings, such as the Rogers tract, have been worked only by lessees, but most of the companies that have large holdings in the district work their property both by company operation of the larger mines and by leasing the smaller mines. The leasing system offers advantages both to the owners and to the lessees, but the system in general has some disadvantages. In mines operated by lessees, ore is mined as rapidly as it is found, and there is very little or no reserve in advance of mining. Production therefore cannot be increased abruptly to take advantage of favorable prices, and costs are increased because mining cannot be planned in advance. Exploration is not always carried out on a scale commensurate with the return from the mine, for the lessee bears most of the risk and thus may jeopardize his profits. As a result, many leased mines are not sufficiently explored. Furthermore, exploration in a group of mines as a whole is uncoordinated and may be haphazard; better results could be obtained for the money if it were spent on a definite and unified program. In spite of these disadvantages, however, the district has undoubtedly profited more than it has lost through the leasing system. Much ore that otherwise would probably remain unmined has been found and mined through the enterprise of the miner-lessees of the Boulder district.

Each of the major companies operates a mill or has operated mills in the past, and according to the usual leasing agreement, all the ore from the lessee's mine must be sold to these mills. At times this is a disadvantage to the lessee, as he cannot shop around to find the best market, but it enables the larger organizations to maintain a more or less steady output and thus to maintain market outlets for the district as a whole. Royalty rates have ranged from 10 to 40 percent, but a 20-percent royalty on the net mill returns appears to be the accepted standard in the district. To encourage prospecting, some companies have at times offered 6 months' royalty-free leases on new locations and some of them lend heavy equipment, such as hoists and compressors, to lessees.

Most of the mines of the district are opened by inclined shafts that follow the dip of the vein. The small, shallow ore bodies do not warrant elaborate shafts and hoisting equipment, and most of the shafts are designed for the use of a bucket for hoisting. A few well-constructed inclined and vertical shafts have been equipped with skips. The underground workings consist mainly of drifts, and except in a few mines, very little crosscutting has been done. The ratio of crosscuts to drifts in the district as a whole is probably no more than 1:20, or possibly even 1:30. This paucity of crosscuts makes it impossible in many mines to get off the vein in order to explore it by drilling, and it leaves untested in many mines the possibility that parallel veins may be present in the walls. The usual procedure in mining is to drift on the vein until ore is reached and pierced and then to start a stope up from the back of the drift. The stopes are generally called shrinkage stopes, although technically they are more nearly of the cut-and-fill type. The mining methods have been described by Vanderburg (1932, pp. 1–15).

As the value of the tungsten per pound or per unit increases with the grade of the ore, an earnest attempt is always made to sort out high-grade ore wherever and whenever possible. If the vein contains a high-grade streak, this is mined with hand tools. If the vein cannot be mined by hand, the stope may be carried up in the wall rock and the vein then mined selectively. In some stopes the vein is too small or too fragile to mine selectively, but the ore as shot down is then rough-sorted in the stope, and much of the coarse waste is retained in the stope as fill.

The ore hoisted from almost all the mines is sorted again at the surface. The ore is passed over screens or fine grizzlies, and the fines and cobbings together constitute the mill ore. The coarse product is sorted by hand, and the tungsten ore found in it is cobbed so as to make as high-grade a product as possible. The incentive for sorting is provided by the mill schedules, which necessarily include deductions for losses in milling and for milling costs. According to a mill schedule based on a price of $20 per unit in ore containing 60 percent WO_3, 2 tons of ore containing 5 percent WO_3 would be worth $95. If, by sorting out waste, the 2 tons could be reduced to 1 ton containing 10 percent WO_3, its value would be $115. One ton of 2-percent ore would be worth $17. If one of the two units contained in this ton of ore can be sorted out as high-grade, assaying 60 percent WO_3, the value of the ore is increased to $27.35 ($20 for 33 pounds of high-grade material, containing 60 percent WO_3, or 1 unit, plus $7.35 for the remaining 0.98 ton of 1-percent ore). Vanderburg (1932, p. 8) states that 70 percent of the material broken in the stopes in the Cold Spring mine in 1931 was discarded by stripping and hand sorting underground, 15 percent was rejected by hand sorting at the surface, and 15 percent was sent to the mill. One ton of sorted ore valued at $38.32 was obtained from 6.51 tons of crude ore having a value, in the crude state, of only $15.95.

Mining costs vary widely, depending on the grade of the ore, the amount mined, the size of the mine, and mining conditions, as well as the widely varying cost of exploration and development. In general, costs are high because the ore bodies are small, erratically distributed, and fairly high in grade. Per-ton mining costs increase rapidly with grade, and costs can therefore be expressed more accurately in terms of units.

The cost of ore hoisted at the chief mine of one of the larger companies operating in 1942 was $6.82 per ton for ore averaging 1.25 to 1.50 percent WO_3, or about $5 per unit. This figure is lower than the average in the district because much of the ore hoisted was stope fill that had been broken many years earlier. In another mine of the same company the cost was about $9.50 per unit in ore averaging 1.5 percent WO_3. In

December 1917 the cost at the first mine was $10.48 per ton for 592 tons of ore averaging 2.56 percent WO_3, or $4.09 per unit. More than half this cost was chargeable to development; an average of 4 ft of development work was done for every 10 tons of ore mined. Another company reported a cost of $14 per unit in 2-percent ore at its chief mine in 1938, but a relatively large amount of development was done. The cost during an earlier period at another of this company's large mines was $7 per unit in ore averaging 7 percent WO_3. At one of the most successful small mines operating in 1944, the cost was $15.29 per ton for 1,651 tons of ore that averaged about 2 percent WO_3, or an average cost of $7.65 per unit. A mining cost of about $7.50 per unit should approximate the average cost for ore from the larger mines and the more successful small mines during the early forties. This allows for an average amount of development but does not provide for extensive exploration. The cost of ore was considerably lower earlier in the history of the district, when ore was easier to find, the dollar had a greater purchasing value, and such taxes as sales, compensation, and social security had not yet been imposed.

In order to show the relative distribution of costs in a tungsten mine, a monthly cost sheet for one of the larger mines operating in 1917 is summarized below. The production was 592 tons of ore averaging 2.56 percent WO_3.

TABLE 9.—*Distribution of mining costs, in dollars per ton, Boulder County tungsten district*

	Labor	Supplies	Explosives	Power	Total
Mining:					
Breaking ore	0.730	0.029	0.530		1.289
Loading and tramming	.832				.832
Overhead	.093				.093
Hoisting	.154	.220			.374
Pumping	.123	.013		0.025	.161
Power	.051	.062		.226	.339
Sorting	.211				.211
Timbering	.350	.234			.584
Shop	.131				.131
General	.727	.032			.759
Total	3.401	0.591	0.530	0.251	4.773
Development:					
Drifts and crosscuts	1.712	0.152	1.607		3.471
Raises	.179	.062	.158		.399
Overhead	.092				.092
Hoisting	.155	.221			.376
Pumping	.124	.013		0.025	.162
Power	.051	.039		.226	.316
Shop	.133				.133
General	.731	.032			.763
Total	3.177	0.519	1.765	0.251	5.712
Grand total	6.578	1.110	2.295	0.502	10.485

MILLING

The ferberite of the Boulder district is heavy (specific gravity, 7.5), and most of it breaks clean from the gangue, which is relatively light and, except for horn quartz, fairly soft. A high-grade product can therefore be made by gravity concentration, which has been the chief method used in the district. However, ferberite slimes easily, and the fine slime is easily lost in milling. Poor recovery due to sliming has been the chief problem in milling throughout the history of the district. Sliming affects all ores, but the coarsely crystalline and the high-grade massive ores, which can be separated from the waste without fine grinding, will make a high-grade concentrate with a lower slime loss than the fine-grained siliceous ores. Some of the ore of the tungsten district consists of fine-grained ferberite dispersed in horn quartz. This horn ore, as it is usually called, must be ground so fine in order to liberate the tungsten that the loss from sliming becomes large.

Tungsten ore was first concentrated in the stamp mills in the gold and silver mining districts that adjoin the tungsten district. The stamps caused excessive loss by sliming and were soon abandoned. Rolls were introduced in order to cut down the proportion of fines in the crushed ore, and jigs were used to catch the tungsten in as coarse a form as possible. In most mills the largest quantity of tungsten and the richest product is obtained as a jig concentrate, in which the particles are generally coarser than one-eighth inch in diameter. Most of the larger mills built in the district have consisted essentially of a jaw crusher, rolls, jigs, and tables, and in many of them slime tables, "rag plants," or vanners have been added in order to catch the slimes. The smaller mills usually comprise a crusher, jigs, and tables, and many of the small temporary mills have only a crusher and jigs. The mills of the district have been described in detail in several of the publications in the list of references and will not be described further here. The reader is referred to the report by George (1909, pp. 76–85) for a description of the early mills and to a report by Vanderburg (1933, pp. 1–15) for a discussion of more recent milling practice.

Other methods than gravity concentration have been tried in the tungsten district but have not proved notably successful. Some ore was treated chemically at about the time of World War I, and a high-grade product in the form of tungsten trioxide—or tungstic acid, as it is often called—was made. This product was pure enough to fulfill the exacting requirements for lamp filaments, but the process was relatively costly. In the years just preceding World War II the Southwest Shattuck Chemical Co., of Denver, treated low-grade ferberite concentrates chemically to produce tungsten trioxide.

Differential flotation was tried as early as 1916, but it apparently was never used successfully until the gravity-flotation mill of Boulder Tungsten Mills, Inc., was put into operation in 1942. According to Ray Sullivan, manager of Boulder Tungsten Mills, a recovery as high as 99 percent was made on newly mined ore by treating the tailings from the gravity unit by flotation. However, the flotation concentrate was relatively low in grade. Most of the material treated in the mill was the accumulated tailings from the gravity mills. These were treated entirely by flotation, but the large and variable amount of organic matter in the old tailings ponds, and the variety of types of organic matter, prevented persistently high recoveries from being made, and at times the recovery was as low as 75 percent. The concentrate produced contained only 5 to 15 percent WO_3. Such a concentrate would have been unsalable earlier in the history of the district, but a market was provided during World War II by the chemical plant of the Metals Reserve Company in Salt Lake City, where low-grade concentrates were treated to make artificial scheelite.

The Boulder district has been characterized by an abundance of mills at all times, but seldom have more than three or four major mills been in operation. In February 1943 the district contained 17 mills, only 5 of which could treat more than 20 tons of ore daily, and in addition there were several hand-jig and washing plants that constituted crude and miniature mills. The so-called "large" mills are large only according to the standards of the district; most of them have capacities of 25 to 100 tons per day. The smaller mills have capacities of 5 to 10 tons per day.

The incentive for mill building is provided by the low prices paid by the custom mills for tungsten in low-grade ores. There are several reasons for these low prices: (1) The greater bulk to be handled per unit of tungsten increases the cost per unit. (2) The lower the grade the lower the recovery. (3) Most of the larger custom mills were designed to handle ore assaying 3 to 15 percent WO_3; ore assaying less than 3 percent is not wanted, and a penalty is assessed against it. This is shown by an abrupt break in the price schedules between the 2-percent and 3-percent levels or between the 3-percent and 4-percent levels. In the past many mills refused ore assaying less than 3 percent WO_3. (4) Much of the low-grade ore offered to the mills is horn ore that has the disadvantages both of giving an extra low recovery and of making a low-grade concentrate that is not easily sold. (5) Much of the low-grade ore contains relatively large quantities of deleterious substances such as phosphorus and sulfur.

The difference between the theoretical value of ore and the value according to an ore schedule based on a price of $20 per unit in ore containing 60 percent WO_3 is illustrated in table 10.

The great discrepancy between the theoretical value of the tungsten in low-grade ore and the price paid by the custom mills tempts the operator of even a small mine to build a mill. The saving on haulage and penalties often more than compensates for the cost of building and operating a small mill, even though the recovery is as low as 60 percent, but in some small mills the recovery has fallen so low—a recovery of only 16 percent was made on horny ore in one mill—that no advantage resulted. Although the small mills have produced a large amount of tungsten from ore that might not otherwise have been treated, they are nevertheless wasteful. Most of the tailings from the small mills are carried away by the creeks, and a large amount of tungsten in tailings has been irretrievably lost during the 45 years of activity in the district.

TABLE 10.—*Actual and theoretical values of tungsten ore containing less than 60 percent* WO_3.

Grade (percent)	Theoretical value per ton, at $20 per unit	Value per ton according to schedule	Actual value in percent of theoretical value
1	$20	$2.00	10
2	40	4.80	12
3	60	10.80	18
4	80	28.80	36
5	100	44.00	44
6	120	58.80	49
7	140	75.60	54
8	160	88.00	55
9	180	102.60	57
10	200	118.00	59
15	300	201.00	67
20	400	284.00	71
25	500	357.00	71.4
30	600	435.60	72.6
40	800	659.20	82.4
50	1,000	880.00	88
55	1,100	1,012.00	92
60	1,200	1,200.00	100

Milling costs in the more efficient mills range from $1 to $2 per unit of WO_3 contained in the heads. Per-ton costs vary widely, depending upon the grade. In the Wolf Tongue mill 25 tons of 4-percent ore can be treated in 24 hours, but only 12 tons of 10-percent ore can be treated in a similar period. According to William Loach, manager of the Wolf Tongue Mining Co., crystal ore assaying 2 percent WO_3 costs $4 per ton, or $2 per unit, to mill with 88- to 90-percent recovery; crystal ore assaying 2 percent WO_3 costs $2.50 per ton, or $1.25 per unit, to mill with 70-percent recovery; crystal ore assaying 8 percent WO_3 costs $8 per ton, or $1 per unit, to mill with 88- to 90-percent recovery.

According to Vanderburg (1933, p. 14), the cost of milling 1,250 tons of ore averaging 5.72 percent WO_3 in the Wolf Tongue mill in 1931 was $6.015 per ton. This is equivalent to $1.05 per unit contained in the mill heads. The cost at one of the larger mills operating in 1942 was about $1.60 per unit in ore averaging about 1.5 percent WO_3. The cost at a small mill operating during World War II was about $6 per unit in ore averaging about 2 percent WO_3.

In order to show the distribution of milling costs, the cost sheet for 1 month for a large mill operating in 1917 is summarized in table 11. A total of 1,770 tons averaging 2.50 percent WO_3 was treated, and the average milling cost per unit in heads was $1.34.

TABLE 11.—*Distribution of milling costs, Boulder County tungsten district*

	Cost per ton, in dollars			
	Labor	Supplies	Power	Total
Crushing	0.223	0.164	0.325	0.712
Concentration	.736	.106	.082	.924
Canvas tables	.219	.047		.266
Sampling	.081		.060	.141
Sacking and drying	.065	.179		.244
Water supply	.072	.022	.012	.106
Steam heat	.112	.314		.426
Miscellaneous	.201	.329		.530
Total	1.709	1.161	0.479	3.349

Recoveries at the large Lakewood mill during 15 months in 1917 and 1918 ranged from 74.7 to 90.1 percent, figured on a monthly basis, and averaged 81.9 percent. The head assays ranged from 1.90 to 2.52 percent WO_3 during the individual months and averaged 2.26 percent. The tail assays ranged from 0.23 to 0.60 percent WO_3 and averaged 0.42 percent. Ore treated per month ranged from 1,557 to 2,251 tons. This ore presumably consisted chiefly of "soft ore" containing crystalline and relatively pure ferberite. The average recovery from a moderately large tonnage of relatively horny ore treated in another mill in the twenties was 64.7 percent. Recovery from a large tonnage of rather low grade ore treated by one of the larger mills during World War II averaged 74.40 percent over a period of a few years. According to Vanderburg (1933, p. 3), recoveries averaged about 90 percent from ore assaying 3.5 to 30 percent WO_3 treated in the Wolf Tongue mill, and the average recovery for the best year was 92 percent. He says that in 1931 the recovery averaged 86.6 percent. About 90 percent of the ore milled was from the Cold Spring mine, which produced ore exceptionally amenable to treatment.

Mill recoveries vary widely and in general are relatively low. The average recovery from all the ore milled in the district can only be surmised, but it is probably not greater than 75 percent. Most of the larger mills and some of the small ones that have operated since about 1910 have had recoveries greater than 75 percent, but some mills have had recoveries of less than 60 percent. The stamp mills that were used during the first few years of mining in the district had recoveries of about 60 percent.

Most of the tungsten recovered by the mills is in a high-grade concentrate obtained chiefly from the jigs. According to Vanderburg's data for the Wolf Tongue mill in 1931, 70.3 percent of the total WO_3 content of the ore milled was recovered in a high-grade concentrate containing 54.38 percent WO_3, and 16.3 percent was recovered in a low-grade concentrate containing 31.73 percent WO_3. Of the total recovery of 86.6 percent, 73 percent was made by the jigs and 13.6 percent was made by the tables. The mill heads averaged 5.72 percent WO_3.

The distribution of values in different concentrates obtained during a month's operation at the Lakewood mill in 1917 is given in table 12.

TABLE 12.—*Tungsten content and value of different types of concentrates, Boulder County tungsten district*

Grade	Net pounds	Percent WO_3	Pounds WO_3	Units	Unit price	Value
First	23,036	65.500	15,111.616	755.581	$23.848	$18,019.09
Jigs	15,794	57.300	9,049.962	452.498	21.109	9,551.78
Slime	9,796	41.700	4,084.932	204.247	15.961	3,259.99
Crude (high-grade ore)	7,545	45.679	3,446.480	172.324	17.274	2,976.72
Total	56,171			1,584.650		$33,897.58

The low-grade concentrates or middlings and the crude ore assaying more than 35 to 40 percent WO_3 are usually mixed with the high-grade concentrates. Although this lowers the quality of the high-grade concentrates, the loss in value is not so great as the value of the tungsten lost if an attempt is made to remill the low-grade concentrates. Most of the concentrates shipped to the market from Boulder County assay 45 to 55 percent WO_3, but some assay as low as 40 percent. In 1940 concentrates could be shipped to the Eastern markets at a cost of about 20 cents per unit in lots of 20 to 40 tons by declaring a value of less than $100 per ton and insuring the car at full value at a cost of $20.

Vanderburg (1933, p. 11) gives the following analyses of the two concentrates produced at the Wolf Tongue mill in 1931:

	High-grade concentrate	*Low-grade concentrate*
WO_3	55.00	32.50
P	.035	.07
S	.06	.30
As	.025	.01
Fe	22.50	11.00
Al_2O_3	.90	1.75
SiO_2	18.50	48 00
MnO	.56	.65
Mo	None	None

A spectrographic analysis made by the U. S. Geological Survey in 1942 showed the following minor constituents in concentrates from the Wolf Tongue mill. The proportions would doubtless change with the sources of ore, but the analysis, which follows, probably indicates correctly the qualitative composition with respect to the minor elements of concentrates derived from ores from the western part of the district.

	Percent		Percent
BeO	0.001	V_2O_5	.08
Co_2O_3	.005	ZrO_2	.03
MoO_3	.001	Tl_2O_3	.002
NiO	.008		

Bi, Cd, Hg, Sb, Sn, In, Ga, Ge, and Ta were not found.

EXPLORATION

The individual tungsten ore bodies of the Boulder district are small and can therefore sustain production for only relatively short periods. In order to maintain production, exploration must be continuous. During the early years of tungsten mining, prospecting at the surface was the chief method of exploration and was highly successful. Possibly two-thirds of the tungsten mined in the Boulder district has come from ore shoots that cropped out at the surface. Exploration by mining began early in the history of the district and has been the chief method of underground exploration used. Most of the blind ore bodies found in the district have been found by driving exploratory drifts or sinking shafts, and most of the miners believe that this is the only reliable method of prospecting, even though it is costly. They feel that drilling is unsatisfactory even if it results in a showing of ore and that it proves nothing if it gives negative results. The tungsten ore bodies are small and are easily missed by the drill unless the holes are closely spaced, and then the costs are comparable to those of mining. Unlike many veins, which may contain traces of ore minerals at most places between ore shoots, many of the tungsten veins are completely barren between ore shoots, and although certain generalizations regarding the possible presence of ore nearby may perhaps be drawn from the appearance of the vein, there are so many exceptions that conclusions based on the presence of anything but ferberite in the core are hardly warranted.

Certain experiences in drilling in the district have led to widespread distrust of the method. Exploration by mining has shown drill holes crossing veins in spots that are completely barren, although rich ore lies only a foot or two away. Some holes have crossed veins in barren horses within large ore shoots; others have cut seemingly rich ore that proved on mining to be in small lenses with no trace of ore nearby. The altered wall rocks, the veins, and the ore may be soft; drilling in the vein zone is difficult; and some drill holes have actually pierced ore without the knowledge of the driller. When this happens, the driller may be justifiably criticized, but it nevertheless constitutes one of the hazards of drilling. If ferberite is cut by the drill, its presence may be shown by a conspicuous chocolate-brown color in the return water, even though no ferberite is recovered in the core. However, water return from the fractured ground and open veins is generally poor, and it often happens that no sludge is obtained when the drill crosses the vein. Moreover, some veins are in iron-stained rock that shows red or brown when drilled, and the color caused by ferberite may not be noticed. Although the popular maxim that "if ferberite is cut, the driller will know it" is generally true, there are enough known exceptions to warrant the collection and testing of sludges, a procedure that is not commonly practiced in the district.

The disadvantages and hazards of drilling notwithstanding, a substantial amount of ore has been discovered by this method. Practically all the mined ore, in contrast to stope fill, produced from the Conger mine from 1938 to 1945 was discovered by drilling. This ore was one of the major sources of the district output during the years 1939, 1940, and 1941. The Vanadium Corp. of America operated one diamond drill almost continuously for several years in the Conger mine and on other properties of the company. The Wolf Tongue Mining Co. has operated as many as three diamond drills intermittently for several years and at an earlier stage did considerable drilling by means of pneumatic hammer drills, using jointed steel. Some ore has been found as a result of this drilling, particularly in the Illinois mine, but to the knowledge of the writers, none of the company's major ore bodies has been discovered by drilling. Diamond drills have also been used for exploration by the Tanner group, Boulder Tungsten Mills, Inc., and Slide Mines, Inc., as well as by lessees of the Wolf Tongue Co. Most of the drilling has been done underground, but in recent years an increasing amount has been done at the surface.

In 1942 and 1943 the U. S. Bureau of Mines, in cooperation with the U. S. Geological Survey, drilled 145 holes in the district, with a total length of 12,385 ft. Ferberite in a quantity believed to be minable was cut in 26 holes. Many of the holes that cut ore were short holes drilled at the edges of stoped ore bodies, and they consequently did not add greatly to the reserves, but a few holes led to the establishment of moderately large reserves. According to an estimate made by J. D. Warne, of the Bureau of Mines, and by Tweto, 1.40 units of WO_3 was found for each foot of hole drilled. This gives a fair idea of the expectable return from a long-range drilling program if considerable drilling is done at the edges of known ore bodies. If the minor reserves established by short holes drilled just ahead of mining operations are neglected, it would appear that a return of 0.75 to 1.0 units of WO_3 per foot drilled could be expected from an extensive drilling program. However, the proportion of blank holes to "hits" is usually large, and the financial success of the drilling program would depend upon the grade of ore as well as the quantity of contained tungsten. If the grade is low, the tungsten may be worth only a few dollars per unit, or little more than the per-foot drilling costs, which commonly range from $2 to $3 per foot. If the grade is relatively high, the per-foot drilling costs would be only a small part of the per-unit value.

In recent years considerable exploration has been done by bulldozer trenching in areas heavily mantled by slope wash or alluvium. Some ore has been found by this method, and more will probably be found in the future, but the area adapted to such exploration is limited and relatively large areas have already been thoroughly prospected by bulldozing. The early-day float pickers succeeded in stripping the surface clean of ferberite float, but other evidence of veins, such as bits of quartz or altered rock, can usually be found in the soil if veins are present beneath covered areas. Random bulldozing is hardly justified unless such indications of veins are found.

Geophysical methods of prospecting for the tungsten ore have met with little success. Most of them are capable only of locating veins, but hundreds of miles of veins are already known, and the problem is not to locate veins but to determine which 50-ft interval on a half-mile of vein contains ore. Ferberite has very low electrical conductivity and differs very little in any of its electrical properties from the barren vein quartz with which it is associated. Its density is great, but calculations by C. A. Heiland, professor of geophysics at the Colorado School of Mines, showed that a torsion balance would have to be within 25 ft of the upper ore body of the Clyde mine, one of the largest ore bodies in the district, before the presence of the ore would be indicated by the instrument. Ore shoots are more open and are better aquifers than other portions of the vein, and it was hoped that they could therefore be located by resistivity measurements. Geophysical work of this sort, carried on for the Wolf Tongue Mining Co., located several areas of relatively high conductivity along different veins. The diamond drill, however, revealed no ore at any of the places indicated, though a strong flow of water was found at most of them.

A vein can easily be traced beneath a thin cover by the use of the equipotential method, in which search coils are used to discover the distortion of an electric current propagated by means of a line electrode. This method also was tried out by the Wolf Tongue Co. and found to be relatively rapid and accurate, but it did not help to locate ore. The magnetometer is of little use in finding ore, although, because of the hypogene oxidation of ilmenite and magnetite where dickite formed, the zone of clay-mineral alteration along the veins has a much lower magnetic strength than the unaltered wall rock and can be easily traced. This is a very minor aid in the search for tungsten ore, which occurs only in small parts of the altered zones.

Because of the difficulty of finding the ore bodies themselves with geophysical methods or the lore of the miner, many operators, both large and small, have been constrained at times to seek aid from men who profess to have special spiritual guidance or use supernatural ore-finding contrivances that do not obey known physical laws. To date, these methods have been as unsuccessful as any other form of wishful thinking.

Although geochemical prospecting is in its infancy, this technique may prove applicable to tungsten prospecting in the future. The presence of tungsten in deposits of secondary iron oxides formed in mine workings (p. 43) indicates that tungsten migrates in solution to a certain degree. It is therefore possible that with development of a simple and reliable test for tungsten in low concentration, tungsten-bearing soils or waters could be recognized and traced toward the source of the dispersion.

Exploration by mining is the most satisfactory method for the miner, but the sparse distribution of ore shoots makes this method costly. Other methods may be less satisfactory individually, but they each have certain advantages. If they are used in conjunction with exploration by mining, and in part as a means of directing such exploration, the chances for economic return should be increased. If geologic structures favorable to the localization of ore, such as changes in the course of a vein, can be located by tracing a vein at the surface, by bulldozing, or by geophysical methods, direction of underground exploration toward these structures or targets should prove more rewarding than random exploration. If geologic targets are found, there is no way other than underground exploration to determine whether the structure contains ore or whether it is merely filled with barren quartz, but it is not always necessary to sink a shaft or drive a drift to find this out. Drilling will at least prove whether or not the structure persists. It may also indicate whether the filling consists purely of quartz, and it may even show ore. Actual mining should not be necessary until drilling has shown that conditions are not unfavorable to ore.

FUTURE OF THE DISTRICT

The increase in output recorded during the years 1939–44 proves that tungsten can still be produced in modest quantity from the Boulder district. However, there can be little doubt that the district has passed its prime, at least insofar as shallow mining is concerned. Peak output was reached in 1917, and the graphs of annual and cumulative production (fig. 63) show clearly that the production rate was much higher during the years prior to 1918 than it was during the 27 years from 1919 to 1945. Since about 1913, production in the Boulder district has depended directly upon the price of tungsten. During World War II the price rose higher than at any other time in the history of the district except for a brief period during 1915–16, and the incentive for mining was therefore presumably at a maximum. It would be a mistake to attempt to compare a $20 price in the 1940's with a $20 price at some earlier time, inasmuch as wages and the costs of supplies were essentially doubled during the war years, but other incentives more than compensated for the difference in costs. Much of the capital risk during the war period was borne by the Government, and many of the mines were reopened with Government loans made through the Reconstruction Finance Corporation or Metals Reserve Company. Exploration by the Bureau of Mines constituted a considerable part of the district expenditures for exploration during this period. The unprecedented high price paid by Metals Reserve Company for tungsten in low-grade ores constituted a price subsidy, and in comparison to the prices that had existed in the past for such ores, more than compensated for the increase in costs.

It thus appears that during the early forties a greater incentive for mining existed than at any other time except during a few months in 1915 and 1916, and the output made may therefore be considered the maximum of which the district is capable at this advanced stage in its history. This maximum is a little less than 700 tons per year in terms of concentrates containing 60 percent WO_3, and the modest output which it represents is emphasized by comparison with the output from the one large mine of the Yellow Pine district, Idaho, which for a time produced this much tungsten each month.

Probably much tungsten still remains within a few hundred feet of the surface in the Boulder district, but practically all the ore shoots that reached the surface have doubtless been found. The ore that remains is in blind shoots that in general are small and sparsely and erratically distributed. The cost of finding them is high, and capital will not be risked in searching for them unless an outlook for a sustained high price for tungsten exists to offer some hope of return on the investment. Judging by the reaction of mining to the price changes in 1944, it appears that a price of $20 per unit is about the lowest limit at which tungsten can be mined at a profit according to the 1944 scale of costs. Many mines closed when the price fell to this level, but very few of them closed with ore in sight. Fairly promising prospects remained in several of them, but the mines closed because of the uncertainty over the future price of tungsten. Thus it seems that although tungsten can be mined at a price of $20 per unit according to the 1944 scale of costs, it cannot be both found and mined at this price except with imprudent risk. Unless costs should decrease, it seems probable that a local price of $30 per unit[1] would be necessary before mining would be stimulated again. If this price should be realized, or if costs should decline, the district could probably maintain a production of 200 or 300 tons of high-grade concentrates annually. Such an output would require the discovery of five to eight new ore shoots of average size each year.

The possibility of ore at depths greater than a few hundred feet in the Boulder district has not been tested. In a few of the larger mines a little work has been done below the bottoms of ore shoots followed down from the surface, but in most of these the vertical extent of such exploration is only a small fraction of the vertical extent of the mined ore shoots. The only exploration of moderately large extent done at depth in the district was undertaken in the Conger mine, which was sunk 400 ft below the ore shoots. Unfortunately, however, no work was done except on the Conger vein, and as this normal-fault fissure flattened in the lower part of the mine, there was little chance of finding ore bodies in this part of the vein. In the Vasco No. 6, Cold Spring, Clyde, and Tungsten (Chance) mines, large ore shoots were found below shoots mined earlier, but exploration stopped a short distance below the lower shoots.

No geologic factors are known that should restrict ore to within a few hundred feet of the surface. Within the district as a whole, ore has been mined through a vertical range of about 2,500 ft, and ore has been found on single veins through a range of almost 1,000 ft. The character and occurrence of ore in such veins do not change perceptibly within the observed vertical range; therefore, if ore exists at greater depths than have been ordinarily reached by mining, it is probably in ore bodies of a type similar to those in the upper parts of the veins. If blind ore bodies in the upper parts of the veins are commercially marginal deposits because of the expense involved in finding them, blind ore bodies of similar size and frequency at greater depth would certainly be submarginal. There is no particular reason why ore bodies at depth should be larger, richer, or more abundant than the near-surface bodies, but the fact remains that the size, grade, and frequency of such possible ore bodies is not known and cannot be known without deep exploration.

[1] In terms of the 1944 dollar.

MINE DESCRIPTIONS

Most of the mines that were open at any time between 1930 and 1945 have been examined or mapped. Detailed descriptions are given of 54 mines that have produced 10,000 units or more of WO_3, and the essential features of more than a hundred smaller mines are given briefly or by means of maps.

Although it is difficult to classify the mines on the basis of value of output, the group described in detail probably includes all the mines whose gross output has exceeded $100,000 and most of the mines whose output has exceeded $50,000. However, there are a few mines with a relatively small output that achieved a fairly high production in dollar value because their output came at a time when the price of tungsten was high.

In the descriptions, emphasis has been placed on the fracture pattern and the character of the country rock because of their importance in localizing ore. Considerable emphasis has also been placed on the production records, because little information concerning these important records has been readily available and the incomplete data here presented have been gathered with such difficulty that the process should not be needlessly repeated. Many of the mines of the district have been operated by a long succession of lessees, most of whom kept no permanent records. A few property owners have kept records for individual mines, but many such records have been lost with the transfer of the property. The result is that complete production records exist for very few mines except those of the Wolf Tongue Mining Co.

The individual mines are listed alphabetically in the index of this report, but in the following pages they are grouped according to position in the district, as this arrangement should facilitate reference to descriptions of neighboring properties. The mines are discussed under the following geographical headings:

1. The Beaver Creek area (pl. 4), which is the part of the district that lies south of Nederland and Barker Reservoir.
2. The Nederland area and Sherwood Gulch (pl. 5), which comprise the area north of Nederland and west of Hurricane Hill.
3. The Tungsten Post Office-Hurricane Hill area, which lies along the east flank of Hurricane Hill.
4. The Gordon Gulch-North Boulder Creek-Rogers tract area, which makes up the central part of the district.
5. The Boulder Falls-Sugar Loaf area, which extends from a point near the junction of Middle and North Boulder Creeks northward to Sugar Loaf Post Office.
6. The eastern part of the district, which includes the mining areas in Black Tiger Gulch, Millionaire Gulch, and the vicinity of Logan Mountain.

The mines are described from west to east and from south to north within the different groups, insofar as this is practicable.

BEAVER CREEK AREA

TUNGSTEN (CHANCE) MINE

The Tungsten mine, or Chance mine, as it is often called, is 1½ miles southeast of Nederland and 3,300 ft west-southwest of Tungsten Mountain at an altitude of about 8,530 ft. According to George Cowdery, chief owner of the mine in 1933, a prospector named Henry Loughlin discovered the vein in 1900 but made no shipments. In 1902 John McRay put down a 15-ft shaft and mined a small amount of ore, but the vein was little developed until 1906, when Orin Beach began work in this locality and patented the claims on the Tungsten vein and other veins nearby. Beach sold his holdings to Gus Carlburg and Alfonse Ardourel, who organized the Tungsten Mining, Milling & Exploration Co. According to Cowdery, this company recovered about $175,000 worth of ore from the Tungsten vein above the 80-ft level from 1907 to 1909 and sold most of it to the Primos Chemical Co. This ore, which is said to have averaged about 20 percent WO_3, was found west of the shaft. After it had been mined out, the mine was believed to be exhausted, the Tungsten Mining, Milling & Exploration Co. failed in 1909, and the property was turned over to the Wolf Tongue Mining Co. for leasing in 1910.

The property lay idle for several years, but about 1915 W. W. Cowdery organized a leasing company and development work was started on the March vein just south of the Tungsten vein. In 1916 the Tungsten vein was explored to the east on the 120-ft level by Cowdery, and a small vertical ore shoot was found (fig. 64). Encouraged by this find, Cowdery sank a

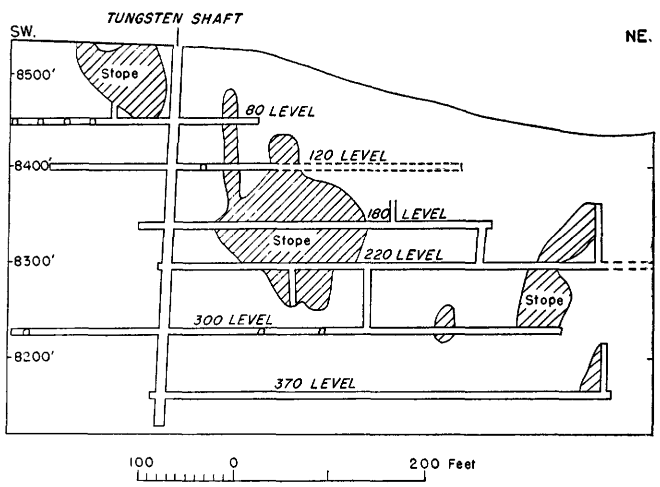


FIGURE 64.—Workings on the Tungsten (Chance) vein, Boulder County, Colo., in 1930, projected on a plane striking N. 50° E. and dipping 70° NW.

shaft, and in 1917 a drift to the east on the 180-ft level tapped the large ore shoot from which most of the mine's output came. The ore in this shoot was in three streaks, each said to contain 10 to 18 in. of 20-percent ore. The ore body was stoped through a width of 10 to 15 ft; the ore is reported to have averaged 4 to 5 percent WO_3 and was sorted into ore containing about 15 percent. Later in 1917 the shaft was deepened to an inclined depth of 307 ft, but because no ore was found in a drift to the east on the 300-ft level, the 220-ft level was driven, also without success. In 1918 the 300-ft level was continued northeastward and another blind shoot of ore was found (fig. 64). The shaft was then sunk to the present depth of 396 ft on the incline and 368 ft vertically below the surface, and the 370-ft level was turned. Most of this work was done by the leasing company, but about 1917 the Cowdery brothers began to acquire ownership. The property lay idle from 1919 to 1929, when George Cowdery finally obtained control of the property and began further explorations. Some good ore was found in the hanging wall of the large stope made in 1917 and 1918, but no new ore bodies were discovered. The property was closed in 1933 and allowed to fill with water. It was unwatered in 1939 by Tom Walsh, and a substantial amount of ore was taken from the hanging wall below the large stope and from veins found in the footwall adjacent to the large stope.

The total output from the Tungsten mine is relatively large, although not known accurately, and the mine ranks as one of the foremost producers in the district. The average value of tungsten in 1907–9 was about \$7 per unit (fig. 63), and the \$175,000 reported to have been produced at this time is equivalent to about 25,000 units of WO_3. It is reported that 7,000 tons of ore assaying at least 5 percent WO_3 was milled in 1917–18; this indicates a minimum of 35,000 units in crude ore. A substantial amount of ore was also produced in 1916, in 1930–33, and in 1939–41. The total recovered output probably exceeds 60,000 units, or 1,000 tons of 60-percent concentrates.

The mine is in the Idaho Springs formation, and the country rock, which is mapped as an injection gneiss is largely biotite schist and gneiss that contain many layers of aplite and pegmatite. The Tungsten vein strikes about N. 50° E. and dips 65°–75° NW. (pl. 6). In its barren parts the vein is a fairly well defined, straight, gouge-filled fissure less than a foot wide (fig. 54). Where ore shoots occur, the vein is generally split into several parallel fissures, which make a sheeted zone several feet wide, and the dip is steeper than 68°. The best ore was found where the course of the vein was more northerly than the average. Because of the innumerable seams of pegmatite in the walls of the vein, displaced segments cannot be correlated with confidence, but the displacement exceeds 10 ft and may be as much as 50 ft. Much of the ore was moderately fine grained, but seams of coarsely crystalline ferberite were found close to the walls of the vein. The wall rock near the ore shoots is invariably altered for several feet from the vein, but in the barren stretches a short distance away the rock is fresh in appearance.

In the southwestern part of the mine the vein swings to a more westerly course, the dip is flatter than normal, and the vein seems to be feathering out. Moreover, in this part of the mine there is more schist and less gneissic aplite than in the northeastern part, and the prospect of finding more ore by further development to the southwest is not encouraging. In the northeastern part of the mine, in contrast, the vein is strong and has a more northerly course than the average of the barren parts, and the possibility of finding ore by exploration in this direction seems better.

The March vein, which lies southeast of the Tungsten vein, was worked on the 80- and 120-ft levels of the Tungsten mine (pl. 6). It strikes N. 70° E. and dips about 75° S. Although not a strong vein, it contained good ore at the surface, and the ore shoot, which plunged northeast, was also stoped on the 120-ft level. The vein was only feebly productive where it was opened on the 80-ft level. It was also reached by a crosscut on the 75-ft level of the Sunday mine but was found to contain only scattered lenses of ferberite too small to mine. Where cut by a diamond-drill hole about 90 ft below the 120-ft level, the vein is a sheeted zone 2 ft wide seamed by veinlets of ankerite and some light-gray horn. The March vein seems to be part of the general zone of short intersecting fractures, trending east and northeast, that marks the west end of the Sunday vein. It cannot be traced far on the surface and probably does not persist for any great distance.

SUNDAY MINE

The Sunday mine is opened by a shaft 200 ft deep situated about 400 ft S. 70° E. of the Tungsten (Chance) shaft. Five short levels known as the 45-, 75-, 100-, 150-, and 200-ft levels are turned from the steeply inclined shaft (pl. 6). The early history of the mine is not known, but judging by the quality of the ore mined in later years, a substantial production must have come from the main ore shoot above the 100-ft level (fig. 65). The mine was operated intermittently from 1937 to 1943 by Tom Walsh, who reports that \$20,000 worth of ore was produced above the 100-ft level in 1937–38, chiefly form the ore shoot between the shaft and a northward-trending fault west of the shaft. The shaft was subsequently deepened to the 150-ft level, and in 1942 a body of coarse-grained disseminated ore was

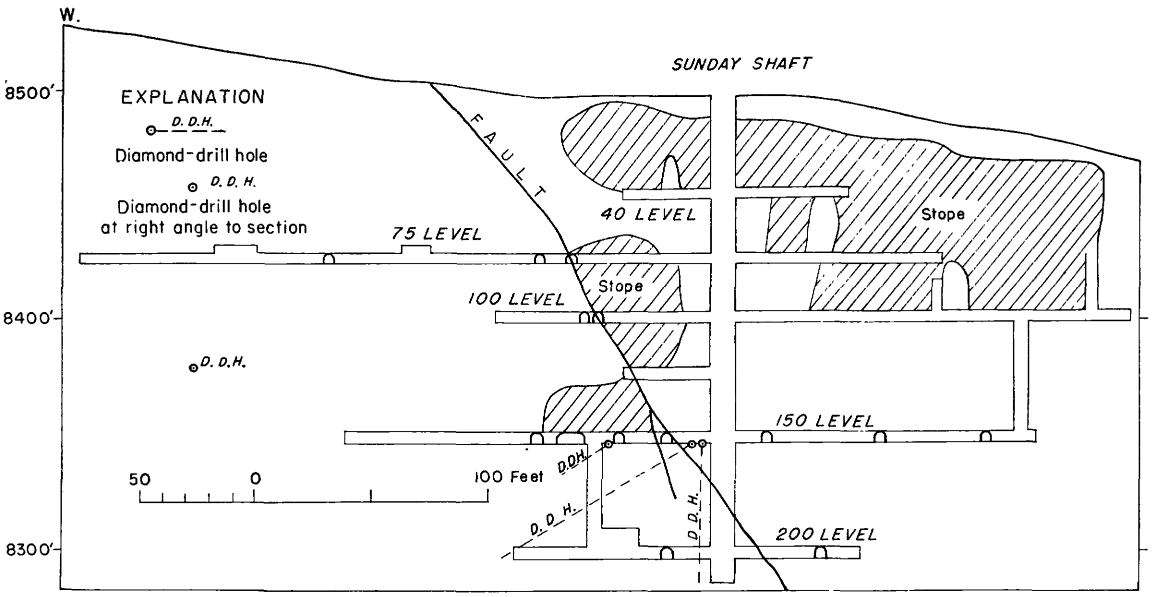


FIGURE 65.—Longitudinal projection of the Sunday mine, Boulder County, Colo., showing stopes.

found along the Sunday vein under the fault (pl. 6; fig. 65). This ore body yielded 30 tons of concentrates assaying 61 percent WO_3. The shaft was sunk deeper in 1943, and the 200-ft level was driven, but no ore was found below the 150-ft level.

The country rock is interlayered schist, pegmatite, and aplitic injection gneiss. The ore has a distinct preference for walls of gneiss or pegmatite. The Sunday vein follows a minor eastward-trending fault which dips steeply to the south. The south wall moved down and east at an angle of about 25°, with a displacement of a few feet. About 60 ft west of the shaft, on the 75-ft level, the Sunday vein is offset 20 ft by a reverse fault that strikes north and dips east. The fault flattens from a dip of 66° on the 75-ft level to a dip of 48° on the 200-ft level. Although there was some postmineral movement, the fault is premineral and influenced the localization of ore. One ore shoot, characterized by exceptionally coarse ferberite, was found just above the fault near a split in the vein on the 100-ft level, and another, consisting of disseminated ferberite, was found on the under side of the fault on the 150-ft level.

Most of the ore in the Sunday mine contains coarsely crystalline ferberite which forms seams in the country rock and forms the matrix of a rather open breccia. Very little quartz is present. The coarsely crystalline ore above the reverse fault on the 100-ft level was in numerous thin open seams through widths of 8 to 14 ft. The ore in the eastern shoot was finer-grained and was 1 to 2 ft wide.

The disseminated ore on the 150-ft level is almost unique in the Boulder district because it was formed by replacement rather than as a filling in openings. It occurred in strongly sericitized, greenish, leached, and vuggy injection gneiss. Most of the ferberite was in irregular grains up to half an inch in diameter scattered through the sericitized rock, but some was in clusters of crystals in small vuggy openings. The irregular ferberite grains clearly replaced both the sericitic matrix and unaltered coarse grains of pegmatitic potash feldspar. Small grains of scheelite were disseminated in the sericite and occurred rarely as drusy, colorless crystals in vugs. A very little pyrite and chalcopyrite were also present. The disseminated ferberite was found through widths of 3 to 15 ft on each side of the vein for a distance of about 45 ft along the vein. The ore assayed 1 to 20 percent WO_3 and averaged 2 to 3 percent. The Sunday vein itself was barren or contained only thin seams of ferberite. The ore cut off abruptly against the eastward-dipping reverse fault. It died out in the floor of the 150-ft level, and although several holes were drilled below the level and a raise was put up below the ore body from the 200-ft level, no more than a trace of ferberite was ever found below the level.

The gougy reverse fault evidently impounded the mineralizing solutions, causing them to permeate the wall rocks, which were replaced by sericite and ferberite.

Two drill holes, 110 and 145 ft deep, on the extension of the Sunday vein in the gulch 700 ft east of the Sunday shaft (pl. 4), disclosed strongly sericitized injection gneiss identical to that in the replacement ore body. The altered rock, like that in the mine, contained a little pyrite and chalcopyrite and traces of scheelite and molybdenite, but ferberite was absent.

The reverse fault of the Sunday mine is barely identifiable in trenches north of the mine, and it apparently dies out northward on the schistosity. It has not been identified in the northeastern workings of the Tungsten mine, where it should appear if it persisted to the north.

MAMMOTH MINE

The shaft of the Mammoth mine is on the south slope of Tungsten Mountain at an altitude of about 8,700 ft (pl. 4). The vein was discovered about 1905 by Nicolas Timmote, and in 1908 Messrs. Gustafson and Robinson drove an adit about 140 ft along the vein and sank a 30-ft winze. They mined ore from the bottom of the winze to the surface; some of this ore is said to have been 6 ft wide, and much of it was more than 4 ft wide. No high-grade ore was found, but the rough-sorted ore assayed about 13 percent WO_3. The Old shaft was sunk by a Mr. Hildrid in 1912 and 1913, and ore was mined from the first, or 100-ft, level up to the old workings. Although the shaft was sunk for 157 ft, no drifting was done at the bottom until W. L. Tanner and Edward Scardel leased the mine a few years later. They drove the eastern, or footwall, drift on the second level, as shown in figure 66, but found no ore. They then raised through to the old stopes and there noticed some thin veins and feeders of ferberite penetrating the west, or hanging, wall. They therefore drove a crosscut northwestward on the second level and found a good body of ore. They had stoped this about halfway up to the 100-ft level when their lease expired in 1918, and as the price of tungsten dropped at about this time, the work was discontinued. About $44,000 worth of tungsten is reported to have been shipped to the Rare Metals Co. during this latter period of operation.

The mine was reopened about 1930 by Messrs. Henderson, Walsh, and MacKenzie, who found a large body of ore south of the old workings. They sank a new shaft to the fourth level and stoped the vein for more than 200 ft to the south. According to Tom Walsh, ore valued at $220,000 was taken out in 18 months during 1934–35, when the price of tungsten was only $12 per unit. The mine was operated more or less steadily from 1935 to 1944 by Messrs. W. L., S. H., and G. J. Tanner, its owners, who found ore below the old workings at the north end of the mine. The shaft was sunk to the fifth level at this time, but the level proved to be almost barren.

The total production from the mine is not known but is relatively large. As determined from the value, the production since 1913 has been at least 30,000 units of WO_3 in concentrates. Judging by the size of the stopes and the reported grade of the ore, the production prior to 1913 must have been several thousand units.

The mine is in contorted biotite schist that is complexly injected by pegmatite, aplite, and granite. The schist contains many small lenses of quartzite in addition to the larger mass shown on the map of the fourth level (fig. 66). The schist and the granitic intrusive rocks are so intimately mixed that only the predominant rock type at any locality can be shown on a map and only generalized contacts can be drawn between "schist" and "pegmatite." The rock is most pegmatitic in the upper, northern, part of the mine and becomes more schistose downward and southward, but all the "pegmatite" shown in figure 66 contains some schist and all the "schist" contains abundant small masses and stringers of pegmatite, aplite, and granite. The wall rocks are strongly altered in wide zones along the veins. Pegmatite and granitic rocks are altered to clays, and schist is chloritized. Locally the rocks are silicifed and sericitized for a few inches adjacent to the vein walls.

The Mammoth vein strikes about N. 20° E. and dips 50°–85° NW. through most of its course, but at the north end of the mine it turns abruptly to the east, especially at the surface and on the upper levels. Displacement along the vein could not be determined in the mine, but displacement along the Mammoth vein in the Black King tunnel, 500 ft to the northeast, indicates that the west, or hanging, wall moved down and northeast relative to the footwall. As might be expected from the direction of movement, ore was localized in the part of the vein trending in a more northeasterly direction and, where the dip is steep, in the northward-trending part, but only where the walls were pegmatitic.

The Mammoth vein joins the Fitzsimmons No. 6 vein in the southern part of the mine. The Fitzsimmons No. 6 vein was ore bearing at the surface and on the third and fourth levels of the Mammoth mine. It strikes N. 55° E. and dips steeply northwest in the Mammoth mine. Southwest of the Mammoth it turns west and was fairly productive in the shallow workings that comprise the Fitzsimmons No. 4 mine. The Mammoth vein was not found southwest of the junction with the Fitzsimmons No. 6 and evidently ends at the junction.

At the surface and on the tunnel level east of the Old shaft, the Mammoth vein jogs northward about 50 ft along a small westward-dipping vein that contains some horn quartz and a little ferberite. Although the jog suggests faulting, the northward-trending vein is weak and apparently does not persist in depth; it is evidently an older vein that deflected rather than faulted the Mammoth vein. The pattern of northward-trending drifts on the tunnel, second, and fourth levels suggests a continuous north-south fracture that flattens somewhat with depth, but the available evidence suggests that different fractures within a north-

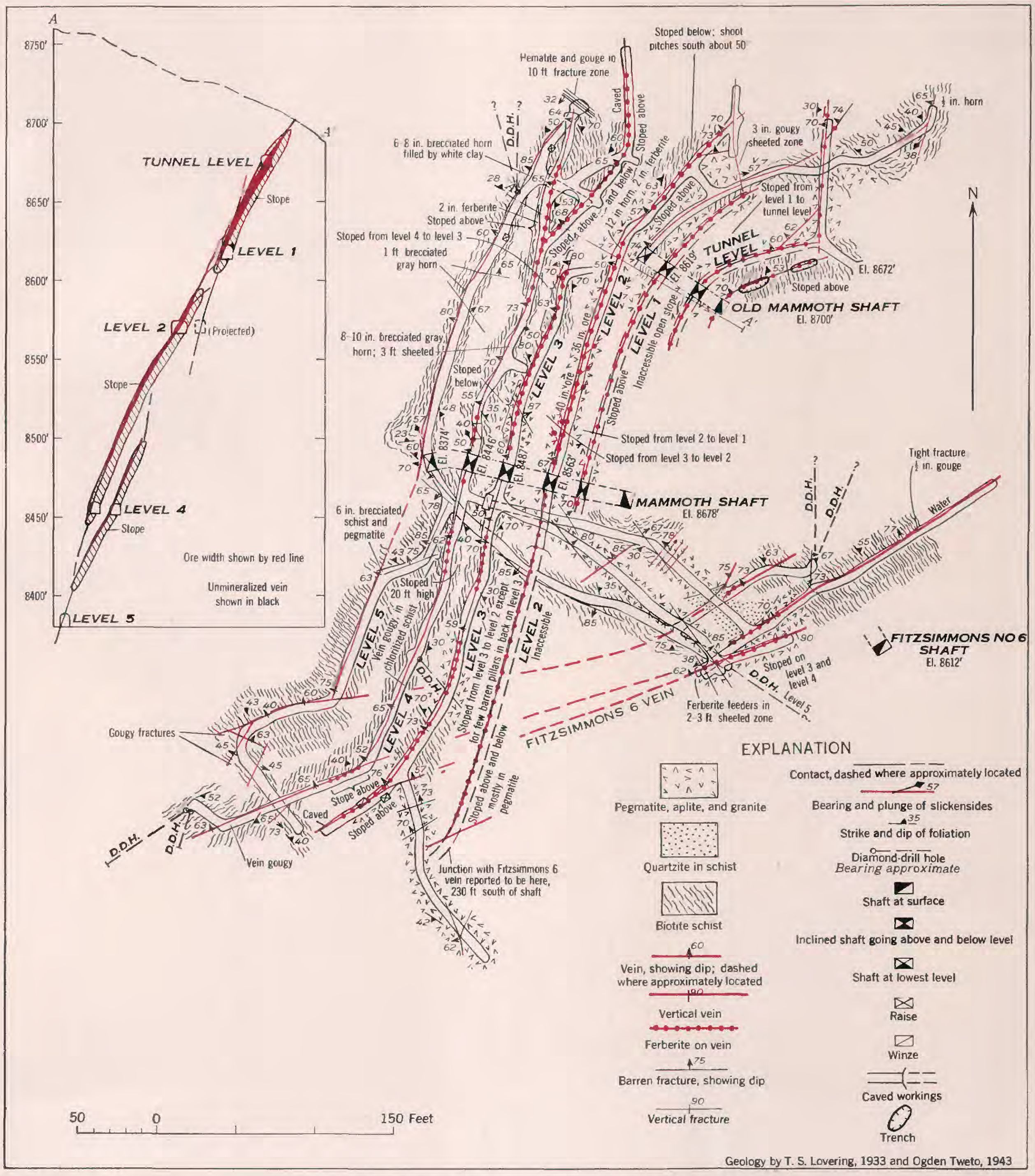


FIGURE 66.—Geologic plan of the Mammoth mine, Boulder County, Colo.

ward-trending zone were explored on all three levels. The short drift trending north on the second level was driven after Lovering mapped the mine in 1930 and was inaccessible to Tweto in 1942, but it is opposite a barren fracture that strikes north and dips 57° E. in the footwall drift. The north-south drift on the fourth level was inaccessible in 1942 but seems to be continuous with a branch of the Mammoth vein, which splits about 75 ft to the southwest on the fourth level. The northward-trending segment of the vein evidently dips steeply west and was extensively stoped. It was not found on the fifth level but may steepen below the fourth level and lie a little east of the workings on the fifth level. It may be cut off to the north by a strong breccia-reef fracture zone that strikes northwest and dips 32° SW. in the breast of the drift on the fifth level.

Almost all the ore in the Mammoth mine was in a single large ore shoot which was stoped almost continuously for 500 ft on the second level. Near the Old shaft the shoot extended from the surface down almost to the fifth level. From this deepest point the bottom of the shoot rose southward, following the top of a mass of schist. South of the New shaft the bottom was at about the third level. Much of the ore was 2 to 4 ft wide, and at places the stopes are 12 to 15 ft wide. The ferberite was in veinlets in the country rock and also formed a filling in brecciated gray horn quartz. All the ore was crystalline and vuggy, but the ore in the southern part of the shoot was somewhat finer grained than that in the northern part.

SMALLER MINES

CROSS NO. 2 MINE

Location: Altitude, about 8,570 ft; 2,000 ft N. 87° W. of Tungsten (Chance) shaft.

Workings: Steeply inclined shaft 190 ft deep; levels at 50, 120, and 180 ft each extend less than 100 ft to northeast; 50-ft level extends short distance to southwest.

Geology: Vein in granite; strikes N. 50° E; and dips 65°–80° NW.; reported to be very weak at bottom of shaft.

Ore: Small ore shoot localized on southwest side of Maine-Cross breccia reef, which intersects vein just east of shaft. Ore shoot extended 30 ft along strike of vein; plunged 70° NE.; extended to depth of 115 ft.

History and production: Worked in 1907, 1911–12, 1914, and 1916. Production in 1907–1917 was 308 units of WO_3 in ore averaging 10.18 percent WO_3. Apparently no work done since 1918. Mine owned by Wolf Tongue Mining Co. in 1945.

LOWER RAMBLER MINE

Location: Altitude, about 8,590 ft; 1,800 ft N. 82° W. of Tungsten shaft (pl. 4).

Workings and geology: See figure 67.

Ore: Small feeders of ferberite scattered throughout mine; locally, and particularly in shaft, abundant enough to make ore.

History and production: Shaft sunk in thirties; $4,000 worth of ore reportedly taken from it. Small production from level workings driven by Tom Walsh in 1943. Mine owned by Cowdery brothers in 1943.

MISSING LINK SHAFT

Location: Altitude, about 8,575 ft; 100 ft southwest of Lower Rambler shaft.

Workings: Hundred-foot shaft; stope along northeast side from bottom of shaft to surface, extending 20 to 30 ft from shaft.

Geology: Vein in granite strikes N. 20° E. and dips 75°–80° SE. Vein is sheeted zone as much as 7 ft wide; contains as much as 5 ft of brecciated horn quartz cemented by ferberite in places.

Ore: Pockets and seams of coarsely crystalline ferberite in horn breccia and sheeted granite. As much as 18 in. of ore assaying 16 percent WO_3 at places.

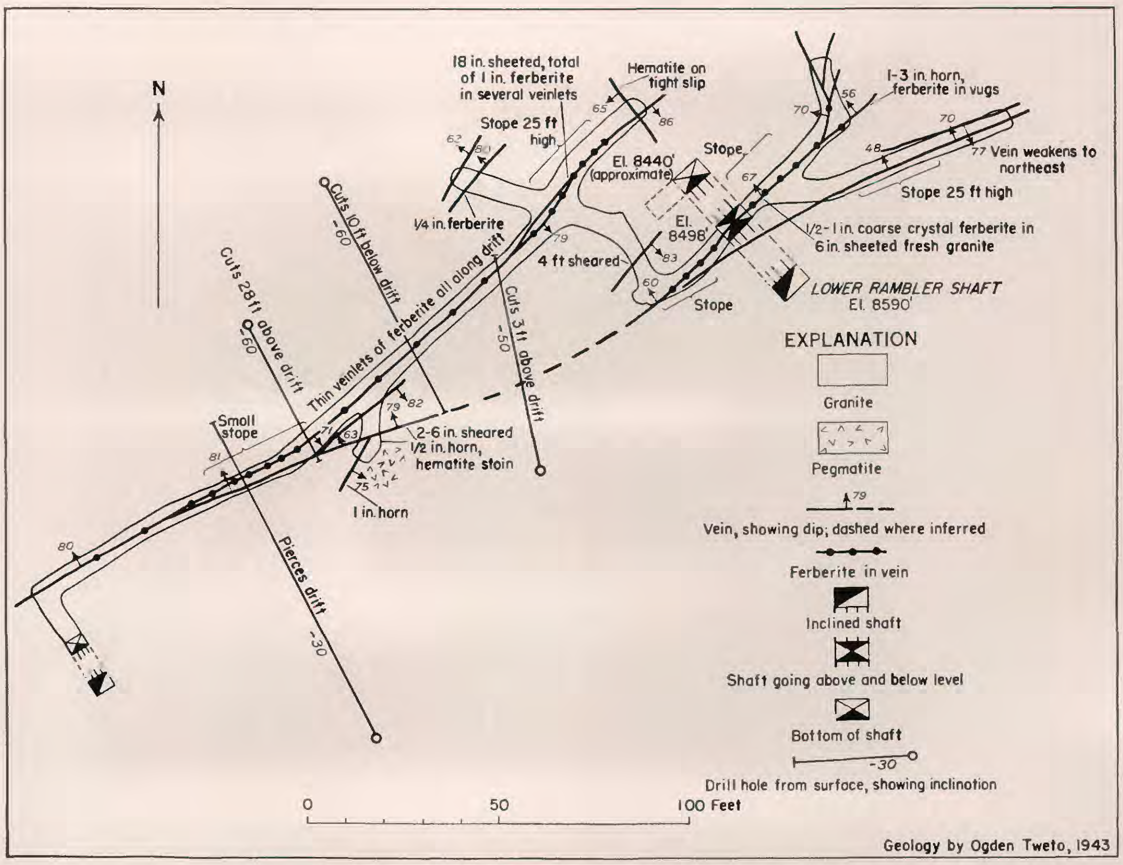


FIGURE 67.—Geologic plans of the Lower Rambler mine, Boulder County, Colo.

History and production: Worked chiefly in 1915-16. Total production said to be 100 to 150 tons of ore averaging 5 percent WO_3; most of tungsten produced was in sorted high grade assaying about 40 percent WO_3. Mine owned by Cowdery brothers in 1943.

BRACE TUNNEL

Location: Altitude, 8,475 ft; 1,675 ft S. 73° W. of Tungsten shaft.

Workings and geology: See figure 68.

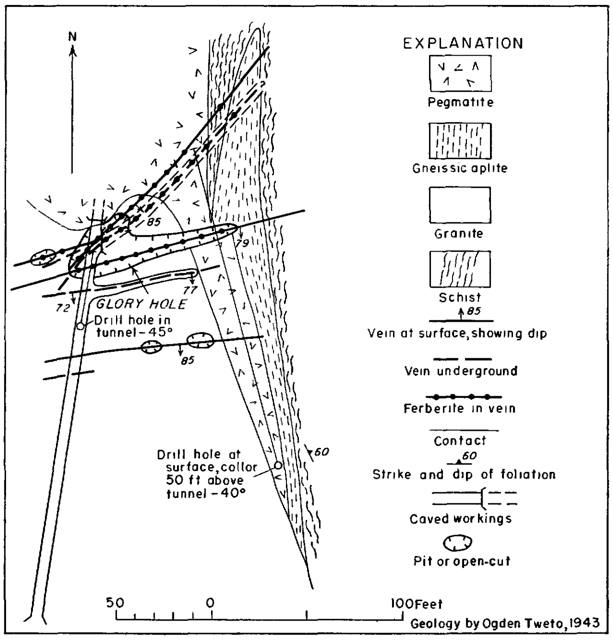


FIGURE 68.—Surface and underground geology of the Brace Tunnel, Boulder County, Colo.

Ore: Glory-hole stope on two veins at intersection. Coarse ferberite in brecciated red and brown quartz and altered rock; most of ore was 8 to 10 in. wide, but some was 3 ft wide. Ore said to have assayed 6 to 8 percent WO_3.

History and production: Chief production in 1907–10 and 1915–17; minor operation at times up to 1945. Total output valued at $100,000 according to J. G. Clark, of Gold, Silver, & Tungsten, Inc., the owner in 1943. Two holes drilled below glory hole by Bureau of Mines in 1943 showed no ore at depths of 43 and 90 ft below tunnel level.

RODERICK SHAFT

Location: Altitude, 8,570 ft; 175 ft north of Brace glory hole.

Workings: Fifty-foot inclined shaft and irregular stope along one side; about 100 ft of level workings.

Geology: Small seams of high-grade ferberite in two small northeastward-trending veins and an eastward-trending vein, near intersection. See plate 4. Veins in pegmatite and granite.

History and production: Shaft sunk in 1942 by Roderick and Putnam; about 500 units of WO_3 produced, 1942–44, in ore assaying 1.5 to 2 percent WO_3. Mine owned by Gold, Silver, & Tungsten, Inc., in 1944.

RAMBLER MINE

Location: Altitude, about 8,635 ft; 1,450 ft N. 65° W. of Tungsten shaft.

Workings: See figure 69. Also extensive trenches at surface southwest of shaft.

Wall rock: Schist and injection gneiss cut by small dikes of pegmatite and aplite.

Vein: Strike, N. 55°–60° E.; dip, 65° NW. at surface and to depth of 50 ft, where it flattens to 45°. Several branching veins to southeast (pl. 4).

Ore: Seams of coarsely crystalline ferberite in sheeted zone. Good ore to depth of 50 ft, where vein flattened and pinched. Maximum depth of ore in trenches southwest of shaft, 35 ft.

History and production: Worked chiefly about 1907; probably no work since 1918. Production said to be 300 tons of "good ore" (probably 10 to 15 percent WO_3). Mine owned by Cowdery brothers in 1943.

MINNESOTA MINE

Location: Altitude, about 8,610 ft; 1,400 ft N. 50° W. of Tungsten shaft (pl. 4).

Workings: Shaft about 100 ft deep; two short levels.

Geology: On Rambler vein system, near northeast end. In schist.

History and production: Small production in 1917–18 from shallow ore body. Mine reopened in thirties; little production. Owned by Wolf Tongue Mining Co. in 1945.

BLACKHAWK PITS

Location: Altitude, 8,600 ft; 950 ft N. 76° W. of Tungsten shaft (pl. 4).

Workings: Several trenches and shallow shafts, all caved in 1943.

Geology: Seams of coarsely crystalline ferberite in small, sheeted zones showing en echelon pattern in pegmatite; veins die out in schist that surrounds pegmatite.

History and production: Produced several tons of "high-grade" ore, probably assaying more than 35 percent WO_3, in 1907–10 and 1915–17. Mine owned by Cowdery brothers in 1945.

PIONEER MINE

Location: Altitude, 8,575 ft; 825 ft west of Tungsten shaft.

Workings: Hundred-foot shaft; stope above drift extending about 100 ft eastward from shaft.

Geology: Vein strikes N. 75° E. and dips 80° S. In schist.

History and production: Probably last operated in 1917. Output unknown, probably not large. Mine owned by Gold, Silver, & Tungsten, Inc., in 1945.

MARCH WORKINGS

See descriptions of the Tungsten and Sunday mines; also plate 6.

MARY NELSON MINE

Location: Altitude, 8,375 ft; 1,200 ft S. 76° E. of Tungsten shaft.

Workings: Shaft about 100 ft deep; two levels.

Geology: Small ore shoots on vein that strikes N. 43° E. and dips 75° NW., near intersection with two eastward-trending veins (pl. 4). Mine in aplite.

History and production: Output unknown, probably not large. Chief production by Clark and Tanner about 1916.

ELSIE SHAFT AND WINDY TUNNEL

Location: Elsie shaft at altitude of about 8,380 ft; 1,300 ft S. 44° W. of Mammoth shaft (pl. 4). Windy tunnel portal 300 ft S. 25° W. of Elsie shaft.

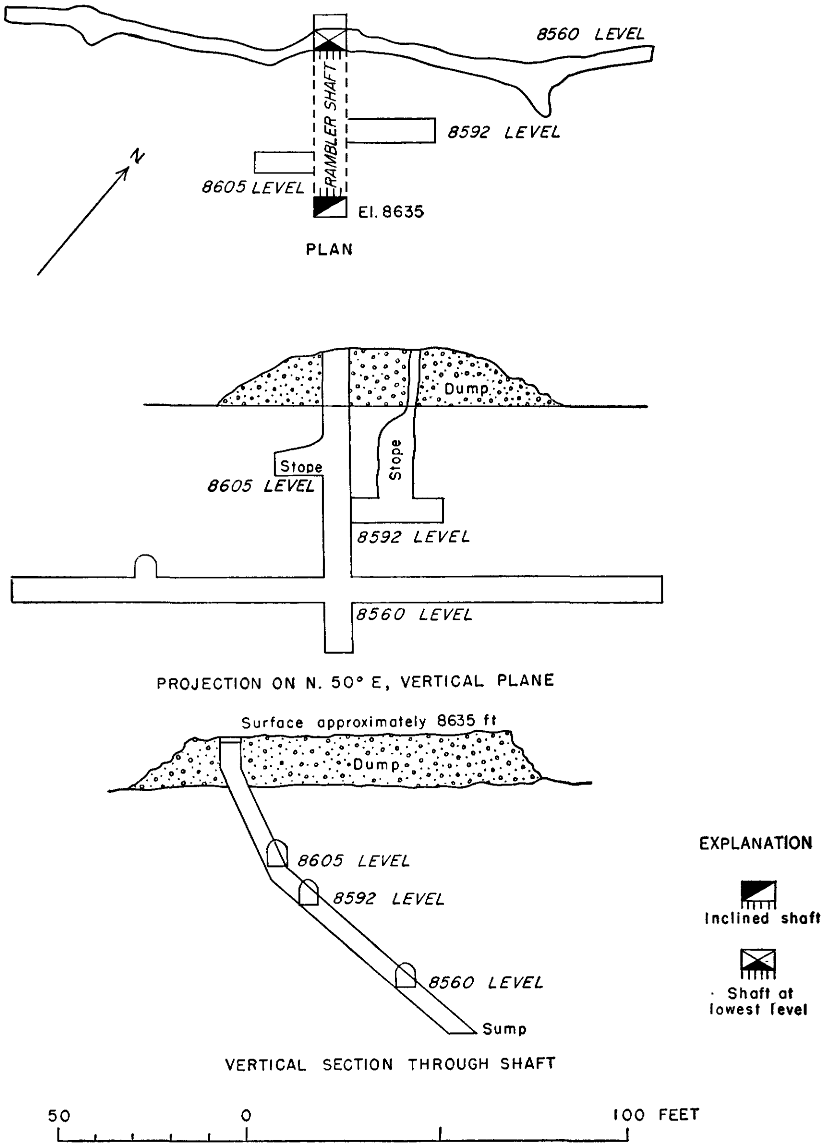


FIGURE 69.—Plan, projection, and section of the Rambler mine, Boulder County, Colo., about 1915.

Workings: See plate 7. Windy tunnel is first level of Elsie shaft; a lower level extends northeastward from shaft. Caved tunnel and glory hole on upper part of Elsie vein, northeast of shaft.

Geology: See plate 7.

Ore: Ore shoot about 250 ft long near surface; extended to tunnel level, a maximum depth of 175 ft. Some ore mined on level below tunnel. Ore shoot plunged steeply southwest. Coarsely crystalline and very pure ferberite in veinlets and cementing breccia of country rock in sheeted zone as much as 5 ft wide. Ore assayed 6 to 8 percent WO_3.

History and production: Elsie vein, discovered in 1905, mined from 1906 to 1910 by Wilson, Harrison, and Ogilvey. Windy tunnel started in 1910 by Frank Robinson and extended in 1913–14 by Ben France; last 900 feet driven by J. G. Clark in 1916–17. Some laterals driven by Tanner brothers, the owners, in 1943–44. Total output of Elsie shaft unknown but fairly large. Production in 1916–18 valued at $40,000 to $50,000, indicating about 2,000 units of WO_3.

FITZSIMMONS NO. 1 MINE

Location: Altitude, about 8,560 ft; 450 ft S. 25° E. of Mammoth shaft.

Workings and geology: See figure 70.

Ore: Slender ore shoot plunged about 45° W.; crossed shaft just under third level. Veinlets of crystalline ferberite in broad sheeted zone in schist and injection gneiss. Very little quartz. Ore assays about 2 percent WO_3. Ore localized where vein bends to left and flattens.

History and production: Production to 1938 reported to be 20 tons of 60-percent concentrates by Fan Steel Corp., lessee at that time. Mine reopened in 1943 by Boulder Tungsten Mills, Inc.; some diamond drilling done in walls. Small production. Mine operated in 1944 by Guy Tanner for Tanner brothers, the owners; about 500 units produced.

FITZSIMMONS NO. 4 MINE

Location: Altitude, about 8,525 ft; 850 ft S. 62° W. of Mammoth shaft.

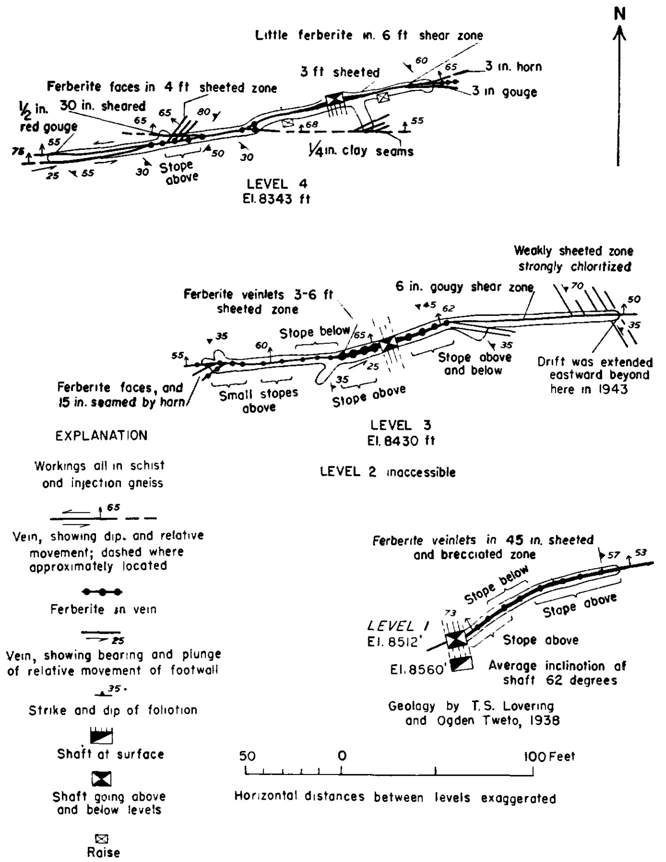


FIGURE 70.—Geologic plan of the Fitzsimmons No. 1 mine, Boulder County, Colo. Horizontal distances between levels are exaggerated.

Workings: Several shafts and shallow connecting workings and trenches.

Geology: Vein strikes N. 85° E. and dips 60° N.; western extension of Fitzsimmons No. 6 vein. In schist and pegmatite. Vein very weak in Windy tunnel, 250 ft below surface workings.

Ore: Seams of high-grade ferberite in sheeted zone.

History and production: Apparently worked intermittently for many years. Output unknown, probably not large. Mine owned by Tanner brothers in 1945.

FITZSIMMONS NO. 6 MINE

Some production from shallow shafts 200 ft southeast of Mammoth shaft (pl. 4). Worked chiefly through Mammoth mine. See description of Mammoth mine; also figure 66.

BLACK KING TUNNEL

Location: Altitude, about 8,625 ft; 800 ft N. 63° E. of Mammoth shaft (pl. 4).

Workings and geology: See plate 7.

Production: None. Tunnel driven to explore several veins at depth; no ore was found. Tunnel owned by Gold, Silver & Tungsten, Inc., in 1945.

BLACK ROVER TUNNEL

Location: Upper workings at altitude of about 8,700 ft; 1,600 ft S. 75° E. of Mammoth shaft (pl. 4). Lower-tunnel portal at altitude of 8,450 ft; 1,100 ft S. 47° E. of Mammoth shaft.

Workings: Mine consists of upper shaft workings and unconnected lower tunnel. Shaft workings probably shallow, but extent unknown; completely inaccessible in 1943. See plate 7 for lower tunnel.

Geology: See plate 7 for lower tunnel. Shaft workings on two veins in small area of granite surrounded by schist (pl. 4).

History and production: Production all from upper workings, mostly before 1916; mine operated on small scale at times from 1916 to 1931, chiefly by C. C. Clemmens. Total output probably 1,000 to 5,000 units of WO_3. Mine owned by Gold, Silver & Tungsten, Inc., in 1945.

NEDERLAND AREA AND SHERWOOD GULCH

ILLINOIS MINE

The Illinois mine, owned by the Wolf Tongue Mining Co., is four-fifths of a mile northwest of Nederland and a few hundred yards southwest of the Conger mine (pl. 5). It was operated intermittently up to 1929, and a moderate output was achieved from shallow workings, but the main period of productivity was that from 1936 to 1943. All the workings below the tunnel level (pl. 8) were driven after 1936. The total output from the mine up to June 1, 1943, was 10,129 tons of ore that averaged close to 2.56 percent WO_3 and contained 25,905 units of WO_3. The ore mined near the surface during early operations averaged 13.1 percent WO_3.

The mine was opened by a tunnel (now covered by the dump) and a vertical shaft whose collar is at an altitude of about 8,660 ft. The tunnel is 45 ft below the shaft collar, and five levels below the tunnel are at depths of 145, 200, 300, 400, and 500 ft below the shaft collar. The fourth, or 400-ft level is the most extensive. It connects with the Illinois Extension shaft, which in turn connects with the Beddig and Conger mines, and extends beyond the shaft to a point under the shaft workings of the Niagara mine.

GEOLOGY

As shown in plate 8, the main Illinois vein follows an eastward-trending dike of hornblende monzonite porphyry which cuts pre-Cambrian schist, granite, and gneissic aplite. The schist strikes north-northwest and dips 60°–80° E. Most of it is strongly injected by aplite and pegmatite, and the resulting injection gneiss grades at places into gneissic aplite. The larger bodies of gneissic aplite were intruded parallel to the schistosity except locally where they cut sharply across the schist. The granite boundaries are less closely related to the earlier foliation, and many of them strike northeast or east. Much of the granite is gneissic, and some is fine-grained and grades locally into gneissic aplite.

Most of the rocks are strongly altered near the veins. Granite and aplite are sericitized and silicified adjacent to the vein walls and have a characteristic greenish-gray color. Farther from the veins the rocks have the soft and chalky character typical of argillic alteration.

Schist shows similar types of alteration locally, but most of it is chloritized. In general, the sericitic and siliceous alteration becomes more extensive with depth, and the clays diagnostic of argillic alteration become less abundant. The rocks on the fifth level are hard and green and are sericitized and moderately silicified at most places. Argillic alteration on this level is restricted almost entirely to the granitic stringers in moderately chloritized schist. The cores of many holes drilled below the fourth level show a wide zone of intensely silicified rock along the south side of the Illinois vein. This zone contains considerable disseminated pyrite and is cut by small pyrite veins that contain a trace of ferberite. The monzonite porphyry appears strongly altered along the dike wall followed by the Illinois vein, but it is not intensively altered where it has not been sheared. Most of the feldspar and hornblende phenocrysts have been replaced by dickite or by sericite and hydrous mica, or locally by chlorite, but the groundmass is comparatively fresh. The porphyry is locally silicified where the Illinois vein is within the dike.

The eastward-trending Illinois vein is a strong and persistent master fissure from which many smaller veins branch. Its average dip is about 85° S., but it is vertical in many places and locally dips steeply north. As shown in cross section (pl. 8), almost all the branch veins dip southeast above the third level, but at greater depth several dip northwest. All the productive branch veins are on the south side of the Illinois vein except the Willis, which diverges northeastward from the Illinois west of the shaft on the upper levels. Some of the minor veins shown in pl. 8 locally are mere cracks along which the rock is slightly altered. Few of these minor fractures contain any gangue such as horn quartz, but they are filled with ferberite at places and a fracture that is narrow and empty at one place may contain a streak of minable ferberite at another a few feet away.

Grooves and striations along the Illinois vein are nearly horizontal. The displacement of the main porphyry dike along the vein east of the shaft on the fourth level, and of a possible cross dike west of the shaft on the third level, indicates that the right-hand side moved forward a minimum of 100 ft. The abrupt thinning of the main dike at the shaft on the fourth level (pl. 8), and the way in which irregular thin dikes and lenses of porphyry follow the vein west of the shaft, suggest that the porphyry was intruded after the original Illinois fissure had formed. The northeastward-trending branch veins in which a large part of the ore was found have the same relation to the Illinois vein that feather joints have to a master fault. Displacements along these veins are small or imperceptible.

The veins with a northeasterly or easterly trend are crossed by minor fractures with a northerly or northwesterly trend that are related to the breccia reefs. Several of these early fractures are distinguished in plate 8, and many others were evidently reopened and mineralized when the tungsten veins were formed. The fractures define a weak shear zone which is probably an extension of the Maine-Cross breccia reef (pls. 4, 5). The fractures of this shear zone contain hematite at some distance from the veins, but near the veins they show strong chloritic alteration. Late movement on some of them displaced the Illinois vein and its branch veins at several places—for example, on the tunnel level, 75 ft west of the shaft, where a northward-trending premineral fault cuts the Illinois vein. The west side moved 4 ft down and north at an angle of 28°.

ORE BODIES

The ferberite of the Illinois mine ranges from moderately fine grained to coarse "crystal ore" and is pure and free of quartz. According to William Loach, general manager of the Wolf Tongue Co., the ore from the Illinois was more amenable to milling than any other ore treated in quantity during the company's long experience in tungsten mining and milling. The ore occurs typically in seams a fraction of an inch to 2 inches thick scattered through sheared or sheeted zones up to several feet wide. The coarse ferberite is younger than the fine-grained ore. It occurs in vugs and in cross-breaking fractures within the vein such as those shown in the Willis vein on the tunnel and first levels. The coarse vuggy ore is partly covered by opal and fine-grained quartz, and a little barite is present locally. Seams of ankerite are present in the barren parts of many of the veins, but they seem to be most common above ore and were found to mark the upward termination of two blind ore shoots.

Sulfide minerals are minor constituents of the ore at many places. Pyrite is the most abundant, but in the Willis vein sulfides of silver, copper, lead, and zinc also are present. Although the amount of base metals is commercially insignificant, the sulfide-bearing ferberite ore is of great interest in establishing the time of deposition of the ferberite relative to that of the sulfides. A study of polished sections of this ore shows that the paragenesis is (1) horn quartz, (2) fine-grained ferberite, (3) quartz, (4) coarse ferberite and some galena, (5) sphalerite and quartz, (6) freibergite, (7) miargyrite, (8) galena, (9) chalcopyrite, (10) miargyrite and polybasite (supergene?), (11) chalcocite (supergene), (12) bornite (supergene).

The Willis vein joins the Illinois about 150 ft west of the shaft. The Willis ore shoot extends from a point near the junction to a minor shear zone with a north-northwesterly trend in schist about 60 ft to the northeast. In general, the vein narrows southwestward from the shear zone. Coarse crystalline ore is found close to the shear zone, but as the vein is followed southwestward, the ore is seen to become lower in grade and finer-grained; finally, near the junction with the Illinois vein, it gives way to barren or sulfide-bearing horn quartz. Ore on the third level was distinctly coarser than ore from the corresponding part of the ore shoot on the first level. The Willis vein lengthens, and the length of the sulfide-bearing zone increases, with depth. The change from tungsten ore to sulfide-bearing quartz is repeated on successive levels at about the same distance from the shear zone; hence it is inferred that the shear zone guided the ascending metalizing solutions in the vein. It would seem that here the silver mineralization is a minor phase of the tungsten mineralization. The fact that the sulfides are mostly later than the ferberite is in harmony with the location of the two types of ore with respect to the structure localizing the ore shoot.

The localization of ore is apparently related to both wall rock and structure. Ore occurs between granite walls both where the gneissic structure is parallel to the vein and where it is at an angle to the vein. In gneissic aplite the ore is noticeably poorer where the foliation is parallel to the vein, and ore between schist walls is confined to the parts of the vein that cut sharply across the schistosity. On the third level an ore body in schist was widened by numerous veinlets of ferberite which extended into the walls between the leaves of schist or injection gneiss. Some excellent ore has been found between prophyry walls. Little ore is found where both walls are chloritized or strongly sericitized. At least one wall of most of the ore shoots is silicified, but some of the shoots on the small veins are in essentially unaltered rock. There is some evidence to suggest that silicification is strongest beneath ore shoots, but some large silicified areas seem unrelated to ore. The best ore has been found between walls that are fresh, moderately silicified, or both silicified and sericitized. Along most ore-bearing veins, one altered wall is much softer than the other; one wall may be silicified and the other sericitized or chloritized, or one may be sericitized and the other argillized.

Although the main Illinois vein is soft, gougy, and barren at most places in the mine, it contained one large ore shoot that was persistent from the surface down almost to the fourth level. As shown in plate 8, this shoot raked east at about 55° and was closely related in character and structure to the wall rocks. It had one wall of porphyry and one of granite in most places and lay on the west and under side of a mass of eastward-dipping schist and gneiss. The west edge of the shoot shows a fairly close relation to fractures with a north-northwesterly trend, and the richest ore was in streaks bounded by similar fractures. The ore was in a relatively wide zone and of good quality. The walls of the stope between the third and fourth levels were as much as 32 ft apart (fig. 71*B*), and the average width of the stope between the second and third levels was 8 ft. The ore was 2 to 6 ft wide between the tunnel and first levels. The vein at the surface contained 30 in. of coarsely crystalline ore that assayed about 25 percent WO_3, and a blanket of rich float ore extended down the hill from the outcrop for about 30 ft. The rich ore, followed down from the surface, appeared to become abruptly leaner at about the tunnel level, and the ore from old underhand stopes in the tunnel is said to have assayed about 2½ percent WO_3 through widths of 4 to 6 ft.

The northeastward-trending branch veins are barren at their junctions with the Illinois vein, and there is little indication of the commercially valuable ore that is present a few feet from the intersections (fig. 71*A*). The ore shoots on the branch veins appear to be closely related to the fractures with a north-northwesterly trend and to contacts between schist and granite or aplite. A large part of the output from the Illinois mine came from six of the branch veins, which are distinguished by stope symbols in plate 8. (1) The Willis vein, north of the Illinois vein and west of the shaft, was stoped from a point above the tunnel down to the third level. (2) A vein southeast of the shaft on the tunnel level was stoped above the tunnel and down to the first level. (3) A vein south of the shaft on the first level was stoped above this level and down to the second level. (4) The western vein south of the shaft on the second level (pl. 8) was stoped from the floor of the second level down to the fourth level. (5) A vein southeast of the shaft on the second level was stoped above this level and down to the third level. (6) A vein east-southeast of the shaft on the third level was stoped above the third level and down to the fourth level.

Exploration for ore was carried on by diamond drilling and crosscutting in the walls of the Illinois vein. A large amount of drilling was done, and the locations of some of the holes, especially those that were not later followed by mine workings, are shown in pl. 8; several holes drilled after the spring of 1942, however, are not shown. The maze of workings shown in pl. 8, together with several thousand feet of drill holes, adequately explored the mine down at least to the fourth level. Although the fifth level was less thoroughly explored, considerable work was done there. A little ore was found on an eastward-trending vein

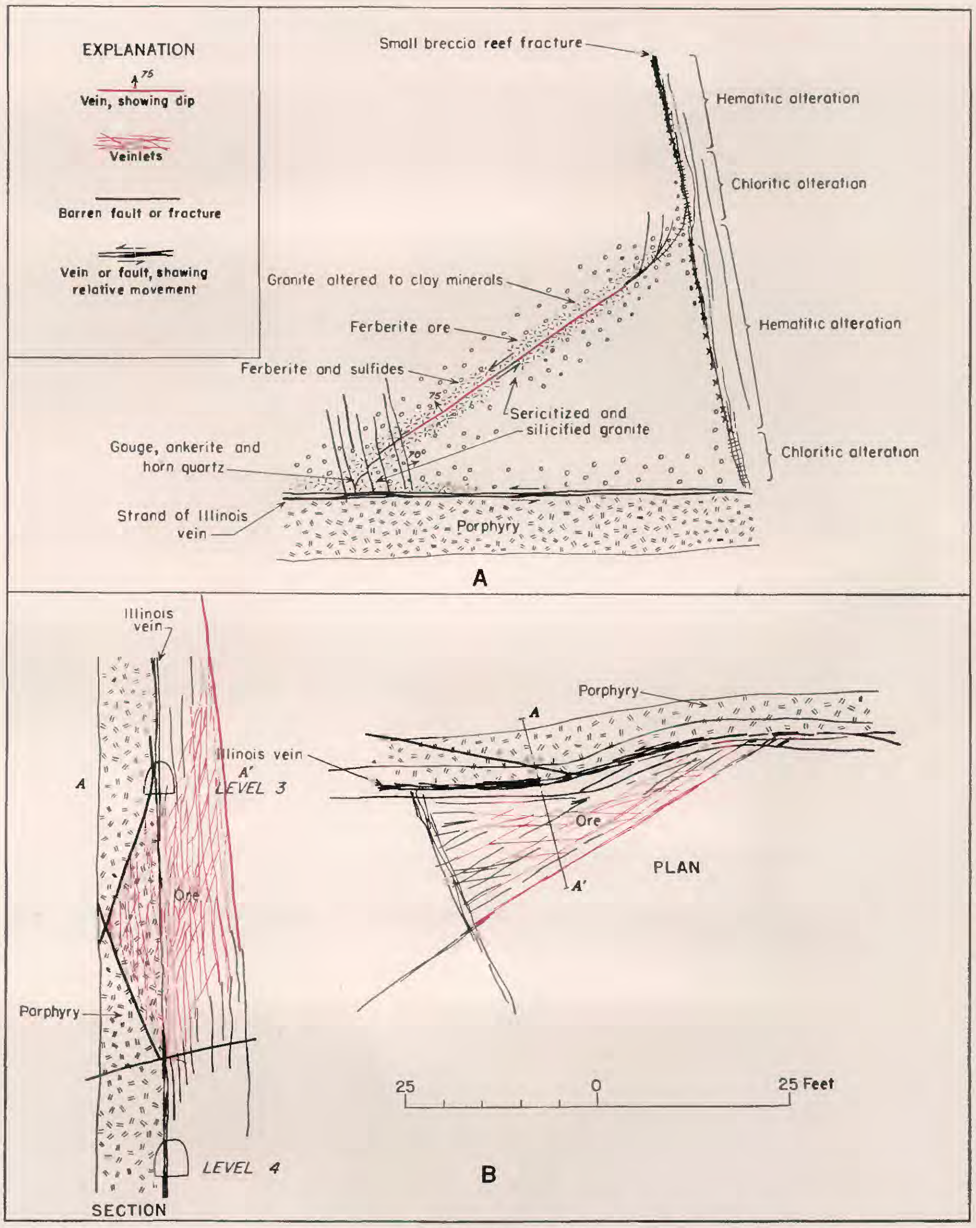


FIGURE 71.—Ore occurrences in the Illinois mine, Boulder County, Colo. *A*, Willis vein between the tunnel and the first level, showing the fracture system, and the distribution of altered rocks and ore. *B*, Plan and section of an ore shoot on the Illinois vein, 200 ft east of the shaft on the third level (from data furnished by Naylor Todd).

that had been explored and found barren on several of the higher levels. The ore was of good quality and was best in the floor of the level, but holes drilled beneath the ore gave discouraging results.

QUAY MINE

The Quay mine is at the extreme west edge of the tungsten district, about a mile northwest of Nederland (pl. 5). It is owned by the Colorado Tungsten Corp. but has been operated almost entirely by lessees. Little of the early history is known. The mine was leased along with the rest of the Colorado Tungsten Corp. ground by the Primos Mining & Milling Co. from 1915 to 1919. Some ore was produced from shallow workings before 1915, but most of the early production took place from 1915 to 1917. According to E. J. Crook, who was one of a group of sublessees at that time, $53,000 worth of ore was mined and sold at an average price of $20 per unit. This output came from a shallow ore body that was worked through four short levels turned from the Old shaft (fig. 72), which reached a vertical depth of 134 ft. The mine was closed from 1918 to about 1936, when it was reopened by M. A. and W. W. MacKenzie, A. J. MacDonald, and E. J. Crook, who subleased it from the Wolf Tongue Mining

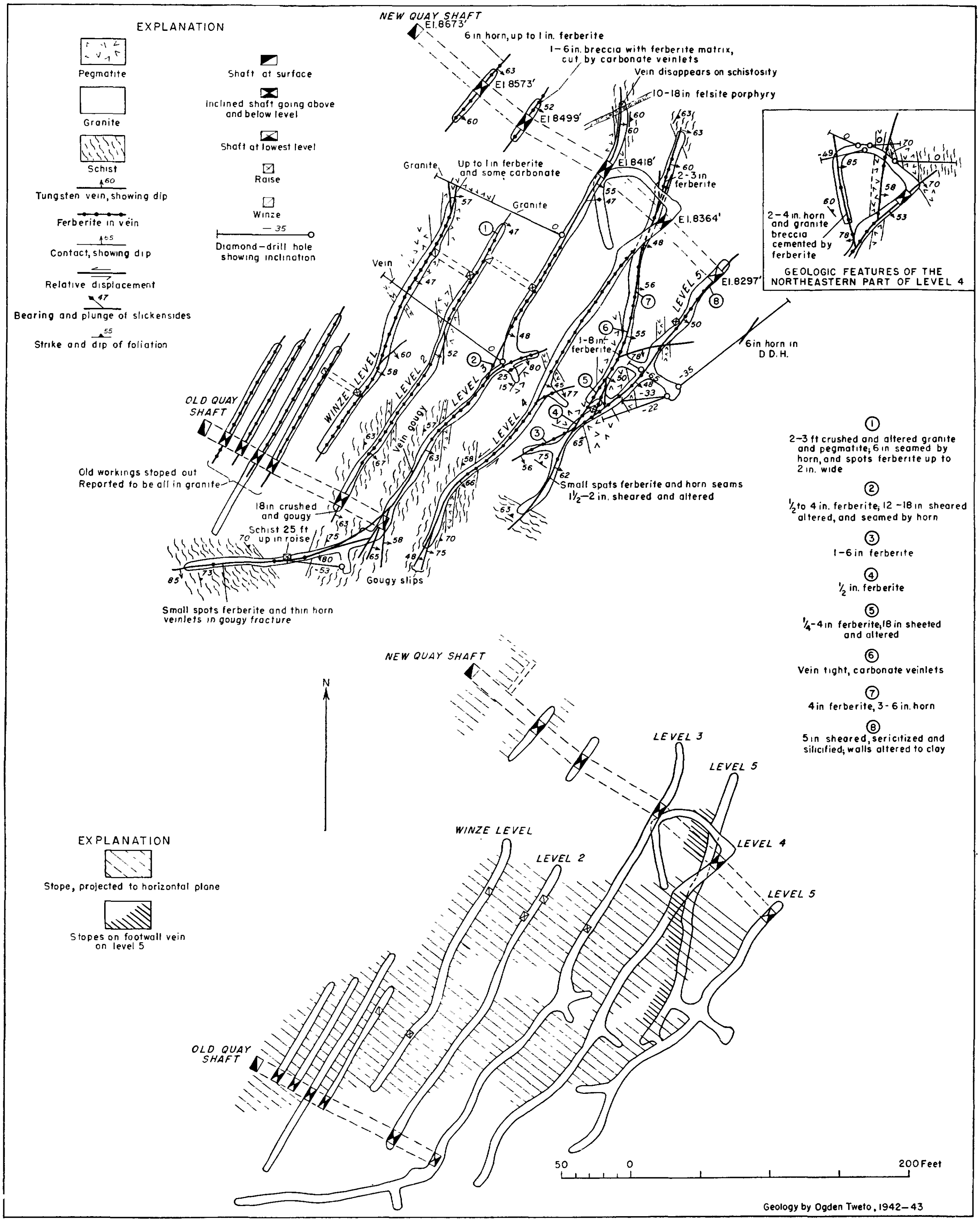


FIGURE 72.—Geologic plan of the Quay mine, Boulder County, Colo., and composite map of the Quay mine, showing stopes. The shaded areas are stoped areas projected to the horizontal; heavy shading represents stopes on the Footwall vein on the fifth level.

Co. These men found ore in a winze below the old workings, deepened the Old shaft, and later sank the New shaft. Rich ore was found on all the lower levels, and the period from about 1936 to the summer of 1944 was the most productive stage in the history of the mine.

The total output from the Quay mine is at least 30,000 units of WO_3, most of which was produced during the 1936–44 period of operation. The ore shipped from 1936 to 1943 averaged 13.07 percent WO_3.

The New shaft is at an altitude of 8,673 ft and reaches a vertical depth of 376 ft. It is a relatively flat inclined shaft whose average dip is 53°, but locally the dip is as low as 43°. The three main levels turned from the New shaft are known as the third, fourth, and fifth levels of the Quay mine. The so-called second level is turned from the Old shaft, and the next level above this is known as the winze level (fig. 72). Four closely spaced levels above the winze level are caved and are known only as the old workings. These levels were at vertical depths of 44, 78, 110, and 134 ft below the collar of the Old shaft.

The Quay mine is in a strip of Boulder Creek granite a few hundred feet wide that lies between northward-trending masses of schist of the Idaho Springs formation (pl. 5). The pegmatite shown at the surface east of the New shaft in plate 5 gives way to schist at depth. The granite is medium- to coarse-grained and moderately gneissic. It is cut by small dikes and larger irregular masses of coarse-grained pink and white pegmatite. The granite is sericitized and locally silicified for 6 to 24 in. from the vein walls and beyond that is strongly argillized for several feet. In general, the zone of alteration to clay minerals is stronger and wider on the footwall than on the hanging-wall side of the vein. A small dike of felsite porphyry cuts the schist at the north end of the third level, and an irregular mass of similar porphyry seems to follow the Footwall vein on the fifth level for a short distance near the north end of the drift.

The Quay vein strikes about N. 30° E. in the granite and at most places dips 45°–60° SE. It turns to a more northerly course and weakens and feathers out in the schist southwest and northeast of the granite. The vein splits at the southwest end of the fifth level. The southern branch flattens upward and joins the northern branch just below the fourth level. Both veins were productive from the junction down almost to the fifth level. Most of the mine's output came from the Quay vein, but some came from a northward-trending vein in the footwall on the fifth level. Like many of the branch veins in the tungsten district, this vein was marked in the footwall of the Quay vein only by a thin ferberite feeder, but within a few feet of the junction the feeder widened into several inches of good ore. The Footwall vein contained lenses of ore through most of its length up to the schist at the north end of the drift. It was stoped at intervals along the drift just before the mine closed in 1944, but the extent of the stopes is not known to the writers, and only the approximate locations of the stopes are shown in figure 72.

At most places in the granite the Quay vein consists of 1 to 2 ft of sheeted sericitized granite which is seamed by veins of gray horn quartz and ferberite. In some parts of the vein the ore consists of many small veinlets of pure ferberite, but in most places it is in one to three streaks having a total width of 3 to 15 ins. Such streaks generally dip a little more flatly than the vein and thus tend to "shingle" in it. The ore consists of streaks of vuggy ferberite and scattered inclusions of rock and horn, and much of the ore was mined as "high grade." During 1 year of operation, for example, the production was 311.59 tons of mill ore assaying 6.35 percent WO_3, equivalent to 1,978 units of WO_3, and 44.89 tons of "high grade" assaying 42.07 percent WO_3, equivalent to 1,888 units.

The ferberite is medium- to coarse-grained and well crystallized. Although it is usually accompanied by horn quartz, it is not intergrown with quartz so as to make horny ore. A little pyrite accompanies the ferberite, and locally pyrite is fairly abundant. In at least one locality, at the south end of the stope above the fifth level, the ore is a mixture of silt and fine-grained ferberite. The black, ferberite-bearing silt is faintly stratified and lies on top of massive ferberite as indicated in figure 73, which shows only a thin layer of the silty ore. The silt contains some clay minerals that may be of hypogene origin, but it consists mainly of fine detrital fragments of quartz, altered feldspars, and micas. The ferberite mixed with it is very finely granular. The sharp contact between pure and silty ore, the faint stratification, and the pronounced horizontal orientation of rock fragments in slightly silty ferberite that grades upward into normal massive vein ferberite above the silty band suggest that tungsten deposition was temporarily interrupted during a period in which circulation of water—or ore solution—was very active. Thin seams of red horn and pyrite like the one shown on the hanging wall of the vein in figure 73, cut the ferberite ore at several places in the Quay mine.

Scheelite is apparently present in minor quantity throughout much of the Quay vein. The ultraviolet lamp shows small grains, stringers, and faces of scheelite in pieces of otherwise barren vein matter found on the dumps, but the scheelite is too sparse to be of economic significance.

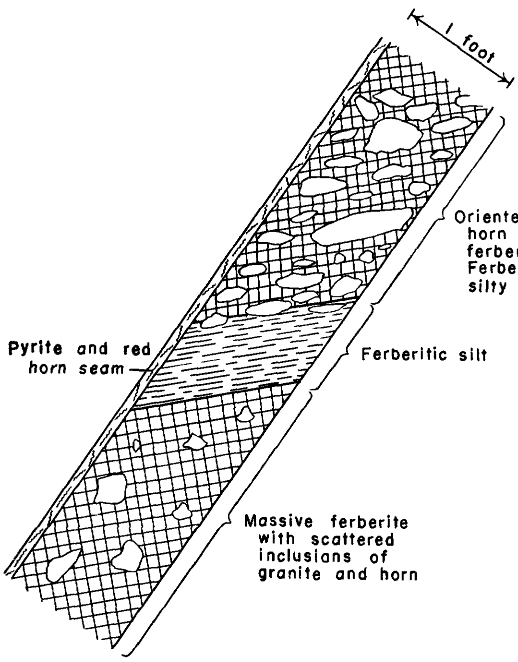


FIGURE 73.—Sketched cross section of the Quay vein Boulder County, Colo., at south end of the stope, 40 ft above the fifth level, showing silty ore.

Although the large stoped area shown in figure 72*B* gives the impression of a single ore shoot split through much of its length by a narrow and irregular barren zone, the richest ore was in three fairly well defined shoots. These shoots all plunged east, about parallel to the schist-granite contact. They overlapped in the vein, and as they were bounded by leaner but minable ore, they are only imperfectly outlined by the stope pattern. One shoot, or streak, of rich ore extended from the surface at the Old shaft down through the old workings about to the winze level. The top of the second shoot or streak overlapped the upper one on the northeast side and extended to the fifth level on the southwest side of the barren pillar. The third rich streak began at about the winze level northeast of the pillar and extended to the fifth level, but it narrowed and became lower in grade between the fourth and fifth levels.

The Quay vein is ore bearing through most of its course across the granite mass and becomes barren and dies out in the schist that lies on either side of the granite. This distribution of eastward-dipping wall rocks seems to have been the principal feature controlling ore deposition. Within the granite there is little or no difference in the structure of the ore-bearing and barren parts of the vein. The only explanation for the barren pillar is that branch veins join the Quay vein at the pillar on the various levels. The Quay vein displaces pegmatite dikes a few feet, with the right side ahead, but no reliable evidence such as grooves or slickenslides was found in the mine and the exact direction of the movement is not evident. The ore zone widened in the steeper part of the vein just above flat rolls and at turns to a more easterly course, suggesting relative movement of the hanging wall down and south. This is not in accord with the observed displacement, but it is possible that there was more than one period of movement and that the major displacement occurred at an early stage when the hanging wall moved up or east. The persistence of ore through flat zones where the dip is less than 45° strongly suggests reverse fault movement.

The Quay vein has been thoroughly explored in the granite down to the fifth level except at shallow depth near the New shaft. The ore narrowed and became poorer just above the fifth level, and as the few holes drilled below the level gave negative results, further exploration at depth does not seem promising. The vein appears to die out in schist northeast and southwest of the mine, and further exploration along the strike therefore does not seem warranted except near the surface in the vicinity of the New shaft, where the vein is in granite and pegmatite. The best remaining prospects seem to be in the walls of the vein, which have been only slightly explored. Several veins can be observed to branch into the walls from the Quay vein, and exploration for parallel veins is warranted by the relatively high productivity of the main vein. A few short holes were drilled into the walls by the Bureau of Mines as shown in figure 72*A*. One of the very short holes, later followed by a crosscut, led to the development of the Footwall vein. A vein 3 ft wide, comprising abundant gray vuggy horn quartz in sheared granite encased by a strongly sericitized zone 2 ft wide, was cut at a depth of 100 ft in the more southerly of the two flat holes in the footwall on the third level. The hole to the north was not drilled far enough to cut this vein.

BEDDIG MINE

HISTORY AND PRODUCTION

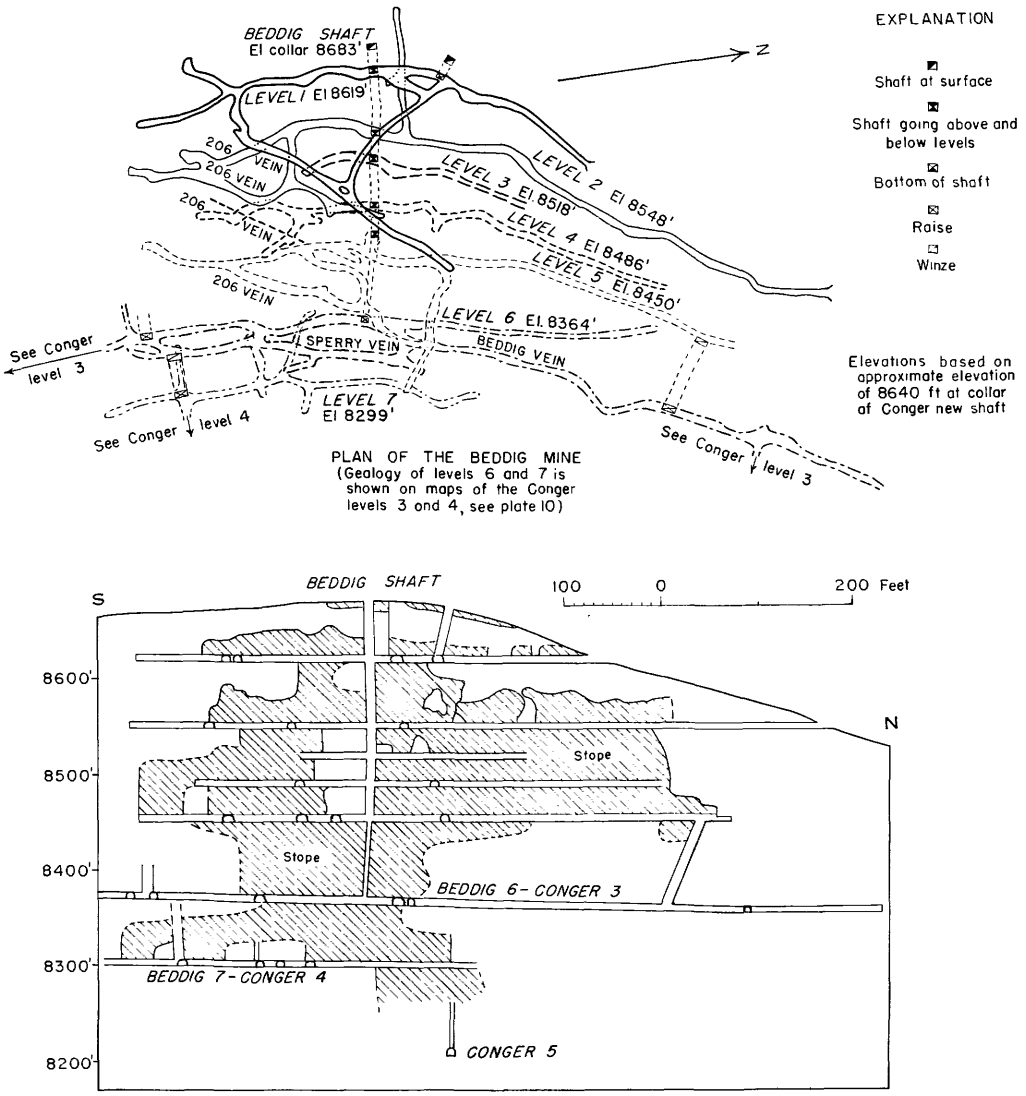
The Beddig mine is about a mile northwest of Nederland and is just west of the Conger mine (pl. 5). Its production has been relatively large, and it probably ranks among the first five mines of the district in total output. It is one of the many mines on the Crow patent, an agricultural patent that has been owned by the Colorado Tungsten Corp. since 1905. The mine was worked intensively by this corporation from 1905 to 1907 and was developed down to the fifth level at that time. The Crow patent was later leased by the Primos Chemical Co., and the Beddig was operated in conjunction with the adjoining Conger mine from 1915 to the end of 1918. A little work was done by sublessees between 1934 and 1945 while the Crow patent was leased by the Wolf Tongue Mining Co., but only a small production resulted.

The production from the Beddig mine is not known accurately, but from records covering intervals in the productive history, together with a few old stope maps and the known history of the mine, the output is estimated as at least 60,000 units of WO_3. Most of the ore was produced by the Colorado Tungsten Corp. from 1905 to 1907 and by the Primos Chemical Co. from 1915 to 1918. The average tenor of the ore appears to have been a little more than 3 percent WO_3, but the ore mined up to 1914 was of higher grade. According to figures given by O. H. Hershey in a report to the Primos Co. in 1914, the ore from the Crow patent yielded 6 percent WO_3 in terms of recovered concentrates, and the average grade of the crude ore must have been at least 8 percent WO_3. As 75 percent of the Crow production came from the Beddig and the similar Crow No. 4 mine, the Beddig ore at this time probably averaged close to 8 percent WO_3. A relatively large tonnage of lower-grade ore was mined during World War I. The average grade of 11,796 tons mined from the Beddig vein in the Beddig and Conger mines from November 1917 to January 1919 was 2.14 percent WO_3.

As shown on the map of the Beddig workings (fig. 74), the two upper levels of the mine are tunnels, and the third, fourth, and fifth levels are turned from the Beddig inclined shaft, which also connects with the tunnels. The fifth level is at a vertical depth of 233 ft below the shaft collar. The sixth and seventh levels on the Beddig vein are parts of the third and fourth levels of the Conger mine (pl. 9). A crosscut to the Beddig vein was also made on the fifth level of the Conger but very little drifting was done.

GEOLOGY

The upper levels of the Beddig are mostly in stopes (fig. 74) and have been largely inaccessible for many



LONGITUDINAL PROJECTION OF THE BEDDIG MINE, SHOWING STOPES ON BEDDIG VEIN

FIGURE 74.—Plan and projection of the Beddig mine, Boulder County, Colo.

years. The geology of the two lower levels is shown on the maps of the third and fourth levels of the Conger (pl. 10).

The Beddig vein strikes north-northeast parallel to the Conger vein and dips about 45° E. toward the Conger. Grooves and displaced porphyry and pegmatite dikes show that it follows a reverse fault, whose east, or hanging, wall moved up and northwest 1 to 7 ft. A small amount of horizontal movement occurred on minor subparallel fractures whose left walls moved forward a few inches. The stopes are in the flatter parts of the vein, which is barren and tight at most places where the dip is 50° or more. Coarse-grained biotite pegmatite is the predominant wall rock where the vein contained ore; where the vein is in schist and gneiss of the Idaho Springs formation, it is a barren gouge seam 3 to 10 in. thick. The irregular and somewhat indefinite contact between the schist and pegmatite in the Beddig and Conger mines dips northeast.

The Sperry vein, a nearly vertical vein in the hanging wall, joins the Beddig vein between the sixth and seventh levels (the third and fourth levels of the Conger) and has been stoped extensively above the junction. Stopes above the third level of the Conger on the Sperry vein and a small branch vein produced nearly 5,000 tons of ore averaging about 2½ percent WO_3 in 1917-18.

An unnamed vertical vein in the footwall branches from the Beddig at the north end of the main stope on the third level of the Conger. This vein was followed northward for 250 ft, and although it was not productive on the level, it was apparently worked in a stope some distance above the level. At the breast of the drift the vein is open and vuggy and contains gray copper and other sulfides. It follows a fault which shows considerably greater displacement than the Beddig fissure. Porphyry dikes near the breast are displaced as much as 20 ft, with the right side ahead, and grooves indicate that the movement was almost horizontal.

As indicated by the workings shown in figure 74, the "206" vein, a vein with a northeasterly trend in the hanging wall of the Beddig, was worked on all levels from 1 down to 5. This vein dips about 45° SE. Little is known of it except that old maps indicate stopes near the junction with the Beddig vein on levels 1 to 5 and that 1,100 tons of 3-percent ore was obtained from it on the second level in 1918. The "206" vein was apparently the only productive vein in the walls of the Beddig on the upper levels. It was not identified on the sixth level near the junction of the Beddig and Sperry veins and is evidently cut off by the vertical Sperry vein.

As shown in the longitudinal section (fig. 74), the ore on the Beddig vein was in a single irregular ore shoot that had a few barren spots in it. The shoot had a stope length of about 500 ft on the fourth and fifth levels. It narrowed to less than 200 ft on the sixth level, and, although it widened again on the seventh, it contained barren blocks and the ore was relatively thin. The seventh level is essentially the bottom of the shoot, but some stoping was done below the level at the north end. The thinning of the vein on the seventh level coincides with an increase in dip to about 50°, and the position of the vein on the fifth level of the Conger indicates a further increase in dip below the seventh level of the Beddig (pl. 9*C*). Although the ore shoot as outlined by the stopes on figure 74 does not show any pronounced trend, or rake, the thickest ore and the richest part of the shoot were in a streak that rakes northeast at a low angle. This streak lay south of the shaft on the first level, crossed the shaft between the first and second levels, and was near the north end of the stope on the fifth level. In a general way, it followed a dike of hornblende monzonite porphyry which strikes N. 75° E. across the Beddig and Conger mines and dips about 55° N.

The ore in the Beddig mine was a breccia of rock fragments cemented by ferberite and quartz, and the ore seam, according to Hershey, was half an inch to 3 ft wide. Vugs in the ore were partly filled with quartz and opal, and some of the ore on the fifth level contained relatively abundant pyrite and marcasite. A specimen of the sulfide-bearing ore is shown in figure 27.

CONGER MINE

HISTORY AND PRODUCTION

The Conger mine has been the most productive mine in the tungsten district, and for many years in the early part of the century it vied only with the Union mine at Atolia, Calif. (Lemmon and Dorr, 1940, pp. 208–209, 232–235), for the position of the greatest tungsten mine in the United States. The mine is about a mile northwest of Nederland (pl. 5) and is only a few hundred yards from the west edge of the productive area. Surface openings on the vein are at altitudes of 8,500 to 8,700 ft.

The Conger vein was discovered by Sam Conger in 1900, only shortly after float ore nearby had been identified as ferberite by his partner, W. H. Wanamaker. Conger and Wanamaker sank a shaft 80 ft deep on the vein, but as the grade of ore fell off at this depth, and as it was generally believed that all the tungsten ore pinched out within 100 ft of the surface, they went no deeper and later sold their holdings to Messrs. Lake and Barnsdall. In 1904 the Wolf Tongue Mining Co. proved the continuation of ore with depth on the Oregon claim, which included the south end of the Conger ore shoot. This encouraged Lake and Barnsdall to deepen the Conger shaft and thus led to the development of one of the greatest vein tungsten mines in the United States. Lake and Barnsdall operated the Conger mine from 1904 to 1908, when they sold their property to the Primos Chemical Co. This company combined the Lake-Barnsdall property with that of the Stein & Boericke Mining & Milling Co. as the Primos Mining & Milling Co., a subsidiary which operated the Conger mine from 1908 to 1919, its most productive stage.

The Primos property was acquired by the Vanadium Corp. of America in 1920, but the Conger mine remained idle until 1938 except for minor operations by lessees in the upper workings and at the surface. The Vanadium Corp. reopened the mine and built a 50-ton mill in 1938 and operated them until the spring of 1945. The mine was unwatered to the fifth level, but this level was abandoned in 1941 and the water was allowed to rise almost to the fourth level. As the mine was used as a storage and settling reservoir for water for and from the mill, the workings below water level filled with slimes, and the mine probably could not be reopened below the fourth level again except at a high cost.

Considerable diamond drilling was done by the Vanadium Corp. after the mine was reopened in 1938, and ore was found in several veins on the east, or hanging-wall, side of the mine. A large amount of ore was mined from these veins during the first 3 or 4 years, but as they became worked out, an increasingly greater demand was made on the fill in the old stopes as a source of mill feed. By the time the mine closed in 1945, most of the Conger ground above the fourth level had been thoroughly explored, and almost all the recoverable fill in the extensive old stopes had been removed.

The production of the mine is not accurately known, but from the incomplete records available, the total output appears to have been between 400,000 and 500,000 units of WO_3 in ore. Thus, assuming a 75-percent mill recovery, the output was at least 5,000 tons of concentrates containing 60 percent WO_3. In a report by O. H. Hershey to the Primos Co. in 1914, the Conger production is said to have been about 60,000 tons of ore averaging 6.0 percent WO_3, or 360,000 units WO_3, but judging by the records of the Primos mill, this estimate appears to be too high—probably in tonnage rather than in grade. The production during the last 17 months of the Primos Co.'s operation, from September 1917 to January 1919, amounted to about 30,000 units in ore that averaged about 2 percent WO_3. No record of the output from 1914 to 1917 is available. This period included the tungsten boom, and every effort was presumably made to produce as much ore as possible during the period of high prices. A comparison of Hershey's stope diagrams with those of the Primos Co., together with the sources of the 1918 production, indicates that a large tonnage was mined from 1914 to 1917, and it seems probable that at least 50,000 units was produced during these 3 years. The output from the Vanadium Corp.'s operation of the mine from 1938 to 1945 and from small-scale, near-surface operations from 1920 to 1938 amounted to more than 40,000 units in concentrates.

WORKINGS

The workings of the Conger mine are shown in plate 9. The mine comprises about 5 miles of horizontal workings, of which about 85 percent is drifts. It is opened by an adit and two shafts. The Old shaft (Conger incline) is an inclined shaft down to the old eighth level, which is equivalent to the sixth level of the New shaft. The New shaft is vertical and 606 ft deep. It extends to the seventh level, from which an inclined winze was sunk to the eleventh level. The four levels turned from the winze are 100 ft apart on the plane of the vein, or 80 ft apart vertically. The eleventh level thus is 926 ft below the collar of the New shaft, and the mine has a maximum vertical depth of 991 ft measured from the collar of the Old shaft. The Conger is almost 400 ft deeper than any other mine in the district.

In addition to the 11 levels numbered from the New shaft, the so-called intermediate level, which lies between the second and third, is a major level. This is the fourth level of the Old shaft and does not connect with the New shaft. The workings are concentrated in the upper part of the mine. Work during the last period of operation was centered on the second and fourth levels, which are the most extensive in the mine. Below the fourth level the extent of the workings falls off rapidly, and the lower five levels comprise only about 2,000 ft of workings, or less than one-tenth of the total.

The Beddig mine was worked in conjunction with the Conger by the Primos Co., and some of the workings on the third and fourth levels of the Conger are on the Beddig vein. These workings comprise the sixth and seventh levels of the Beddig mine. The Beddig was later leased by the Wolf Tongue Mining Co., and a connection was made between the Illinois Extension shaft and the sixth level of the Beddig (third level of the Conger) as shown in plate 9.

WALL ROCKS

The veins of the Conger mine are confined largely to an elongate area of pegmatite and granite that trends north, parallel to the foliation of the enclosing schist of the Idaho Springs formation (pl. 5). The western and southernmost workings of the third and fourth levels are in schist, as shown in plate 10. A little schist also is present at the north ends of these levels, and schist covers an extensive area at the surface still farther north. The granite shows many textural and compositional varieties. It ranges from fine- to coarse-grained. Some of it is massive, and some is gneissic and grades into biotite gneiss which in turn grades into schist. Dikes and irregular masses of pegmatite and alaskite are abundant in the granite. On the fourth level, near the Old shaft, somewhat schistose gneissic aplite forms a transition zone between granite and schist.

The pre-Cambrian schist and granitic rocks are cut by dikes of Tertiary felsite and hornblende monzonite porphyry which trend about N. 75° E. across the mine. The felsite dikes dip steeply south and are only a few inches to 3 ft wide. The hornblende monzonite porphyry occurs in two major dikes and several smaller branching dikes. The large southern dike is 20 to 40 ft thick, dips 55°–60° N., and is continuous from the surface, where it is about midway between the two shafts, down at least to the sixth level, where it is about 75 ft north of the New shaft. The northern dike is 50 ft thick, is almost vertical, and was cut near the north ends of the third, fourth, fifth, and sixth levels. It is not exposed on the second level but may be present beneath the dumps near the portal of the tunnel. The age relations between the felsite and the monzonite are not clear, but there is some suggestion that the felsite is older. Some of the felsite dikes appear to be cut by monzonite dikes, and the felsite dikes on the average are displaced a little more than the monzonite dikes by the vein fissures. Both types of dikes were evidently intruded later than the first movement along the fissures, as small spur dikes of both types turn and follow the fissures at places and most of the dikes are displaced less than the pre-Cambrian rocks.

Where the walls of the veins are granite they show more alteration than where they are pegmatite and monzonite, but all the wall rocks have been attacked by hydrothermal solutions to some extent. The veins are marked by a wide argillized zone in the granite, and the usual casing of sericitized and silicified rock is present next to the veins. Adjacent to ore the casing is 1 to 5 ft wide, but along the barren parts of the veins it is generally less than 2 ft wide and at places it narrows to a few inches.

VEINS

All the more important veins of the Conger mine follow premineral normal faults which had a horizontal component of movement. The veins are irregular in strike and dip, and the widths of the fractured zones vary greatly in different places.

Near the Old shaft, and south of it, the Conger vein is a single vein that strikes a few degrees east of north and dips 50°–75° E. The vein splits about 200 ft north of the Old shaft on the intermediate, third, fourth, and fifth levels. The left, or western, branch trends a little west of north for a few hundred feet and then changes to a northerly course. It dips 60°–80° E. The right, or eastern, branch strikes about N. 10° E. and dips 60°–70° E. near the junction. Farther north it is nearly vertical, although the dip ranges locally from 75° E. to 75° W. There has been some confusion over the terminology of the two branches. The Primos miners and Hershey called the western branch the Conger vein and called the eastern branch the Middle vein. During the last period of operation the term "Middle vein" was not used, and the term "Conger vein" was applied to the western branch on and above the second level and to the eastern branch below the second level. Which vein is called the Conger is a matter of little importance, but in order to make the present discussion clear and to make the written accounts consistent, the western branch and the vein south of the split will be considered the Conger vein, and the eastern branch will be called the Middle vein.

The Conger vein follows a normal fault whose east side moved downward and southward a minimum of 27 ft on a plunge of about 40°. The vein splits north of the northern ore shoot on the second level (pl. 10), but on the fourth level and probably on the third it joins the Beddig vein, and it may reunite with the Middle vein near the north end of the fourth level. As shown in the cross sections (pl. 9) the Conger vein flattens below the fifth level near the Old shaft and below the fourth level near the New shaft, and as might be expected of a normal-fault fissure, the vein becomes tighter and barren where it flattened.

The Middle vein follows a premineral fault whose east wall is displaced several feet down and south. Grooves that plunge about 45° S. probably represent the main movement, but younger grooves that plunge 5°–15° S. indicate later movement which was probably of minor extent. From the fifth up to the intermediate level the Middle vein makes a well-defined junction with the Conger vein. On the second level, however, it splits into several branches, the strongest of which dip west, and there is no clearly defined junction with the Conger vein. The branching veins become weaker upward, and the Middle vein is not recognizable at the surface. As shown in the longitudinal projection (pl. 9), the junction of the Conger and Middle veins is irregular but in general plunges steeply northeast down to the sixth level. According to Hershey, the steeply dipping Middle vein reunites with the Conger vein at or just below the sixth level, and only the single Conger vein was explored on the lower levels (pl. 9).

Of the several veins that branch from the Conger and Middle veins, the Jumbo and the Watchman were the most productive. The Jumbo vein diverges northeastward from the Conger vein south of the Old shaft. It strikes about N. 30° E. and has an average dip of about 60° SE. It is a normal fault whose southeast wall moved down and northeast. The vein was stoped extensively from the surface down to its intersection with the westward-dipping Watchman vein on the intermediate level. Below this level ore was found at intervals in overlapping fractures of the Jumbo vein zone down to the fourth level.

The Watchman vein diverges northeastward from the Conger vein near the Old shaft on the fourth level, striking about N. 30° E. and dipping steeply northwest. It follows a premineral fault along which there was evidently more than one period of movement, but the net displacement of the hanging wall was a few feet down and southwest. Near the junction with the Conger vein the Watchman vein consists only of narrow seams of gray horn quartz in strongly sericitized and silicified granite. Ferberite appeared in the vein about 20 ft from the junction, and a streak of ferberite 1 to 8 in. wide was stoped northeastward for 300 ft. The Watchman ore shoot was the source of the best ore mined during the last period of operation, and the vein was stoped from the fifth level up to the intersection with the Jumbo vein on the intermediate level. The vein is weak and barren above the intersection and probably does not reach the surface (pl. 10).

The relatively flat but productive Pratt Freak vein splits from the east side of the Middle vein on the second level. It was stoped up to its junction with the Jumbo vein on the first level. The westward-dipping "209" vein diverges from the Middle vein on the second level near the New shaft and extends southward to the Jumbo vein. The west wall of the "209" vein moved down and south at about 20° for several feet. The vein splits into several barren fractures about 150 ft north of the junction with the Jumbo vein on the second level, but farther north it was stoped above and below the level. It dips into the Conger and Middle veins just below the third level, and a large stope was made on the vein near the junction (pls. 9, 10). This stope was one of the major sources of ore in 1917–18.

In 1944 good ore was found in a vein zone that may represent the Conger in the footwall of the Middle vein north of the shaft on the fourth level. The veins steepened upward, and the stope which followed this footwall zone broke into the stope on the Middle vein. The footwall veins contained as much as 6 in. of pure ferberite, but as they were discovered about the time that the price of tungsten fell in the spring of 1944, and as the ore pinched southward, they were explored for only a short distance south of the junction.

Eastward-trending fractures of the Illinois vein system and accompanying porphyry dikes were cut at the south ends of the third and fourth levels. These fractures are barren. On the fourth level they are displaced by the Conger vein.

As shown in cross section (pl. 9), the vein pattern in the Conger mine suggests a group of tension fractures between the Conger and Jumbo fissures. Other westward-dipping tension fractures of the series represented by the Pratt Freak, "209," and Watchman veins might be expected below the Watchman vein if the Jumbo vein zone persists downward, but the two flat holes 85 and 105 ft long drilled eastward from the Watchman vein on the fifth level (pl. 9) were not long enough to reach the next lower fracture zone if one exists.

MINERALOGY

Much of the ore in the Conger and Middle veins is ferberite and quartz that fills a breccia of country rock and early horn quartz fragments. The ore in many of the minor veins is a streak of pure ferberite which in many places is accompanied by streaks of horn quartz. So-called "peanut ore," which consists of scattered small fragments of rock and horn in ferberite, is abundant locally. The ferberite of the Conger mine occurs in relatively pure form, and although it may be accompanied by horn quartz, it is not extensively intergrown with the quartz. Most of it is crystalline and medium-grained, but some late, coarsely crystalline ore is found in vugs. A little pyrite accompanies the ore in many places, and pyrite is disseminated in the sericitized wall rocks. Some dickite, siderite, and marcasite and rarely a little galena occur with the ore. Late opal and accompanying gray and brown horn quartz are found in minor quantity at many places.

The Conger mine is in the footwall of a strong and distinctively mineralized shear zone which lies about 300 ft east of the New shaft (pl. 9). This zone is 40 to 50 ft wide, trends a little east of north, about parallel to the Conger vein, and dips 60°–65° E. It is known to extend from the vicinity of the Grayback shaft northward for about 1,500 ft to a point opposite the New shaft of the Conger, and it may continue farther. It has not been traced south of the Grayback shaft, but mineralization characteristic of the shear zone is present on eastward-trending fractures near the Grayback. The shear zone has been cut in many drill holes both from the surface and underground in the Conger and Grayback mines. It contains abundant sulfides and some graphite and is cut by horn veins that contain a trace of tungsten (p. 53). The shear zone has not been tested as a possible source of base metals, but the size of the zone and the local abundance of sulfide minerals make thorough sampling desirable.

ORE SHOOTS

The ore shoots are associated with competent wall rocks and with changes in course and dip that favored opening of the vein. In general, steep dips seem to have been more important in localizing ore than changes in course, but the distribution of ore along the Conger vein shows a close relationship to a more easterly course. Schist and gneiss are the wall rocks least favorable to the localization of ore, and pegmatite or alaskite forms the walls of the widest ore body along the Conger and Middle veins. The Jumbo and Watchman veins, on the contrary, carry better ore in granite than in pegmatite. As in the adjacent Bedding mine, some ore was localized where veins cut large dikes of monzonite porphyry. The first stope north of the New shaft on the third and fourth levels is localized between walls of porphyry, and the stope north of the shaft on the sixth level is probably at the intersection of the vein and a large porphyry dike.

As shown in plate 9, two large ore shoots were found in the Conger mine, one on the Conger vein and one on the Middle vein. Smaller shoots also were found on these veins, as well as on the several branching veins. The main ore shoot on the Conger vein had an average stope length of about 400 ft in the Conger mine, and the south end of the upper part of the shoot was also worked in the old Oregon mine. The ore was several feet wide in places, and many small gash veins in the footwall were filled with ore. The shoot was stoped almost continuously from the surface down to a point within a few feet of the sixth level, a vertical depth of about 550 ft. However, there was a constriction in the shoot between the second and intermediate levels. This largely barren zone is said to coincide with a strip of schist wall rocks, and for a time the bottom of the shaft was within this barren zone. When the Old shaft was finally sunk through the schist, rich ore was found again and continued downward for almost 300 ft. On the third level the ore shoot did not extend north of the junction with the Middle vein, but on the other levels irregular arms of thinner ore extended northward as much as 200 ft from the junction. This extensive ore shoot, the largest in the tungsten district, accounted for the large production prior to 1914, and Hershey reported that most of it was mined out by that time.

Another important source of early output was a relatively small ore shoot on the Conger vein about opposite the New shaft on the second level. This ore was the richest found in the mine. It formed a shoot about 175 ft long, 50 ft high, and 8 to 16 ft wide. It bottomed abruptly a short distance below the level and was cut off with equal sharpness under a gently dipping cross fracture at the top of the stope.

The main ore shoot on the Middle vein extended northward for 250 to 300 ft from the junction with the Conger vein. This was a blind ore shoot and was stoped from about 80 ft below the surface down to the fifth level, a vertical distance of almost 400 ft. There is also a small stope below the fifth level, but the early description and maps do not indicate clearly whether the stope is on the Conger or Middle vein. It may be on both.

A relatively large ore shoot on the Middle vein north of the New shaft plunged south at about 50° and was stoped through a pitch length of more than 400 ft, from a point just below the surface down almost to the sixth level. This shoot was a major source of ore during the last few years of the Primos Co.'s operation, but the upper part was mined earlier through old surface workings of which little is known. The ore mined from the shoot in 1918 averaged 3 to 4 percent WO_3, and pillars left on the fourth level show a vein of horn quartz and breccia 6 to 15 in. wide seamed and filled by ferberite having a total thickness of 2 to 6 in.

All the ore shoots weakened where the veins flattened below the fifth level, and practically no stoping was done below the sixth level. The flattening in dip, rather than excessive depth, was evidently the reason for the bottoming of the ore. On the sixth level, according to Hershey, the vein contained seams of horny ferberite and small lenses of "peanut ore" for a distance of 60 ft beginning 120 ft south of the New shaft, but from there southward for 700 ft to the end of the drift it was gougy, with local patches of breccia seamed by light-colored horn quartz.

The character of the vein in the winze workings below the seventh level is of considerable interest because these are the deepest workings in the district, but unfortunately there are no reliable descriptions available except a note of Hershey's concerning the eleventh level. The vein has been variously described by men who claim familiarity with the Conger as "all talc" (gouge), "all horn," and "all sulfide," and the only point of agreeement is that it is wide and strong. Hershey, however, described the eleventh level in a letter to the Primos Co. in August 1916, and as the dip of the vein is uniform at 55° throughout the length of the winze, his description is possibly applicable to the entire winze workings. He wrote:

The Conger 11th level has been driven north from the winze 140 feet on the vein to near the face. The vein is chiefly gouge, there being just enough barren quartz to identify it as the vein instead of a post-mineral fault gouge. There is no ferberite except possibly a trace on a branch at the face. The rock is chiefly gray granite, with a little pegmatite and dyke rock near the face. The drift south is 150 feet on the vein, dipping 50 to 55, chiefly gouge, with enough thin black quartz lenses to identify the vein, but no ore. It is in pegmatite, with some gray granite, usually favorable formations. The great increase of the gouge and corresponding great decrease of even barren quartz, the absence of any known vein nearby on the east that might unite with the Conger vein at reasonable depth and make an ore body, and the passing of a high market price for concentrate, combine to warrant the recommendation to quit downward development of the Conger mine.

SUGGESTIONS FOR PROSPECTING

Down to the fourth level the Conger has been explored more thoroughly and systematically than most of the tungsten mines, but a few prospects still remain. Further exploration below the fourth level is probably out of the question because the workings are filled with mill slimes, but if these workings ever should be reopened, prospecting in both walls would be justified by the results achieved higher in the mine. The hanging, or east, wall of the Conger and Middle veins has been thoroughly prospected above the third level and south of the New shaft on the fourth level, but the footwall side seems worthy of further prospecting, especially below the third level and north of the New shaft. An ore-bearing vein in the footwall north of the shaft on the fourth level was explored for only about 60 ft. This may be the united Conger and Beddig vein. If so, a 400-ft segment of it, which is probably in granite and pegmatite, is unexplored. If this vein is not the Conger, then the Conger also must lie out in the west wall. Exploration eastward from the drift north of the shaft also is warranted because several small veins branch into the east wall, and experience with the productive veins in the east wall farther south showed that they were almost imperceptible near their junctions with the Conger vein. Further exploration northward also is desirable. The vein approaches schist in this direction, but the schist is seamed by large dikes of aplite and pegmatite, and rich ore has been found in surface workings where veins of the Conger system cross the dikes. The veins also turn to a more easterly course, and as the east walls of the veins moved south, this course is favorable to the formation of openings and thus to the deposition or ore. Exploration of the strong vertical vein in the footwall of the Beddig vein below the third level of the Conger is warranted, but as this vein is on property under different ownership from the Conger ground, the work has never been done.

CROW NO. 4 MINE

Little is known of the Crow No. 4 mine except that it was an important producer during the early days of tungsten mining.

The mine, which is on the Crow patent of the Colorado Tungsten Corp., is on the north side of Sherwood Gulch about half a mile northeast of the Conger mine and 1.2 miles north-northwest of Nederland (pl. 5). The known workings are shown in figure 75. The mine comprises a rather flat inclined shaft, reaching a depth of 233 ft on the incline or 170 ft vertically, and five levels at depths of 48, 94, 140, 180, and 222 ft on the incline or 38, 73, 108, 133, and 162 ft vertically.

Most of the production probably took place before 1907. Figure 75, which is a reproduction of a section dated October 1907, shows that the vein had been extensively stoped by that time. In a report to the Primos Chemical Co. in 1914, O. H. Hershey credited the No. 4 mine with an output of 200 tons of 60-percent concentrates. The Primos Co. credited the mine with an output of 1,116 tons of mill ore and 1.15 tons of "high grade" from the end of 1915 to October 31, 1918. The grade and source of this ore are not known. The mine has not been operated since 1918.

The total output from the Crow No. 4 mine is probably at least 15,000 units of WO_3, and it may be considerably greater.

The rocks at the surface are schist and small dikes of pegmatite that follow the foliation of the schist (pl. 5). The mine is probably in schist, injection gneiss, and pegmatite. The vein strikes N. 50° E. and dips about 50° SE. A section through the shaft shows a dip of 51° from the surface to the third level, 38° from the third to the fourth level, and 46° from the fourth to the fifth level. If the section is drawn accurately, the width of the vein would seem to be 2 to 4 ft. A steep vein that splits into the footwall on the third level was evidently ore bearing, and a wide body of ore was mined along the line of junction with the main vein. The workings shown in figure 75 and notes on an old map indicate that a northward-striking vein which dips steeply east crosses the Crow No. 4 vein east of the shaft on all levels. This vein was stoped through a length of about 100 ft from above the second level down at least to the fourth level. One map shows another northward-striking vein crossing the Crow vein 60 ft west of the shaft on the third level. Judging by the absence of drifts, the long crosscuts to the northwest and southeast on the second level, which were evidently driven by the Primos Co. after 1915, did not cut any productive veins.

The ferberite in the Crow No. 4 mine was fairly

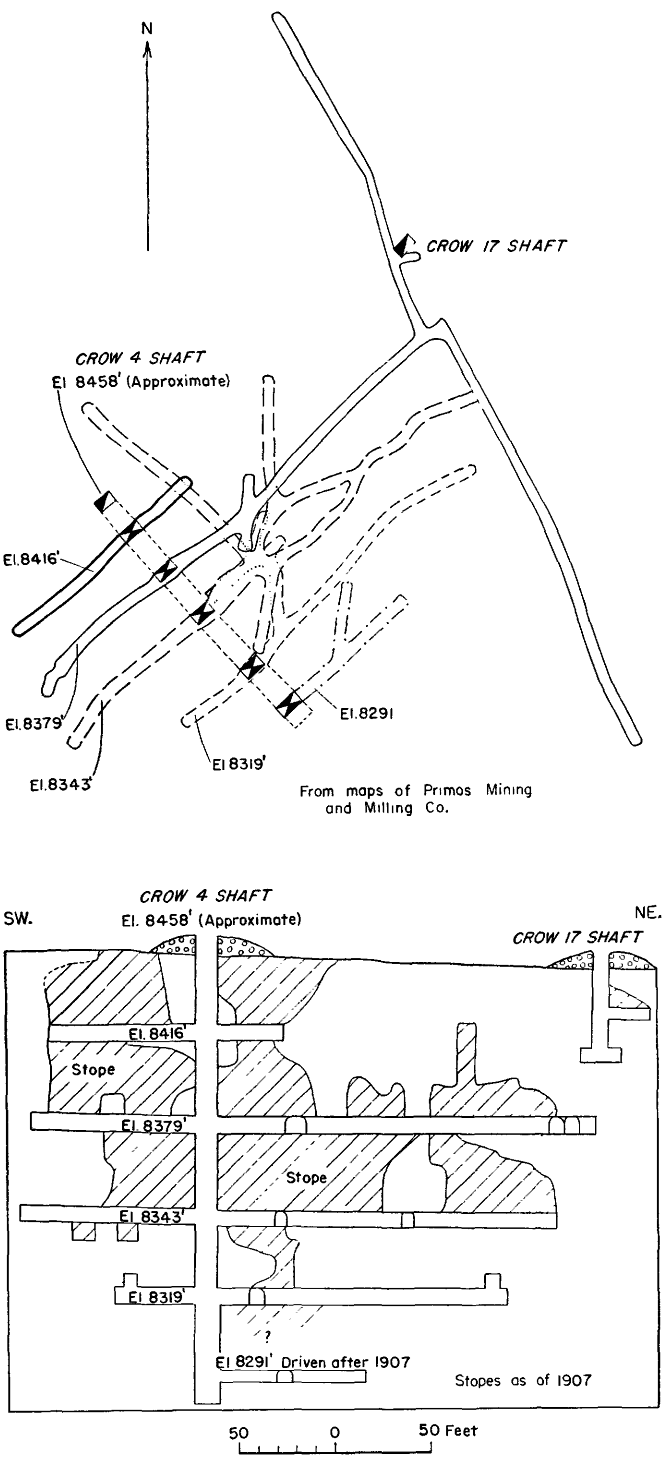


FIGURE 75.—Plan and section of the Crow No. 4 mine, Boulder County, Colo.

coarsely crystalline, and the ore is said to have been relatively free of quartz. As inferred from data given by Hershey, the ore produced prior to 1914 must have averaged at least 12 percent WO_3.

CROW NO. 18 MINE

The Crow No. 18 mine is in Sherwood Gulch a few hundred feet west of the hairpin turn where the Nederland-Ward road crosses the gulch (pl. 5). The shaft and most of the upper workings are on the Crow patent, which is owned by the Colorado Tungsten Corp., and the lower workings are chiefly on the property of the Vanadium Corp. of America, as shown in plate 11. The inclined shaft has a uniform dip of 64° NW. and reaches a vertical depth of 254 ft. Three levels at vertical depths of 123, 167, and 254 ft are turned from the shaft as indicated in plate 11, and a short sublevel, the winze level, is 38 ft below the second level. An old shaft and an upper level that was about 85 ft below the collar of the present shaft are shown, but these workings were evidently inaccessible as early as 1916.

The early production, which came from above the present first level, was apparently not large. In a report to the Primos Co. in 1914, O. H. Hershey credited the No. 18 mine with an output of 12 tons of 60-percent concentrates. The mine was operated by the Primos Co. from 1916 to the end of 1918, when the major part of its output was achieved. At this time 3,574 tons of ore averaging about 3 percent WO_3, or about 10,700 units of WO_3, was produced. The mine was under water from the end of 1918 to 1943, when it was reopened by J. D. and W. L. MacKenzie. These operators sank the shaft from the second to the third level and found an excellent body of ore below the old winze level. Almost 3,000 units of WO_3 in ore averaging about 3.50 percent WO_3 was produced by the summer of 1944, when the mine closed because of the fall in the price of tungsten.

The total output from the No. 18 mine appears to be 14,000 to 15,000 units of WO_3. An additional output that probably amounts to 2,000 or 3,000 units came from shallow shafts, trenches, and float "beds" in the immediate vicinity of the No. 18 shaft. As shown in plate 5, there are numerous veins near the No. 18 mine and along the north side of Sherwood Gulch in general. Most of these veins are small and short, but many of them contained pockets of high-grade ore where they cross aplite and pegmatite dikes at the surface. These small deposits and the surrounding float "beds" have been exploited by countless one- or two-man "leaser" operations. Although the tonnage from individual operations was low, the grade was generally high, and the collective importance of these minor enterprises is shown by the fact that in 1 year the Primos mill purchased from lessees a total of 25,000 units of WO_3 in small lots of ore that averaged about 15 percent WO_3. Two shallow shafts which are near enough to the No. 18 mine that their production could be credited to it are good examples of these small operations. One shaft produced 2.65 tons of ore averaging 37.13 percent WO_3, or 98.4 units, in a year; the

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other shaft produced 14.14 tons of 34.54-percent ore, or 488.5 units, at intervals during 4 years.

The area north of Sherwood Gulch consists largely of Idaho Springs schist which is intruded by many aplite and pegmatite dikes that trend north-northwest parallel to the foliation of the schist. Most of the aplite is gneissic, but some is massive. Much of the schist is intimately injected by aplite and pegmatite, and even the larger bodies of these intrusive rocks are contaminated by abundant inclusions of schist. The Crow No. 18 mine is mostly in such rock. A few of the larger masses of schist are distinguished in plate 11, but as it is impracticable to map the countless variations between schist and aplite, most of the wall rock is shown as gneissic aplite with schist inclusions.

The No. 18 vein is in reality a vein zone that consists of several overlapping and branching veins. This zone strikes about N. 30° E. on the upper levels but turns to about N. 45° E. at depth. It dips about 65° NW., but the individual fractures dip 55° to vertically or even steeply southeast. In general, one main ore-bearing vein can be traced down to the second level, but on the winze level, 38 ft lower, the identity of individual veins is lost in a broad shattered zone, and below that most of the ore was on veins dipping almost vertically or steeply south. The displacement along the main vein zone could not be determined with certainty. There is some suggestion that the northwest, or hanging, wall moved down and slightly southwest in the upper part of the mine, but on the third level the southeast wall of the main ore-bearing vein moved down and southwest at an angle of 45°.

The Footwall vein, which strikes east-northeast and dips almost vertically, joins the No. 18 vein at the shaft on the first level and a few feet west of the shaft on the second level. It was stoped extensively above the first level and between the first and second levels. A strong horn vein at the south end of the first level strikes parallel to the Footwall vein but dips 43°–65° N., and on the second level these two veins are only a few feet apart (pl. 11). Several northwestward trending fractures that contain hematite and belong to the breccia-reef stage of fracturing are distinguished as barren faults in plate 11. A persistent gougy fracture that strikes east-northeast and dips 40°–47° N. also is included in this group because it is consistently barren and because the tungsten-bearing veins end against it or are faulted by it. This fault is exposed 25 ft north of the shaft on the first level and at the north end of the second level; it can be seen at the top of a stope alongside the shaft about 30 ft above the first level. As shown in plate 11, this fault exercised an important control on ore deposition; ore is localized in the steep veins immediately under the fault.

Most of the ore in the No. 18 mine was in a long slender ore shoot that plunged north at about 50°. The ore in this shoot was not all on a single fissure, but the various overlapping ore-bearing fissures are all in the same vein zone. In the upper part of the mine the upper, or northeast, edge of the shoot is plainly defined by the flat fault, and there is some suggestion that the intersection of an east-northeastward-trending horn vein with the main vein zone influenced the location of the lower, or southwest, edge (pl. 11). The most productive parts of the shoot were in wide shattered zones that were stoped to a width many times that of the rest of the vein. Such zones occur where veins intersect in relatively pure, or schist-free, aplite. At the intersection of the Footwall and No. 18 veins on the first level, numerous ferberite veinlets extended from the veins into the shattered walls, and ore was stoped to a width of as much as 25 ft near the intersection. On the winze level ore was mined through an average width of about 15 ft in shattered aplite at the junction of several veins within the No. 18 vein zone. The winze produced 1,732 tons of ore averaging 3.50 percent WO_3 in 1917–18, and the 1943–44 production came from the downward extension of this body.

The ferberite in the No. 18 mine is mostly compact and finely crystalline, but some is coarse and vuggy. Most of it is accompanied by veins of gray to black horn quartz, and some occurs as a filling in horn breccia. In parts of the ore body on the third level, the vein was a streak of pure ferberite 4 to 6 in. wide between walls of sericitized aplite, but some of the ore on the winze level just above this was quite horny. Scheelite is a fairly abundant accessory constituent of the ferberite veins. It occurs chiefly as impure replacement veinlets in sericitized aplite within the veins. It is invariably accompanied by a little ferberite, and it occurs to a minor extent as a coating on ferberite crystals in vugs. Scheelite was present in most of the ore mined in 1943–44, and possibly a tenth of the total tungsten content was in the form of scheelite. Pyrite is present in minor quantity throughout the mine. It forms disseminated grains in sericitized aplite adjacent to the veins and occurs sparingly within the veins whether ferberite is present or absent. Much of the hematite in the northwestward-trending fractures has been replaced by pyrite, presumably at the time of the tungsten mineralization.

Although the No. 18 mine is small and fairly shallow, it has achieved a substantial output and seems worthy of further exploration and development. The individual fractures may weaken abruptly or play out, but the vein zone as a whole seems strong and persistent. Exploration below the ore body mined on the third level is warranted by the persistence of good ore in one fissure or another from the surface down to that level. The ore on the third level was mined to a depth of 18 or 20 ft in an underhand stope, and it is said that only a few feeders were present at the bottom of the stope, but the numerous veins on the third level and the "jumping" of ore from one vein to another observed higher in the mine suggests that ore may exist on a parallel vein below the third level. The distribution of the ore below the second level emphasizes the need for crosscutting in exploring wide vein zones of this type, and as the vein zone seems to be widening downward, exploration at greater depth should include extensive crosscuts.

The productive Footwall vein has not been explored below the second level. It probably joins the southern vein, which trends east-northeast, just below the level (pl. 11), and although the structure below the junction can hardly be anticipated, one of the two veins may be expected to persist downward and should be worth exploration.

Exploration is also warranted on the north side of the flat fault. The abrupt ending of the ore against the flat fault and the weakness of the only vein in the drift northeast of the fault on the first level suggest a possibility that the No. 18 vein is displaced and that the weak vein in the drift is not the main vein. If this is true, the displaced segment must lie east of the drift north of the fault, for it is obviously absent in the crosscut west of the drift. The relation of the vein and the ore to the fault is similar to that found in the Sunday mine, where ore was found in the steep Sunday vein both above and below a relatively flat premineral fault that displaces the vein.

LONE TREE MINE

The Lone Tree mine is on the north side of Sherwood Gulch, about 1,700 ft east of the hairpin turn where the Nederland-Ward road enters the gulch (pl. 5). It was owned and operated by the Primos Mining & Milling Co. during its most productive years, but it is now owned by the Vanadium Corp. of America. The mine was one of the most important producers in the district from about 1907 to 1912, but the main ore body was worked out at that time and since then the output has been small. According to a report made by O. H. Hershey to the Primos Co. in 1914, the Lone Tree produced 4,000 tons of ore that averaged about 10 percent WO_3, or 40,000 units of WO_3. This ore was valued at $40 per ton, making a gross production of $160,000. The mine was closed in 1913. It was reopened in 1916–17 and was worked near the surface at times after that, but the output since 1913 appears to have been small.

Maps made in 1910 and 1916 show four levels, but Hershey states that two levels were driven below the ore, which bottomed a short distance below the third level. Apparently the fifth level was not accessible in 1916. The shaft dips 69½° NW. The four levels shown on the maps are at depths of 44, 113, 215, and 286 ft on the incline, and according to Hershey the fifth level is at a depth of about 350 ft. The known workings are shown in figure 76.

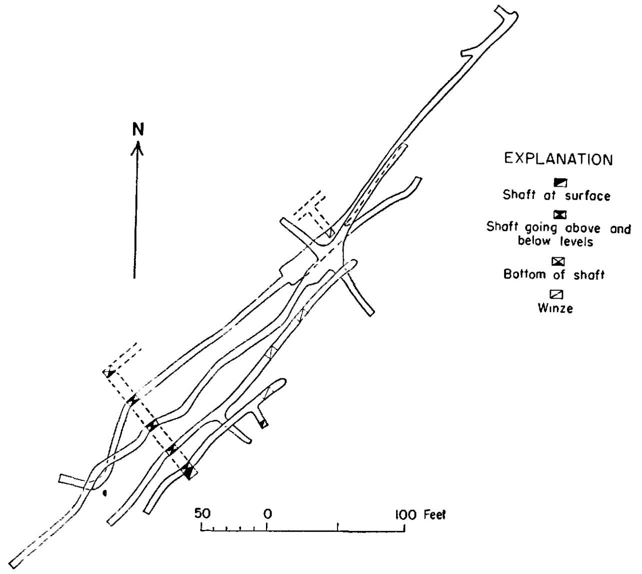


FIGURE 76.—Workings of the Lone Tree mine, Boulder County, Colo., in 1916.

As shown on the surface map (pl. 5), a small body of granite lies west of the schist at the Lone Tree shaft. The granite contact dips east, and the ore shoot, which raked northeast, probably followed the contact down. The Lone Tree vein strikes northeast and dips about 70° NW. It is joined at the shaft by a hanging-wall vein that strikes N. 70° E. and dips 80° S. This vein was ore bearing at the surface and was exploited by a shallow tunnel, but the mine map does not indicate that it was worked at depth. According to Hershey, the main Lone Tree ore shoot was 175 ft long at the surface and on the "40-ft" (44-ft) level, 150 ft long on the "140-ft" (113-ft?) level, and 80 ft long on the "220-ft" (215-ft) level. It bottomed at about 250 ft. Hershey says the two lower levels "yielded small streaks of ore and some mill dirt."

RAKE-OFF MINE AND LILY TUNNEL

The Rake-off mine and Lily tunnel are at the turn in Sherwood Gulch 1½ miles northeast of Nederland (pl. 5). The Rake-off mine is just west of the section line that marks the east edge of the Boulder County Ranch, an agricultural patent owned by the Vanadium Corp. of America. The Lily tunnel is on a claim, owned by the Wolf Tongue Mining Co., just east of the section line (fig. 77). The two mines are in the

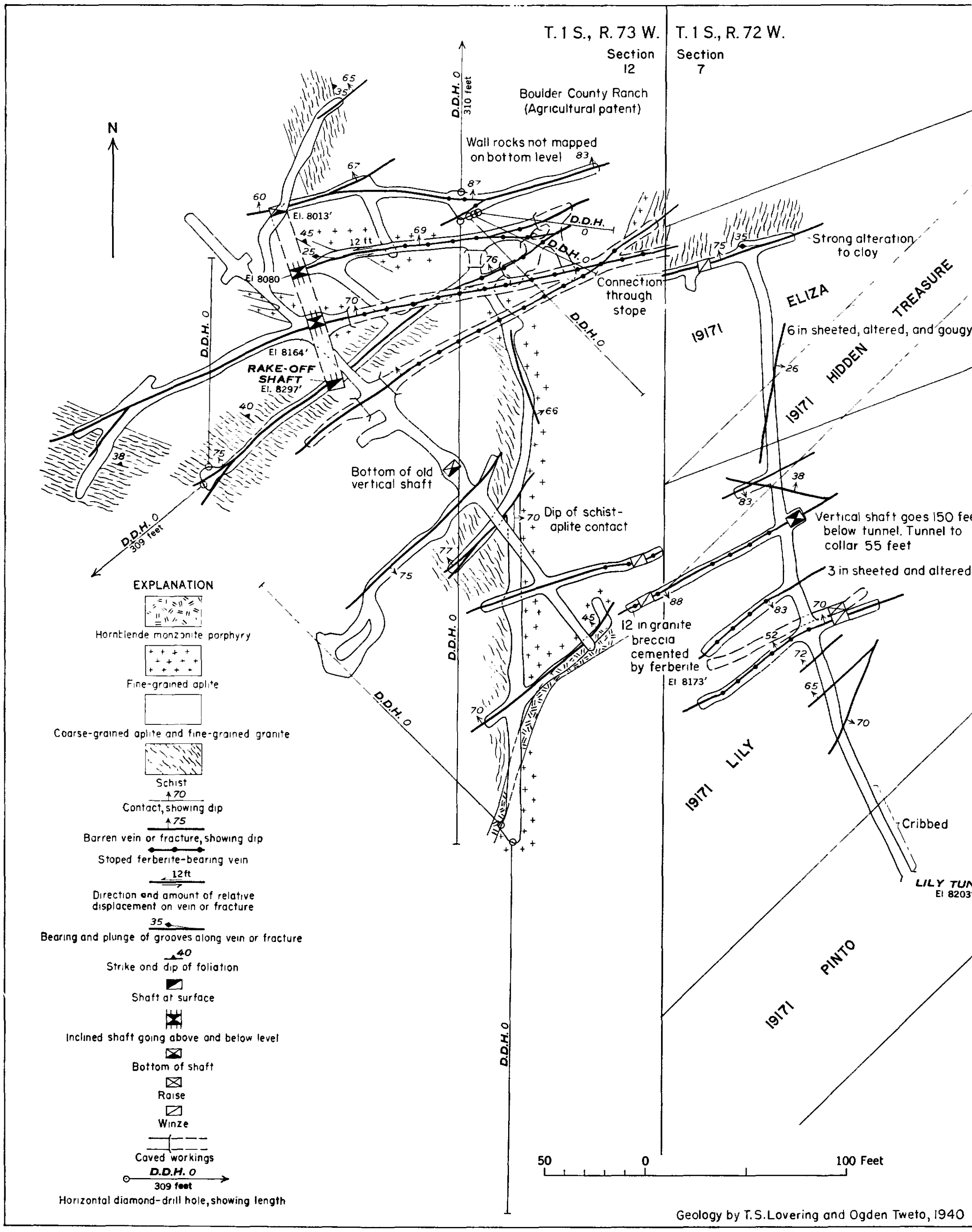


FIGURE 77.—Geologic sketch plan of the Rake-off mine and Lily tunnel, Boulder County, Colo.

midst of several veins (pl. 5). The original Rake-off workings were on two intersecting veins about 100 ft south of what is now regarded as the main Rake-off vein. They were opened by a tunnel and a vertical shaft that bottomed on what is now the first level. Exploration on this level led to the discovery of ore on the main Rake-off vein and a branch vein, which were developed by the inclined shaft and workings shown in figure 77. The main vein was also reached by the Lily tunnel, but the production from the tunnel came chiefly from veins in the southern group.

The present Rake-off workings comprise a northward-sloping shaft, whose collar is at an altitude of 8,297 ft, and three levels at vertical depths of 133, 217, and 284 ft. The portal of the Lily tunnel is at an altitude of 8,203 ft, about 40 ft above the first level of the Rake-off.

The total production from the Rake-off is not known, but it must have been fairly large. The known output from such relatively minor sources as the Lily tunnel, some of the old Rake-off workings, and minor veins worked on the first level and near the surface at times from 1923 to 1944 totals approximately 10,000 units of WO_3, and the output from the main Rake-off ore bodies was presumably at least as great. The mine was operated by the Primos Mining & Milling Co. until about 1915. The production came from the old workings, and according to Hershey's report to the Primos Co., the output to June 1914 amounted to 450 tons of ore averaging 7 or 8 percent WO_3. The mine was apparently operated by lessees from 1915 to 1918, when the main Rake-off ore shoot was mined. It was unwatered in 1939 by the Vanadium Corp., and considerable cross-cutting and diamond drilling was done, but the only new ore found was one small shoot on a vein southeast of the shaft on the first level.

Except for the Lily tunnel, which was mapped earlier by Lovering, the Rake-off was mapped hurriedly by the writers during a brief visit just before the mine closed in 1940, and only the general features of the geology are shown in figure 77.

The Rake-off mine is at the north end of a "thumb" of relatively coarse-grained aplite that extends southward for more than a mile between the Boulder Creek batholith to the east and the extensive schist area to the west (pl. 5). In the mine an irregular mass of fine-grained aplite separates the schist from the coarser aplite in most places. The contact of the aplite and schist strikes north and dips about 70° E. on the 200-ft level, but it flattens above the level. A crosscut on the second level follows the contact of the schist and aplite 250 ft to the south and cuts a dike of hornblende monzonite porphyry about 50 ft from the breast. The dike is also exposed in a drift that branches from the crosscut and follows a small northeastward-striking vein. The dike maintains a north-northeasterly course until it reaches the northeastward-striking vein, which it then follows. The dike was not seen in the nearby workings of the Lily tunnel and does not break through to the surface. It is probably an apophysis of an eastward-trending dike of similar porphyry that crops out close to the road near the portal of the Lily tunnel.

The Rake-off vein strikes N. 80° E. and dips 65°–75° N. A little more than 100 ft east of the shaft it crosses an ore-bearing vein that strikes N. 55° E. and dips steeply northwest. Most of the ore was found on the two veins west of this intersection and east of the schist area. The best ore was found between aplite walls, but excellent ore was found where only one wall was aplite. Where both walls were schist, the vein was barren. Only a short segment of the vein carried ore on the third level, even at the junction. The north wall of the Rake-off vein moved down and west at an angle of 25° to 40°, and the net displacement was 12 ft.

Several nonpersistent echelon fractures are cut by the Lily tunnel and the southern part of the Rake-off workings. The original Rake-off tunnel was on a vein of this group. According to Hershey, the tunnel began in an open-cut made in stoping an ore body about 75 ft long and 1 ft wide, which assayed 7 to 8 percent WO_3. In the tunnel, about 55 ft to the northeast, another ore body was found which extended for 60 ft to the old shaft. The vein contained 12 in. of ore that assayed about 12 percent WO_3. The ore was in fine-grained granite, and it pinched out 15 to 18 ft above the tunnel, where the granite gave way to schist. The vein worked in the old tunnel is barren on the first level of the new workings, where it is followed by a drift that lies a few feet south of the old vertical shaft (fig. 77) and is probably in schist. In 1940 a narrow shoot of high-grade ferberite was found on a vein 55 ft farther south, or 170 ft southeast of the main shaft. This vein was not found on the second level.

Most of the production from the Lily tunnel came from two veins cut at distances of 130 and 185 ft from the portal. Both veins strike northeast. The first dips 50°–70° NW., and the second is nearly vertical. Both veins lie between highly argillized walls of coarse-grained aplite. The ore consists of brecciated granite cemented by horn quartz bearing moderately coarse-grained ferberite. Although small, the veins were relatively rich. The 131 tons of ore produced from the Lily averaged 25.51 percent WO_3.

The Rake-off vein is barren where it is cut by the Lily tunnel. Schist forms the north wall, and altered coarse-grained aplite the south. The aplite is strongly altered close to the vein. Analyses of the fresh and sericitized aplite from the Lily tunnel are given on page 62.

CLYDE MINE

HISTORY AND WORKINGS

The Clyde mine is on the south side of Sherwood Gulch about 1½ miles northeast of Nederland (pl. 5). It was operated more or less continuously by the Wolf Tongue Mining Co., its owner, from 1907 to 1929 and was one of the most productive mines in the district during this period. Only minor work at the surface and on the dump has been done since 1929. The mine has produced about 28,000 units of WO_3 in approximately 8,000 tons of ore that averaged about 3.5 percent WO_3.

As shown in plate 12, the mine is opened by an adit, an inclined shaft from the surface, and an underground shaft with its collar on the adit or tunnel level. The surface shaft follows the main Clyde vein and connects with levels at vertical distances of 38, 83, 211, and 253 ft below the collar. The third level is the adit level. The inclined underground shaft has its collar 52 ft east of the third station on the surface shaft and was sunk on the Footwall vein. From it the fourth, fifth, sixth, and seventh levels were turned at depths of 253, 330, 405, and 503 ft below the surface. In 1930 only the tunnel level was accessible, but a map of the entire mine was available and is shown in plate 12. The total length of drifts and crosscuts is 4,725 ft.

COUNTRY ROCK AND ROCK ALTERATION

The country rock above the fourth level is coarse-grained aplite or fine-grained granite cut by alaskite, fine-grained aplite, and pegmatite. Below the fourth level schist was found in the eastern part of the workings, and in each succeeding level it was found west of its position on the level above. From information given by the late Will Todd, one-time superintendent of the Wolf Tongue mines, it seems probable that the schist-granite contact dips about 32° W., below the fourth level and has a much gentler dip above it (pl. 12).

The aplite and granite are strongly silicified and sericitized for a distance of about 50 ft between the Clyde and the Footwall veins on the tunnel level. The unusually great width of this zone is caused by the presence of innumerable small fractures connecting the two veins. On the south side of the Footwall vein the sericitized zone is thin, and the granite beyond it is bleached and soft and argillized. Where the vein is in plagioclase-poor rocks such as the alaskite and aplite, both the sericitic and the argillized zones are only weakly developed.

MINERALOGY

In addition to the ferberite and quartz, veins of the Clyde mine contain some less common minerals. This is one of the very few places where molybdenite was observed, and it is one of the relatively few mines where tetrahedrite was found associated with ferberite. The molybdenite occurred in thin vertical seams in the footwall of the Footwall vein, and its relation to the ore could not be determined. The tetrahedrite was found associated with pyrite and barite at the top of a blind ore shoot on the Footwall vein. All three minerals were later than the ferberite. Above the blind ore shoot, the vein filling consists of several generations of horn cut by a seam of open, friable breccia which is loosely cemented with fine-grained quartz. Barite crystals are abundant in crevices in the breccia and are partly coated with beidellite and other clay minerals and with cencentrically layered opal. Pyrite occurs in thin veinlets and is also disseminated through a late dark-gray horn quartz. A few tiny veinlets of marcasite also are present.

The top of the stope on the Footwall vein is marked by a network of iron-stained cracks, but most of the rock shows no supergene alteration. The iron stain probably reflects the local abundance of pyrite, which is now being attacked by ground water as a result of the active circulation caused by the mine opening. The water rising from a drill hole which tapped the vein about 175 ft below the tunnel level smells strongly of sulfur, and a black deposit of iron sulfide forms in the water near the hole but gives way to a brown deposit of ferric hydroxide at the edges of the stream.

Ferberite occurs as the matrix of a horn breccia, as veinlets in the quartz gangue, and to a small extent as rounded masses in a loosely cemented vein breccia. The vein filling outside the ore shoots is chiefly brecciated horn, cemented by later horn. Below the fourth level, the vein filling outside the ore shoots is said to be horn as far east as the schist contact and soft gouge beyond.

VEINS

The Clyde and the Footwall veins occupy overlapping fissures within a fault zone that predates mineralization. The Clyde vein was worked only from the surface down to the tunnel level, and the Footwall vein was worked from a sublevel 60 ft above the tunnel level down to the lowest level. The Clyde vein becomes stronger to the west with depth and dies out or "horsetails" to the east. It extends much farther east at the surface than on the tunnel level. It is well defined west of the surface shaft on the tunnel level, but in the main crosscut 100 ft to the east the only indication of its presence is a series of weak fractures in a broad sheeted zone on the strike of the vein. The Clyde vein strikes N. 70°–78° E. and dips 72°–78° N.

The Footwall vein strikes N. 50°–75° E., but its course is about N. 70° E. in the steep and productive part. Where the vein flattens, the course bends to the northeast. The Footwall vein is vertical on and above the tunnel level; below the tunnel it dips steeply north down to a line about 50 ft above the schist, where it flattens to about 50°. As the schist contact dips gently west, the flattening occurs at a shallower depth in the eastern part of the mine than in the western part.

The Footwall vein follows a premineral fault which has been reopened by many successive movements. The direction of early movement is shown by deep grooves on the granite and pegmatite walls and by the slicing and drag of pegmatite dikes as they reach the vein. The north wall moved west almost horizontally. Later movement is shown by interior faulting of the vein filling and by deep grooves on the earlier horn quartz vein filling. Most of the grooves plunge about 45° W., and the north wall at this time moved down and west. The amount of displacement is not known, but the early horizontal movement exceeded 25 ft, and judging from the reported position of the schist-granite contact on the foot- and hanging walls in the lower levels, the later movement must have been nearly twice as great. Along eastward-trending veins such as the Clyde and Footwall, such movement should tend to produce openings where the vein strikes northeast of its general course and where the dip is steeper than average.

The walls of the Clyde and Footwall veins were fractured in many places by the repeated movements along the fault zone, and many nonpersistent fractures diverge from the master fissures. Most of the minor fractures strike N. 50°–65° E., but a few in the south wall extend nearly parallel to the Footwall vein or diverge slightly east of it. Most of the minor fractures are marked by horn seams; a few contain ore, and others carry faces of molybdenite.

Several open cavernous fissures and fracture zones 1 to 12 in. wide are cut by the tunnel. Most of them trend east-northeast, but as shown by the map (pl. 12), their position cannot be foretold from their strike for more than a few feet. Although they are short and discontinuous individually, they apparently form part of an irregular but connected fracture system. When the open northwestward-trending sheeted zone 300 ft south of the portal was first cut, a heavy flow of water issued from it, and in a short time the Clyde shaft and the Hoosier shaft, 850 ft to the south, were completely drained. A little ferberite is present on one of the northeastward-trending open fissures 200 ft south of the portal, and near the Clyde vein a seam of horn is displaced by another, suggesting that the fractures were formed near the close of the period of mineralization.

The portal of the Clyde tunnel is above workings turned from the Gale shaft, as shown in plate 12, and the Gale vein was also explored for a short distance in the tunnel. It is a weak vein that breaks into discontinuous small fractures near the intersection with an eastward-trending vein in the Gale mine, but it was fairly productive. The vein becomes stronger to the southwest, and indications of it, or of overlapping veins, are found at the surface as far southwestward as the vicinity of the Phillip Extension and Hoosier mines. It evidently is a persistent vein zone, and its intersections with the Clyde and other eastward-trending veins seem worthy of exploration.

ORE SHOOTS

One ore shoot has been worked on the Clyde vein and two others on the Footwall vein. The shoot found on the Clyde vein extended from a line 10 ft below the surface to a depth of 95 ft, where, according to Will Todd, it ended abruptly on a gently dipping seam of reddish-black "graphite" (molybdenite and hematite?). The shoot was about 100 ft long, and some of the ore was 5 ft wide. At the surface the only indication of ore was a few narrow vertical seams of ferberite trending diagonally across the vein in a northeasterly direction. They passed through a northward-dipping seam of soft white clay, below which the ore was 4 to 6 ft wide and averaged 20 percent WO_3. The ore proved to be cut by these gently dipping seams of clay every few feet as it was followed down. The opening of the space filled by the ore was probably caused by movement on the northward-dipping minor fractures.

The ore shoot in the Footwall vein directly below the ore body of the Clyde vein was about 125 ft long and extended vertically downward 75 to 100 ft from a line about 200 ft below the surface. Its lower eastern tip joined the central part of a lower shoot that plunged about 30° W. (pl. 12). The ore in both shoots was 3 to 6 ft wide in many places, and near the upper end of the westward-plunging ore body it reached a maximum of 14 ft.

The two ore shoots were in the steeply dipping part of the vein, and the plunge of the lower shoot is related to the flattening of the vein. The shape of the lower ore shoot suggests that it was controlled by the tightening of the premineral normal fault where the dip flattened below and where it feathered out into the main Clyde vein above. The barren zone between the vertical ore shoot and the upper part of the plunging ore shoot shown in plate 12 has no obvious structural cause. As shown in figure 51, this part of the vein is more than 5 ft thick, with open spaces as much as a foot wide and several feet long. These openings are coated with chalcedony, quartz, barite, dickite, and beidellite, and some are reported to have a few thin faces of ferberite. This part of the vein may have been a dead space between two diverging streams of ferberite-depositing solutions, which ceased to carry tungsten before they completely filled all available space, but it is possible that the two ore shoots were formed at different times and represent the courses to different outlets.

SUGGESTIONS FOR PROSPECTING

The most obvious place to seek ore in the Clyde mine is along the western extension of the lower ore shoot on the seventh level. Ore was mined up to the property line by the Wolf Tongue Mining Co., but according to

Will Todd the diminished size and lower grade of the ore shoot at the side line suggested that the termination of the ore was not far away. However, the intersection of the Clyde and Gale veins should lie only a short distance west of the side line, and this might have localized ore. The westward plunge of the ore shoot carries it under an unexplored stretch of the vein about 200 ft in extent at the tunnel level (pl. 12). The presence of ore shoots above it near the underground shaft suggests the possibility of blind ore to the west of the present workings in either the Footwall vein or the main Clyde vein.

PHILLIP EXTENSION MINE

The Phillip Extension mine is at an altitude of 8,390 ft on the west flank of Hurricane Hill, about a mile northeast of Nederland. It is on the Crow patent of the Colorado Tungsten Corp., and early workings

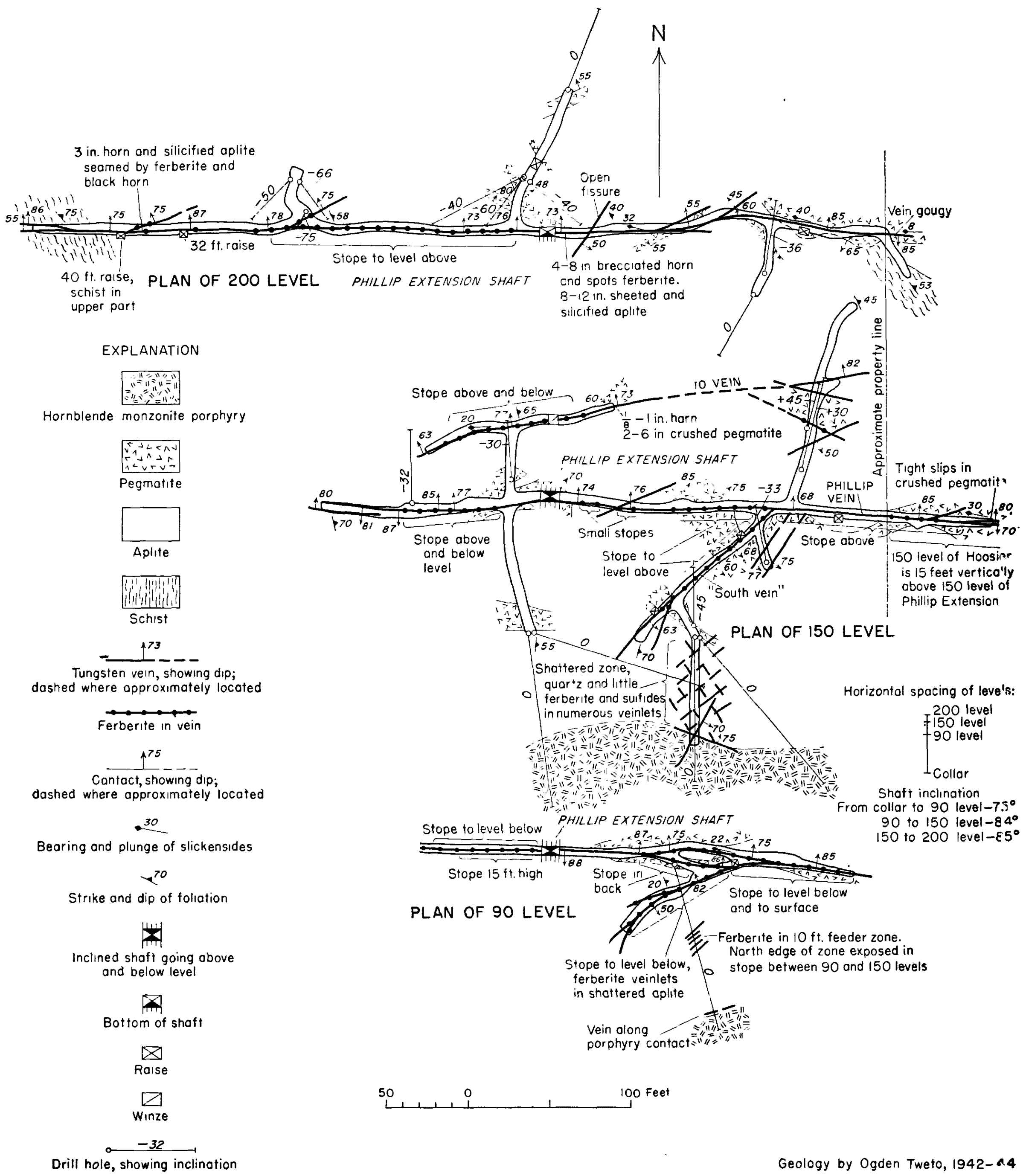


FIGURE 78.—Geologic plan of the Phillip Extension mine, Boulder County, Colo.

on the site were known as the Crow No. 10 mine. The Phillip Extension shaft was sunk about 1938 by Hollofield and Prime, who subleased the property from the Wolf Tongue Co. Thus the mine is relatively late, although some work on the site was done earlier in several shallow shafts and trenches. It comprises a steeply inclined shaft and three levels known as the 90-, 150-, and 200-ft levels (fig. 78). Hollofield and Prime worked the mine until 1944; Elmer Hetzer reopened it in 1945 and was still operating it early in 1946. The mine has produced about 12,000 units of WO_3 in recent years, and the production from the old surface workings might raise the total to 15,000 units. The ore shipped by Hollofield and Prime up to June 1943 averaged 6.79 percent WO_3.

The Phillip Extension mine is in aplite except at the ends of the 200-ft level, which are in schist. The aplite is cut by dikes of white to orange pegmatite, and the Phillip vein seems to follow a zone of discontinuous pegmatite bodies at the surface. A persistent eastward-trending dike of hornblende monzonite porphyry lies 130 ft south of the Phillip Extension shaft at the surface and has been cut in the southernmost mine workings and in several drill holes.

Wall-rock alteration is relatively weak along the Phillip vein, and much of the ore was between walls of fresh aplite. At places the walls are slightly argillized to a depth of a few inches, and in the eastern part of the mine they are sericitized and silicified.

The Phillip vein is at the north edge of a cluster of eastward-trending veins (pl. 5). Several veins that were productive at the surface branch from the Phillip vein, which follows one of the stronger fissures. The Phillip vein trends about east, but it has a sinuous course and the strike ranges from N. 70° E to S. 80° E. It dips 75°–85° N. at most places in the Phillip Extension mine, but through most of its length in the adjacent Hoosier mine it is a warped surface that dips steeply north in some places and steeply south in others. The Phillip vein is in aplite that is fractured or locally is strongly shattered, and it records several stages of movement, some of which were later than the ore, as shown by slickensided and gougy ferberite. Although grooves on the walls of the Phillip vein consistently plunge 20°–40° W., the hanging wall is displaced westward at some places and eastward at others. Similarly, the vein is a strong wide fissure zone at some places, but at others it is a mere crack that is barely distinguishable. During some of the periods of the recurrent slipping, the movement apparently shifted from the vein to minor fractures and shattered zones in the walls at places.

The South vein, a productive vein that joins the Phillip vein from the footwall, was well defined in the drift on the 150-ft level of the Extension mine, but it became indistinguishable in shattered rock in the stope above the level. It has not been identified on the 200-ft level. The No. 10 vein lies about 45 ft north of the Phillip vein on the 150-ft level. It strikes east-northeast and dips 60°–80° N. It was productive above and just below the 150-ft level but was never found on the 200-ft level. It evidently dies out eastward also, as the only fractures in the crosscut east of the shaft on the 150-ft level are very weak. The No. 10 vein is in about the right position to be the extension of the Hoosier vein (fig. 80), but the crosscut indicates that the two veins are separated by a zone of intersecting minor fractures.

The ferberite of the Phillip vein is noted for its purity. Most of it is soft, crystalline, and vuggy. It occurs as veinlets of pure ferberite in sheeted, shattered, or crushed rock or as thicker seams cutting horn breccia or interleaved with bands of horn. Ferberite lies against horn, and drusy ferberite crystals coat horn fragments, but very little of the ferberite is intergrown with horn. Much of the gray horn has a slightly greenish or pinkish cast. At some places lobes and tongues of horn extend into aplite, and some of the horn has clearly replaced aplite.

As shown in figure 79, three irregular ore shoots have been mined on the Phillip vein, one in the Phillip Extension mine, one in the Hoosier mine, and one shared by the two mines. The western shoot, just west of the Phillip Extension shaft, was blind and extended from the 90- to the 200-ft level except for a small prong at the west edge. A drill hole cut a little ore 15 ft below the level at this locality, but four other holes showed a very weak vein with no ore at depths of about 50 ft below the stope. The middle shoot was about 75 ft east of the Extension shaft and extended 175 ft eastward to the western part of the Hoosier mine. Its bottom was essentially at the 150-ft level of the Phillip Extension mine (19 ft below the 150-ft level of the Hoosier). There is no sign of ore on the 200-ft level below the ore shoot, and a raise from the 200-ft level did not strike ore until it was just below the floor of the 150-ft level. The location of the top of the shoot is not known to the writers, and it is possible that the vein was stoped to the surface. The eastern shoot was in the Hoosier mine.

The No. 10 vein contained one small ore shoot. The vein was stoped through a length of 75 ft on the 150-ft level and to a height of about 30 ft above the level. No ore shows in the back of the stope, but ore was mined to an unknown extent higher in the vein from the old Crow No. 10 shaft, which is now under the dump. The No. 10 vein cannot be distinguished on the 200-ft level, but two holes drilled down from the

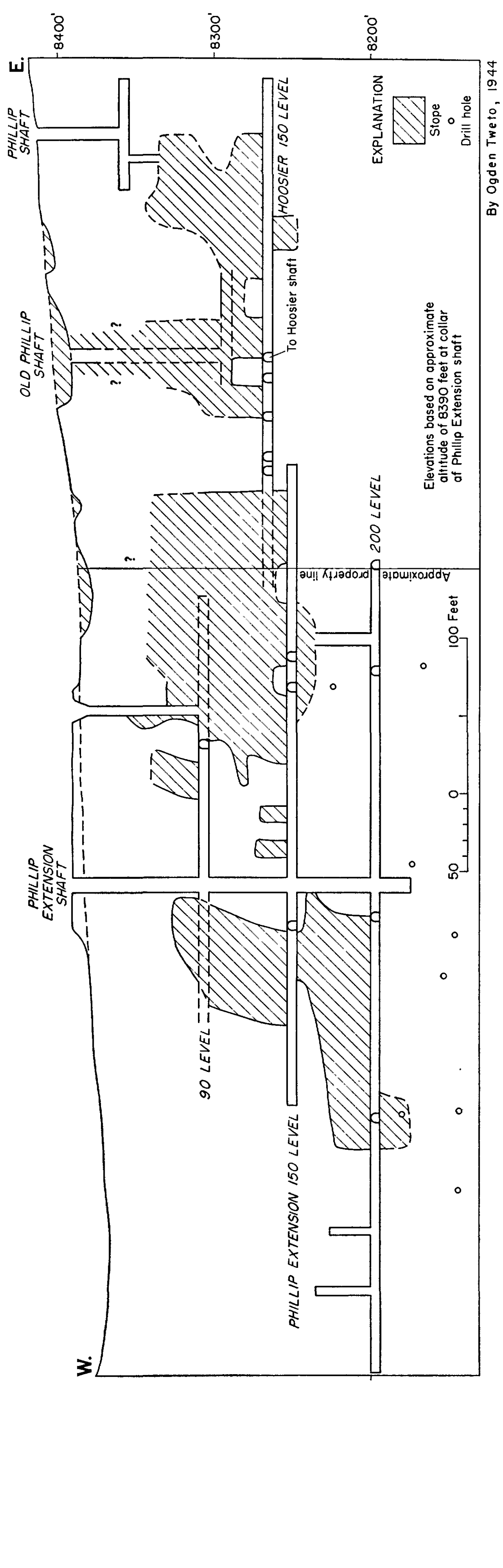


FIGURE 79.—Vertical projection of the Phillip vein, Boulder County, Colo., showing stopes and drill holes.

150-ft level showed some ferberite at a depth of about 25 ft, and some ore was mined below the level after a raise was put through from the crosscut on the 200-ft level. This ore is said to have been in feeders of soft crystalline ferberite in a shattered or sheeted zone that widened and died out downward.

The South vein was stoped through a length of 75 ft from the 150- up to the 90-ft level, and some underhand stoping was probably done below the 150-ft level before the mine closed in 1944. A short distance above the level the vein gave way to a broad shattered zone that contained many veinlets and discontinuous larger streaks of ferberite through widths of 5 to 10 ft. Ore in the shattered zone became leaner above the 90-ft level. Early in 1946 Hetzer was mining in a similar "feedered" zone that had been cut 25 ft southeast of the shattered zone of the South vein in a flat hole drilled from the 90-ft level (fig. 78). Several vertical feeders exposed in the hanging wall of the stope on the South vein about midway between the 150- and 90-ft levels probably represent the junction of this southeastern feeder zone with the South vein. Hetzer was also getting ore from a vein in the hanging wall of the Phillip vein on the 90-ft level in 1946.

The Phillip Extension is a relatively shallow mine, and its substantial output warrants exploration at greater depth. Holes drilled below the 200-ft level showed no ore and only a weak vein, but the very weakness of this vein in contrast to the fracturing and shattering characteristic of the Phillip Extension mine suggests that an overlapping fissure may be present at greater depth. The absence of the No. 10 vein on the 200-ft level, and of veins in holes drilled from the hanging-wall side, suggests that if such an overlap occurs, the lower vein is in the footwall, as it is in the nearby Clyde mine. Thus, if an intensive exploration campaign should be undertaken, investigation of the footwall of the Phillip vein below the 200-ft level should be considered. Several veins south of the Phillip Extension mine were ore-bearing at the surface but have not been explored at depth. These veins could be reached easily by drilling from the eastern part of the mine. The presence of ferberite on minor fractures and in shattered zones that contain no identifiable vein justifies further exploratory drilling in the vicinity of the Phillip Extension mine. Several holes were drilled by Hollofield and Prime and by the Bureau of Mines, and ore, especially in "feedered zones," was found in several holes, but all the holes were short and large areas remain unexplored.

HOOSIER MINE

The Hoosier shaft is at an altitude of about 8,410 ft on the west flank of Hurricane Hill, about 400 ft northeast of the Phillip Extension shaft (pl. 5). The

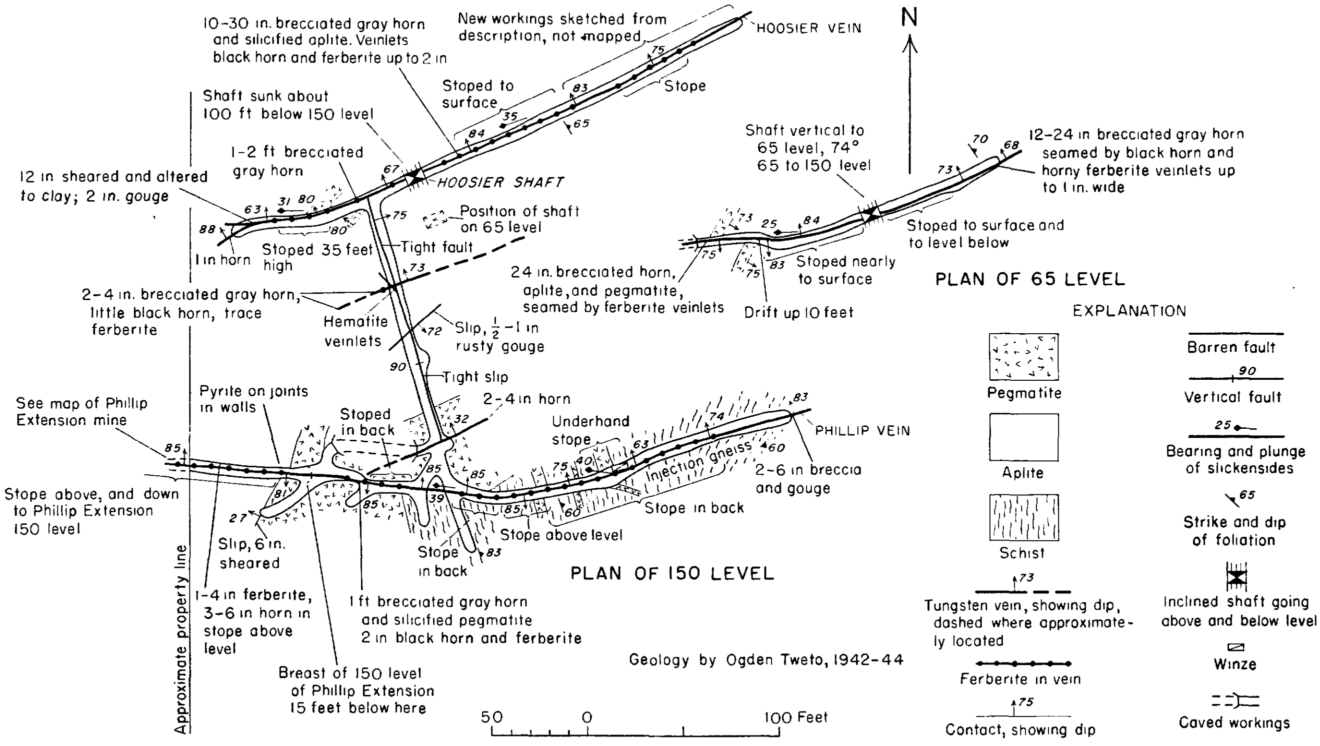


FIGURE 80.—Geologic plan of the Hoosier mine, Boulder County, Colo.

mine exploits two veins, the Hoosier on the north and the Phillip on the south (fig. 80), on claims of the same names owned by the Wolf Tongue Mining Co. The western part of the Phillip vein was worked in the Phillip Extension mine, and the eastern part was also opened by the shallow Old Phillip and New Phillip shafts (fig. 79).

The Hoosier vein was discovered by Conger and Wanamaker shortly after they identified tungsten in the district. It was presumably worked at an early date, but the early history is unknown. It produced more or less continuously from 1907 to 1919 and was worked again in 1923–25. It was apparently under water from 1925 until 1942, when it was reopened by Naylor and George Todd. At that time the mine comprised two levels turned from the Hoosier shaft at depths of 65 and 150 ft. The Todds extended the workings on the Phillip vein westward to a connection with the Phillip Extension mine, and later the Wolf Tongue Co. extended the drift on the Hoosier vein eastward and sank the shaft about 100 ft. The production from 1907 to 1942 was 5,078 units in ore that averaged 11.62 percent WO_3; some ore was doubtless produced prior to 1907, and a substantial production was achieved after the mine was reopened in 1942.

The Hoosier mine, like the adjacent Phillip Extension mine, is largely in aplite, but the workings on the Phillip vein are chiefly in schist which underlies the body of aplite at the surface (pl. 5). The schist is seamed by dikes of pegmatite and, near the contact with the aplite of the Phillip Extension mine, by dikes of aplite. Both the schist and the aplite are sericitized and locally silicified along the Hoosier and Phillip veins.

The Hoosier vein strikes about N. 70° E. and dips 65°–85° N. Grooves on successive generations of horn quartz record several periods of movement along the fissure. All the movement seems to have been in about the same direction, and the north, or hanging, wall moved down and west at 25°–35°, a total distance of about 20 ft. The Phillip vein trends almost due east in the Hoosier mine, but it has a sinuous course and is warped around bodies of pegmatite in the schist. It is about vertical but dips steeply south in some places and steeply north in others. The north wall is consistently displaced to the east, in contrast to the opposed directions of displacement found in the Phillip Extension mine, and as grooves on the vein walls plunge about 40° W., it evidently rose and moved a few feet east.

Ore on the Phillip vein, like that of the Phillip Extension mine, consisted of seams of crystalline ferberite in sheeted rock and of brecciated rock and horn quartz cemented by ferberite. In the ore shoot near the property line, the vein was only a few inches wide, but in stopes farther east it was evidently 12 to 18 in. wide. The Hoosier vein is wider and more siliceous than the Phillip. It contains considerable black horn quartz, and most of the ferberite observed near the edges of old stopes is fine-grained and somewhat horny, but the ferberite within the ore shoots is said to have been soft and free of horn.

The easternmost of the three ore shoots found on the Phillip vein lay entirely within the Hoosier mine, and the center shoot was partly in the Hoosier mine (fig. 79). The eastern shoot was irregular, and judging by the contortions of the vein as it warps around pegmatite masses, the ore was probably pockety. Some ore was obtained from a shallow underhand stope below the 150-ft level. The fact that ore was stoped down to the level through most of the 180-ft length of the shoot suggests that the bottom has not been reached, but the shoot may bottom abruptly like the other two ore shoots on the Phillip vein. The upper limits of the western part of the shoot are not known. Some ore was mined from the Old Phillip shaft (fig. 79), but there are conflicting reports as to the depth of this shaft, and no data concerning the location and extent of the stopes are available. The vein in the short drift at the bottom of the New Phillip shaft contains some ore, and some stoping may have been done off the shaft above this level.

The ore in the Hoosier vein was mostly in a single shoot that plunged northeast. There are stopes on both sides of the shaft from the surface to the 65-ft level, but on the 150-ft level the main stope is east of the shaft and only a small isolated stope is present west of the shaft. In 1944 the 150-ft level was driven eastward, and ore was found a short distance beyond the old breast, which was evidently in a rather small barren pillar. In 1944–45 the Hoosier shaft was sunk about 100 ft on the incline, and ore was found through most of this distance.

The showing of ore in the new lift in the Hoosier mine proves the persistence of ore to a greater depth than has been mined previously in the Hoosier-Phillip Extension area, and it should encourage deeper exploration of the Phillip vein, which was productive down to the 150-ft level, the lowest workings on it in the Hoosier mine.

SMALLER MINES

ANNA C. MINE

Location: Altitude, about 8,740 ft; 475 ft S. 66° W. of Quay (old) shaft.

Workings: Inclined shaft about 125 ft deep; two levels, lower one short.

Geology: Vein strikes north, in granite and pegmatite; dips 75° E. at surface, flattening to about 55°–60° at first level. Stopes near shaft probably reached surface; some ore stoped in south part of mine near Sisson workings.

History and production: Production unknown, probably not more than 1,000 units of WO_3. Mine worked in 1916–17 and at times later; last worked by Harrison Cobb in 1942–43.

SISSON MINE

Location: Altitude, about 8,730 ft; 180 ft south of Anna C. shaft.

Workings: Eighty-foot vertical shaft and one level, which probably connects with the Anna C.

Geology: On Anna C. vein, which is mostly in schist at the Sisson.

History and production: Production not known; probably less than 1,000 units of WO_3. Hole drilled by Slide Mines about 1940 showed a little ore on vein below workings. Worked by H. Cobb about 1942.

MINNIE FOY MINE

Location: Altitude, about 8,695 ft; 675 ft S. 82° W. of Illinois shaft.

Workings: Shaft about 125 ft deep; two levels.

Geology: On western extension of Illinois vein system (pl. 5). In schist, pegmatite, and granite.

History and production: Production unknown; probably less than 1,000 units of WO_3. Mine last worked by Gresser in 1942. Owned by Sisson family.

NIAGARA MINE

Location: Altitude, about 8,530 ft; 800 ft S. 62° E. of Illinois (pl. 5).

Workings: See pl. 8*A*.

Geology: Shaft workings on vein that strikes N. 77° E. and dips 85° S.; open-cut and tunnel 100 ft farther south on vein that strikes N. 50° E. and dips 80° NW. (pl. 5). These upper workings are in granite, but a drift that enters below them from the Illinois Extension shaft is in schist.

History and production: Open-cut and tunnel workings old; most of work at shaft done by Wolf Tongue Mining Co., the owner, in 1943. Mine moderately productive.

ILLINOIS EXTENSION MINE

See description of Illinois mine and plate 8*A*. Connects with Illinois, Niagara, and Beddig-Conger mines.

OREGON MINE

Location: Altitude, about 8,685 ft; 800 ft S. 28° W. of new shaft of Conger mine.

Workings: Mine originally continuous with old Conger workings; largely stoped out and inaccessible for many years.

Geology: On southern part of Conger vein and exploited part of main Conger ore shoot. See description of Conger mine and plate 9*B*.

History and production: Work on part of Conger vein on Oregon claim begun at least as early as 1903 or 1904; resulting large output led to further development of main Conger mine, where work had been stopped at depth of 80 ft. Output from Oregon up to 1907 not known but fairly large. From 1907 to 1919 and from 1923 to 1929 mine produced about 5,000 units of WO_3 in ore averaging 14.51 percent WO_3. According to Hershey, production to 1914 estimated at about $50,000, equivalent to about 10,000 units of WO_3. Mine owned by Wolf Tongue Mining Co.

GREYBACK MINE

Location: Altitude, about 8,670 ft; 1,400 ft S. 11° E. of New shaft of Conger mine (pl. 5).

Workings: See figure 81. Old workings at foot of the hill about 500 ft south of shafts shown on Greyback vein also called Greyback workings.

Geology: See figure 81. Greyback vein productive chiefly from old shafts west of present mine, where vein crosses a lens of aplite, and 500 ft farther south, where it crosses pegmatite. Very little ore obtained through raises from 200-ft level of the Greyback, where vein is in schist.

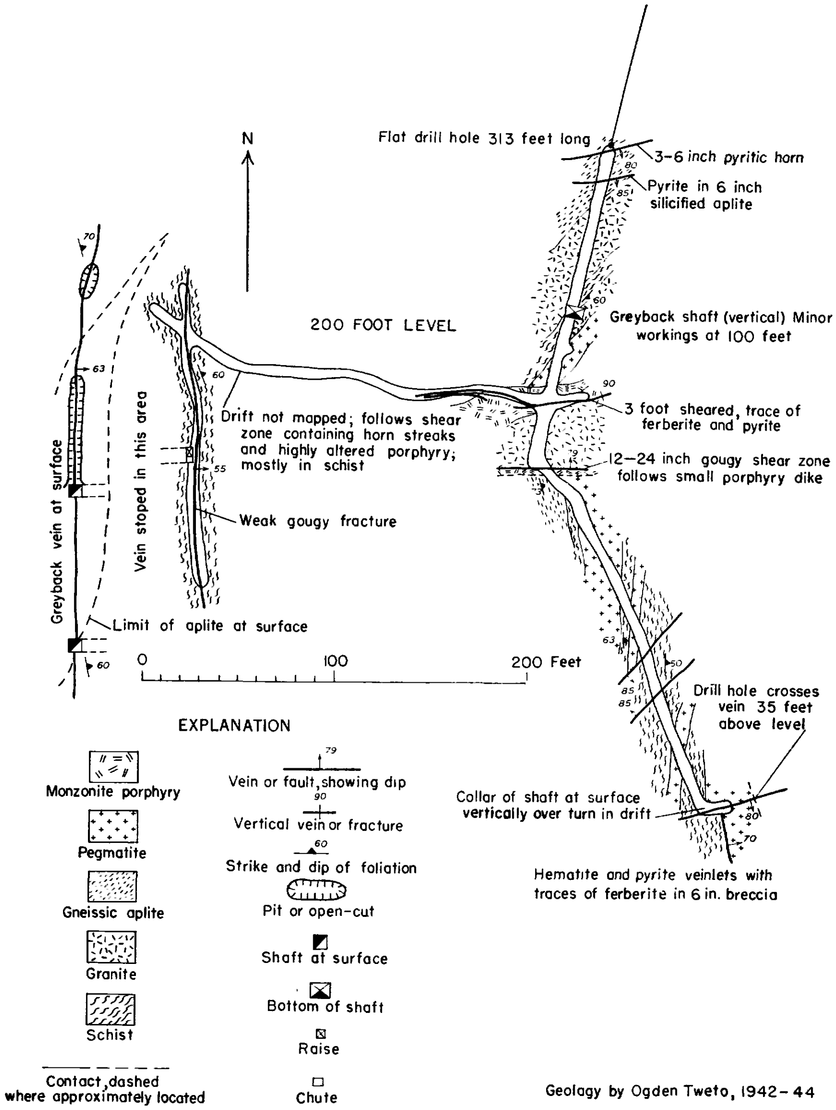


FIGURE 81.—Geologic plan of the Greyback mine, Boulder County, Colo.

History and production: Work in trenches, tunnels, and shallow shafts along outcrop done long ago; production not known but probably at least 1,000 units of WO_3. New Greyback workings (shaft and 200-ft level) driven by Vanadium Corp. of America, the owner, in 1940 and 1944.

BIG SIX MINE

Location: Altitude, about 8,565 ft; 2,725 ft S. 45° E. of New shaft of Conger mine (pl. 5).

Workings and geology: See figure 82.

Ore: Ore shoot had a stope length of about 40 ft on each level; plunged northeast; localized where at least one wall is aplite. Three drill holes showed a little ore at depths of 20 to 30 ft below bottom level; some underhand stoping done, but vein barren where cut by a hole 65 ft below level (not shown on map). Ore in main stopes consisted of veinlets of ferberite in brecciated horn quartz and sheeted aplite and schist. Ore mined in 1943 assayed about 1 percent WO_3.

History and production: Mine owned by Crow Estate; worked by many different lessees at intervals from 1915 or earlier up to 1943, when operated by Boulder Tungsten Mills, Inc. Production not known; probably less than 1,000 units of WO_3.

TOWNLOT MINE

Location: Altitude, about 8,375 ft; at north edge of Nederland, near schoolhouse.

Workings: Shaft workings; extent unknown; probably not more than 150 ft deep.

Geology: Vein strikes N. 33° E. and dips 65° SE. Mostly in schist but crosses a small body of aplite, where ore shoot was apparently localized.

History and production: Mining at surface begun by school children shortly after Conger discovery. Hershey gives estimated output of $8,000 to $10,000 by 1914, suggesting about 2,000 units of WO_3. About 300 units produced in 1917–18, the last period of operation.

McKENZIE TUNNEL

Location: Altitude, 8,250 ft; at foot of slope at southeast edge of Nederland.

Workings and geology: See figure 83.

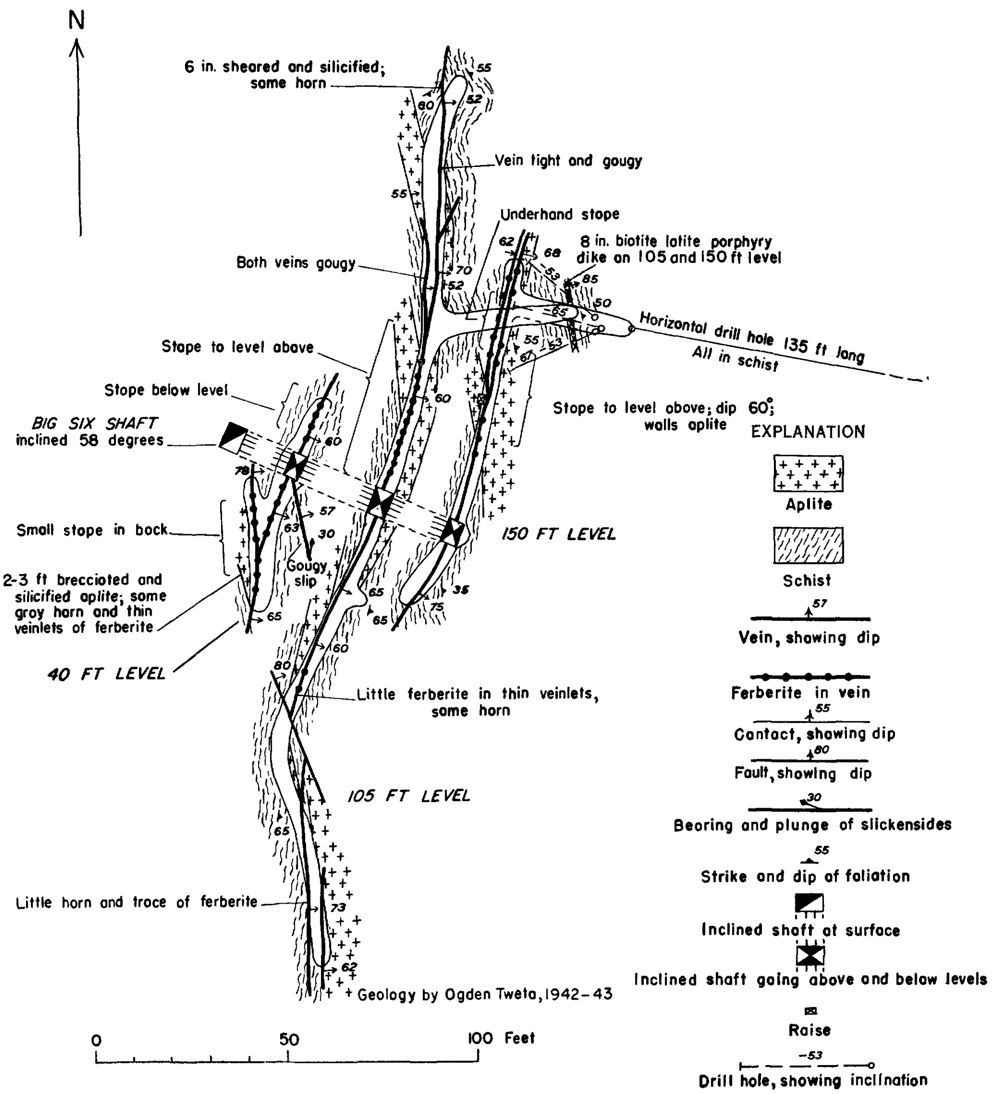


FIGURE 82.—Geologic plan of the Big Six mine, Boulder County, Colo.

Ore: Seams of high-grade, coarsely crystalline ferberite with horn quartz in sheeted aplite and injection gneiss. Ore shoot at old shafts above middle part of tunnel.

History and production: Operated at times by McKenzie family, the owners; last worked in 1943–44, when a small amount of sorted ore assaying 17 to 20 percent WO_3 was produced. Total output unknown; probably less than 1,000 units of WO_3.

"1½" AND "1¾" WORKINGS

Location: Old workings along main road where it crosses ridge north of Nederland, at altitudes of 8,440 to 8,475 ft.

Workings: Several old and probably shallow shafts, all caved for many years.

Geology: Several short veins in schist and aplite (pl. 5) apparently productive where they cross narrow bands of aplite.

History and production: Fairly large production said to have been made from vein outcrops and rich float "beds" during first few years of mining in district.

SPIDERLEG MINE

Location: Altitude, about 8,460 ft; 1,475 ft N. 37° E. of new shaft of Conger mine.

Workings: See figure 84.

Geology: Workings on overlapping veins in two vein zones, one trending about north and one northeast. Most of veins dip east, but chief vein in southern part of northward-trending workings dips west. Mine in schist that contains many elongated bodies of pegmatite; veins productive where they cross some of these.

History and production: Veins worked near surface before 1914, when Hershey reported that ore 24 to 30 in. wide and 75 ft long had been mined but had pinched out only a few feet below surface. Most of workings shown in figure 84 driven in 1941–42 by Vanadium Corp. of America, the owner; about 3,800 units of WO_3 in ore averaging about 1.2 percent WO_3 produced at this time. Total output probably at least 5,000 units.

BOBCAT MINE

Location: Altitude, about 8,465 ft; 2,800 ft N. 36° E. of new shaft of Conger mine.

Workings: From data given by Hershey in 1914, it appears that shaft is 140 ft deep, with a drift 200 ft long at bottom; mine also said to be 200 ft deep, with three levels.

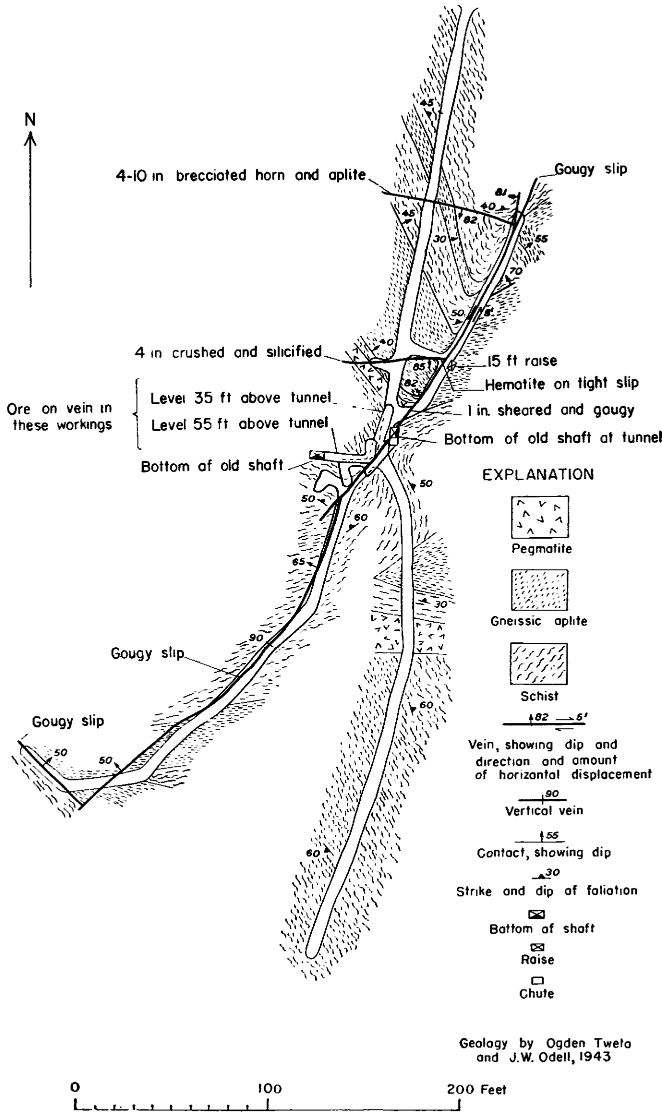


FIGURE 83.—Geologic plan of the McKenzie tunnel, Boulder County, Colo.

Geology: Bobcat vein one of longest in Sherwood Gulch area; strikes N. 70° E. and dips 65° N. Mine in schist that contains pods of aplite, pegmatite, and gneissic diorite.

History and production: In 1914 Hershey reported that mine had produced 400 tons of ore assaying 3 to 4 percent WO_3 from an ore body 3 ft wide, 40 ft long, and 40 ft deep. Mine closed at that time. Moderate production from near-surface operations by lessees at times since then. A little diamond drilling from the surface by Vanadium Corp. of America, the owner, in 1943; no ore found.

GREENHORN TUNNEL

Location: Altitude, 8,350 ft; in bottom of Sherwood Gulch.

Workings: See figure 85.

Geology: Crosscut tunnel driven south to reach a group of short veins, trending northeast, which are in aplite and die out in adjoining schist. See pl. 5.

History and production: Old tunnel of Colorado Tungsten Corp. Most of production apparently before 1915, possibly before 1907; worked by lessees at times up to 1944.

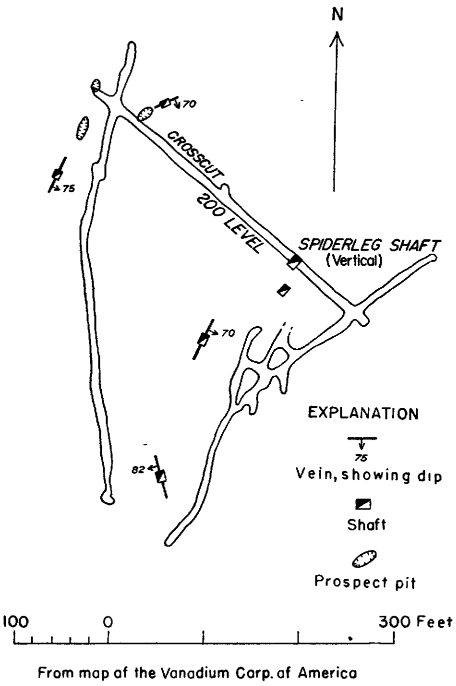


FIGURE 84.—Workings of the Spiderleg mine, Boulder County, Colo.

CROW NO. 2, NO. 13, AND NO. 37 MINES

Location: Altitude, 8,340 to 8,360 ft; 1,700 ft east of Greenhorn tunnel.

Workings: See figure 86.

Geology: Workings on a group of intersecting veins trending north-northeast, northeast, and east-northeast. In pegmatite surrounded by schist. Small veins of high-grade ore.

History and production: Records fragmentary. Hershey reported in 1914 that Nos. 2 and 13 had produced 7 tons of concentrates; No. 37 produced about 200 tons of ore in 1916–18. Mines worked at times on a small scale since then. Total production probably 1,000 to 5,000 units of WO_3. Owned by Colorado Tungsten Corp.

CORKSCREW MINE

Location: Altitude, about 8,315 ft; 900 ft S. 83° W. of Lone Tree shaft.

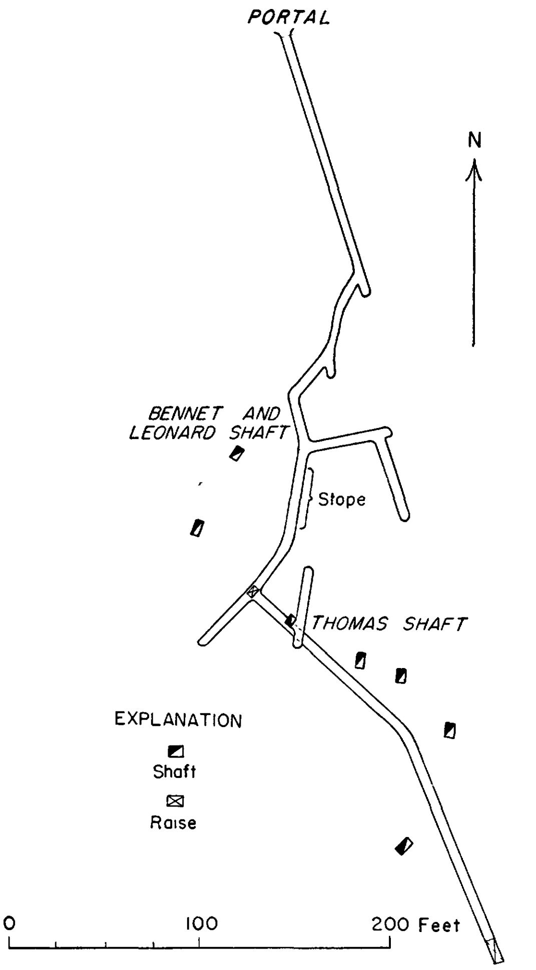
Workings: Shaft workings; depth and extent not known; probably less than 200 ft deep.

Geology: Vein strikes north and dips 57° E.; intersects several short northeastward-trending veins. Rock is schist cut by narrow bands of pegmatite and aplite. Ore all found near surface.

History and production: Chief production sometime before 1914. Minor production from shallow workings by lessees since then, particularly in twenties. A little diamond drilling from surface in 1943 by Vanadium Corp. of America, the owner; no ore found.

NABOB MINE

Location: Altitude, about 8,310 ft; 275 ft east of Lone Tree shaft.



From map of the Primos Mining and Milling Co., about 1916

FIGURE 85.—Plan of the Greenhorn tunnel, Boulder County, Colo., about 1916.

Workings and geology: According to Hershey in 1914, shaft 75 ft deep on 70° incline to south; drift 50 ft to southwest at bottom of shaft in schist; drift to northeast, 83 ft long, and a short crosscut into footwall (northwest side). Stope begins 8 ft from shaft and is 50 ft long, in granite; north end of drift is in schist. Stope 40 ft high in 1914. Ore 6 to 18 in. wide except in one place where granite was "feedered" through a width of 4 or 5 ft; consisted of a breccia of granite and horn quartz cemented by ferberite.

History and production: Hershey said production was 150 tons of 7- or 8-percent ore (1,050 to 1,200 units) in 1914, but stoping was still in progress above level, and, as ore assaying 4 or 5 percent WO_3 was present in floor, mine was presumably deepened and production increased considerably. Mine apparently closed by 1916; not operated since except for minor near-surface work by lessees about 1940. Owned by Vanadium Corp. of America.

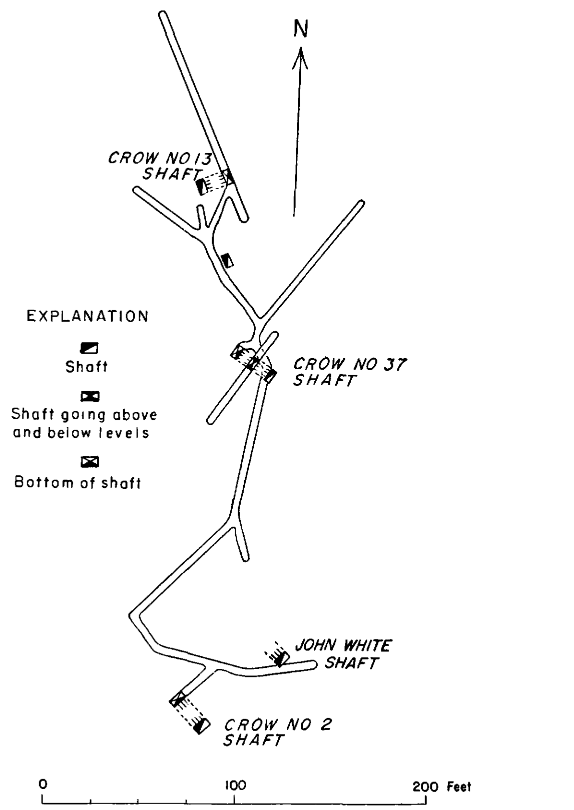
GALE MINE

See description of Clyde mine and plate 12A.

HUMMER MINE

Location: Altitude, 8,405 ft; 250 ft N. 39° W. of Hoosier shaft.

Workings and geology: See figure 87.



From map of the Primos Mining and Milling Co., about 1916

FIGURE 86.—Workings of the Crow No. 2, No. 13, and No. 37 mines, Boulder County, Colo., about 1916.

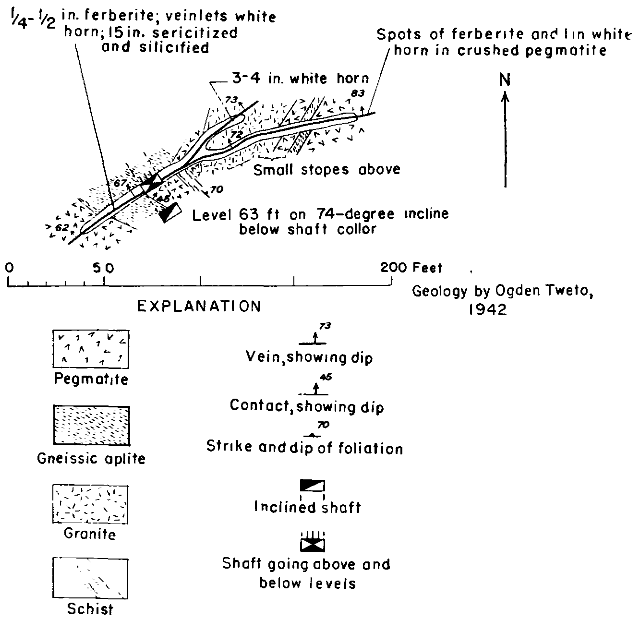


FIGURE 87.—Geologic plan of the Hummer mine, Boulder County, Colo.

History and production: Shaft sunk by Johnson brothers about 1940; good ore obtained in shaft, but very little found in drifting. Mine owned by Wolf Tongue Mining Co.

ST. ELMO MINE

Location: Altitude, 8,450 ft; 250 ft S. 36° E. of Hoosier shaft
Workings: Hundred-foot shaft and two levels, inaccessible for many years.
Geology: Ore in vein following north contact of an eastward-trending porphyry dike, where dike is in contact with aplite. Aplite gives way to schist in lower part of mine; ore pinched out.
History and production: Mine not worked for many years; production unknown but probably not large.

LAST CHANCE NO. 1 MINE

Location and workings: Line of trenches and shallow shafts about 400 ft long; east end 550 ft south of Hoosier shaft. Eastern part of workings on Last Chance claim of Wolf Tongue Mining Co.; western part on an agricultural patent of Colorado Tungsten Corp.
Geology: Strong vein strikes east-northeast; about vertical; productive near surface, in aplite and minor pegmatite, but penetrates schist and becomes barren at depths of 30 to 75 ft.
History and production: Vein worked on two different properties by many lessees; most of production probably before 1918. Total production unknown; probably at least 1,000 units of WO_3.

TUNGSTEN POST OFFICE—HURRICANE HILL AREA

CLARK TUNNEL AND BARKER MINES

The Clark tunnel at Tungsten Post Office (pl. 5) was driven to explore and work some of the veins controlled by the Tungsten Production Co., predecessor of Gold, Silver, & Tungsten, Inc. The portal is at an altitude of 8,033 ft. The tunnel extends N. 77° W. for 2,150 ft and, as shown in plate 13, connects with the third level of the Vasco No. 6 mine, one of the more productive mines of the district. The tunnel is mainly in gneissic granite and biotite gneiss in the border zone of the Boulder Creek batholith, but in a few places quartz-biotite schist and injection gneiss of the Idaho Springs formation are present. There is far less schist in the tunnel than at the surface directly over it, and the biotite gneiss of the tunnel gives way to gneissic granite below the tunnel in the Vasco No. 6 mine. The breast of the tunnel is in schist, which may continue westward for some distance.

About 200 ft from the portal the tunnel cuts the Barker No. 1 vein, the northern extension of which is called the Vasco No. 8 vein and has been worked in the Vasco No. 8 and No. 2 mines (pl. 13). The vein strikes north-northeast and dips steeply west. It lies in the angle between the Hurricane Hill breccia reef and the Five vein and is faulted by the Murphy vein. Ore in the Barker No. 1 mine came chiefly from small stopes on levels 25 ft above and 50 ft below the Clark tunnel level and from cuts at the surface. A level exploring the Barker No. 1 and Murphy veins 95 ft below the tunnel level was only slightly productive. The output from the Barker No. 1 mine is not known but is probably 2,000 or 3,000 units, and the same vein was also productive in the Vasco No. 8 mine.

About 350 ft from the portal the Clark tunnel cuts the Hurricane Hill breccia reef, which is also exposed at several places in lateral workings of the tunnel. The reef is a shear zone 20 to 30 ft wide. It consists of parallel gouge streaks a fraction of an inch to a foot wide separated by sheared and granulated rock which is locally silicified and seamed by veinlets of dense maroon quartz and specular hematite. The hematite veinlets locally attain thicknesses of several inches, and during World War I a small body of high-grade hematite near the intersection with the Murphy vein was mined and sold to chemical companies. The average dip of the Hurricane Hill reef in the several exposures in the Clark tunnel workings is about 55° NE. Although the reef is an early fracture and is offset by the tungsten veins, movement on it evidently continued intermittently for a long time, as the Murphy vein is displaced a total of 15 ft by some of the younger slips within the reef. The amount and direction of early movement on the reef are not known, but the amount is probably large; during a later stage the hanging wall moved southeast and, as suggested by a few grooves, possibly up.

At a distance of 450 ft from the portal the Clark tunnel intersects the small Barker No. 2 workings, from which both tungsten and hematite have been obtained in minor quantity. The tungsten ore is on the Murphy vein immediately under the Hurricane Hill reef and on small fractures in the acute angle between the vein and the reef. The veins have been stoped from the tunnel level up to the reef through a stope length of 25 to 50 ft. A small production is reported from a winze that supposedly connects with the drift on the Murphy vein from the bottom level of the Barker No. 1 shaft. The strong and persistent Murphy vein is one of the most prominent fractures in the Clark tunnel. It faults several ore-bearing veins and has proved barren in most places, but the little ferberite on it in the Barker No. 2 workings and between the faulted segments of the Barker No. 1 vein proves that it is not later than the ore. The ferberite in these occurrences was plainly deposited there and was not dragged into the vein. The Murphy vein displaces the Hurricane Hill reef and Barker No. 1 vein about 25 ft with the right side forward. Grooves along the vein consistently plunge 20°–45° W., and the north wall evidently moved down and west. West of the Hurricane Hill reef the Murphy vein dips 60°–83° N., but east of the reef it dips 68°–78° S.

About 650 ft from the portal the tunnel cuts the Barker No. 3 vein, which contained a narrow streak of high-grade ferberite. The vein has been opened for only 110 ft and has been stoped to a height of 65 ft for half this distance. Some ore was also obtained from an underhand stope and from a 25-ft winze. The output from the vein is not known accurately because shipments from this vein and from another mine also known as the Barker No. 3 were not always distinguished. However, at least 1,000 units of WO_3 came from the Barker No. 3 of the Clark tunnel. This is a large output for workings of such small extent, and it warrants further exploration of the vein. The vein has not been opened south of the Murphy vein, where it is presumably offset about 15 ft eastward as shown in plate 13. It was cut in two drill holes at depths of 45 and 63 ft below the tunnel level. The drill cores show only fractured and sericitzed gneiss, with a wide argillized zone on each side, but core recovery in the vein zone was poor.

About 720 ft from the portal the Clark tunnel cuts the Barker No. 4 vein, which strikes a little east of north and dips steeply west. No ore was found in a drift northward on the vein for 300 ft to the Hurricane Hill reef, but a few spots and small lenses of ferberite show in the drift on the segment of the vein between the Five vein and the breccia reef. A little ferberite was mined from a shallow winze just north of the Clark tunnel, and ore was cut a short distance below the tunnel level in two drill holes put down by the Bureau of Mines in 1943. Boulder Tungsten Mills, Inc., lessees of the Clark tunnel workings at the time, sank the winze to a depth of 50 ft, drifted south beneath the tunnel, and found a little ore, which was stoped to within about 10 ft of the tunnel floor. The offset segment of the Barker No. 4 vein south of the Murphy vein was opened by a crosscut in 1943, but only a tight fracture was found.

About 1,100 ft from the portal the tunnel cuts the Five and Vasco No. 6 veins. The Five vein is so called because it was correlated on an old map with the Vasco No. 5 vein, but as the veins are on opposite sides of the Hurricane Hill reef and there is some doubt about the correlation, the miners' term "Five" seems preferable to "Vasco No. 5." The Five vein is bordered by a wide zone of soft rock that is chloritized and argillized. This makes heavy ground where it crosses the Clark tunnel. The vein evidently splits and steepens or reverses dip on the north side of the tunnel, as the Barker No. 4 vein is displaced by fractures that dip vertically or steeply south in two zones about 50 ft apart. It is possible that the Five vein splits up and dies out on the southwest side of the Hurricane Hill reef, but the reef exposures in the Barker No. 2 and No. 4 drifts are not in line and the reef may be displaced by the Five vein as suggested in plate 13. The Five vein south of the Clark tunnel is a horn vein 6 to 24 in. wide. It does not contain ferberite on the tunnel level, but a large body of good ore was found on it below the tunnel in the Vasco No. 6 mine. The junction of the Murphy and Five veins has not been identified in the drift on the Five vein. The Murphy vein, like many others observed approaching a junction at an acute angle, probably ends as a persistent fracture a few feet short of an actual junction, its movement being taken up on many small fractures.

A lateral drift extending southward from a point near the breast of the Clark tunnel was driven in search of the Longshot vein, which contained a small body of good ore near the surface. The lateral exposed a small and barren vein, but it was not driven far enough to reach the Longshot.

VASCO NO. 6 MINE

The Vasco No. 6 mine is about a thousand feet west of Tungsten Post Office (pl. 5) and is opened by an inclined shaft whose collar is at an altitude of 8,328 ft. As shown in plate 13, eight levels are turned from the shaft, and the Stevens tunnel, which is above the first shaft level, constitutes another level. The third level connects with the Clark tunnel, and most of the work in the lower part of the mine was done through the Clark tunnel. The mine reaches a vertical depth of 618 ft.

The Vasco No. 6 has been one of the most productive mines in the district; incomplete records show an output of 950,587 lb, or 47,529 units, of WO_3, and the total output may have reached 60,000 units. Some unrecorded production came from workings above the Stevens tunnel level before the Vasco Mining Co. began operation in 1915. From 1915 to 1920 the Vasco Co. developed the mine down to the third level and mined out the upper ore shoot shown in figure 88. During this period 1,619 tons of ore which averaged 12.00 percent WO_3 was produced.

The Vasco group of mines was purchased by the Tungsten Production Co. in the early twenties. The new owner developed the mine down to the eighth level, and a large ore body on the Vasco No. 6 vein and adjacent parts of the Five vein was discovered. From 1925 to 1927 a total of 5,243 tons of mill ore having an average grade of 4.40 percent WO_3 and containing 23,032 units was produced. In addition, a large but unknown amount of tungsten was produced as "high grade" assaying 40 to 65 percent WO_3. A small output resulted from intermittent operation of the upper part of the mine from 1928 to 1943. In 1943 Boulder Tungsten Mills, Inc., unwatered the mine and did considerable diamond drilling on the lower levels but found no new ore.

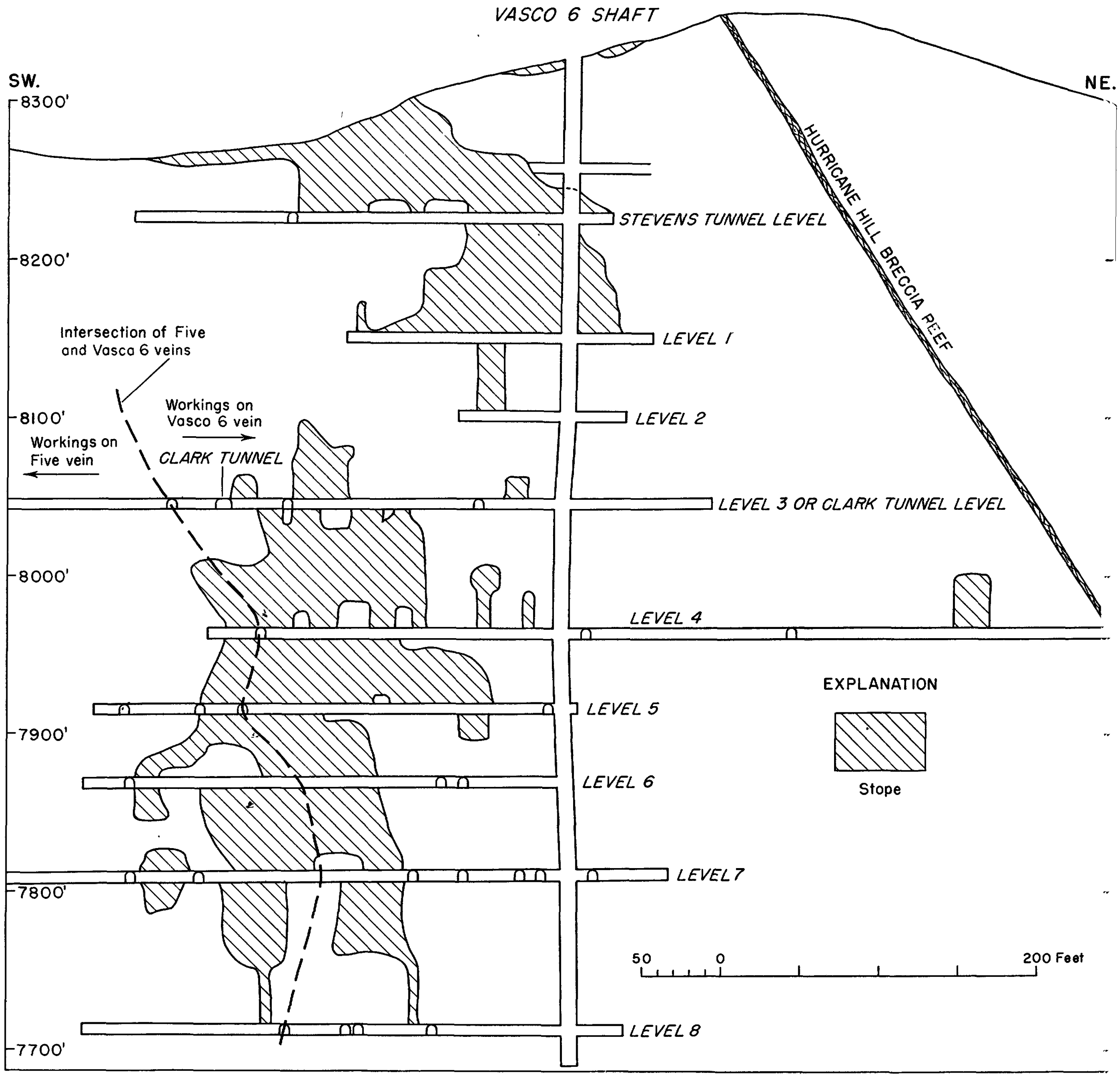


FIGURE 88.—Longitudinal projection of the Vasco No. 6 mine, Boulder County, Colo.

The country rock of the Vasco No. 6 mine changes progressively with depth. The collar of the shaft is in schist, and judging by the dumps the upper workings are in mixed schist and granitic rocks. This mixture gives way in depth to biotite gneiss which is a border facies of the Boulder Creek granite. At the Clark tunnel level the wall rocks are about half biotite gneiss and half granite. The gneiss is less abundant on the fourth level, and below that the mine is mostly in gneissic granite, although small bodies of biotite gneiss and dioritic gneiss persist down to the eighth level. Monzonite and biotite latite porphyries occur in small dikes in the lower workings, and both types become slightly more abundant with depth. A 2-ft dike of biotite latite porphyry north of the shaft on the fourth level fingers out upward and on the third level is represented only by two or three seams less than an inch wide. Two small dikes of monzonite porphyry are present north of the shaft on the fourth level, and a dike a few inches thick on the fifth level increases in thickness to 10 ft on the seventh level. Dikes of monzonite and biotite latite porphyries found south of the shaft on the eighth level have not been recognized higher in the mine.

The Vasco No. 6 vein strikes northeast and dips 62°–85° NW. About 200 ft southwest of the shaft it joins the Five vein, which strikes N. 75° E. and dips 60°–80° N. On the fourth level the Vasco No. 6 vein displaces northward-dipping pre-Cambrian contacts an average of about 10 ft, with the right side ahead, but it displaces southward-dipping monzonite porphyry dikes about 15 ft with the left side ahead (pl. 13). Although opposite horizontal displacements of contacts dipping in opposite directions could result from dip slip normal faulting during a single period of movement, two periods of movement separated by intrusion are inferred because essentially vertical monzonite porphyry dikes on the lower levels also show a left-hand displacement and dikes of the relatively young biotite latite porphyry are displaced with the left side ahead. The few grooves and striae found on the walls of the vein are inconsistent in direction but in general plunge steeply. During early movement the hanging wall probably moved steeply down and south. After the intrusion of the monzonite porphyry the hanging wall probably moved steeply down and north for about half the amount of the original movement. The biotite latite prophyry was intruded late in the second stage of movement and is therefore displaced only about 2 ft. The Vasco No. 6 vein is strong and well defined in the upper levels, but it begins to break up on the sixth level, and on the seventh and eighth levels its place is taken by a network of intersecting fractures except for a short segment near the Five vein.

The Five vein is a strong fracture which has been explored on all levels from the Clark tunnel down to the eighth level. Its north wall moved downward and westward at 20° to 40°. The vein dips 60°–75° N. on the Clark tunnel level, flattens to 45° below the tunnel, and steepens to 70°–80° near the fourth level. The vein splits just above the fifth level; one branch continues downward with the normal dip of 60°–70° N., and the other turns into the footwall, dipping vertically or steeply to the south. The flatter branch was ore bearing and was explored on all the lower levels. The vertical branch was explored on the sixth level, where the dip is about 80° S., but was found barren there and was not explored deeper.

As shown in figure 88, two ore bodies were found in the Vasco No. 6 mine. Little is known of the geology of the upper ore body, but the ore was evidently localized in a steeply dipping part of the normal-fault fissure. The lower ore body was on the Five and Vasco No. 6 veins near their junction. The Five vein is a strong but barren horn vein on the Clark tunnel level. The Vasco No. 6 vein also is barren for most of its exposed length on this level, and a small pocket of lean ore near the Clark tunnel was the only indication of the rich ore below. Fairly good ore was found on the Vasco No. 6 vein on the fourth level. On the fifth and sixth levels, where the vein steepens to 80°, wide and rich ore was mined through a stope length of 150 ft. Some ore was found on the Five vein on and above the fourth level, but it pinched out where the vein flattened 50 ft above the level. The best part of the ore on the Five vein extended from a little above the split on the fifth level down to the seventh level and was continuous with the ore on the Vasco No. 6 vein. The ore on both veins decreased in quality and quantity near the seventh level, and the ore body bottomed about halfway between the seventh and eighth levels. Some of the ore was very rich, and widths of as much as 2 ft of pure ferberite are reported. In addition to the main streak, the walls were locally "feedered" so as to make stope widths of as much as 15 ft.

The Five vein is persistent east of the Vasco No. 6 vein from the third level down to the split on the fifth level, and in this zone the Vasco No. 6 vein simply joins the more persistent Five vein and ends. Below the split on the fifth level, the vertical branch of the Five vein continues eastward into the footwall of the Vasco No. 6 vein, but the flatter, ore-bearing branch turns into the Vasco No. 6 vein except for small fractures that continue eastward for a short distance beyond the junction or turn and then die out. There is consequently no unexplored ground on the ore-bearing split of the Five vein below the fifth level except west of the present workings. The segment of the vein that continues eastward on and above the fifth level has been explored for only about 100 ft on the fifth level and for about 25 ft on the fourth level. Further exploration to the east on this strong vein in the zone between the third and fifth levels seems warranted and constitutes one of the few remaining prospects in the mine.

The vertical split of the Five vein was followed for about 200 ft on the sixth level. The vein there is remarkably strong and consists of 18 to 36 in. of brecciated gray horn and silicified granite between walls of hard, sericitized granite. The breccia is coarse and cavernous, ideally prepared for ore, but this part of the vein was evidently sealed off during tungsten mineralization. Branching veins at the east end of the drift contain spots and small lenses of ferberite, however, and further exploration down and east seems warranted. At the west end of the drift several strong horn seams which probably represent the Murphy vein enter from the south wall. A drill hole showed a little ferberite in this zone 40 to 50 ft from the drift, and further exploration of this strong vein zone is warranted.

The Vasco No. 6 vein has hardly been explored northeast of the shaft except on the fourth level, where it was followed out to the Hurricane Hill breccia reef. The vein is tight and unpromising near the shaft on the fourth level, but at localities 150 and 300 ft from the shaft it contains spots of ferberite in horn quartz, and a little ore was obtained from one small stope. These showings suggest a possibility of ore nearby, and if the mine should be reopened again, exploration above and below the drift should be considered.

As the Vasco No. 6 mine is the deepest to which the writers had access, the geology of the barren eighth, or bottom, level is of interest. Several intersecting veins are present in the northeast half of the level (pl. 13). The Vasco No. 6 vein persists only as a short segment that lies in the drift between the two crosscuts farthest from the shaft. The southwestern part of the eighth level follows the Five vein. The most striking features of the level are the strong sericitic and siliceous alteration and the abundance of gray horn quartz. The sericitic casing is locally as much as 2 ft wide. Argillic alteration is relatively weak and is absent in some places where the sericitized rock grades into fresh granite. Horn quartz is present on all the veins, and the Five vein contains as much as 30 in. of brecciated gray horn. A little black horn is present locally on some veins. Although the level was devoid of commercially valuable ore, nearly every vein contains a little ferberite, which occurs in scattered spots or small lenses in the horn. The ferberite is crystalline and high-grade and is of much better quality than the fine-grained and horny ore at the bottom of the ore shoot above the eighth level. A vein at the crosscut farthest from the shaft contains as much as 8 in. of light-pinkish dolomite.

The veins and altered wall rocks of the eighth level are similar to those higher in the mine and show no features unfavorable to ore. The Five vein looks almost the same on the eighth level as it does on the Clark tunnel level; thus it seems possible that ore may be present below the eighth level. Two diamond-drill holes were put down by Boulder Tungsten Mills to depths of 90 and 110 ft below the level. Both holes cut several small veins, and one cut a small ferberite veinlet, but it is doubtful that either hole reached the main Five vein. Three flat holes were drilled into the walls (pl. 13). The two holes in the footwall cut several veins, and one hole cut half an inch of ferberite on a branch of the Five vein. The short hole into the hanging wall did not cut any veins.

VASCO NO. 2, NO. 3, NO. 5, AND NO. 8 MINES

The Vasco No. 2, No. 3, No. 5, and No. 8 mines and the Barker No. 1 mine of the Clark tunnel are on a vein zone that extends northeastward from the Hurricane Hill breccia reef (pl. 13). This zone includes the Vasco No. 8, No. 5, and No. 3 veins, each of which has been worked in more than one mine. The Vasco No. 8 vein was worked largely through winzes or underground shafts from the Vasco No. 8 tunnel and the Clark tunnel level of the Barker No. 1 mine. Levels at 68 and 125 ft below the No. 8 tunnel, and a sublevel at 22 ft, are turned from the principal winze in the tunnel. The northeastern part of the vein was worked through the Vasco No. 2 shaft on two levels 87 and 188 ft below the collar. The Vasco No. 5 vein was worked principally through two tunnels 87 ft apart vertically and through a winze or underground shaft in the lower tunnel of the Vasco No. 5 mine. A sublevel at 25 ft and three levels at 91, 176, and 220 ft are turned from this shaft. The shaft levels are called the third, fourth, and fifth levels of the Vasco No. 5 mine. The southwestern part of the vein was worked on the first or 87-ft level of the Vasco No. 2 shaft and through a complicated winze system below this level. The Vasco No. 3 vein was worked almost entirely through two tunnels 79 ft apart vertically but was followed for a short distance in workings at the northeast end of the lower tunnel of the Vasco No. 5 mine, 160 ft below the lower tunnel of the Vasco No. 3.

The total output from these veins is probably about 40,000 units of WO_3, more than half of which came from the Vasco No. 5 mine. Records of production prior to 1915 are not available, but an indication of the early output from the Vasco No. 5 mine is given by O. H. Hershey, who, in a private report made to the Primos Chemical Co. in 1914, credited the mine, then known as the No. 5 mine of the Rogers upper tract, with a production of $75,000 worth of ore. As the local price for tungsten ranged from $5 to $7.50 per unit for several years prior to 1914 (fig. 63), an output of 10,000 to 15,000 units of WO_3 is indicated. A rather large output from the Vasco No. 3 mine also dates from this period, and smaller amounts evidently came from the Vasco No. 2 and No. 8 mines. The recorded production of the four mines from 1915 to 1945 is:

	Units WO_3
Vasco No. 2	3, 801
Vasco No. 3	4, 749
Vasco No. 5	9, 119
Vasco No. 8	1, 564
Total	19, 233

Tenors calculated from the well-kept records of the Vasco Mining Co., which operated the mines from 1915 through 1918, show the general character of the ore:

Mine	Net tons ore, 1915–18	Units WO_3	Percent WO_3	Value
Vasco No. 2	98. 5	606. 25	6. 15	$5, 973. 00
Vasco No. 3	278. 0	4, 480. 00	16. 12	48, 468. 61
Vasco No. 5	529. 4	6, 094. 85	11. 51	56, 477. 69
Vasco No. 8	73. 6	1, 664. 45	22. 61	21, 379. 28

The figures given for the Vasco No. 5 mine do not include 2,834.5 tons of stope fill which assayed 0.62 percent WO_3; the fact that the Vasco Co. during its first year of operation could obtain this much fill from the old stopes is corroborative evidence that the early output was relatively large.

The Vasco property was acquired by the Tungsten Production Co. in the early twenties, and although this company did extensive exploratory work, particularly in the Vasco No. 5 mine below the lower tunnel, only a moderate output resulted. This came from the Vasco No. 5 mine from 1927 to 1931 and from the Vasco No. 2 mine in 1929 and 1930. More than half the total recorded production from the Vasco No. 2 mine dated from 1943–44, when the mine was operated by H. M. Gregory and ore was obtained from the Williams winze workings on the Vasco No. 5 vein at the northeast end of the mine.

The Vasco No. 2, No. 3, No. 5, and No. 8 mines are in the western border zone of the Boulder Creek batholith, and the country rock grades from mixed schist, biotite gneiss, and gneissic granite in the Vasco No. 8 and No. 2 mines to massive granite in the No. 5 and No. 3 mines (pl. 5). Much of the rock in the Vasco No. 8 mine and the southwestern part of the No. 2 mine is coarse-grained, dark biotite gneiss that contains abundant streaks of schist and appears to have resulted from reaction between granite and schist. Small sheets of gneissic granite occur within the schist and the gneiss. As it was impracticable and unnecessary to distinguish all the intergrading rock types on the map, only "biotite gneiss" and "granite" are distinguished on the map of the Vasco No. 2 mine (pl. 13), but both types are impure, intergrade, and include many compositional and textural varieties.

Two siliceous "dikes" cut the granite in the Vasco No. 5 mine and localize the two main ore shoots on the vein. The "dikes" are zones of abnormally siliceous biotite granite that contain dikes and irregular masses of aplite, pegmatite, and alaskite. In some places the "dikes" consist almost entirely of aplite and pegmatite, or of alaskite, but in others they are only vaguely defined streaks of siliceous granite which grades imperceptibly into the normal granite. The "dikes" are so irregular in size, form, and attitude that little can be learned of them in single exposures, but drill holes and exposures through the workings of the No. 5 and No. 2 mines indicate that they trend west, dip about 45° N., and range from 10 to 50 ft in width.

The Vasco No. 5 vein has an average strike of about N. 50° E. and dips 42°–85° NW. (pl. 13). It follows a premineral fault along which the hanging wall moved several feet down and toward the southwest. The vein is strong and persistent from the underground shaft of the Vasco No. 5 southwestward to the intersection with the Vasco No. 2 vein, a short vein in the middle of the Vasco No. 2 workings. As shown in plate 13, three veins paralleling the Vasco No. 5 vein extend southwestward from the Vasco No. 2 mine, suggesting that the No. 5 vein may weaken and die out to the southwest. However, the main No. 5 vein is a strong shear zone where it leaves the Vasco No. 2 drift, and it may possibly cross the Hurricane Hill reef with a change in course and continue as the Five vein of the Clark tunnel and Vasco No. 6 mine. Northeast of the Vasco No. 5 shaft the No. 5 vein "horsetails" and disappears. The vein flattens to about 45° and becomes barren below the lower tunnel in the Vasco No. 5 mine. The spacing of the levels indicates that the dip remains relatively flat down to the fourth level but steepens between the fourth and fifth levels. Farther southwest, in the Vasco No. 2 mine, the dip remains steep, and the vein was ore bearing down to the lowest level of the Williams winze, but the vein must flatten considerably between the bottom of the winze and the drift on the fifth level, which is 74 ft below (pl. 13).

The Vasco No. 2 and Vasco No. 8–Barker No. 1 veins trend about N. 20° E. across the angle between the Vasco No. 5 vein and the Hurricane Hill breccia reef. They dip 50°–80° W. In the Vasco No. 2 mine the No. 8 vein displaces a northwestward-trending fracture and pegmatite seams about 5 ft, with the left side ahead. Grooves and striae are almost horizontal, and the west wall evidently moved north almost horizontally. Although the Barker No. 1 vein is an extension of the Vasco No. 8 vein, in the Barker No. 1 workings contacts on the west wall are offset to the south, and a few grooves suggest steep-angle movement. The Vasco No. 8–Barker No. 1 vein is cut and displaced by the Murphy vein at the north end of the Barker No. 1 mine, and the conflicting directions of displacement suggest independent movement in the two segments after the faulting along the Murphy vein had occurred. The Vasco No. 8 vein dies out after intersecting the Vasco No. 2 vein about 150 ft north of the Vasco No. 2 shaft. The No. 2 vein strikes about parallel to the No. 8 vein but turns sharply to the southwest where the No. 8 vein dies out, and a drill hole shows that it continues southwestward as a minor fracture in the hanging wall of the No. 8 vein (pl. 13). The No. 2 vein shows a displacement of only a few inches, with the right side ahead. The vein continues northward beyond the intersection with the No. 5 vein, as shown by two drill holes. It was barren in both holes.

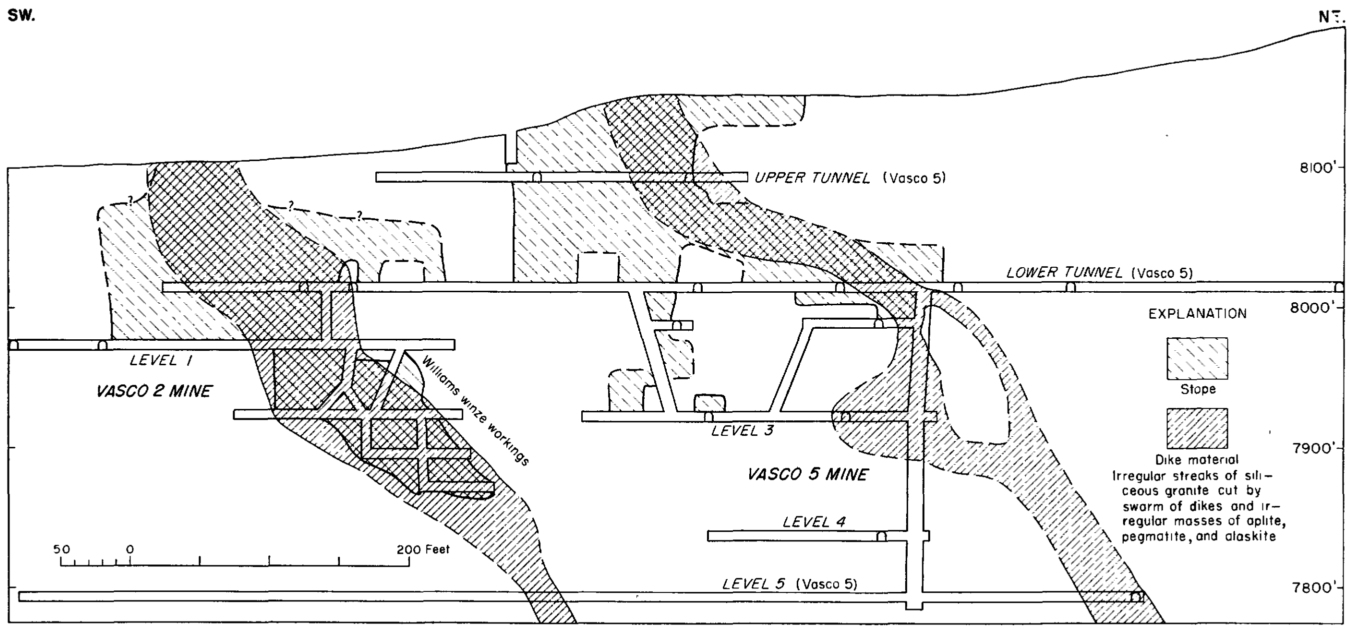


FIGURE 89.—Vertical projection of workings on the Vasco No. 5 vein, Boulder County, Colo., showing the relation of the ore bodies to siliceous "dikes" in the vein walls.

The Vasco No. 3 vein strikes N. 15°–20° E. and dips 60°–75° SE. It is a long, persistent vein and has been traced on the surface northward for 2,000 ft across the ridge north of Middle Boulder Creek (pl. 5), but as the Vasco No. 3 workings have long been inaccessible, the detailed geology of the vein is not known.

The largest and most productive ore shoot in this group of mines was in the No. 5 mine above the lower tunnel. This ore shoot was localized in and under one of the irregular siliceous "dikes" (fig. 89). The upper workings have long been inaccessible, but the shoot was described by O. H. Hershey in 1914 as follows:

> The ore is largely quartz and ferberite cementing fragments of granite and pegmatite. The ore shoot between the surface cuts and No. 1 tunnel is said to have been 125 feet long and to have contained 30 inches thickness of good-grade ore. On the No. 2 level * * * the ore shoot is 90 feet long. It is partly in gray granite and partly in an alaskite dike and occurs at and near the intersection of the main vein with a small barren vein.

The ore shoot ended abruptly where the vein flattens a few feet below the lower tunnel. According to notes on an old map, the siliceous "dike" was found on the bottom level at the turn 160 ft northeast of the shaft, but the vein was evidently too flat for ore to be localized there.

A second ore shoot on the No. 5 vein was found at the intersection with another siliceous "dike" at the southwest end of the lower tunnel of the Vasco No. 5 and the northeast end of the Vasco No. 2 mine (fig. 89). The "dike" dips 80° N. in the No. 5 tunnel, but in the Vasco No. 2 mine it flattens to about 45°, and this dip persists down to the fifth level of the No. 5 mine. Above the Vasco No. 2 drift the ore body was both in and southwest of the "dike," but in the Williams winze it was confined largely to the "dike," which there is aplitic. The ore in the Williams winze consisted of seams, lenses, and nodules of finely crystalline ferberite in brecciated and vuggy, dark-gray to black horn quartz and was 3 to 18 in. wide. The aplite adjacent to the ore body is moderately sericitized, but as is commonly true of the fine-grained and siliceous wall rocks, it appears only slightly altered.

An ore body on the Vasco No. 2 vein was stoped for a length of 100 ft in the Vasco No. 2 tunnel; below the tunnel it split into two prongs localized at the intersections of the vein with the Vasco No. 5 and No. 8 veins. Both prongs have been explored by winzes below the 87-ft level of the Vasco No. 2 shaft, and several inches of vuggy, crystalline ferberite was found a few feet below the level near the intersection of the No. 2 and No. 5 veins. Several attempts were made to explore the vein at depth by diamond drilling in this locality, but as the holes were collared almost on the vein, they were not successful.

The single ore shoot of the Vasco No. 8 mine had an average stope length of about 75 ft and raked north at about 60° near the top and at about 30° near the lowest level. As might be expected of a vein on which the west wall moved northward almost horizontally, the ore shoot is localized where the vein has a more easterly course than the average. The segment having this course is in a strip of granite, and as the rest of the vein is in schist and gneiss, the change in course was probably caused by refraction of the vein upon crossing the relatively thin band of granite.

The writers have little first-hand information on the Vasco No. 3 mine. The approximate extent of the ore shoot as indicated on old maps is shown in plate 13. The vein was evidently stoped continuously from the surface down to and probably below the upper tunnel. It was stoped at places above the lower tunnel and was stoped in the floor for a short distance. Evidently no ore was found on the Vasco No. 3 or other veins in the northeastern part of the Vasco No. 5 lower tunnel.

VASCO NO. 4 AND NO. 10 MINES

The Vasco No. 4 and No. 10 mines are on a single vein which trends northeast and dips 60°–85° NW. The vein is explored to a depth of 323 ft by the inclined shaft of the Vasco No. 10, which is at an altitude of 8,363 ft, about 1,400 ft north of Tungsten Post Office (pl. 5). Seven levels are turned from the shaft at vertical depths of 30, 66, 114, 158, 206, 256, and 323 ft (pl. 14). The Vasco No. 4 is opened by a shaft and two tunnels. The lower tunnel is the chief means of access to the mine and connects through a 20-ft winze with the fifth level of the Vasco No. 10 mine. A level 70 ft below the lower tunnel and about 195 ft below the collar of the Vasco No. 4 shaft is continuous with the sixth level of the Vasco No. 10 (pl. 14). The short bottom level of the Vasco No. 4 is 210 ft below the shaft collar.

The output from the Vasco No. 10 mine from 1915 to 1945 was about 20,000 units of WO_3, according to records which may not be complete, and an additional 3,000 units came from the Vasco No. 4 mine. The output from the two mines prior to 1915 is not known but probably was not large. The best ore in both mines was obtained from the upper workings by the Vasco Mining Co. from 1915 to 1919. In this period 2,020 tons of ore averaging 8.74 percent WO_3 was produced from the Vasco No. 10, and 136 tons averaging 8.20 percent WO_3 was produced from No. 4. A piece of ferberite weighing more than a ton was taken from the fourth level of the No. 10 mine by the Vasco Co. and sent to the U. S. National Museum. Most of the ore mined after 1919 came from the lower levels and was lower in grade. The average tenor of 2,447 tons mined from No. 10 by the Tungsten Production Co. from 1926 to 1930 was 2.55 percent WO_3, and 662 tons from the Vasco No. 4 averaged 2.37 percent WO_3. The mines were operated in 1934–35 by George Jump and in 1943–44 by the Boulder Tungsten Mills, Inc.

The Vasco No. 4 and No. 10 mines are in gneissic and biotite-streaked granite near the edge of the Boulder Creek batholith. The granite is cut by several dikes of both massive and gneissic aplite and by a dike of hornblende monzonite porphyry. The porphyry dike is very irregular in detail, but its persistent occurrence near the Vasco No. 4 shaft on the various levels indicates that its average dip is about vertical, and the surface map (pl. 5) shows the average strike to be N. 75° E.

The Vasco No. 10 vein zone in the lower tunnel of the No. 4 mine contains as many as four strong fractures in an area 10 to 30 ft wide. The tunnel follows first one and then another of these fractures (pl. 14). The fractures are gougy sheared or sheeted zones in the outer part of the tunnel, but to the northeast they become stronger and are filled with horn quartz which locally attains a thickness of as much as 4 ft. The quartz is gray to dark gray and grades into black, ferberite-bearing horn near the No. 4 shaft and at the northeast end of the tunnel. In the No. 10 mine the vein is a single vein of breccia 6 to 60 in. wide in a sheeted zone 4 to 8 ft wide. The breccia consists mainly of dark-gray horn quartz, but silicified wall-rock fragments are abundant locally. The gray horn breccia is cut in places by banded gray and black and some reddish horn. On the upper levels the breccia was filled with ferberite and black horn, but on the lower levels it is open and contains vugs as much as 8 ft long. The rock adjacent to the vein is sericitized in a zone 2 to 18 in. wide and beyond that shows argillic alteration.

Successive stages and directions of movement along the fissure are indicated by differences in the direction of grooves, by superimposed grooves, and by differences in the direction of offset of porphyry and aplite dikes. Most of the displacement was caused by steep normal-fault movement which displaced the eastward-dipping aplite dikes with the right side ahead. The porphyry dike is displaced a few feet with the left side ahead, however, and as the vein contains much more quartz and ferberite filling in the Vasco No. 10 mine, where the course is a little more easterly than in the Vasco No. 4 mine (pl. 14), the hanging wall probably moved downward and northeastward at a later stage prior to the deposition of the ore. Further movement is recorded by the brecciation of the early gray quartz, and it was probably as a result of this movement that the ore-bearing solutions were shut off from the open breccia along much of the vein.

The ore in the upper workings of the Vasco No. 10 mine was moderately coarse grained ferberite which occurred as a filling in vein breccia and as veinlets cutting both the breccia and banded horn veins within the breccia. The ore became finer-grained and more horny with depth in the main ore shoot, which bottomed on the fourth level, but crystalline ferberite was present on a vein in the hanging wall on the fifth and sixth levels. Coarse, open horn breccia in the main vein on the fourth and fifth levels, just below and southwest of the ore body, is dusted with tiny crystals of pyrite, galena, sphalerite, tetrahedrite, and adularia, as if the openings had contained a dilute and stagnant mineralizing solution. A white clay that consists of allophane and beidellite fills some of the small crevices and coats the upper surfaces of some of the breccia fragments. The breccia contains small patches of black horn which grades into the gray horn. Locally the breccia is stained by black manganese oxide, and as a little green copper stain also is present, the manganese is probably supergene. No sulfides were seen in association with ferberite, but traces of copper stain are found at places on the ferberite. Banded gray and black horn in a branch vein northeast of the shaft on the fourth level contains a quarter-inch streak of pale-pink to lavender fluorite. The barren vein on the seventh level contains abundant white clay in a distinct vein as much as 6 in. wide within the main vein. The clay consists of beidellite and minor cimolite and is similar to clay filling vugs in ore in the lower part of the Vasco No. 2 mine except that the latter also contains alunite in tiny grains. There is no trace of sulfides or ferberite in the open vein breccia on the seventh level.

The main Vasco No. 10 ore shoot was an irregular body that extended from a point near the surface down to the fourth level, where it bottomed abruptly except for a small prong at the northeast end (pl. 14). On the fifth and sixth levels a branch vein that joins the main vein from the north and dips 65°–80° E. was stoped for a length of about 50 ft (pl. 14). The Boulder Tungsten Mills prospected this vein by diamond drilling on the fourth level and found a strong horn vein but no ore. Only two small ore bodies have been found in the Vasco No. 4 mine. The longer and richer one was trenched through a length of more than 200 ft at the surface but bottomed a short distance below the surface except for a narrow prong which was mined down to the bottom level near the No. 4 shaft (pl. 14). This narrow extension of the ore shoot, if it is genetically a part of the same shoot, was relatively low in grade and horny. A small blind body of horny ore about midway between the No. 4 and No. 10 shafts was stoped above and below the lower tunnel level. Two veins of gray and black horn, each as much as 4 ft wide, and several feet of intervening silicified granite seamed by horny ferberite and gray and black horn were mined through widths of as much as 15 ft. The black horn contains considerable ferberite, and the mined ore is reported to have assayed 1 to 2 percent WO_3, but the ore is so hard and siliceous and the ferberite so fine-grained that the material could not be milled profitably.

The black horn characteristic of the Vasco No. 4 mine grades into gray horn; some of it is brecciated, and it seems to be related more closely to the brecciated gray horn than to the ferberite and black horn that fill openings in brecciated gray horn in the Vasco No. 10 ore shoot. Thus there is a suggestion of two stages of ferberite deposition, an early one that was transitional from the gray horn mineralization and a younger one in which ferberite and black horn were deposited in the openings in brecciated gray horn. At least some of the black horn of the second stage is younger than the crystalline ferberite. The traces of black horn in the barren breccia adjacent to the Vasco No. 10 ore shoot are a product of the earlier stage, and the film of sulfide and clay minerals and adularia is believed to represent the final, stagnant phase of the early stage. Although the film of sulfides was not noted between the ferberite filling and the rock and quartz fragments in the breccia in the ore shoot, the occurrence of the film on the breccia right up to the edge of the ore strongly suggests that it is older than the ore filling the breccia. The rare traces of copper stain on the ore may have come from the sulfide film.

The bottom of the Vasco No. 10 ore shoot is at a higher altitude than the highest ore in some of the nearby Vasco mines. The relatively small area filled by ferberite in comparison to the space available on the vein, and the indication of two stages of tungsten deposition, suggest that a large part of the No. 10 vein was sealed off and isolated from the mineralizing solutions during the main period of tungsten deposition. The vein may have been dammed off by fault movement which closed some restricted channelway below the present workings, or it may have been plugged by deposition of clay such as the beidellite on the bottom level. In either event, the solutions that deposited the ore in the Vasco No. 10 ore shoot probably gained access to the upper part of the vein by some indirect route, perhaps through minor and intersecting fractures. This would explain the abrupt ending of the flat-bottomed ore shoot in an open breccia which contains small amounts of sulfides and clay. The difference between the clay in the open breccia near the ore shoot and in the vein on the seventh level gives some support to the theory that the vein may have been clogged by clay deposition. The clay in the breccia on the fourth and fifth levels consists of beidellite and allophane, but the beidellite has grown in and clearly replaces the allophane, and the clay may have been deposited as almost pure allophane. The clay on the seventh level appears to have been deposited as beidellite mixed with some cimolite. Thus it is a different clay, and as it occurs as a distinct, strong vein rather than as a thin coating on breccia and a filling in minor crevices, it must be a product of a different and more active stage of mineralization. Most of the beidellite clay found in the district is in pockets in the upper parts of veins and above ore shoots. As beidellite is chronologically a product of a late stage possibly following the deposition of the ore, or spatially is a product of the upper parts of veins, ore may lie below the beidellite clay horizon in the Vasco No. 10 vein. A drill hole on the seventh level put down by the Boulder Tungsten Mills in 1943 showed no change in the vein at a depth of 50 ft below the level. A second hole was later drilled to a somewhat greater depth, but the record of this hole has been lost. Exploration of the No. 10 vein below the present workings would require considerably more than two shallow drill holes, and if intensive exploration of the Vasco No. 10 should be undertaken again, investigation of the No. 10 vein at depth should be considered.

The Vasco No. 10 vein splits up and is barren near the portal of the lower tunnel of the Vasco No. 4 mine. It may die out a short distance to the southwest, but as it is nearly on the strike of the Barker No. 4 vein in the Clark tunnel, some prospecting in the area between the portal of the Vasco No. 4 tunnel and the Hurricane Hill breccia reef, about 800 ft to the southwest, is warranted (pl. 13).

VASCO NO. 7 MINE

The Vasco No. 7 shaft is on the southeast slope of Hurricane Hill, about 1,700 ft northwest of Tungsten Post Office, at an altitude of 8,425 ft (pl. 5). The mine is one of the oldest in the district, having been started as a prospect shaft for silver before tungsten mining began. It comprises an inclined shaft 336 ft deep and five shaft levels, the first of which is a tunnel. A sixth level is turned from a winze 109 ft below the fifth shaft level, and a sublevel lies 40 ft below the fifth level (pl. 15). The total output from the mine is not known. Records which are probably incomplete indicate a minimum output of about 6,500 units of WO_3 from 1915 to 1945, and as the mine is said to have been fairly productive prior to 1915, the total output is probably at least 10,000 units. The average tenor of the ore mined from 1915 to 1920 was 9.89 percent WO_3. The mine was operated by the Tungsten Production Co. in 1926–27, when the fifth level was driven, and by the Boulder Tungsten Mills, Inc., in 1943–44, when the work through winzes below the fifth level was done.

The Vasco No. 7 mine is in granite that is cut by dikes of aplite and a dike of hornblende monzonite porphyry. Like most of the Vasco mines, it is in the border zone of the Boulder Creek batholith, and the gneissic, streaky granite shows many variations in composition and texture. The aplite includes both massive and gneissic varieties, and some of the gneissic aplite is seen to grade into gneissic granite as it is traced downward in the mine. The aplitic dikes all trend northwest and dip northeast, mostly at 45° to 60°. A dike of hornblende monzonite porphyry is exposed on all levels and is very irregular in form, size, and attitude. Marked differences in the size and trend of the dike on opposite sides of the vein indicate that the vein fracture existed at the time the porphyry was intruded, but the dike is displaced about the same distance as the pre-Cambrian dikes. Alteration of the wall rocks along the Vasco No. 7 vein is relatively strong. Rock in and immediately adjacent to the vein is strongly sericitized and silicified, and the succeeding zone of argillic alteration is wide and strong, particularly on the footwall side.

The Vasco No. 7 vein strikes northeast and at most places in the mine dips steeply northwest. However, at the southwest end of the fourth and fifth levels the vein gradually steepens to a vertical dip and finally dips steeply to the southeast. A footwall vein branches eastward from the No. 7 vein on the second and third levels; it is weak on the fourth level and was not recognized on the fifth level. The main Vasco No. 7 vein makes a sharp turn to the north where the footwall vein branches from it on the second level, and on and above this level the footwall vein is the stronger and more productive vein. The tunnel level was not accessible in 1943–44, but the position of the tunnel on the level map (pl. 15) indicates that a stope near the shaft was on the footwall vein. Near the portal the tunnel probably follows the main vein.

Wall rocks along both veins are displaced with the right side ahead. The maximum horizontal displacement of northeastward-dipping aplite dikes along the main vein is about 20 ft, and as grooves on the walls of the fissure consistently plunge about 40° SW., the hanging wall evidently moved about 15 ft down and southwest relative to the footwall. Grooves along the footwall vein indicate that movement was almost horizontal; the north wall is displaced about 5 ft to the west on the third level, but only a 2-in. displacement was noted on the fourth level.

Three ore shoots were exploited in the Vasco No. 7 mine, and the ore in the winzes below the fifth level probably constitutes a fourth shoot. One shoot was mined on the footwall vein near the junction with the main vein above the second level. Two shoots were found on the main vein (pl. 15), and in harmony with the direction of movement along the vein, one shoot occurred where the vein steepens southwest of the shaft, and one occurred where the vein turns to the left northeast of the shaft on the third, fourth, and fifth levels. The southwestern ore shoot extended from a point above the tunnel level, and possibly from the surface, down almost to the fourth level. The shoot was irregular in shape and raked northeast in the upper part and southwest in the lower part.

The top of the main northeastern ore shoot was evidently between the second and third levels, but some stoping may have been done on the same vein above the second level. The shoot was about vertical and narrowed from a stope length of 125 ft on the third level to two narrow prongs in the back of the fifth level. Ore was present for a length of only a few feet in the floor of the fifth level at the northeastern winze, but in the sublevel 40 ft below, ore extended discontinuously for 90 ft back toward the shaft. As much as 6 in. of vuggy, crystalline ferberite containing some brecciated gray horn and as much as 30 in. of lower-grade "feedered" ore were found at places in the floor of the sublevel. Fairly good ore was cut 47 ft below the sublevel in a drill hole put down by the Bureau of Mines in 1943, and the 120-ft winze opposite the shaft was sunk as a result by the Boulder Tungsten Mills, Inc. Lenses of crystalline ferberite 4 to 18 in. wide were found in the winze beginning at a depth of 67 ft. A level was turned at 109 ft in the winze, and discontinuous lenses of high-grade ore were found on the vein on both sides of the winze. The drill hole was not found in a raise or stope above the drift and may be in the footwall of the vein explored by the drift on the sixth level. Work in the Vasco No. 7 mine was stopped abruptly before exploration was carried to a logical conclusion when the Metals Reserve Company, under whose direction Boulder Tungsten Mills was operating, withdrew from the tungsten business in the spring of 1944.

Although the ore found below the fifth level was in discontinuous lenses, many of the lenses were large enough to mine, the ore was of good quality, and the frequency of the ore pods suggests that an ore shoot may be nearby. The Vasco No. 7 mine, with a total vertical depth of 445 ft, is one of the deeper mines of the district, but the character of the ore, the vein, and the altered wall rocks near the bottom of the mine is no different from their character in the workings above. In general, the vein appears stronger on the fifth level and in the winze workings than on the fourth level. The Vasco No. 7 is about midway between the Vasco No. 6 and Cold Springs mines, both of which were mined to an altitude 200 to 300 ft lower than the fifth level of the Vasco No. 7. If the price of tungsten should warrant future mining in the Boulder district, further work in the lower part of the Vasco No. 7 mine would be justified.

Few prospects remain in the upper part of the Vasco No. 7 mine, but it might be noted that the reversal of dip and the weakening of the vein at the southwest end of the fourth and fifth levels suggest that a vein may be present in the hanging wall and extend southwestward from this vicinity. The presence, if not the quality, of such a vein could be easily determined by diamond drilling.

VASCO NO. 1 MINE

The Vasco No. 1 mine is at an altitude of about 8,510 ft on the east flank of Hurricane Hill, about 2,500 ft northwest of Tungsten Post Office (pl. 5). It was one of the most productive mines of the district for a time during the early days of tungsten mining. Records of the output from this mine alone are not available, but some suggestion of the degree of productivity is indicated by the record of total output from the Rogers patent, upper tract, when the tract was purchased by the Vasco Mining Co. in 1915. According to reports published in the Boulder Daily Camera early in 1916, production from the tract totaled 5,500 tons of ore averaging 14 percent WO_3 up to September 1915. This is equivalent to 77,000 units of WO_3. According to men familiar with the district at the time, the No. 1 mine was the chief source of this output, although a considerable amount came from Nos. 3, 4, 5, and 7, and relatively small amounts came from Nos. 2, 6, 8, and 10. As the output from the Vasco No. 5 mine, which was the second most productive mine in the tract up to 1915, was probably about 12,000 units up to June 1914, it is probable that the output from the Vasco No. 1 mine up to 1915 was at least 30,000 units of WO_3, and it may have been substantially more. The grade of the ore must have been close to the average of 14 percent for ore from the tract as a whole. The mine was operated by the Vasco Mining Co. from 1915 to 1918, by the Tungsten Production Co. in 1926–27, and by the Boulder Tungsten Mills, Inc., in 1943, but the total output from these operations was less than 1,000 units of WO_3.

As shown in figure 90, the mine comprises an inclined shaft reaching a vertical depth of 220 ft and four short levels at vertical depths of 46, 95, 142, and 220 ft. The two upper levels extend into open stopes and were largely inaccessible in 1943.

The vein strikes northeast and at most places dips about 70° NW. The hanging wall moved down and west at 40° to 45° for as much as 60 ft. This is one of the largest displacements known on a tungsten vein in the district. The vein is strong and at most places on the two lower levels consists of 2 to 5 ft of brecciated horn quartz and fragments of silicified wall rocks. Little is known of the character of the vein in the ore shoots, but widths of as much as 5 ft of rich ore are reported, and judging by the size of the vein below the

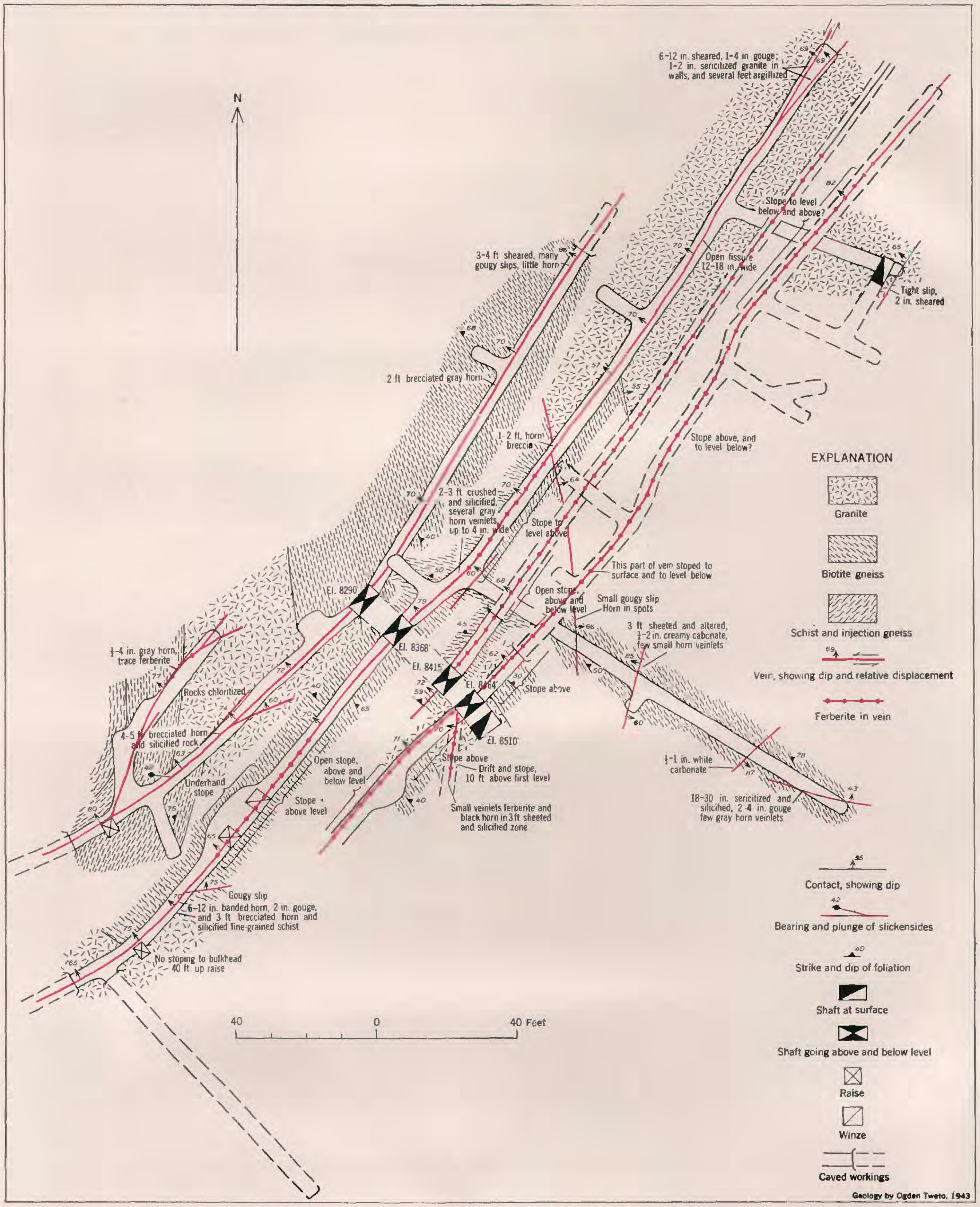


FIGURE 90.—Geologic plan of the Vasco No. 1 mine, Boulder County, Colo.

ore shoots, an average width of at least 2 ft may be inferred. On and above the first level a single ore shoot having a stope length of at least 250 ft was worked. The ore shoot split below the first level. The main shoot northeast of the shaft appears to have extended to the second level, and a narrow prong near the shaft extended to the third level (fig. 90). A prong southwest of the shaft raked steeply southwest below the first level and was stoped to about 25 ft below the third level. No ferberite is present in the wide vein of open breccia below the ore shoots on the third and fourth levels. The northeastern prong of the ore shoot dies out in open breccia on the third level, and as the vein for 80 ft to the northeast is an open fissure as much as 18 in. wide, the ore mined down to the second level northeast of the shaft may have bottomed in an open fissure. This fractional utilization of the space available for ore deposition must reflect either a limited supply of tungsten or some vagary in circulation of the ore-forming solutions which caused part of the open ground on the vein to be bypassed.

The wall rocks of the Vasco No. 1 vein grade downward and northeastward from schist through injection gneiss and biotite gneiss to gneissic granite. The northeastern part of the third level is in granite, and judging by the dip of the granite contact and the presence of granite near the shaft on the first level, the stopes northeast of the shaft on the first and second levels are probably largely in granite. Considerable ore was found between walls of schist on both sides of the shaft. This occurrence is unusual, but as the fissure is strong and cuts the schistosity at a high angle, it evidently remained open enough to be filled by ore.

The dip and course of the vein, the character of the gangue, and the wall-rock alteration show very little change with depth except southwest of the shaft on the fourth level, where the vein swings to the west and the walls are strongly chloritized. The similarity of the vein on the upper and lower levels suggests that the limitation of ore to the upper part of the open space available on the vein is a reflection of some quirk in the circulation system rather than of any physicochemical differences, and as the Vasco No. 1 is a relatively shallow mine, further exploration at depth seems warranted geologically. The increasing quantity of granite to the northeast, together with the presence of numerous aplite dikes in the granite at the surface, and a rapid increase in the degree of sericitization and silicification in the last few feet of the drift on the third level make further prospecting to the northeast desirable also.

FOREST HOME AND COLD SPRING NO. 2 MINES

The Forest Home shaft is at an altitude of about 8,490 ft on the east flank of Hurricane Hill (pl. 5). It is about 3,500 ft northwest of Tungsten Post Office and 1,500 ft west-southwest of the Cold Spring mine. The mine comprises an inclined shaft that dips steeply north and two levels at depths of 107 and 200 ft. The first level connects near its east end with the Cold Spring No. 2 shaft, and the southern drift east of this connection (pl. 16) is part of the Cold Spring No. 2 mine. The Forest Home claim is owned by Gold, Silver, & Tungsten, Inc., and the adjacent Cold Spring claim is the property of the Wolf Tongue Mining Co. The northern side line of the Cold Spring claim (senior claim) lies a few feet south of the Forest Home shaft and extends N. 66½° E.

The history and production of the mines are known only imperfectly. The Forest Home was operated during World War I by J. G. Clark, of the Tungsten Production Co., predecessor of Gold, Silver, & Tungsten, Inc., and is reported to have produced $80,000 worth of tungsten in 2 years. As the price of tungsten fluctuated rapidly and widely at that time, the average price may have been anywhere between $20 and $50 per unit, suggesting a tungsten output of 1,600 to 4,000 units. Some production came from the Forest Home, notably from a rich float "bed" known as the "Potato Patch," before the first war, but the amount is unknown. The mine was operated by a Mr. Whitesides from 1917 to 1921 and was evidently operated briefly at times between 1921 and 1941. It was reopened by Elmer Hetzer and Ed Henderson in 1942, and Hetzer continued operation alone from 1943 to the summer of 1945. The Cold Spring No. 2 was worked to a minor extent through the Forest Home in 1943–45, but the main periods of operation were 1908–9 and 1918. In 1944 the Cold Spring No. 2 was almost wholly inaccessible, and the shaft was almost indistinguishable at the surface. The No. 2 is known to have produced about 2,000 units of WO_3 in ore averaging 8½ percent WO_3. The recorded output from the two mines amounts to 10,000 to 12,000 units of WO_3, and the total output, including the production from many shallow shafts and trenches in the vicinity, is probably at least 15,000 units.

The Forest Home and Cold Spring No. 2 mines are in a structurally complex zone where the Cold Spring vein splits up and is intersected by a northeastward-trending vein zone that lies between the strong eastward-trending Cold Spring and Madeline fracture zones. (See descriptions of the Cold Spring and Western Star mines and pls. 5, 16, 17, 18.) Westward from the main Cold Spring mine, the Cold Spring vein trends about S. 75° W. almost to the Cold Spring No. 2 mine, where it turns to a more southwesterly course and then splits. The southern branch, which trends S. 40°–60° W., is evidently the main Cold Spring vein. It is present in the Cold Spring No. 2 shaft but splits into several branches southwest of the shaft. The northern branch is the Forest Home vein, which trends S. 75°–80° W. The north, or hanging wall of the Forest Home vein is broken by many fractures, as shown in pl. 16. This fracturing seems to die out downward, for it is much weaker on the second level than on the first, and the Cold Spring vein is a well-defined single fissure on the fourth level of the Cold Spring mine, 143 ft below the lowest Forest Home workings.

The accessible workings of the Forest Home mine are almost entirely in coarse-grained, moderately gneissic Boulder Creek granite. Old stopes near the shaft above the first level were mostly in aplite, however, and the distribution of aplite at the surface suggests that the Cold Spring No. 2 workings are partly in aplite. The granite in the walls of the Forest Home vein is intensely altered to clays for several feet, and the drifts along the vein are tightly lagged. The wall rocks of the numerous minor veins in the hanging wall of the main vein are fresh or only slightly altered. Unlike the Forest Home vein, which contains as much as 3 ft of soft, gougy material, these small veins are almost free of gouge.

Owing to the uniformity of the wall rocks and the tight lagging along the drifts, the displacement along the Forest Home vein could not be determined with certainty, but an aplite dike at the surface appears to be displaced with the right side about 25 ft ahead. Grooves along the vein plunge about 20° W., and the north wall probably moved down and west like the north wall of the Cold Spring vein. Most of the minor veins are normal faults on which the northwest walls moved down and northeast, but the displacement along some of them appears to be as little as 1 in.

Except for one rather small ore shoot on the Forest Home vein near the surface, the production all came from the minor veins, and the Forest Home vein itself is completely barren at most places in the mine. It contained ore at the surface immediately east of the shaft and was stoped down to an old level at a depth of about 60 ft. This ore was evidently localized where one wall of the vein was aplite and where the vein dipped steeply. On the first, or 107-ft level, the vein flattens progressively from a dip of 83° N. at the west breast to 50° N. opposite the Cold Spring No. 2 shaft, and the only ore mined from the vein on this level came from two small stopes in the western part. The Forest Home vein was completely barren on the second level.

The chief source of ore in 1916–17 was a southward-dipping vein that is in the hanging wall only a few feet from the Forest Home vein on the first level (pl. 16). This vein strikes about parallel to the Forest Home west of the Cold Spring No. 2 shaft, but opposite this shaft it turns sharply to N. 30° E. It was stoped to a height of about 50 ft above the level, and the stope is continuous through the turn. The vein in the back of the stope is a sheeted zone 6 to 18 in. wide that contains seams of medium-crystalline ferberite and a little horn quartz. The rock is essentially fresh, although most of it is iron-stained.

Most of the ore mined in the Cold Spring No. 2 came from the lower level, at the east end of the first level of the Forest Home, but some ore may have been obtained from the upper level, as the veins were productive at the surface. The bottom of the Cold Spring No. 2 shaft is shown to be 10 ft above the first level of the Forest Home on the available maps, but a hole drilled under the incline connecting the shaft and the drift broke into old workings at a depth of 35 ft below the first level of the Forest Home. The extent and production of these workings and the means of access to them are not known.

The ore mined in 1943–45 came chiefly from the group of northeastward-trending veins on the first level. The main vein of this group, in the drift 135 ft east of the shaft, was discovered by diamond drilling in 1943. There was no sign of it in the hanging wall of the Forest Home vein, and after it had been opened up by a drift it was observed to die out completely about 10 ft short of a junction with the Forest Home. The vein dips 80°–85° N. at most places, but locally it is vertical or dips steeply south. It was stoped through a length of 70 ft on the first level and up to old workings at the surface. In searching for this vein on the second level, a vein of similar appearance but different course was found at the east end of the level a few feet north of the main drift on the Forest Home vein. A raise put up at the short crosscut from the Forest Home (pl. 16) is almost at the junction of this lower vein and the "upper" vein which was worked on the first level. The lower vein was stoped on both sides of the raise, beginning about 30 ft above the level, and farther northeast was stoped from the back of the second level. It is irregular in dip but in general dips north through most of the distance between the two levels. Near the raise it flattens suddenly in the floor of the first level and dies out as a thin veinlet dipping about 10° NW. Farther northeast it reverses dip and branches but continues upward and northeastward. The strongest and most productive branch of this vein, which is in the southern branch of the drift that trends northeast on the first level (pl. 16) dips 60°–65° SE. and was stoped to a height of 40 ft above the drift, where the stope joins another stope on a steeper branch vein to the northwest.

These veins are all small. At many places in the stopes they were no more than a 1-in. seam of ferberite between walls of fresh granite, and the maximum width was about 6 in. In the wider parts of the veins the ferberite was in veinlets in sheeted granite or in lenticular bodies a few feet in diameter and a few inches thick that contained some horn quartz as well as ferberite. Such narrow veins could be mined only because of the high quality of the ferberite and the persistence of the seams and at a time of relatively high tungsten prices. The ferberite is a finely crystalline, compact variety that contains practically no quartz.

The Forest Home mine is the only locality known in the district in which manganese minerals accompany the ferberite. Some of the ore mined in 1943–44 contained a few small vugs that were lightly coated with powdery alabandite, the manganese sulfide. The alabandite gives the ferberite a greenish-black velvety sheen, although the coating on individual ferberite crystals is extremely thin. The powder is fine-grained, and most of the particles seem to be irregular in shape, but under relatively high magnification an occasional triangular crystal face is seen. The edges of ferberite crystals coated by alabandite are slightly rounded, as if the ferberite had been attacked by solutions that deposited the manganese sulfide.

Just before the mine closed in 1945 some ore was obtained from an irregular vein in the footwall of the Forest Home on the first level, about 80 ft east of the shaft. Hetzer says that the vein contained 6 to 48 in. of ore where it crossed a relatively flat aplite dike. The ore was unusual because some of it had a reddish cast like that of hubnerite and was associated with manganese oxides. These consisted of pyrolusite and psilomelane and were in botryoidal crusts one-sixteenth to one-eighth inch thick. Judging by the jig concentrates, manganese was fairly abundant in the ore, and Hetzer says that most of it was in a hanging-wall streak in which it coated the upper surface of a vuggy ferberite vein. Considering the occurrence of alabandite elsewhere in the mine, it seems probable that the manganese oxides are oxidation products of alabandite. The observed alabandite content of the hanging-wall veins is almost infinitesimal, but the relative abundance of manganese oxides in the footwall vein suggests that alabandite was more abundant there. The ore from the footwall vein was characterized by a relatively high phosphorous content, and Hetzer says that the table concentrates assayed as high as 0.85 percent phosphorus at times. This may represent monazite and apatite from the wall rocks, as proved for concentrates from the nearby Cold Spring mine. It is unlikely that the phosphorus was in the manganese oxides, because the jig concentrates contained considerable manganese but did not contain an unduly high proportion of phosphorus.

The association of manganese minerals with ferberite low in manganese is somewhat surprising. Is is possible, of course, that the mineralizing solutions continued to carry a little manganese after the stage of ferberite deposition, but the occurrence of manganese minerals, other than slightly manganiferous ankerite, should not be restricted to one small locality. Moreover, the reddish, hubneritic appearance of some of the ferberite in the footwall vein suggests that some of the tungsten mineral itself is manganiferous. Unfortunately an analysis of the ore is not available. A possible explanation for this local concentration of manganese is that the tungsten solutions leached manganese from some local source. The Hurricane Hill breccia reef, which probably lies at a depth of about 1,500 ft below the surface at the Forest Home mine, may have been such a source. Sulfide deposits characterized chiefly by galena occur in the reef at a point on the strike of the Forest Home vein as well as on the north slope of Hurricane Hill; it is possible that manganese was deposited in the reef zone during base-metal mineralization and that the later tungsten solutions obtained manganese from such a deposit.

The Forest Home mine is in the midst of many productive veins, and the substantial production from short workings at shallow depth should encourage further exploration. It seems probable that fewer small veins will be found with depth, but their place may be taken by one or two stronger veins. The widespread occurrence of ore near the surface in small veins that are almost inconsequential as fault fissures should encourage further prospecting in the walls, particularly in the northeastern part of the mine, where aplite and pegmatite are more abundant. Further exploration northeast of the present workings seems warranted by the persistence of the vein zone in that direction, the productivity of veins in this zone at the surface, and by the increasing amount of aplite to the northeast. A surface hole drilled by the Bureau of Mines 510 ft N. 48° E. of the Forest Home shaft cut several horn quartz veins and considerable aplite. This hole was drilled S. 45° E. at an angle of −45° for 190 ft. The main Forest Home vein has been explored for only a short distance west of the shaft, and as the vein steepens westward and also enters an area cut by many aplite and pegmatite dikes, further exploration to the west seems warranted. Similarly, several veins on the Cold Spring claim, south of the Forest Home, are partly in aplite, were productive at the surface in places, but remain to be explored at depth.

WESTERN STAR MINE

The Western Star mine of the Wolf Tongue Mining Co. is about 2,000 ft northeast of the top of Hurricane Hill and about 1,500 ft northwest of the Cold Spring mine (pl. 5). It is opened by a vertical shaft whose collar is at an altitude of about 8,435 ft and by an old inclined shaft. Three levels are turned from the main, or vertical shaft, and a sublevel known as the intermediate level lies between the first and second levels. The first and intermediate levels are at depths of 75 and 122 ft below the collar of the new shaft. The depths of the second and third levels are not known exactly but are approximately 200 and 300 ft. According to Elmer Hetzer, the original Western Star shaft was started as a silver prospect before tungsten mining began, and a vein of tungsten ore stood exposed in it when ferberite was first identified in the district in 1900. The production from the Western Star, including workings on the Georgia A. vein, from 1907 to 1929 was 10,476 units of WO_3 from 1,876 tons of ore that averaged 5.58 percent WO_3, and a substantial output was evidently achieved prior to 1907. The richest ore lay between the surface and the first level near the old shaft, and as the first level had already been driven through the ore by 1904 or 1905 (Van Wagenen, 1906, p. 148), the ore body must have been mined at least in part by that time. The mine was evidently under water for many years prior to World War II. It was reopened for a few months in 1942 by the Wolf Tongue Mining Co. Some ore was produced and some exploration was done, but no major new ore body was found. The writers are indebted to E. E. Wahlstrom and the Wolf Tongue Mining Co. for the information shown in plate 17, which is taken from maps made by Wahlstrom in 1942.

The Western Star workings are on veins in the hanging wall of a strong fault that strikes east and dips 40°–60° N. This is the Madeline fault (Star fault on Wahlstrom's maps), which extends eastward and then northeastward for 2 or 3 miles (pl. 1). In the Madeline mine, which is on the fault about 1,500 ft east of the Western Star, the north, or hanging, wall is displaced down and west. At most places, the fault is a wide gouge streak, in an intensely argillized granite, but it contains horn quartz locally, particularly northeast of the Madeline shaft, and a little ferberite was found in it in the Madeline, Western Star, and Firth mines. In the Madeline mine horn quartz in the upper part of the vein bottoms abruptly in gouge as shown in figure 91.

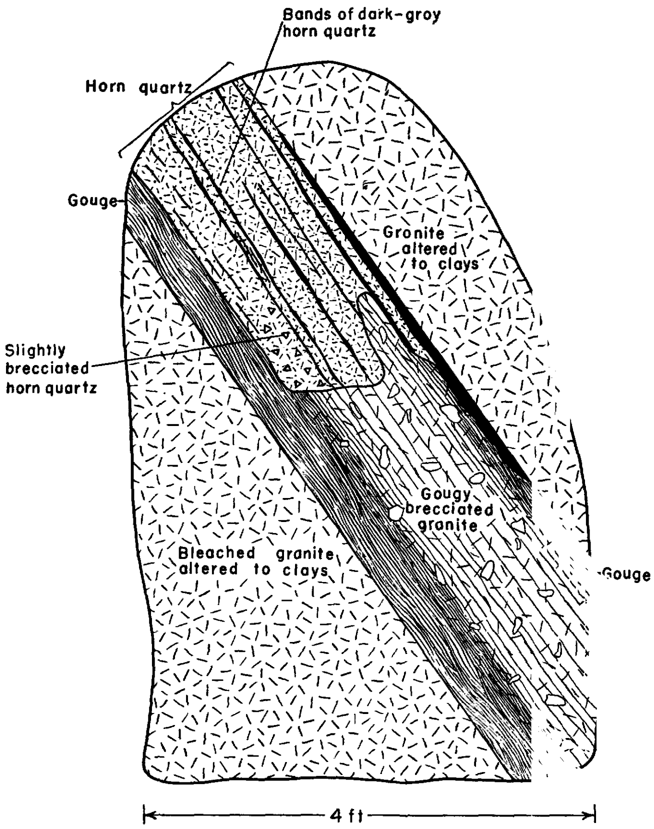


FIGURE 91.—West face of a drift in the Madeline mine, showing the abrupt ending of the wide vein of horn quartz on gouge.

The Western Star vein is parallel in strike to the Madeline fault but dips more steeply; the dip ranges from about 65° N. in the eastern part of the mine to 82° N. in the western part. The vein lies about 125 ft north of the Madeline fault at the surface and is evidently a subsidiary fracture formed by the same stresses that produced the Madeline. It joins the Madeline fault between the first and second levels (probably just below the intermediate level), and as the hanging wall of the Madeline moved downward, the absence of any vein corresponding to the Western Star in a crosscut driven 180 ft southeastward from the Madeline on the second level (pl. 17) indicates that the vein ends at the fault. The hanging walls of the Madeline and Western Star fissures contain many northeastward-trending feather-joint veins. These range from small mineralized joints 2 or 3 ft apart to veins persistent for several hundred feet, but the strongest northeastward-trending veins evidently represent a younger, intersecting vein zone, for the Madeline fault appears to be displaced by a northeastward-trending vein zone on the second level as shown in plate 17.

The exact location and extent of the stopes are not known, but the general location of most of them is indicated by the mill holes or ore chutes shown in plate 17. The mine is mostly in granite, but there is considerable aplite, and a glance at plate 17 shows that most of the ore was found where at least one wall of the vein was aplite. The richest ore in the mine was pierced by the Old shaft and extended through a length of 50 or 60 ft from the surface to or below the first level. According to Will Todd, this ore was coarsely crystalline ferberite filling the Western Star vein and feather joints that were 2 or 3 ft apart in the hanging wall. Both the Western Star vein and the feather-joint veins are cut off abruptly at the Madeline fault, and the only ore found beneath the fault was on the intersecting northeastward-trending vein on the second level (pl. 17). Moderately strong feather-joint veins north of the Old shaft were evidently stoped on the first and intermediate levels. The vein zone that crosses the Madeline on the second level appears to have been stoped at intervals through almost the entire length of the level. The chief source of ore on the third level was apparently in a hanging-wall vein a few feet north of the Madeline fault. This vein dips 40° N., about parallel to the fault.

The Georgia A. vein, a northeastward-striking feather-joint fracture about 75 ft northwest of the shaft, is supposed to have been stoped from the second level to the surface, but the map shows no workings on it on the first level. However, there may have been a connection with the vein through the short crosscut from the north drift on the first level, about opposite the shaft; this crosscut is marked "inaccessible" on Wahlstrom's map. The Georgia A. appears to have been stoped to a minor extent on the third level also. A total of 206 tons of ore mined from the Georgia A. at times from 1907 to 1928 averaged 14.38 percent WO_3.

COLD SPRING MINE

The Cold Spring mine of the Wolf Tongue Mining Co. is about 2 miles northeast of Nederland, at an altitude of about 8,325 ft. Its total production is second only to that of the Conger mine. From 1908 to 1935, inclusive, it produced 2,031,768 lbs, or 101,588 units, of WO_3 from 14,301 tons of ore averaging 7.10 percent WO_3. The mine was opened by the Wolf Tongue Mining Co. in 1908, and with the exception of the years 1919, 1921, and 1922 it produced steadily to 1936, when it was finally closed down and allowed to fill with water. In 1943 the Wolf Tongue Co. sank the Cold Spring No. 4 shaft a few hundred feet west of the Cold Spring, and a level was turned at a depth of about 75 ft. Some ore was obtained from the Footwall vein, but workings on the Cold Spring vein broke into old stopes.

WORKINGS

The mine is opened by two inclined shafts 365 ft apart. The collar of the Old shaft is at an altitude of 8,365 ft, and that of the New shaft is at 8,329 ft. The extensive interconnected levels turned from these shafts are shown in plate 18. The Old shaft follows the Cold Spring vein to the third level and then passes into the footwall of the vein. The New shaft was sunk in slightly altered country rock well in the footwall of the vein, so that it would be just outside the weak, caving rock of the strongly argillized zone, and is inclined steeply to the north, approximately parallel to the vein. Six main levels were turned from the Old shaft at vertical depths of 44, 92, 141, 238, 327, and 425 ft, and the "5–50" sublevel was turned at 376 ft. The New shaft is connected by short crosscuts to the fifth and sixth levels of the Old shaft, and the lowest level of the mine—the seventh—is turned from the bottom of the New shaft 63 ft below the sixth level at the New shaft.

The first and second levels were inaccessible in 1930, but their position, as well as that of the drift in the Cold Spring No. 4 mine, is indicated on the map of the third level in plate 18. Crosscuts from the main drift on the third level have been driven to the 1929 vein 20 ft north of the Cold Spring vein and to the Sharkey vein 100 ft south of it. The fourth level extends only a short distance east of the Old shaft but has been driven 860 ft to the west. A crosscut 110 ft into the hanging wall near the shaft cuts several veins, some of which were followed for a hundred feet or more. The fifth level is the longest one in the mine, extending 1,750 ft east of the Old shaft and 850 ft to the west. A short crosscut was driven northward near the Old shaft on the fifth level to a branching vein which was followed northeastward for a few hundred feet, and another was driven 310 ft northward from a point 1,275 ft east of the Old shaft.

The sixth level follows the vein 363 ft west and 550 ft east of the Old shaft. A crosscut driven 125 ft to the south cut the Sharkey vein close to the New shaft; the vein was followed for 126 ft, but no ore was found.

The seventh level follows two nearly parallel branches of the Cold Spring vein 300 ft west of the New shaft and 230 ft to the east. A crosscut 507 ft long extends southeastward from a point near the New shaft to the Orange Blossom vein, where it is connected with the bottom of the Orange Blossom shaft by a raise 134 ft high. The Orange Blossom vein and two other veins 35 ft and 80 ft northwest of it have been explored from the crosscut by drifts 200 ft to the east and 270 ft to the west. The total footage of the drifts and crosscuts of the Cold Spring mine in July 1930 was 10,100 ft. Most of the mine was accessible at that time. Both the caved and open workings are shown on the map, together with the workings driven after the geologic mapping had been done.

ROCKS

The country rock of the entire mine is dark-gray, coarse-textured gneissic biotite granite of the Boulder Creek batholith. The granite is cut by small seams of pegmatite and aplite, but these seams are not abundant. The gneissic structure strikes northwest and dips about 40° NE. in most of the mine, but there are many local variations in strike and dip.

The country rock for a short distance on both sides of most of the veins is moderately hard and fresh in appearance. This hard "casing," as it is called by the miners, is generally thinner than the vein filling; where the Cold Spring vein, for example, is 5 ft wide the hard casing extends 15 to 20 in. beyond it (fig. 55). The casing gives way abruptly to an envelope of soft argillized rock that is generally three to five times as thick as the vein (see section *E–E′*, pl. 19). Although the change from the hard casing to the soft envelope is sharply marked, the outer edge of the envelope is vaguely defined, and the altered rock grades gradually into fresh rock. There is a little variety in the appearance of the altered rock in the inner half of the envelope, but the maximum alteration appears to be about a third of the distance out from the hard casing and coincides with the maximum development of beidellite. The maximum observed width of the altered envelope is about 30 ft, on the fifth level, in the crosscut to the vein from the New shaft. A detailed description of the mineralogy of the altered rock and the chemical changes that have taken place is given on pages 58–62.

When first exposed, all the altered rock stands up well, but after a time the argillized rock gradually disintegrates and begins to slough into the crosscuts. The silicified casing, on the contrary, stands exposure well, and the miners therefore like to keep the drifts within the casing if possible.

MINERALOGY

Three general types of vein filling are present: barren fault stuff, barren horn quartz, and the ferberite and horn quartz filling of the ore shoots. The barren fault stuff ranges from coarse fragments of Boulder Creek granite in a matrix of more thoroughly crushed granite to a fine-textured gouge. The barren unsilicified parts of the vein have one or more seams of clay gouge 3 to 12 in. thick. Most of the gouge is light gray, but thin seams of brick-red clay gouge, which owe their color to finely disseminated hematite, are present locally. The red gouge is more abundant near ore shoots than in other parts of the vein. The horn quartz filling shows great variety in color and occurrence; in some places the vein consists of only one kind of quartz, but in most places the horn filling has been brecciated during repeated fault movements and many generations of horn quartz can be seen. The early gray and early white horn are the most abundant, and green, red, brown, and black horn are present locally. There is no direct correlation between the occurrence of any of the various types of quartz with that of ore, but in general the later varieties, such as the brown and black, are more abundant near ore shoots than elsewhere.

The ore occurs chiefly as a moderately fine grained branching mass of ferberite and intergrown horn quartz cementing a breccia of horn and wall rock (fig. 52). It fills open spaces with almost no replacement of breccia fragments of country rock (fig. 43). Well-crystalized ferberite is found in vuggy openings in the vein, but the bulk of the ore is compact, massive material that completely filled the openings in the vein. Small amounts of beidellite, barite, pyrite, siderite, and banded chalcedony also occur with the ore, resting on it in druses or filling veins in the ore and the nearby country rock.

According to Will Todd, there was no gossan over the only ore shoot that came close to the surface. The ore has long since been mined, but the horn breccia at the sides of the open pit is iron-stained, slightly porous, and much encrusted with limonite. The iron-stained country rock gave way in the main to essentially unstained rock about 150 ft below, though some oxidation persisted in the vein to a slightly greater depth. The ore shoot itself did not reach the surface but pinched to a feather edge of bright, fresh ferberite about 12 ft below the surface. It widened rapidly downward, and at 40 ft there was 4 ft of ore averaging 18 percent WO_3. The horn was iron-stained, as was the nearby country rock, but the ferberite crystals apparently were fresh. The iron stain probably was caused mainly by the decomposition of the ferruginous minerals in the granite and of the small amount of disseminated pyrite found in some of the horn and, to a much less extent, by the action of organic acids on the finely disseminated ferberite in the black horn of the vein.

STRUCTURE

The Cold Spring vein in general strikes about N. 75° E. and dips steeply north. It is a strong, well-defined fissure as far west as it has been explored in the Cold Spring mine and continues for nearly 600 ft east of the New shaft. Farther east it passes into a zone of overlapping fissures, which toward the east lie farther and farther to the north. Many branch veins diverge at small angles from the main vein. Almost all these branch veins trend in a slightly more northeasterly direction than the main vein, and they are more numerous in the hanging wall than in the footwall.

The Cold Spring vein follows a premineral normal fault whose north wall moved down and west at about 30°. Most of the grooves and striations observed on the walls are nearly horizontal, but some grooves cut in the quartz filling of the vein plunge 35°–40° W. The direction of faulting is clearly shown by interior faulting at places on the fifth level. On the fourth level, about 260 ft west of the Old shaft, a dike of fine-grained gneissic aplite is offset 44 ft along the vein. The grooves on the quartz gangue show that movement occurred intermittently along the fissure after the early horn quartz was deposited, but little or no movement took place after the introduction of ferberite.

Although the average strike is about N. 75° E., the course of the vein swings from N. 83° E. to N. 68° E. at many places west of the Old shaft, and farther east the course ranges from N. 80° E. to N. 57° E. and much of it is close to N. 67° E. The vein dips 65°–85° N. at most places, but locally it is vertical or dips steeply south. Most of the minor veins that branch from it strike N. 45°–55° E. and dip steeply north (pl. 19). Some minor veins strike approximately parallel to the Cold Spring vein but are vertical or dip steeply south. There are several veins of this type in the hanging wall, and ore was mined from two of them.

Only a few faults in the mine are later than the Cold Spring vein, but some of the intermittent movements recorded by the brecciated vein filling followed branching fissures in preference to parts of the main vein, with the result that the main vein is apparently faulted in places by fissures which elsewhere branch from it. On the fifth level, 310 ft east of the New shaft, the Cold Spring vein is offset by a fault that is parallel to the northeastward-trending branch veins nearby. The eastern segment of the vein is offset 25 ft northeast of the western segment, and the right-hand side thus moved forward in harmony with the movement on the main Cold Spring vein.

The main vein is vertical below the sixth level west of the New shaft, but a branch vein passes out into the north wall, continuing the northerly dip of the vein above (see section *C–C′*, pl. 19). This branch vein flattens greatly near the New shaft and apparently faults the main vein. The north side moved down, and here, too, the movement is in the same direction as that along the Cold Spring vein.

The grooves and striations found on the walls of several of the branch veins are nearly all subparallel to those found on the main vein, which suggests that the branch veins were formed in response to the same stresses and approximately at the same time as the main vein. In one branch vein, however, interior faulting and striations show that the north wall moved downward and eastward. This vein is in fresh unaltered rock north of the main vein on the third level, and the fissure probably was formed after the period of hypogene acid alteration, much later than the main period of movement responsible for opening the Cold Spring vein.

ORE SHOOTS

Four major ore shoots and two smaller ones have been found on the main Cold Spring vein, and several small ones occur on nearby branch veins and related fissures. None of the ore shoots cropped out, but one was discovered by surface trenching; the others were discovered by underground development.

The places most suitable for the deposition of ore were those where the walls of the premineral fault moved apart, leaving open spaces. The downward and westward movement of the north wall thus opened the steeper parts and those whose trend is northeast of the average course of the vein. All the ore shoots on the Cold Spring vein occur in segments of the vein which have a relatively steep dip and which trend in a more northeasterly direction than those at either end of the ore shoot.

Branch veins are much more numerous in the barren parts of the vein than along the productive sections. The ore shoots occur on segments of the main vein that lie between junctions with branch veins that diverge southwestward into the south wall, or footwall, at the west ends of the shoots and northeastward into the north, or hanging, wall at the east ends. The presence of many minor fissures diverging from the main vein at a low angle suggests that the faulting was distributed between the main fissure and the minor fissures in such places, but along the parts of the vein that are devoid of branches the movement was concentrated in a single fissure and resulted in greater displacement of the walls. It is in these parts that the largest ore shoots lie.

The Old shaft ore shoot is chimneylike in form and extended from a point within 12 ft of the surface to a little below the fifth level (pl. 18). The best ore was just west of the junction of the Cold Spring vein with some branch veins.

The 1918 ore shoot pinched at the bottom level and a short distance above the fifth level. The ore was cut off abruptly on a gougy vein filling below, and there was little or no horn quartz beneath the ore. The vein above the shoot is moderately open and vuggy and contains minor amounts of the late vein minerals. Immediately east and west of the ore shoot the vein is barren horn quartz. The ore was found just west of a marked split in the vein (pl. 18).

The 1923 ore shoot is just east of the same junction that apparently localized the 1918 shoot. It was 200 ft long and extended from a point 22 ft below the fifth level to 50 ft above it. This shoot, like the others, occurs where the vein is nearly vertical and where, as it is followed westward, it appears to swing slightly to the south. The ore bottomed quite suddenly on an almost horizontal line, and only two small "tits" extended down below the main mass of ore.

The 1927 ore shoot, the smallest and farthest east of the main shoots, was found 30 ft above the fifth level. It was topped 120 ft above this point and had a maximum length of 75 ft. On the fifth level the only indication of the overlying ore shoot was the presence of a few small lenticular areas of ferberite in a quartz vein 16 to 24 in. wide. These spots of ore, as they are called by the miners, were small and widely spaced in the drift but became more and more abundant upward, finally merging into one another to form the bottom of the ore shoot. The 1927 shoot came so close to the surface that the vein was explored for only 10 ft above the main shoot. Spots of ore were present in the back near the west end of the stope, but only a few were seen at other places over the ore shoot.

The Cold Spring vein was stoped at places west of the area shown in the section—plate 18, and the irregular Scogland stope, about 550 ft west of the Old shaft on the fourth level, extended almost to the surface.

Ore has been found on veins striking nearly parallel to the Cold Spring vein and not more than 100 ft away, in the hanging wall or north side. In 1929 a small stope was put up on the narrow '29 vein, which had been located by drilling about 50 ft north of the Old shaft. This vein is 1 to 12 in. wide, and the ore had a maximum width of 8 in. Ferberite intergrown with horn penetrates and cements early horn and granite fragments. The walls of the vein are only slightly altered; in a few places they are silicified, but nowhere are they at all bleached. The vein dips steeply to the north, and the hanging wall moved east almost horizontally but with a slight downward component. Part of this movement took place after mineralization.

The vein filling is generally tighter below an ore body than above it, but more open than in the barren parts of the vein at either side. In some places the ore bottoms on gouge containing very little horn, but drifts under most ore bodies expose veins of brecciated horn quartz through which surface water runs easily, making wet drifts. Generally, according to William Loach and Will Todd, spots of ore are more abundant under an ore body than over it. The spots over the 1923 shoot were no more abundant close to the ore shoot than they were 100 ft above it. Locally they were sufficiently plentiful to form low-grade ore for several feet, but the concentration was haphazard and had no relation to the proximity of the underlying ore shoot. Little exploration has been carried on over the 1918 ore shoot, but the vein on the third level, 150 ft above it, has small spots of ore and suggests a similar distribution to that over the 1923 shoot.

Above most of the ore shoots, the vein is commonly open and vuggy and shows a late seam of brecciated horn cemented by white, friable, fine-grained quartz. Banded chalcedony, dickite, and some low-index clays were found in vugs over the 1923 and 1927 ore shoots. The late clays over the 1923 ore shoot are chiefly beidellite, allophane, and cimolite, but some dickite also is present. At the west end, close to the bottom of the shoot, some late clays coat and seam ferberite nodules, and allophane is abundant as a soft coating along oriented surfaces of ferberite in the vugs.

SUGGESTIONS FOR PROSPECTING

Much of the ground adjacent to the Cold Spring workings has been explored by long-shank hammer drills, and there seems to be little reason to hope that any worthwhile ore shoots will be found in the unprospected ground between the different levels of the mine. Further exploration west of the workings on the sixth level seems warranted, however. The vein at the west breast is strong in spite of its comparatively gentle dip; it has a favorable course at this point; and if it is the continuation of the vein exposed farther west on the fourth and fifth levels, it probably steepens a short distance west of the breast. It seems possible that blind ore may exist in this unexplored section of the Cold Spring vein.

CROSS MINE

The Cross mine is about a mile north of Tungsten Post Office and 1,800 ft northeast of the Cold Spring mine (pl. 5). It is on an agricultural patent that has long been owned by the Wolf Tongue Mining Co. The mine was operated by Nelson Olsen during World War I, when the greatest part of its output was achieved, and was operated again during the twenties. It was reopened by the Wolf Tongue Co. in 1941 and was operated until 1943. According to the records of the Wolf Tongue Co., the total output from the main mine, or Cross No. 1, from 1907 to June 1943 was 37,554 units of WO_3 in 3,247 tons of ore that averaged 11.57 percent WO_3. To this may be added a moderate amount of ore produced long ago from the Cross No. 2 shaft and a small amount produced from the Cross No. 3 shaft in 1943. The Madeline shaft, 1,200 ft to the west (pl. 20), is credited with an output of a few hundred units in ore that averaged 10 percent WO_3, and a small output came from the nearby Firth shaft.

The mine comprises an inclined shaft (Cross shaft), whose collar is at an altitude of about 8,250 ft, and four levels, the lower three of which are at vertical depths of 162, 263, and 359 ft. The first level was inaccessible in 1942, and no record of its location or extent is available. Several shafts southwest of the Cross shaft connected stopes above the second level with the surface, but these workings were all caved in 1942. The second level extended far to the west, where it was connected to the surface by the Cross No. 2 shaft, which also is caved. The drift at the bottom of the Cross No. 2 shaft is on the Madeline fault and about 100 ft lower than the drift in the Madeline mine (pl. 20). The Cross workings are only a few hundred feet north of the east end of the fifth level of the Cold Spring but are mostly deeper. The second level of the Cross is about 35 ft higher than the end of the fifth level of the Cold Spring.

The Cross mine is almost entirely in Boulder Creek granite. The granite is cut by a few small dikes of pegmatite and strongly gneissic aplite and by a small dike of hornblende monzonite porphyry. The porphyry dike is irregular and nonpersistent; its course and thickness change abruptly at some veins, and it appears to follow veins for short distances. The displacement of the dike along the Cross vein underground is much smaller and in a direction opposite to that of the apparent displacement at the surface, and this apparent displacement at the surface is believed to have resulted largely from "jumping" where the dike encountered preexisting fractures rather than from movement along these fractures after the intrusion of the porphyry.

The granite along the Cross vein east of the shaft is strongly argillized. Alteration is weaker along the branching veins west of the shaft, and some of them are between walls of fresh rock, particularly in the lower part of the mine. Some of the veins are bounded by a thin casing of sericitized rock, but on the whole argillic alteration strongly predominates. These veins are closely related structurally to the Madeline fault, and the prevalence of hydrothermal clay-mineral alteration along them is consistent with the intense argillic alteration that characterizes the Madeline.

Most of the workings of the Cross mine are on a group of veins west of the shaft. These converge northeastward and unite to form the Cross vein, which extends east-northeastward from the shaft. The productive veins west of the shaft are known from north to south as the No. 1, No. 2, and No. 3, and Pump veins. West of this group of converging veins are several parallel veins that strike northeast, and west of these is the Madeline fault, which turns from an easterly to a northeasterly course in this locality. The Madeline is a strong normal fault whose north, or hanging, wall moved down and west. The northeastward-trending veins between the Cross shaft and the turn in the Madeline fault form a zone of echelon fractures that trends east from the turn; this zone connects the eastward-trending part of the Madeline with the Cross vein, which has a similar easterly trend and shows the same type of displacement as the Madeline. Thus, in effect, the Madeline fault splits rather than makes a simple turn, and for a distance of a few hundred feet the southern branch is made up of echelon fractures with a northeasterly trend rather than a single fault surface. The individual fractures in the echelon zone show only minor displacements, and the integrated displacement along the Cross vein is only a few feet. Along most of the northeastward-trending veins the right wall moved forward almost horizontally, but some show a small left-hand displacement at places. Both the northeastward-trending veins and the Cross vein weaken with depth, particularly to the west, suggesting an echelon arrangement in the vertical direction also.

Although the Madeline fault is mineralized at places, it is essentially barren. At the Madeline mine a little ore was produced from minor branch veins in the hanging wall, and the Madeline fissure itself contains a thick vein of horn quartz near the surface, but the quartz bottoms abruptly in soft gouge (fig. 91). As a result of the westward movement of the north wall, the mineralization becomes stronger where the vein turns to a more northerly course, but in the Firth mine the vein filling was mostly early barren horn quartz, and only small lenses of ferberite were found.

Practically all the ore obtained from the Cross mine came from above the third level. The Cross vein was stoped through a length of 340 ft east of the shaft on the second level, and the stopes reached the surface at places. On the third level it was stoped through a length of only 50 ft immediately east of the shaft and to a depth of about 25 ft in the floor.

The No. 1 vein, which dips steeply north, was stoped at its junction with the No. 2 vein, 120 ft southwest of the shaft on the second level, but the extent of the stope west of the junction is not known. Weak veins in the northernmost drift near the shaft on the third level probably represent the No. 1 vein. They are barren in the drift, but one of them becomes ore bearing near its junction with the Cross vein, and the stope east of the shaft on the third level is on both veins. A seam of crystalline ferberite 2½ in. thick was observed on the No. 1 vein in this stope 25 ft below the third level.

The No. 2 vein, which dips south, was evidently stoped more or less continuously above the second level from the shaft southwestward for 350 ft to the end of the drift. It was also stoped below the level near the shaft and southwest of the junction with the No. 1 vein. On the third level it was stoped from its junction with the No. 3 vein, 130 ft southwest of the shaft, southwestward for 135 ft. It has not been identified on the fourth level.

According to an old map, the No. 3 vein was stoped more or less continuously through the entire length of the 290-ft drift on the second level, and a line of caved holes suggests that the stopes reached the surface at places. On the third level the No. 3 vein splits near the intersection with the No. 2 vein; both branches cross the No. 2 vein and reunite farther north, forming a "run-around." Both branches were worked, and a stope beginning about 50 ft southwest of the shaft extends southwestward for 310 ft. This stope presumably extends up to the second level except just below the run-around, where the vein is probably cut off just below the second level by a northward-dipping vein that lies between the Pump and No. 2 veins.

The Pump vein, the southernmost of the productive northeastward-trending veins, is said to have been the richest vein in the mine. It was stoped through a length of about 350 ft on the second and third levels. The stope is known to have extended up to the old first level, and locally stopes on the upper branches of the vein reached within a few feet of the surface. On and below the third level the Pump vein dips about 75° SE. At a height of about 60 ft in the open stope above the southwest end of the drift on the third level the Pump vein is joined by one that dips about 75° NW. The main Pump vein steepens above this junction, and the walls of the stope extend vertically up to the second level above which they appear to dip steeply northwest. In the accessible part of the Pump drift on the second level, near the shaft, the Pump vein branches upward. The stronger branch dips 70°–80° NW., and the weaker one dips steeply southeast. Only the northwestward-dipping branch was stoped in the back of the level, but near the surface both branches were worked. On the fourth level the Pump vein breaks up into several weak and barren fractures (pl. 20).

Little is known of the character of the ore. Except in the barren parts, the mine was badly caved in 1942, and many of the veins could not be seen even at the edges of the old stopes. The ore was relatively rich, but the tonnage and grade figures given earlier probably include some concentrates purchased by the Wolf Tongue Co. from lessees. An output of 3,247 tons of ore seems small and incompatible with the large area stoped, even allowing for a large rejection by sorting, and according to one report about 8,000 tons of ore assaying about 1½ percent WO_3 was milled by lessees. If this is true, the tonnage figure may include about 180 tons of 50-percent concentrates (allowing a 75-percent recovery), and the average grade of the remaining 3,067 tons credited to the Cross would be about 9.3 percent WO_3. The veins are said to have consisted of seams of ferberite and horn quartz in sheeted granite, and widths of as much as 3 ft of ore assaying 10 to 15 percent WO_3 are reported. When fill from some of the old stopes was pulled in 1942, veinlets of pure ferberite 1 to 3 in. thick could be seen on large slabs that had fallen into the stopes on the Pump vein.

Some exploration by diamond drilling was carried on in the mine in 1942, and considerable drilling was done at the surface by both the Wolf Tongue Mining Co. and the Bureau of Mines. The drill holes showed several strong veins east, south, and southwest of those explored in the Cross mine, within a radius of a few hundred feet. As indicated by the position of the fifth level of the Cold Spring mine in plate 20, the Cold Spring vein zone lies only a short distance south of the Cross mine. This zone and the northeastward-trending veins between it and the Cross vein comprise the chief remaining prospects in the vicinity of the Cross mine. Bulldozer trenches have proved several of the veins to be barren at the surface, but ore found in trenches on at least two of the veins, together with the strong quartz veins found by drilling, should encourage further prospecting. In 1942 ore was found on a northeastward-striking vein east of the Cross shaft, and the Cross No. 3 shaft was sunk on it. Ore was also cut at a vertical depth of 118 ft in a drill hole 90 ft east of the No. 3 shaft. In 1945 T. J. Henning was mining good ore from a new shaft on a branch vein of the Cold Spring zone almost vertically above the east breast of the fifth level of the Cold Spring.

SMALLER MINES

BARKER NO. 3 MINE

Location: Altitude, about 8,290 ft; just north of Barker Reservoir, 1,175 ft S. 43° W. of Vasco No. 6 shaft. Mine distinct from Barker No. 3 of Clark tunnel (see description of Clark tunnel).

Workings and geology: See figure 92.

Ore: Ore on northeastward-trending vein (fig. 92) localized in granite above northeastward-dipping rib of schist crossing Old shaft at depth of 130 ft and New shaft at depth of 275 ft. No ore on this vein below schist contact. Ore in eastward-trending vein localized near intersection with northeastward-trending vein, going down through rib of schist. Ore was brecciated horn cemented by ferberite.

History and production: Apparently some production before J. G. Clark, of Tungsten Production Co., acquired Barker tract, an agricultural patent, in 1915. Most of production in 1916–18; incomplete records show output of 1,495 units of WO_3 in ore averaging about 11 percent WO_3 at that time. Mine also operated in late twenties; total output may be as much as 5,000 units of WO_3.

DILLON SHAFT

Location: Altitude, 8,375 ft; 1,525 ft S. 85° W. of Vasco No. 6 shaft.

Workings: Eighty-foot shaft irregularly stoped along both sides.

Geology: Vein strikes N. 40° E. and dips 77° NW. In granite. Small ore shoot at shaft was vertical or plunged steeply northeast. Two drill holes cutting vein 100 and 125 ft below outcrop 50 ft southwest and 15 ft northeast of shaft each showed trace of ferberite.

History and production: Worked chiefly in 1907–09 but produced a little ore in 1916; no work since then. Output probably less than 1,000 units of WO_3. Mine owned by Gold, Silver, & Tungsten, Inc.

LONGSHOT NO. 4 MINE

Location: Altitude, about 8,330 ft; 1,000 ft S. 81° W. of Vasco No. 6 shaft.

Workings: See plate 13.

Geology: Vein strikes N. 63° E. and dips SE. Mostly in schist but partly in granite and aplite, where ore was probably localized.

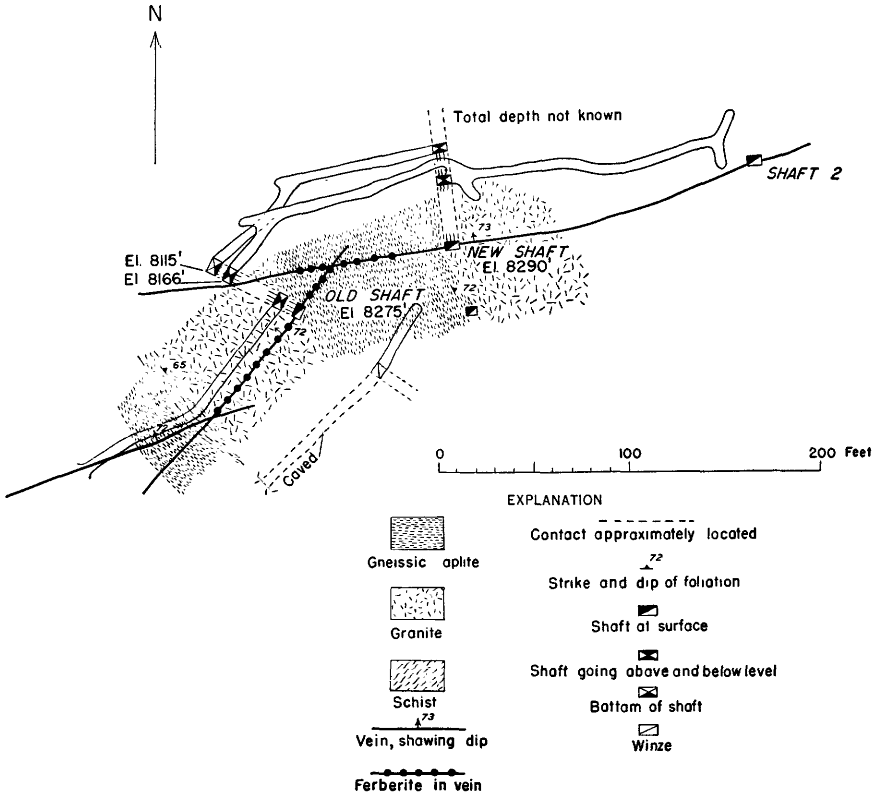


FIGURE 92.—Workings of the Barker No. 3 mine, Boulder County, Colo. (after F. A. Fair), and geologic sketch map of the surface.

History and production: Worked chiefly in 1916–18; worked in 1941 by H. M. Gregory with small production. Total output probably less than 1,000 units of WO_3. Mine owned by Gold, Silver, & Tungsten, Inc.

BLACK DIAMOND TUNNEL

Location: Altitude, about 8,460 ft; 1,100 ft N. 47° W. of Vasco No. 6 shaft.

Workings and geology: See figure 93; also several shallow shafts and short tunnels on plate 5. Crystalline ferberite in many small sheeted zones with northerly to northeasterly trend.

History and production: Productive chiefly in 1916–17; worked on minor scale at times since then. Total output probably less than 1,000 units of WO_3. Property owned by Gold, Silver, & Tungsten, Inc.

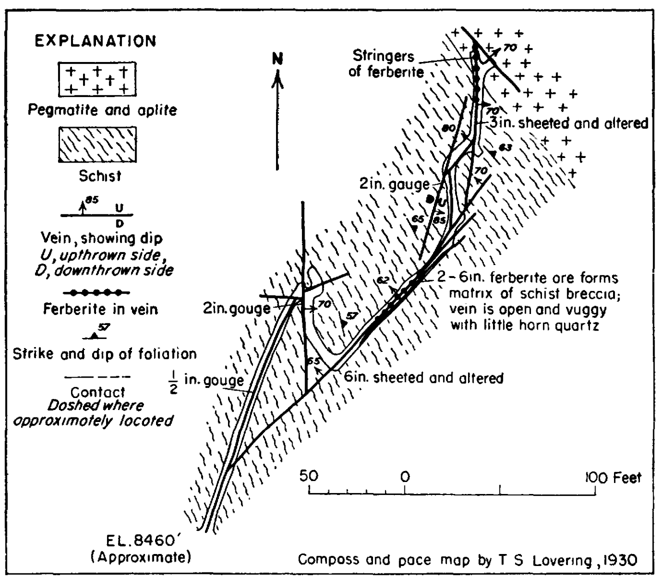


FIGURE 93.—Geologic plan of the Black Diamond tunnel, Boulder County, Colo.

1905 MINE

Location: Altitude, 8,550 ft; beside Hurricane Hill road, 825 ft S. 25° W. of Vasco No. 1 shaft.

Workings: Shaft workings; extent unknown; probably not more than 150 ft deep.

Geology: Vein in hanging wall of Hurricane Hill breccia reef strikes N. 40° E. and dips 72° NW. In aplite and granite.

History and production: Productive in 1916–18 and probably earlier; no production known since then. Incomplete records for 1916–18 show output of about 250 units in ore averaging 12.9 percent WO_3. Total output may exceed 1,000 units. Mine owned by Gold, Silver, & Tungsten, Inc.

JACK AND SUMMIT MINE

Location: Altitude, about 8,535 ft; beside Hurricane Hill road, 350 ft west of Vasco No. 1 shaft.

Workings: See figure 94.

Geology: Veins indicated by drifts in figure 94. In aplite and schist. Presence of stopes on Jack vein not determined.

History and production: Productive 1907–13, 1915–19, 1925–26, and 1928; chief production in 1917–18. Mine may have been worked before 1907; apparently idle since 1928. Output from 1907 to 1928 about 3,300 units of WO_3 in ore averaging 11.77 percent WO_3. Mine owned by Wolf Tongue Mining Co.

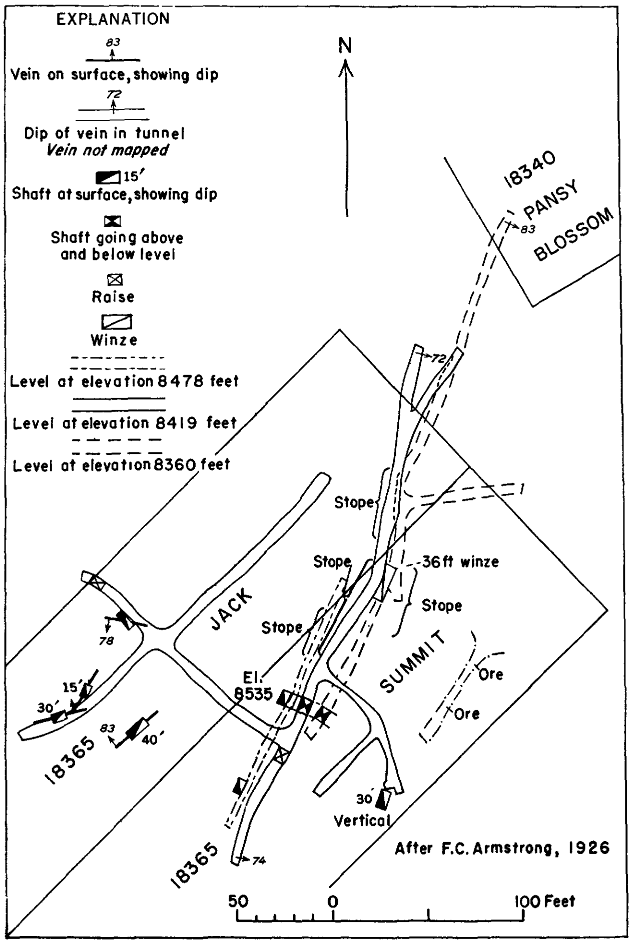


FIGURE 94.—Workings of the Jack and Summit mine, Boulder County, Colo., in 1926 (after F. C. Armstrong).

PANSY BLOSSOM MINE

Location: Altitude, about 8,415 ft; 500 ft south of New shaft of Cold Spring mine.

Workings: Shaft at least 100 ft deep and drift extending 400 ft southwest and 100 ft northeast of shaft. May be other and deeper workings.

Geology: On Orange Blossom vein, which here strikes N. 68° E. and dips 85° NW. In granite cut by dikes of aplite.

History and production: Worked at least as early as 1904; chief production possibly before 1907. Small production annually from 1907 to 1918, inclusive; output during this period about 1,400 units of WO_3 in ore averaging 5.44 percent WO_3. Mine apparently not worked since 1918. Owned by Wolf Tongue Mining Co.

ORANGE BLOSSOM MINE

Location: Altitude 8,329 ft; 475 ft S. 68° E. of New shaft of Cold Spring mine.

Workings: See plate 18, particularly seventh level of Cold Spring.

Geology: See description of Cold Spring mine and plate 18.

History and production: Orange Blossom worked independently of Cold Spring until sometime after 1920; crosscut then driven from seventh level of Cold Spring beneath Orange Blossom shaft workings. Orange Blossom productive almost continuously from 1907 to 1920, inclusive; during this period produced about 3,500 units of WO_3 in ore averaging about 4 percent WO_3. Owned by Wolf Tongue Mining Co.

DOUBLEHEADER MINE

Location and workings: Several shallow shafts and tunnels at altitudes of 8,250 to 8,400 ft; 1,300 to 2,400 ft east of New shaft of Cold Spring mine.

Geology: On two strong vein zones, a northern one trending east-northeast and a southern one trending north-northeast. (Vasco No. 3 vein zone). In granite and aplite and minor gneissic diorite. Veins characterized by abundance of early barren white horn quartz.

History and production: Veins worked on small scale at many localities; small production from time to time; total output probably no more than 1,000 units of WO_3. Shaft sunk in area about 1937 by Vanadium Corp. of America, the owner.

GEM MINE

Location: Altitude, about 8,435 ft; 1,100 ft N. 79° W. of New shaft of Cold Spring mine.

Workings: Shaft, about 150 ft deep, and two levels; older shaft 80 ft to northeast buried under dump.

Geology: Vein strikes N. 68° E. and dips about vertically. In granite cut by strong northward-trending dikes of aplite. Ore chiefly in aplite. Old shaft on No. 2 vein of Nancy Henderson mine, which strikes nearly north and apparently joins Gem vein under Gem dump.

History and production: Production totaled 616 units of WO_3 in ore averaging 9.65 percent WO_3 in 1907–08, 1910, and 1913, probably from buried shaft on No. 2 vein of Nancy Henderson. Production from main Gem workings not known. Mine worked by Todd and Flarty about 1938; owned by Wolf Tongue Mining Co. at time of examination.

TENDERFOOT MINE

Location: Altitude, about 8,400 ft; 900 ft N. 70° W. of New Shaft of Cold Spring mine.

Workings and geology: See figure 95.

Ore: Much of ore obtained near surface in vicinity of Old shaft; substantial production from stope along northeast side of New shaft.

History and production: Chief production in 1907–18, particularly in 1913 and 1916–17; small production in 1923 and 1926–29. Total output from 1907 to 1929, inclusive, was 2,243 units in ore averaging 13.2 percent WO_3; probably some production before 1907. Wolf Tongue Mining Co., the owner, reopened mine in 1943 and did considerable diamond drilling.

NANCY HENDERSON MINE

Location: Old or No. 1 workings at altitude of about 8,450 ft; 1,425 ft N. 88° W. of New shaft of Cold Spring. New or No. 2 workings at altitude of about 8,410 ft; 500 ft northeast of Old workings.

Workings: Old workings were shafts and open-cuts, all caved. For New workings see figure 96.

Geology: Old workings on vein that strikes N. 50° E. and dips 75° NW. In granite cut by dikes of aplite. New workings on vein that strikes N. 10° E. at shaft but turns gradually to N. 40° E. at point 175 ft northeast of shaft. Vein dips 83° E. at shaft, but drill holes show it is vertical or dips 85° W. at places. Mine is in granite. Location of ore shown in figure 96.

History and production: Claim worked before 1913; no record of early production. Worked at times since by many lessees, particularly in 1916–18, 1926–31, 1936–38, and 1941–44. Incomplete records of these operations show

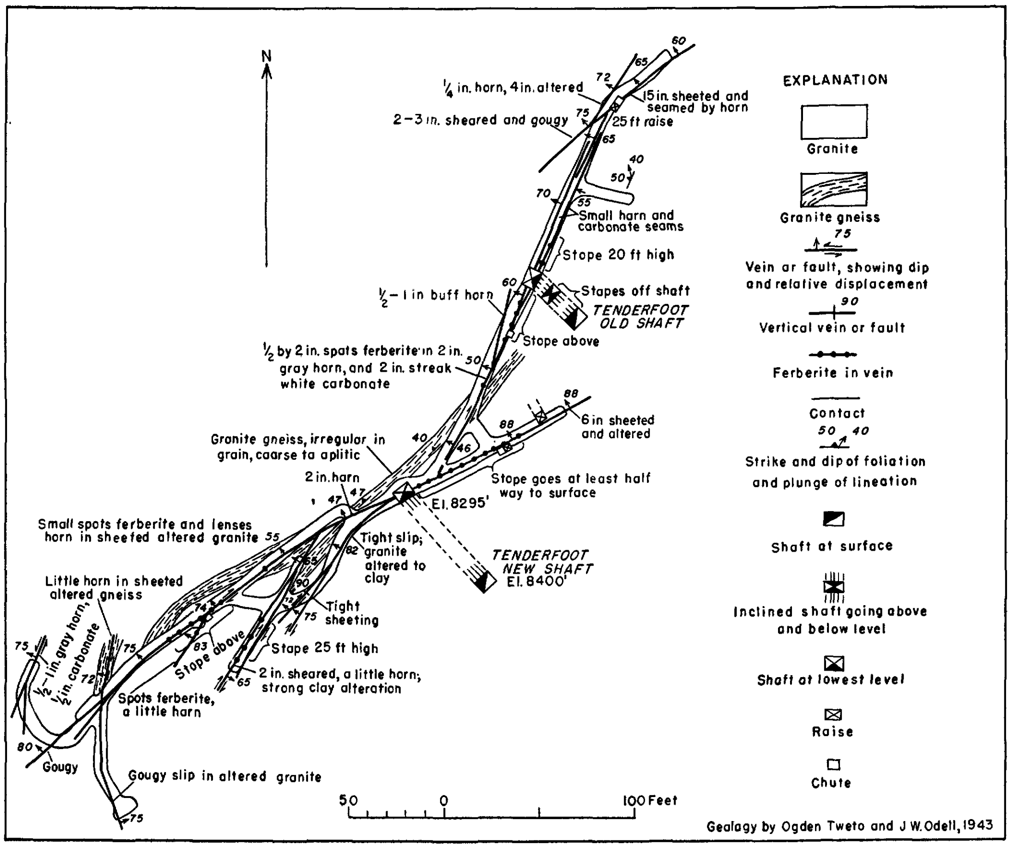


FIGURE 95.—Geologic plan of the Tenderfoot mine, Boulder County, Colo.

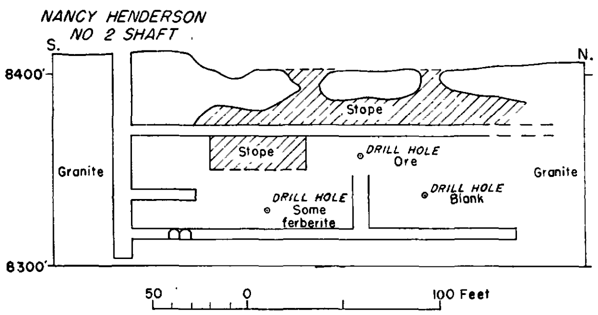


FIGURE 96.—Longitudinal projection of the Nancy Henderson No. 2 mine, Boulder County, Colo.

output of 2,150 units of WO_3; total may be close to 5,000 units. Most of ore shipped assayed more than 10 percent WO_3. Mine owned by Gold, Silver & Tungsten, Inc.; last operated in 1943–44 by Elmer Hetzer.

LAST CHANCE NO. 2 MINE

Location: Altitude, about 8,410 ft; 750 ft S. 40° W. of Western Star shaft.

Workings and geology: See figure 97.

History and production: No record of operation before 1916. Mine operated chiefly in 1916–19 and 1929–30, but lessees have worked at or near surface at times up to 1943, when T. J. Henning was mining nodules of pure ferberite up to 4 in. in diameter in a weathered branch vein. Available production records show output of about 300 units of WO_3 from Last Chance, 1916–29, and from nearby pits on adjoining Only Chance claim, 1912 and 1918. Mine owned by Wolf Tongue Co.

SPENCER TUNNEL

Location: Altitude, about 8,365 ft; 950 ft S. 76° W. of Western Star shaft.

Workings and geology: See figure 98. Tunnel chiefly in granite; some aplite and pegmatite.

History and production: Tunnel driven about 1918. Extended beyond limits shown in figure 98 by Wolf Tongue Mining Co., the owner, in 1944; little, if any, ore found. Production small.

GEORGIA A. MINE

See description of Western Star mine and plate 17.

EDITH MARY MINE

Location: Altitude, about 8,410 ft.; 500 ft SE. of Western Star shaft.

Geology and production: Few hundred units of WO_3 in relatively high-grade ore produced from open-cuts and shallow shafts on northward-trending veins crossing eastern part of Edith Mary and adjoining Little Jap claims.

KICKER MINE

Location: Altitude, about 8,435 ft.; 750 ft N. 63° E. of Western Star shaft.

Workings: See figure 99.

Geology: Workings chiefly on branch of Western Star vein system (pl. 5); strike N. 60° E. and dip 65° NW. In granite.

History and production: Moderate annual output for many years; mine operated in 1907–10, 1912–19, and 1923–29. Also operated a short time in thirties and possibly before 1907. Annual production largest during years 1913–18.

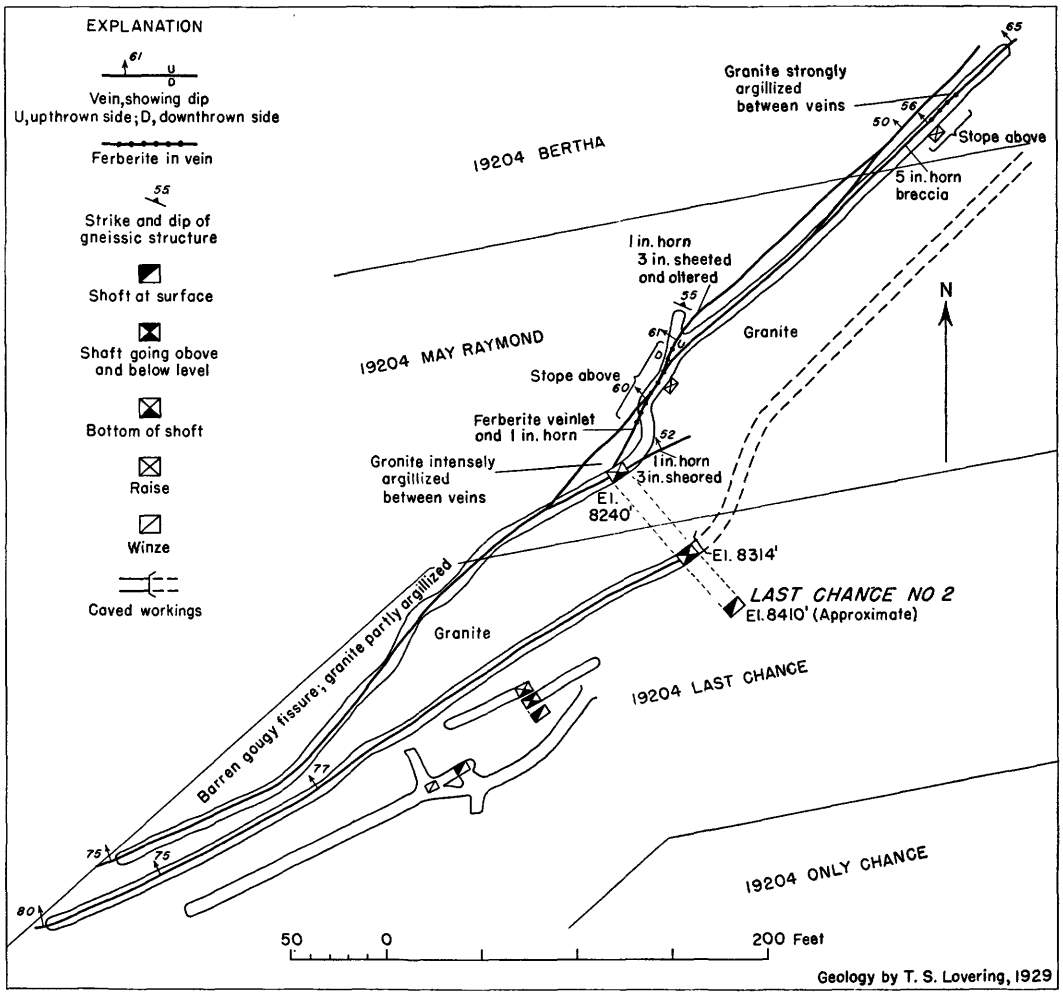


FIGURE 97.—Plan of the Last Chance No. 2 mine, Boulder County, Colo.

Output from 1907 to 1929, inclusive, more than 7,000 units of WO_3 in ore averaging 18.6 percent WO_3; total output probably somewhat greater. Mine owned by Wolf Tongue Mining Co.

PHILADELPHIA AND NEW YORK MINES

Location: Philadelphia at altitude of 8,460 ft; 800 ft N. 51° E. of Western Star shaft. New York shaft about 60 ft northwest of Philadelphia.

Workings: Known workings, which may not be complete, shown on map of Kicker workings (fig. 99).

Geology: Philadelphia on strong and persistent vein that strikes N. 60° E. and dips steeply northwest. In granite. New York on branch vein that strikes N. 30° E.

History and production: Almost all production in 1907–10; mines worked on minor scale at times until 1918. Total output, 1907–29, about 2,800 units of WO_3 in ore averaging 11.9 percent WO_3. Mines owned by Wolf Tongue Mining Co.

CARLBERG MINE

Location: Altitude, 8,350 ft; 1,400 ft N. 74° W. of Cross shaft.

Workings: Shaft, with level at depth of about 100 ft extending 150 ft northeast and 400 ft southwest of it; may be other and deeper workings.

Geology: Vein that strikes N. 60° E. is northeast extension of Philadelphia-Western Star vein system; dips 80°–85° NW. On contact between granite and aplite (pl. 5).

History and production: Worked from 1915 to 1919 and on minor scale at times in twenties; almost all production in 1917–18. Total output, 1915–29, more than 2,500 units in ore averaging 16.28 percent WO_3. Mine owned by Wolf Tongue Mining Co.

MADELINE MINE

See description of Western Star and Cross mines and plate 20.

FIRTH MINE

See description of Cross mine and pl. 20.

BLACK JACK MINE

Location: Altitude, 8,140 ft (tunnel) to 8,265 ft (shafts); 1,000 ft northwest of Cross shaft.

Workings: Tunnel and several shafts of unknown extent (pl. 5).

Geology: Tunnel follows vein that strikes east-northeast; shafts on veins that strike N. 30° E., N. 75° E., and due east. All in granite.

History and production: Chief production, 1907–09; mine may have been worked earlier. Moderate production, 1916–17; minor production in 1929. Total output, 1907–29, about

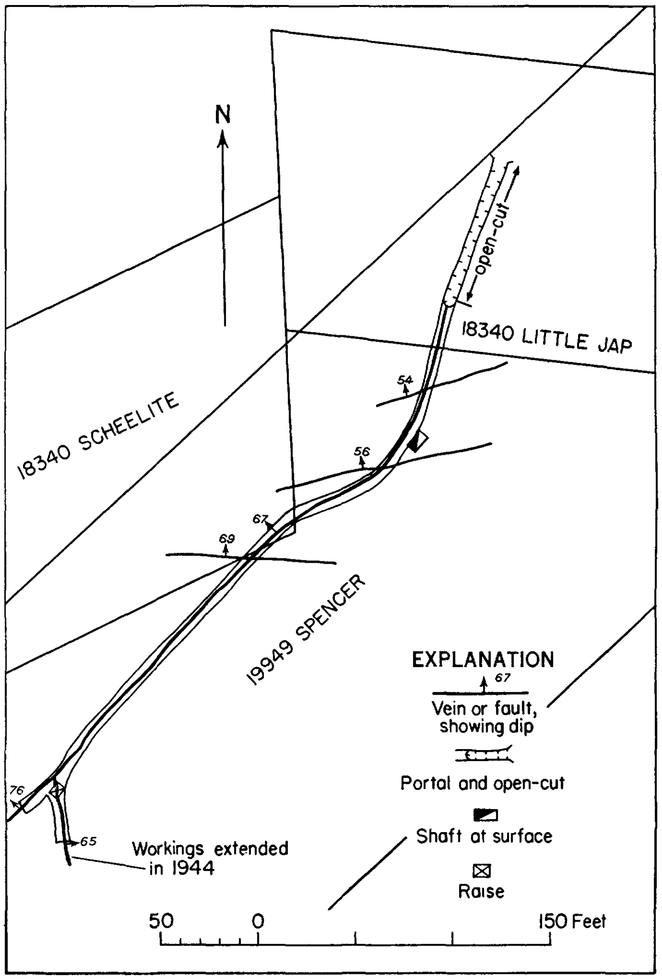


FIGURE 98.—Plan of the Spencer tunnel, Boulder County, Colo., in 1925, showing veins (after F. C. Armstrong).

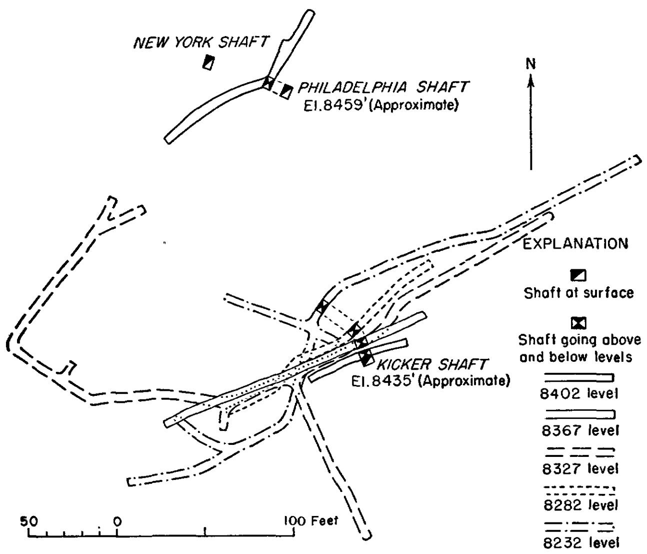


FIGURE 99.—Workings of the Kicker and Philadelphia mines, Boulder County, Colo. (from a map of the Wolf Tongue Mining Co.).

1,500 units of WO_3 in ore averaging 19.34 percent WO_3. Mine owned by Wolf Tongue Co.; worked by M. Bodnar about 1940.

FIRECRACKER MINE

Location: Altitude, about 8,265 ft; just south of Black Jack shafts.

Workings: Shaft and tunnel; extent unknown.

Geology: Vein strikes nearly due east. Along porphyry dikes in granite.

History and production: Worked at times from 1907 to 1918; chief production in 1912–13. Total output, 1907–18, nearly 500 units in ore averaging 25.75 percent WO_3. Mine owned by Wolf Tongue Mining Co.

HUGO MINE

Location: Altitude about 8,155 ft; on north side of North Boulder Creek, 3,350 ft N. 34° W. of Cross shaft.

Workings and geology: See figure 100.

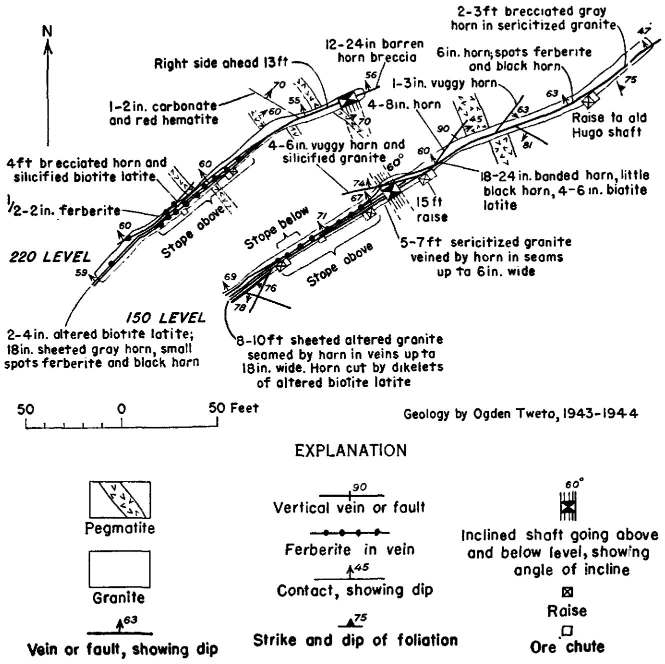


FIGURE 100.—Geologic plan of the Hugo mine, Boulder County, Colo.

Ore: Fine-grained ferberite, horny ferberite, black horn, and a little scheelite fill openings in gray horn breccia cut by altered biotite latite porphyry. Ore occurs in streaks, lenses, and nodules in horn quartz vein. Ore shoot had stope length of about 60 ft; plunged southwest. Top was just northeast of shaft 45 ft below surface.

History and production: Shaft started about 1940 by Union Mining & Development Co., the owner. Most of workings driven by Boulder Tungsten Mills, Inc., in 1943–44. Total output from these workings about 2,000 units of WO_3 in ore averaging about 2.25 percent WO_3. Minor production earlier from old shaft northeast of present shaft.

BONANZA MINE

Location: Altitude, about 8,075 ft; 1,700 ft N. 72° E. of Cross shaft.

Workings: Two shafts, on different veins, probably 200 to 300 ft deep; probably three or four levels.

Geology: Southern shaft on vein that strikes N. 70° E. and is about vertical; northeast of shaft this vein joins eastward-striking vein on which northern shaft is located about 150 ft west of junction. Veins in granite.

History and production: Work carried on continuously in one shaft or other from 1907 to 1919; southern shaft worked from 1923 to 1929 and intermittently up to 1944, when it was operated by M. Bodnar. Good ore discovered in gulch west of mine in 1943 when vein was exposed in placer excavation. Output from two shafts from 1907 to 1929, inclusive, more than 11,000 units of WO_3 in ore averaging about 13 percent WO_3. Mines probably worked before 1907. Owned by Wolf Tongue Mining Co.

BLACK PEARL MINE

Location: Altitude 8,150 ft; 550 ft east-southeast of Bonanza.

Workings: Shallow shaft and open-cut; caved.

Geology: Vein strikes N. 42° E. and dips 70° NW. In granite. Joins Victor vein 100 ft northeast of shaft.

History and production: Small output of fairly high-grade ore, chiefly in 1913. A little ore found by diamond drilling done by Wolf Tongue Mining Co., the owner, in 1943.

VICTOR MINE

Location: Altitude, 8,175 ft; about 4,000 ft N. 64° E. of New shaft of Cold Spring. Although known as Victor mine, it is on Combine claim; Victor claim about 200 ft northeast of shaft.

Workings: Shaft, about 125 ft deep, and two short levels; winze and sublevel at northeast end of lower level. Also two old shafts nearby.

Geology: Vein strikes N. 72° E. and dips 85° N. In granite cut by several small pegmatite dikes. Stope came to surface near shaft; some ore on vein to bottom of winze. Mill ore shipped in 1943 averaged a little more than 1 percent WO_3.

History and production: Victor productive at times since 1910 or earlier; history and production unknown. Operated in early forties by Oscar Faye and later by Faye, Jett, and Phillips. Owned by J. J. Chrisman in 1944.

PHILADELPHIA MINE (Dry Lake District)

Location: Altitude, 8,260 ft; in Dry Lake district, 3,500 ft N. 52° W. of Castle Rock.

Workings and geology: See figure 101; also several caved shafts not included in figure 101.

Ore: Ore on short northeastward-striking cross veins between two strong eastward-striking veins. Northeastward-striking vein just east of shaft on 135-ft level stoped to surface; one southwest of shaft stoped from 110-ft level to surface. Southern eastward-striking vein apparently ore bearing at shallow depth in caved shafts and trenches east of Philadelphia shaft.

History and production: Production said to have been 3,000 units of WO_3, mostly in 1916–18. Mine owned by W. D. Townsend, of Greeley, Colo., in 1943; operated by W. G. Kent from about 1937 to 1942.

DIAMOND SHAFT

Location: Altitude, 8,235 ft; 300 ft southwest of Philadelphia

Workings: Sixty-foot shaft and one short level.

Geology: Strong horn vein; strikes N. 75° E. and dips 75° NW.; cuts dike of aplite 50 to 100 ft wide in granite near shaft.

History and production: Productive in 1916; output probably small. Mine operated for a time in 1942–43. Owned by Gold, Silver, & Tungsten, Inc., and M. M. Rinn in 1944.

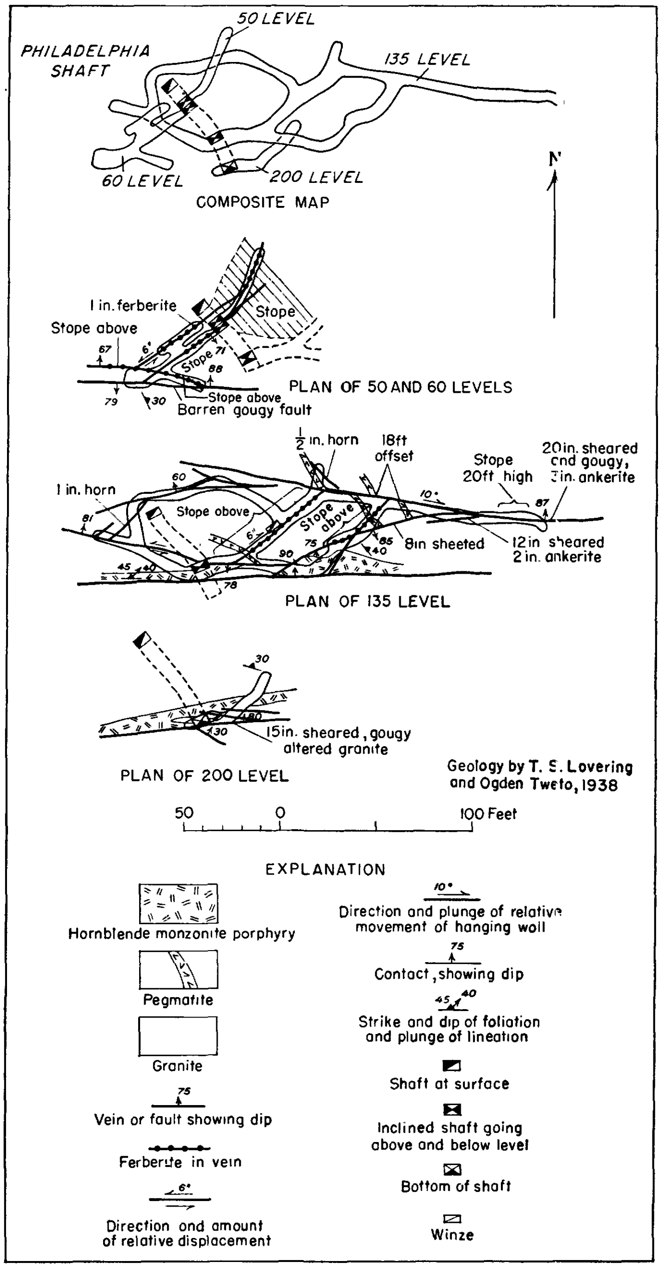


FIGURE 101.—Geologic and composite maps of the Philadelphia mine, Dry Lake district, Boulder County, Colo.

EARLY SPRING MINE

Location: Altitude, about 8,275 ft; 400 ft south of Philadelphia.

Workings: Two or three shafts, probably less than 100 ft deep.

Geology: Veins trending east-northeast intersect small veins trending northeast. Chiefly in granite; some aplite.

History and production: History and production not known; output probably less than 1,000 units of WO_3. One of shafts operated in 1938. Mine owned by A. J. Critz in 1944.

SILVER QUEEN WORKINGS

Location: Altitude, 7,875 ft; beside main Boulder-Nederland road, about 1 mile east of Tungsten.

Workings and geology: See figure 102.

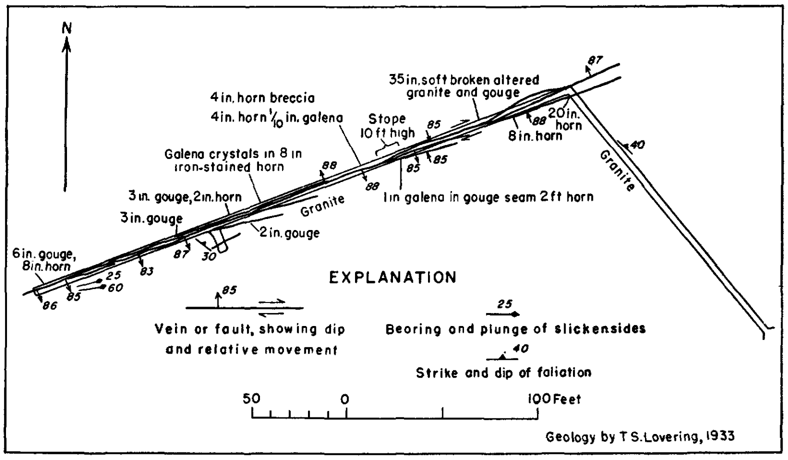


FIGURE 102.—Geologic map of the Silver Queen workings, Boulder County, Colo.

History and production: No tungsten produced from tunnel; minor production from shaft on ridge 900 ft west-southwest of portal of tunnel. Mine owned by V. P. Helburg in 1944.

GORDON GULCH, NORTH BOULDER CREEK, AND ROGERS TRACT

OREGON AND QUAKER CITY MINES

HISTORY AND WORKINGS

The Oregon and Quaker City mines are in Gordon Gulch, in the north-central part of the district, about half a mile northwest of Peewink Mountain (pl. 1). The Gordon Gulch group of mines, which also includes the Ophir, the Misers Hoard, and the so-called Pride, has been highly productive and includes some of the oldest mines of the district. The "Quaker," as it is usually called, was worked during the period from 1900 to 1905 by the Great Western Exploration & Reduction Co. (See description of Misers Hoard and Ophir mines and section entitled "History of the district.") It was worked after 1905 by the Primos Chemical Co. or its subsidiaries, and the adjacent Oregon mine was evidently started shortly afterward. The most productive stage in the history of both mines occurred sometime prior to 1914. The Oregon was reopened by the Primos Co. about 1916 and yielded a substantial amount of ore before it was closed again in January 1919. The holdings of the Primos Co. were acquired by the Vanadium Corp. of America in 1920, but the mines were evidently idle during the next 20 years except for minor operations at the surface. In 1941 the Oregon mine was reopened to the fourth level by George Jump, who operated it, including workings on the Quaker City vein, until 1943. During this period E. W. Webb worked the Quaker City vein in shallow workings near the Quaker City shaft.

The Quaker City vein is part of a strong vein zone that extends eastward from the mines for several miles as shown in plate 1. The Oregon vein is a northeastward-trending branch vein in the hanging wall of the northward-dipping Quaker City vein. As shown in plate 21, the workings of the Oregon mine are on both the Oregon and Quaker City veins, and the third level is continuous with the second level of the Quaker City shaft, which is 575 ft east-northeast of the Oregon shaft. The collar of the northwestward-dipping Oregon shaft is at an altitude of about 7,865 ft. Six levels turned from the shaft are at vertical depths of 84, 139, 260, 337, 433, and 483 ft. The first level is connected with the surface by a tunnel southwest of the shaft. The Quaker City shaft is at an altitude of about 7,800 ft. It dips north, and the two levels turned from it are at vertical depths of about 90 and 195 ft. Much of the Quaker City production came from a crosscut tunnel, now virtually obliterated, that reached the vein at a depth of about 40 ft below the outcrop.

GEOLOGY

The Oregon mine is in gray Boulder Creek granite that is cut by a few dikes or streaks of gneissic granite and aplite and by numerous small dikes of pink Silver Plume granite (pl. 21). The gneissic granite is highly biotitic and is locally schistose. It is closely associated with strongly gneissic aplite and appears to be a late facies of the Boulder Creek granite. The Silver Plume granite is in sharply defined dikes and small irregular masses that cut both the Boulder Creek granite and the streaks of granitic and aplitic gneiss. Both granites are argillized and locally sericitized along the Oregon vein, but the Boulder Creek granite is typically more altered than the Silver Plume granite. The granite in the wide Quaker City vein zone is granulated and silicified, and at most places along the Quaker City vein the two types of granite cannot be distinguished.

The Quaker City vein or vein zone strikes about N. 60° E. and dips 60°–75° NW. at most places. Grooves and striae plunge west or northwest at angles of 20° to 75°. Sets of grooves plunging about 20°, 40°, 60°, and

75° have been noted, and the steepest grooves appear to be the youngest. The Quaker City vein cuts the Rogers breccia reef southwest of the Oregon shaft and displaces it about 150 ft with the right side ahead. Thus the north wall of the Quaker City vein moved down and west at successively steeper angles. In the tunnel on the first level of the Oregon mine, the Quaker City vein is offset slightly by a late fracture within the reef. The northeast wall of the reef moved down and east at about 70°. The direction of this displacement suggests that the late movement may have occurred at the same time as the opening of the Oregon vein (pl. 21). The Quaker City vein zone ranges from 5 to 35 ft in width and averages about 20 ft. It comprises one to three strong horn, breccia, or gouge streaks in sheared and silicified granite that is seamed by innumerable horn veinlets. In some places, as on the fourth level of the Oregon, it contains as much as 10 ft of brecciated gray horn in a single streak; in others there is no large horn vein, and the main fractures are marked by gouge or rock breccia. Well-rounded boulders among sharply angular fragments in the breccia attest to repeated movements along the fracture zone.

The Oregon vein strikes about N. 20° E. and dips 60°–80° NW. It occupies a normal-fault fissure along which the west wall moved down and north at 28°–42°, a distance of 15 to 20 ft. The vein weakens greatly near its junction with the Quaker City vein on the first and second levels, and on the third level it turns parallel to the Quaker City and "horsetails" without making an actual junction (pl. 21). The vein also weakens with depth. On the fourth level its place is taken by a zone of weak overlapping and branching veins, and judging by the level maps, it was not found on the fifth and sixth levels.

The Hildegarde vein is about parallel to the Oregon vein and about 150 ft east of it at the surface. It was productive at the surface and on the second level of the Oregon but has not been opened up deeper in the mine. It could not be identified in the hanging wall of the Quaker City vein on the third and fourth levels, but it was cut 60 ft north of the Quaker City vein in a drill hole on the fourth level.

The Oregon vein contained one relatively large ore shoot that extended from the surface to the third level. On the first level the vein was stoped more or less continuously for 330 ft, beginning about 30 ft northeast of the junction with the Quaker City vein. On the second level the main stope had a length of 225 ft, and there was a small stope south of the shaft also. On the third level the stope was about 100 ft long. Near the northeast end of the drift on the fourth level the vein contains horn breccia and a trace of ferberite, and it is probable that some ore remains in the unexplored block between the third and fourth levels. Ferberite occurred as a filling in granite breccia and in seams in a sheeted zone 5 to 12 ft wide. Hershey described the ore near the surface as "good-grade ore averaging 18 inches thick." Feeders, or small veinlets of ferberite, are abundant in the wall rocks at places, and some small fractures and joint surfaces are coated with crystalline pyrite and chalcopyrite. Small tetrahedrons of amber sphalerite were found resting on ferberite in vuggy ore on the first level. A little colorless scheelite was observed as a coating on ferberite in the Oregon vein, but scheelite is much more abundant in the Hildegarde and Quaker City veins.

Part of the southwestern ore shoot on the Quaker City vein was exposed on the third and fourth levels of the Oregon mine in 1943. This shoot, which raked southwest at about 60°, was evidently stoped almost continuously through a pitch length of about 450 ft from the surface down to the fifth level. It may have been worked below the fifth level, but the short workings on the sixth level suggest that little ore was found there. The shoot maintained a stope length of 90 ft from the surface to the fourth level, but 15 or 20 ft below the fourth level it lengthened to at least 120 ft, and it may have been longer. However, the ore is said to have become leaner below the fourth level, and 1,016 tons mined from the fifth level in 1918 averaged slightly less than 3 percent WO_3. According to the late G. W. Teal, Sr., the ore was 10 to 15 ft thick at places in this shoot.

The vein adjoining the old stopes consists of horn breccia partly filled with fine-grained ferberite and black, ferberite-bearing horn. The coarse and open breccia consists largely of dark-gray and slightly translucent horn quartz, but it contains a few fragments of altered granite. Some of the ore contains massive purple fluorite, which is younger than the black horn and ferberite. Rarely, cubes of fluorite are found resting on ferberite in vugs. Sulfide minerals are relatively abundant in the tungsten ore and are present sparingly at many places in the barren parts of the vein. Near the ore shoot galena is the most abundant of these minerals, but elsewhere pyrite is more abundant than galena. In and near the ore shoot galena occurs chiefly in veinlets and small masses that cut black horn and fluorite. Most of it is intergrown with a little dark sphalerite, but in vugs amber crystals of sphalerite rest on galena. Some of the galena in vugs is coated with beidellite. Dark horn in the Quaker City vein near its intersection with the Rogers reef on the first level contains fairly abundant disseminated galena as well as pyrite and minor sphalerite. Tetrahedrite and ruby silver are rare vug minerals and are younger than the sphalerite. Platy barite crystals are younger than the tetrahedrite. Chalcopyrite and lens-shaped crystals of manganosiderite also were observed in the Quaker City ore, but their position in the paragenetic sequence is unknown except that they are younger than ferberite. Scheelite is a minor constituent of the Quaker City vein at most places and is fairly abundant locally. In an underhand stope below the fourth level a 1-in. vein of scheelite and white horn was seen cutting ferberite, fluorite, and galena, and a film of powdery scheelite coated every surface, including the tiny vug minerals, in a 2-ft streak within the vein. The scheelite and the paragenetic sequence in this vein have been described in greater detail elsewhere (Tweto, 1947a).

A white quartz vein exposed in the footwall of the Quaker City vein on the third level probably represents an older mineralization. The vein contains bands of comb quartz about 2 in. wide next to the walls, and a 2- to 4-in. streak of finer-grained white quartz in the middle. This latter streak contains disseminated pyrite, chalcopyrite, and limonite (originally hematite?) and a little sphalerite and galena. The quartz vein is followed and locally cut by a vein of gray horn quartz that branches from the Quaker City vein. The horn vein is about 12 in. thick near the Quaker City vein but thins rapidly to the southwest, whereas the white quartz vein remains constant in thickness. The white quartz vein is probably older than the tungsten mineralization and of the same age as the sulfide veins found near the Ophir and Misers Hoard mines and northwestward along Perkins Gulch (pl. 1), and it is presumably faulted by the Quaker City vein. A small vein in the footwall of the Oregon vein on the fourth level also is believed to be older than the tungsten mineralization. The drift follows this vein northward from the shaft. The vein contains a narrow seam of gray horn quartz on the fourth level, but in a raise 35 ft above the level it consists of fluorite and calcite, with some specular hematite, pyrite, and chalcopyrite. The fluorite suggests a relationship to the Quaker City vein, but the specular hematite suggests that the vein is unrelated to the tungsten mineralization.

The Oregon and Quaker City veins have been thoroughly explored, but some ore probably remains on the Oregon vein between the third and fourth levels. The Hildegarde vein was productive at the surface and above the second level of the Oregon mine, but it has been explored only by a single drill hole below the second level. This hole showed gouge in the Hildegarde vein near its intersection with the Quaker City vein on the fourth level, but the 200-ft interval between the second and fourth levels is unexplored. It could be explored easily by drilling from the crosscut between the Oregon and Hildegarde drifts on the second level and from the Quaker City drift on the third level.

MISERS HOARD AND OPHIR MINES

The Ophir mine and the Misers Hoard, or "Hoard" mine as it is usually called, are in Gordon Gulch about 1,000 ft northeast of the mouth of Perkins Gulch (pl. 1). Workings a few hundred feet east of the Hoard shaft are known as the Pride mine, although the Misers Pride claim is several hundred feet to the south, as shown in figure 103. The Hoard shaft and the Miser tunnel were driven in search of silver before tungsten mining began. Tungsten ore was presumably exposed in the Hoard mine, as well as at the site of the Ophir mine, when ferberite was first identified in the district, for the Great Western Exploration & Reduction Co. began mining tungsten at the Hoard and Ophir mines in 1900, the same year that Conger and Wanamaker began mining in the western part of the district.

During the first few years of tungsten mining the Gordon Gulch mines were among the most productive in the district. According to Van Wagenen (1908, p. 146), the Gordon Gulch group (Hoard, Ophir, Pride, and Quaker City) supplied half the district output in 1904 and had produced 600 tons of 60-percent concentrates, or 36,000 units of WO_3, at that time. Six hundred tons is roughly two-thirds of the output credited to the district through 1904. In 1905 the Stein & Boericke Mining & Milling Co., a subsidiary of the Primos Chemical Co., acquired the Gordon Gulch group from the Great Western Exploration & Reduction Co. The new owners continued to operate the mines, but judging by old maps and sections, the ore bodies were largely worked out by 1907. In 1908 the Stein & Boericke holdings were combined with those of Lake and Barnsdall in the western part of the district, and the Primos Mining & Milling Co. was formed. A new mill was built at Lakewood, and the old Gordon Gulch mill was dismantled. The Hoard, Pride, and Ophir have been worked on a small scale at times since 1909, but the production has apparently been small. In 1920 ownership of the mines passed to the Vanadium Corp. of America.

The Misers Hoard vein may be regarded as the master footwall fracture of a wide eastward-trending shear zone, the continuation of the Quaker City vein zone in this locality; the Ophir vein, which strikes N. 60° E. and dips 70° NW., is a branch vein of this zone (fig. 103). According to Hershey, both veins were mineralized with lead-silver ore of low grade before they were reopened and the tungsten ore deposited. The Misers Hoard vein is in a normal fault that dips 70°–75° N., and the north wall moved down and west at approximately 30°. On the Ophir vein, however, the north

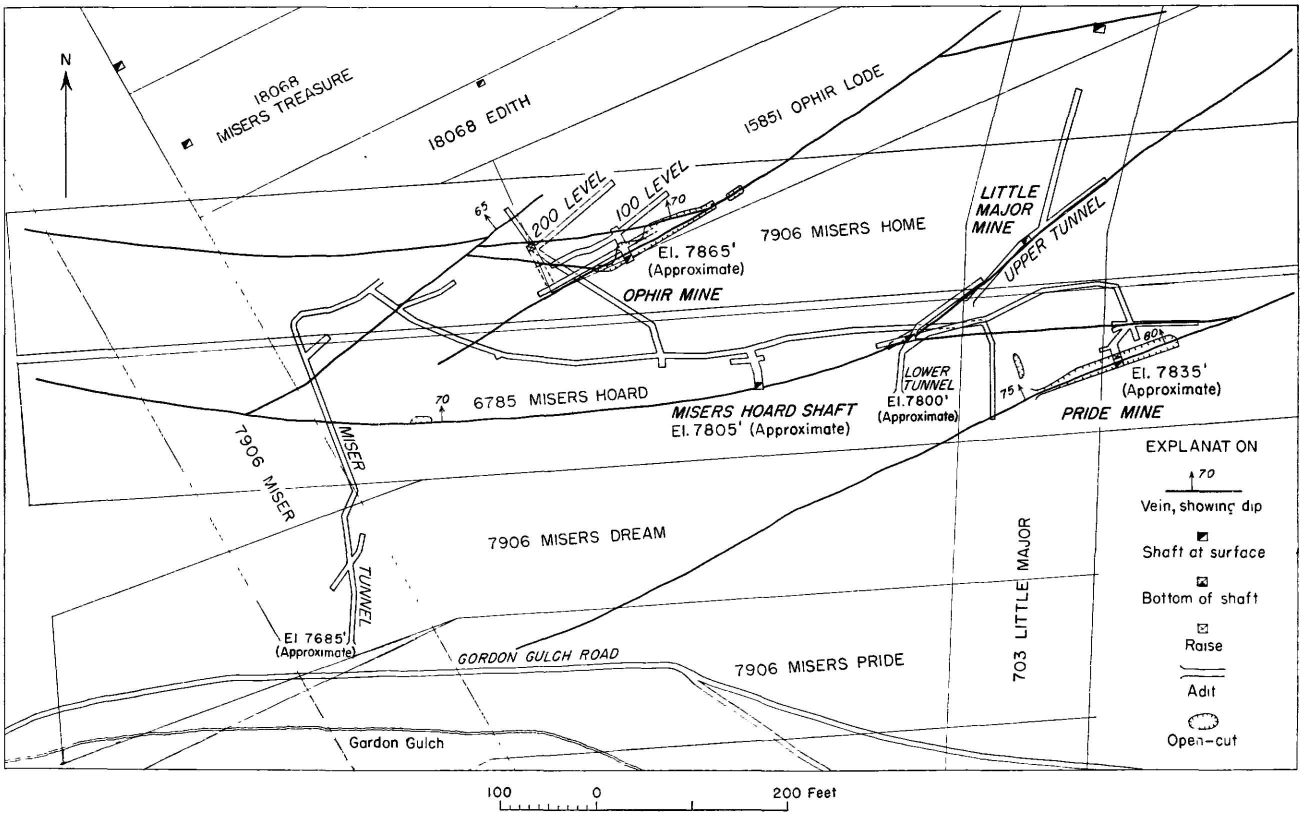


FIGURE 103.—Veins and underground workings of the Misers Hoard-Ophir area, Boulder County, Colo., about 1914 (after a map of the Primos Mining & Milling Co., with minor revisions).

wall moved up and east at about 20°. According to the late G. W. Teal, Sr., no tungsten ore was found in the part of the Misers Hoard vein that strikes due east. A stope 40 to 50 ft long, just east of the Hoard shaft, where the vein turns east-northeast, is said to have followed a seam of 12-percent ore about 4 in. thick. The ore did not extend to the floor of the drift, and it pinched out below the surface. Some ferberite also occurs in the Misers Hoard vein in open pits about 350 ft west of the shaft. Most of the ore produced near the shaft came from the intersection of the Little Major and Misers Hoard veins, about 200 ft east of the Hoard shaft. The Little Major vein is a northeastward-striking branch of the Misers Hoard vein with very much the same relation to it that the Oregon has to the Quaker City vein. It carried some high-grade ferberite and has been explored on two levels.

A shoot of rich ferberite ore occurred in a vein striking east-northeast that joins the Hoard vein from the south about 500 ft east of the Hoard shaft. The ore shoot lay about 100 ft southeast of the junction and was mined in a deep open-cut known as the Pride cut. According to Hershey's report, the ore in the open-cut was as much as 12 ft wide and averaged approximately 8 percent WO_3.

The Ophir vein, like the Misers Hoard vein, has several branches on the west side (pl. 1). The highly productive Ophir ore shoot had a maximum length of about 200 ft, but the richest ore was in three well-defined shoots within the larger shoot. These were localized at the intersections of three steep branch veins with the main Ophir vein and plunged steeply southwest. High-grade ore several feet thick is said to have occurred in the acute angles between the branch veins and the main Ophir vein. At each junction the ore on both the main vein and the branch vein thinned rapidly to the southwest, but both veins and the intervening "feedered" rock were mined as mill ore up to the next rich shoot to the southwest, and ore was stoped for a width of as much as 25 ft in an open-cut at the surface. The ore at all three junctions bottomed abruptly at a depth of about 100 ft below the collar of the Ophir shaft. According to Hershey, the main Ophir vein in the lower tunnel level is a "sheeted zone several feet wide having a light to dark gray gouge accompanied by a zone of crushed granite, which is in part soft and gougy and in part well cemented and stained dark gray." Locally galena, sphalerite, tetrahedrite, and quartz were observed. A raise from the lower tunnel, about 210 ft below the collar of the Ophir shaft, followed a gougy fracture of this character up to the bottom of the ferberite ore shoot.

ROGERS NO. 1 AND NO. 11 MINES

The Rogers No. 1 and No. 11 mines are in the central part of the tungsten district, on the south side of North Boulder Creek not far west of Gordon Gulch, and are approximately 1,500 ft south-southwest of Switzerland Park at altitudes of about 8,075 and 7,800 ft (pl. 1). The Rogers No. 1 mine has been the most productive mine on the Rogers tract and one of the most productive in the eastern part of the district. According to records that are probably almost complete, it has produced about 37,000 units of WO_3. All but about 3,000 units of this total was in ore that averaged more than 10 percent WO_3. About half the total was produced prior to 1916, and much of the remainder was produced between 1916 and 1926, probably mostly in 1916–18. The mine was worked by the Phillip Bauer Co. from 1907 to 1909 and was presumably the chief source of ore for this company's Clarasdorf mill. After 1909 it was worked under the direction of Eugene Stevens. Little work appears to have been done after World War I, but a small output was achieved in 1942–44, when the mine was operated on a minor scale by Slide Mines, Inc. The output of the Rogers No. 11 mine is about 2,000 units in ore that averaged less than 2 percent WO_3. Most of this was produced in 1942 by Slide Mines.

As shown in plate 22, the Rogers No. 11 vein is reached by a 140-ft crosscut tunnel from which a drift extends 450 ft to the west and 50 ft to the east. A short sublevel 50 ft below the main tunnel is turned from a winze 240 ft west of the crosscut. The vein strikes N. 75°–85° E. and dips 67°–88° N. in the eastern part of the mine; in the western part the strike swings to N. 65° E., and the dip is steeply to the south. The mine is in Boulder Creek granite, and owing to the uniformity of the rock, the displacement along the vein could not be determined with certainty. A relatively flat pegmatite exposed near the winze and in the hoist chamber appears to be displaced with the north side about 7 ft down. However, there are several sets of grooves along the vein, and these all plunge at low angles. Some of the grooves plunge east and some plunge west, and many of them are on horn quartz of various types, indicating several periods of nearly horizontal movement along the vein.

The Rogers No. 11 vein is a composite vein consisting of 2 to 3 ft of fissured and brecciated early light-gray horn quartz and a thin late vein of black horn and ferberite. The younger vein winds a sinuous course through and along the older light-gray horn vein. The black horn and ferberite filled only part of the openings in the gray horn, and the younger vein contains many open cavities several feet long and as much as a foot wide. Small kidneys of galena were found in one or two of these cavities. The wide and persistent early quartz vein and the weak ferberite vein suggest that the fissure was dammed off after the deposition of the early light-gray horn, and although later movement produced ample openings, only a little ferberite and black horn was available to fill them.

The Rogers No. 1 mine comprises two tunnels whose portals are 325 and 600 ft southwest of the Rogers No. 11. The tunnels are 135 ft apart vertically, and the lower tunnel is 140 ft higher than the Rogers No. 11. The entire production has come from the upper tunnel and from open-cuts above it. The vein strikes N. 35° E.; it dips about vertically at the surface, flattens to a dip of 74°–80° NW. at the upper tunnel, and steepens slightly to a dip of 80°–88° NW. in the lower tunnel. It follows a normal fault along which the north wall moved down and northeast at about 30° for about 20 ft. The Rogers No. 1 vein and a branch of the Rogers breccia reef intersect near the portal of the upper tunnel and near the southwest end of the lower tunnel (pl. 22). The reef is a wide sheared or brecciated zone that trends north-northwest and dips about 85° E. It is partly silicified and contains abundant horn quartz in the Rogers tunnels. It contains disseminated pyrite near the Rogers No. 1 vein and abundant hematite beginning about 100 ft southeast of the vein.

Complex structure at the intersection of the reef and the vein records successive movements on both fractures (see sketches, pl. 22). The reef is older than the vein and is offset about 20 ft by the vein in the lower tunnel. Later movement on the reef broke the vein, offsetting the northeastern segment 15 to 25 ft to the south. Later movement on the Rogers No. 1 vein produced a diagonal connection between the offset segments of the vein and displaced the reef slightly. Finally, minor late movement on the reef displaced the new diagonal segment of the No. 1 vein about 12 in. in a direction opposite to that of the early movement.

The Rogers No. 1 vein is gougy near the portal of the lower tunnel. At a point about 40 ft from the portal it is joined by a horn vein from the east. From this junction southwestward to the Rogers reef the vein consists of 1 to 3 ft of gray- to dark-gray horn quartz breccia and contains local seams and pockets of black horn and traces of ferberite, pyrite, and copper stain. Southwest of the reef in the lower tunnel the vein is less horny and contains veinlets of black horn and a little ferberite. The horn vein that joins the footwall from the east 40 ft from the portal is probably the Rogers No. 11 vein. Although the main horn quartz seam turns and follows the Rogers No. 1 fracture, an actual crossing of the Rogers No. 1 and No. 11 veins may be represented by a horny vein that branches into the hanging wall of the Rogers No. 1 at a point 100 ft from the portal.

In the upper tunnel the segment of the Rogers No. 1 vein northeast of the Rogers reef is a weak gouge seam at most places, but locally it is almost indistinguishable in the crushed pegmatite near the reef. Southwest of the reef, the wide brecciated zone between the younger diagonal vein and the end of the older faulted segment to the north is largely gougy but contains considerable brecciated black horn and a little ferberite. The main ore shoot of the Rogers No. 1 mine lay a short distance southwest of the reef and extended about 250 ft southwestward along the vein (pl. 22). The richest part of the shoot was near the surface, where the vein is vertical or locally dips steeply south. The ore thinned and became leaner where the dip flattened slightly, near the tunnel, and small stopes below the tunnel extend to a depth of only 40 ft. Ore that averaged about 10 percent WO_3 was mined through widths of as much as 12 ft in the cuts or open stopes near the surface. Southwest of the ore shoot the Rogers No. 1 vein is shown by bulldozer trenches to swing to a more southerly course. This swing to the left on a vein along which the left wall moved forward causes the vein to tighten and the ore to pinch out.

The barren or nearly barren character of the Rogers No. 1 and No. 11 veins northeast of the breccia reef is in marked contract to the richness of the Rogers No. 1 vein southwest of the reef. Both the veins northeast of the reef are strong horn veins, but the Rogers No. 11 vein shows clearly that the horn represents an early stage of mineralization and that the veins were dammed off during the later, ferberite-depositing stage. Considering the contrast in the veins on the two sides of the Rogers reef and the intermittent movement along the reef, it seems probable that late movement on the reef accounted both for the damming off of the veins to the northeast and for the opening of the Rogers No. 1 vein southwest of the reef. If this is true, it is improbable that any large ore bodies are present on the Rogers No. 1 and 11 veins between the Rogers reef and the Rogers No. 11 mine. On the other hand, the Rogers No. 1 vein southwest of the reef in the lower tunnel seems to be a good prospect, and the presence there of banded black and gray horn and a little ferberite, rather than of massive horn breccia, is encouraging.

The Rogers No. 11 vein intersects an eastern branch of the Rogers breccia reef in a covered and unexplored area about 500 ft east of the Rogers No. 11 mine. The relation of the vein to this reef is analogous to that of the Rogers No. 1 vein to the western branch of the Rogers reef, and the area therefore is worth exploration.

SMALLER MINES

ROCKY MOUNTAIN MINE

Location: Lower tunnel at edge of North Boulder Creek at altitude of 7,750 ft.; 4,500 ft. southwest of Peewink Mountain.

Workings and geology: See figure 104; also caved shaft workings above tunnels shown in figure 104.

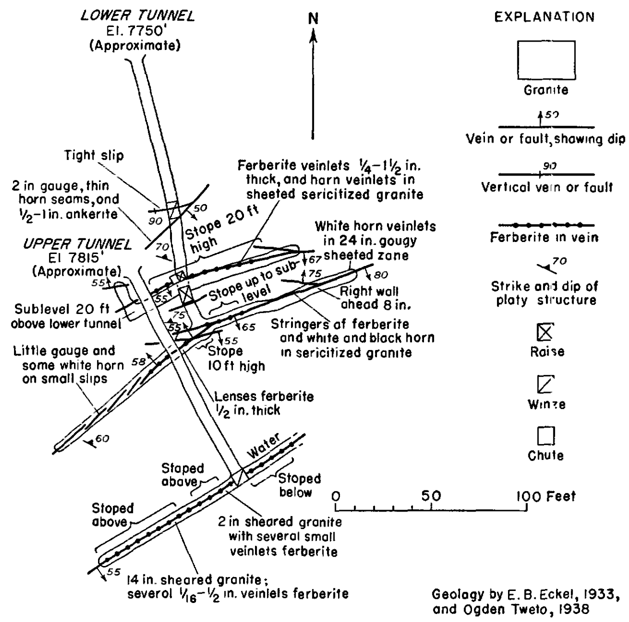


FIGURE 104.—Geologic plan of the tunnel workings of the Rocky Mountain mine, Boulder County, Colo.

Ore: Chief stopes in upper tunnel and probably off shafts; only a small stope in lower tunnel and sublevel 20 ft. above it. Ore shoot in upper tunnel plunges northeast; ore is ferberite veinlets in sheared or sheeted granite. Lower tunnel opens different veins.

History and production: Stopes suggest output of several hundred units of WO_3. Mine worked by Fansteel Corp. in 1938.

PEEWINK MINES

Location: Lower tunnel at altitude of 7,635 ft at southeast base of Peewink Mountain; upper workings at altitude of about 8,200 ft, just east of top of Peewink Mountain.

Workings and geology: See figure 105.

Ore: All ore mined from lower tunnel came from east-northeastward-striking vein and vein that branches north-northeast from it, at inner end of tunnel. These veins stoped extensively above tunnel; some ore may have been mined from two winzes on main vein. Ore of upper workings in so-called blow-out 75 ft long, 5 to 20 ft wide, and 15 to 60 ft deep. Rock sliced up by steeply dipping, east-northeastward-striking fractures, which contain veinlets of crystalline ferberite, and gently dipping, northward-striking fractures, which contain ferberite as filling in seams of breccia.

History and production: Peewink mines most productive in 1915–16, although worked at least as early as 1912. Available records fragmentary; record of shipments made from March 2 to May 11, 1916, shows output of 840 units in ore averaging 12.8 percent WO_3 and valued at \$39,154, or \$46 per unit in ore. Mines operated at times up to 1943 by many different lessees. Total output probably several thousand units of WO_3.

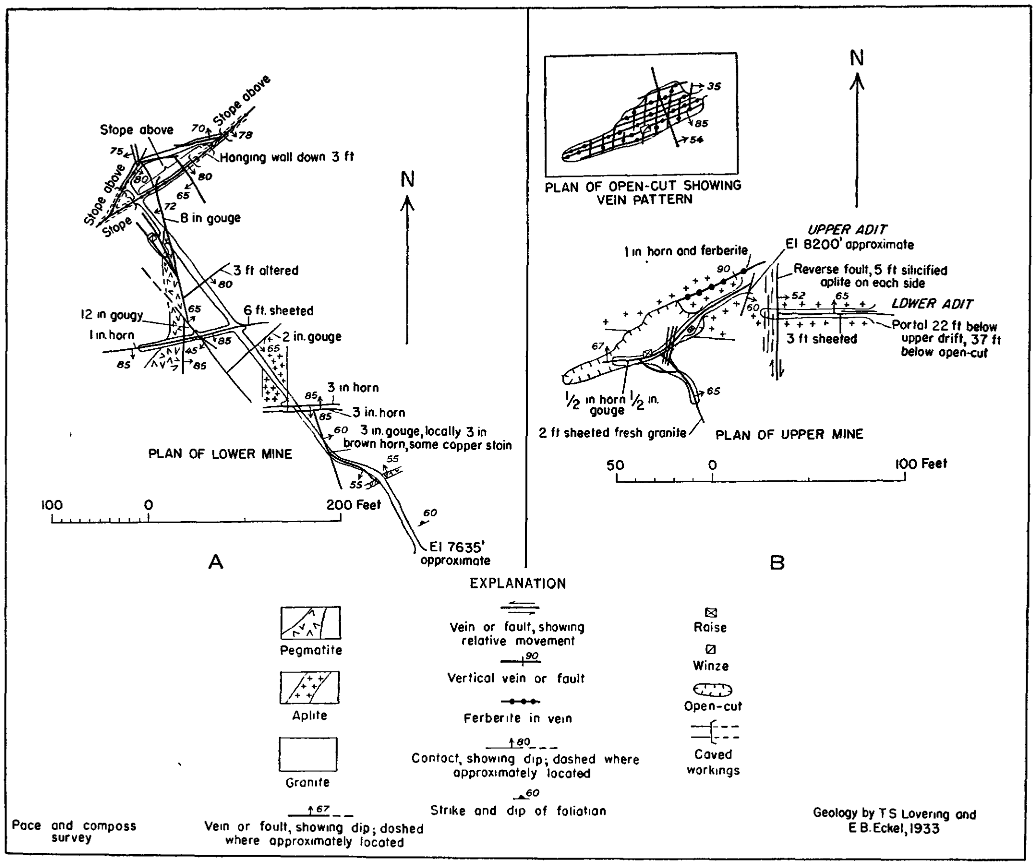


FIGURE 105.—Geologic plans of the lower and upper Peewink mines, Boulder County, Colo. The upper mine is 1,300 ft. west-northwest of the portal of the lower tunnel and is on a different fracture system.

HILDEGARDE MINE

See description of Oregon and Quaker City mines and plate 21.

EXCHANGE MINE

Location: Altitude, about 7,750 ft; in Perkins Gulch, 2,500 ft N. 8° W. of Peewink Mountain.

Workings: Tunnel, caved for many years.

Geology: On north-northeastward-striking branch of Quaker City vein zone. In aplite.

History and production: According to Hershey's report (1914), mine yielded about 100 tons of 5-percent ore (500 units). Ore had maximum thickness of 1 ft and average of 4 in. Mine owned by Vanadium Corp. of America; apparently not worked since before 1914.

LITTLE MAJOR MINE

See description of Misers Hoard and Ophir mines and figure 103.

PENNSYLVANIA MINE

Location: Altitude, about 7,715 ft; on northeast side of Gordon Gulch, 2,350 ft N. 54° E. of Peewink Mountain.

Workings and geology: See figure 106.

Ore: Mine exploited two ore shoots. One near shaft extended from surface to just above bottom level; one 50 to 60 ft farther east extended from surface to a few feet below second level. Ore mined from lower part of western shoot in 1943 was as much as 3 ft wide; consisted of seams of "peanut ore" as much as 6 in. wide cutting brecciated gray horn quartz and silicified granite. This ore contained considerable scheelite in form of crusts of drusy crystals lining vugs.

History and production: Mine probably first worked on extensive scale during World War I. Property widely known earlier for excellent ore showing at surface, but remained unworked for many years while owned by James McNally. Worked in twenties by Alec McClellan; considerable production. In 1942–44 worked by Earl Craig and sons; about 2,850 units of WO_3 produced. Total output not known but may be as much as 10,000 units of WO_3. Mine owned by John Jordan in 1943.

EVENING POST WORKINGS

Location: Tunnel at altitude of 7,560 ft in valley of North Boulder Creek at Switzerland Park, 3,200 ft S. 84° E. of Peewink Mountain. Shaft workings at altitude of 7,960 ft; 1,000 ft south of tunnel portal and directly over breast of tunnel.

Workings and geology: See figure 107. Shaft about 150 ft deep; probably three levels. On short vein that strikes N. 45° E. in granite cut by dikes of limburgite porphyry and aplite.

History and production: All production from shaft; no ore in tunnel. A little work done by Sewell and Bronson in upper part of shaft workings in 1943. Mine owned by Henry Lawerence, of Switzerland Park.

ROGERS NO. 2 MINE

Location: Altitude, 8,175 ft; in Dry Lake district, 3,750 ft N. 15° W. of Castle Rock.

Workings and geology: See figure 108.

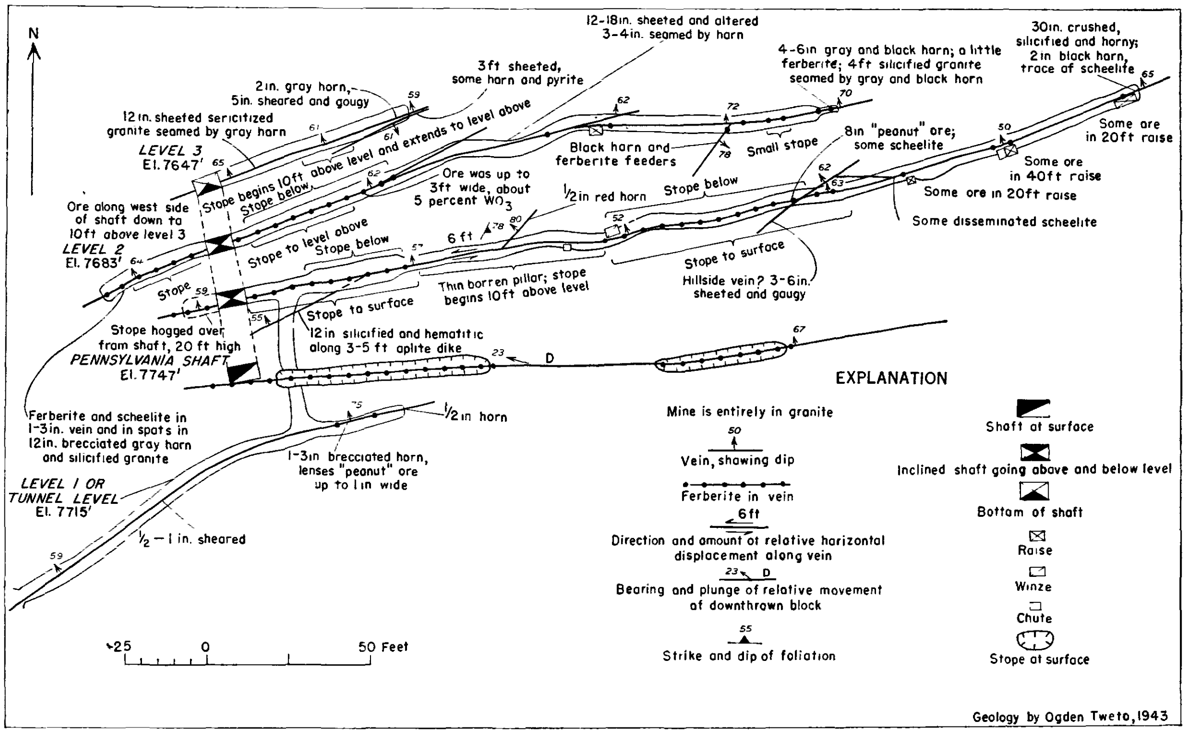


FIGURE 106.—Geologic plan of the Pennsylvania mine, Boulder County, Colo.

Ore: Seams of high-grade ferberite in sheeted granite. Vein flattens rapidly between 75- and 118-ft levels; ore pinches.

History and production: Produced 2,763 units of WO_3 in sorted ore averaging 27.63 percent WO_3 up to 1916 and 2,031 units in ore averaging 26.17 percent WO_3 from September 1916 to 1926, mostly in 1917–18. Operated in 1943 by J. A. Smith; a small output. Total output at least 5,000 units of WO_3. Mine owned by Rogers Estate, c/o Platt Rogers, Pueblo, Colo.

ROGERS NO. 3 WORKINGS

Location: Altitude, about 7,960 ft; 1,900 ft S. 12° E. of upper tunnel of Rogers No. 1 mine.

Workings: Numerous small shafts, tunnels, and open-cuts.

Geology: On eastward-trending veins of Rogers No. 4 and No. 5 vein system, near intersections with norwestward-trending fractures of Rogers breccia reef system. In aplite and granite.

History and production: Produced 1,528 units of WO_3 up to 1926; apparently not operated since then.

ROGERS NO. 4 MINE

Location: Altitude, 7,810 to 7,860 ft; 2,300 ft south of upper tunnel of Rogers No. 1 mine.

Workings and geology: See figure 109.

Ore: Most of production from upper tunnel; horny ferberite in white horn quartz breccia in strong shear zone in granite.

History and production: Produced 1,209 units of WO_3 in sorted ore averaging about 8 percent WO_3 up to 1926, probably all before 1919. Minor production from upper tunnel about 1940. In 1942 Slide Mines, Inc., extended lower tunnel about 300 ft; little ore found; only small production.

ROGERS NO. 5 MINE

Location: Altitude, 7,850 ft; 300 ft northwest of lower tunnel of Rogers No. 4 mine.

Workings and geology: See figure 110.

Ore: Fine-grained horny ferberite and black, ferberite-bearing horn quartz in veinlets and as breccia filling in wide silicified shear zone cut by many veins of gray horn quartz.

History and production: Mine worked at times before 1916 and again about 1930; only small production. Worked in 1943–44 by Slide Mines, Inc., which drove lower level. Total output seemingly a few hundred units of WO_3 in low-grade horny ore.

ROGERS NO. 7 MINE

Location: Altitude, 7,750 ft; 175 ft S. 30° E. of Ruby tunnel (upper tunnel of Rogers No. 13 mine).

Workings and geology: See figure 111; also extensive trenches at surface.

History and production: Worked chiefly prior to 1919; small production at times since then. Worked on minor scale in 1943. Output to 1926 was 490 units in ore averaging 9.85 percent WO_3; apparently less than 100 units produced since.

ROGERS NO. 9 MINE

Location: Altitude, 7,925 to 7,975 ft; 3,600 to 3,800 ft S. 58° E. of Peewink Mountain.

Workings: Several open cuts and tunnels, all caved in 1943.

Geology: Vein strikes east-northeast and dips 75° SE. In aplite and pegmatite at mine; elsewhere in granite.

History and production: Produced 612 units of WO_3 in ore averaging about 8 percent WO_3 to 1926, probably all before 1919. Except for small output of sorted high-grade ore in 1929, apparently no operation since then.

ROGERS NO. 12 MINE

Location and workings: Several trenches and shallow shafts 400 ft northeast of Rogers No. 2 shaft; altitude, 8,150 to 8,175 ft.

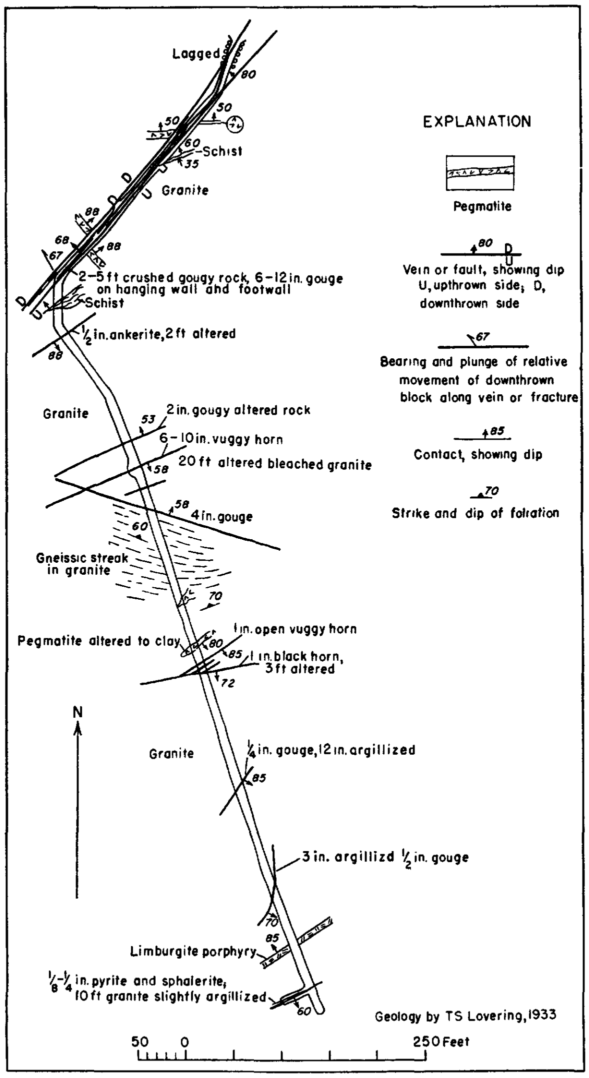


FIGURE 107.—Geologic plan of the Evening Post tunnel, Boulder County, Colo.

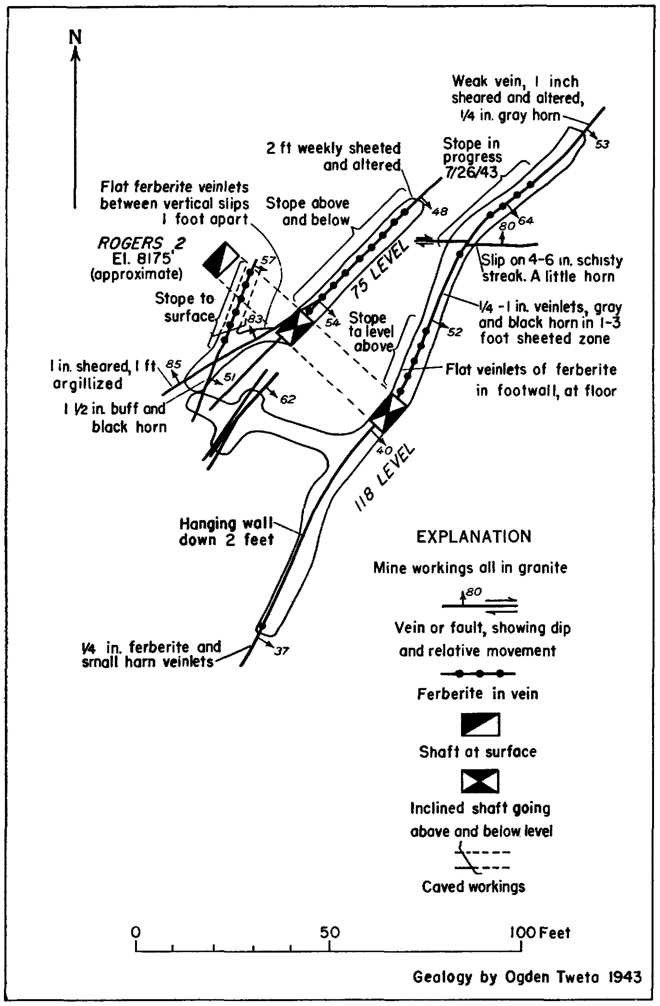


FIGURE 108.—Geologic plan of the Rogers No. 2 mine, Boulder County, Colo.

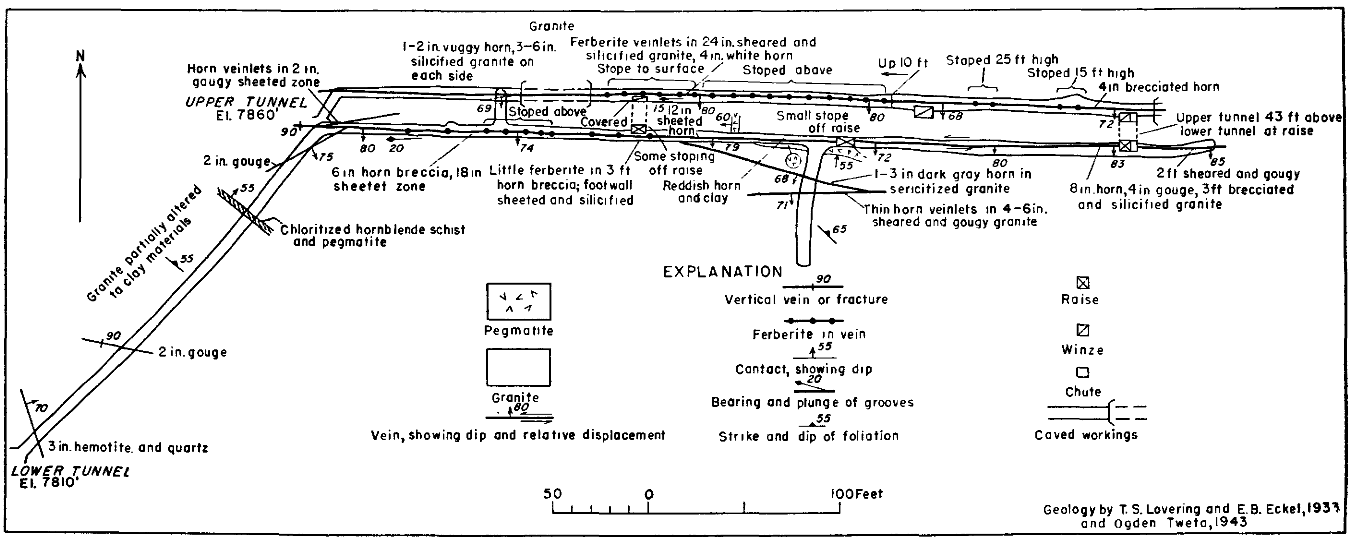


FIGURE 109.—Geologic plan of the Rogers No. 4 mine, Boulder County, Colo.

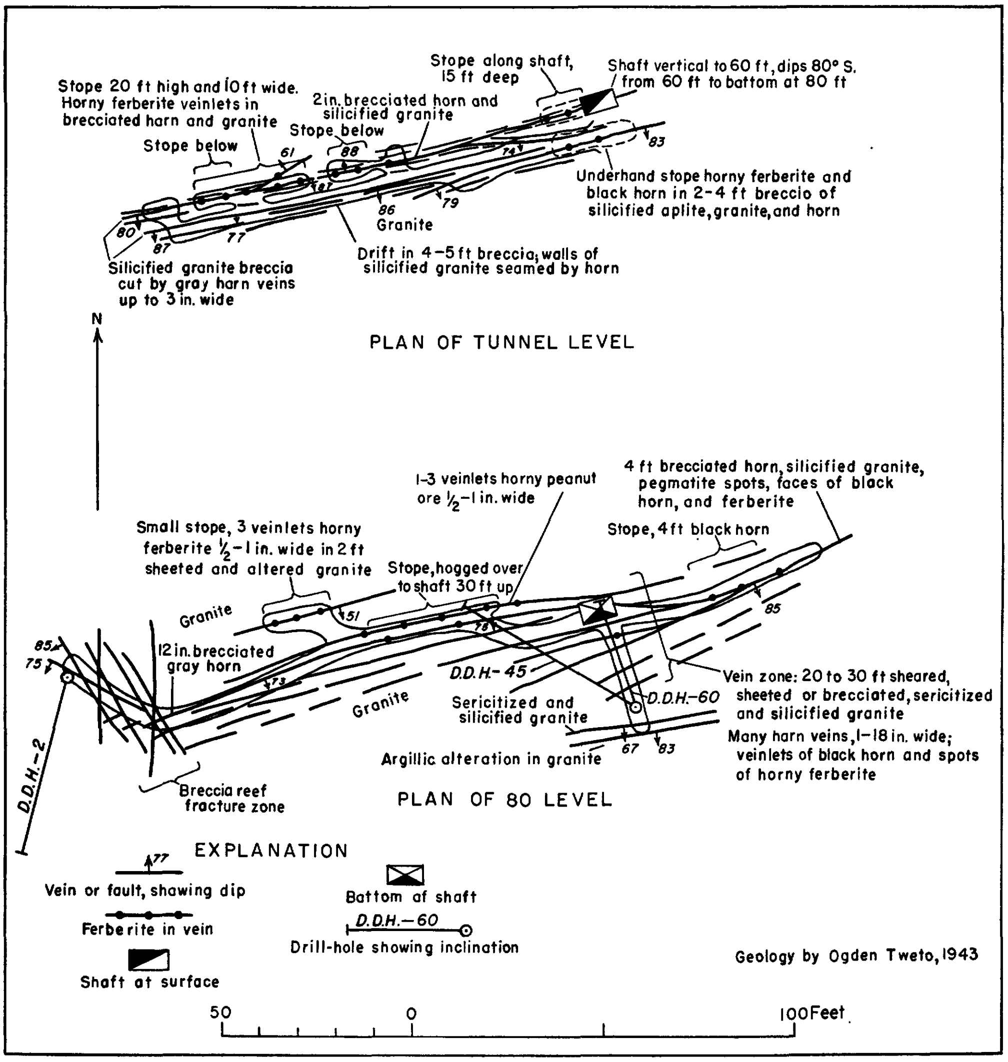


FIGURE 110.—Geologic plan of the Rogers No. 5 mine, Boulder County, Colo.

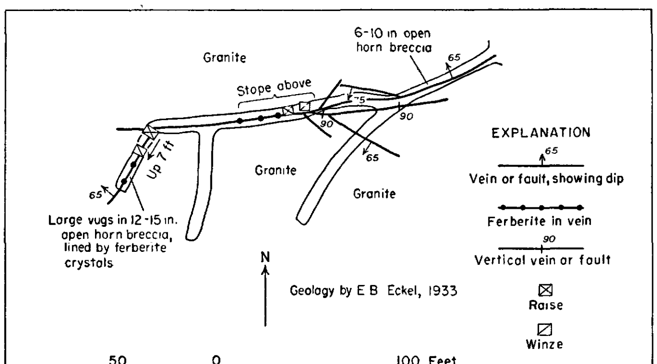


FIGURE 111.—Geologic plan of the Rogers No. 7 mine, Boulder County, Colo.

Geology: On northeast extension of Rogers No. 2 vein and small branch veins. Ore chiefly at junctions of branch veins with main vein; all shallow.

History and production: Produced 727 units in ore averaging 20.77 percent WO_3 to 1926, probably all before 1919. Very little work done since then.

ROGERS NO. 13 MINE

Location: Tunnels at altitudes of 7,740 and 7,760 ft; 3,650 ft S. 30° W. of Peewink Mountain. Upper tunnel called Ruby tunnel.

Workings and geology: See figure 112; extensive trenches, from which most of production came, not shown.

History and production: Produced about 1,800 units of WO_3 in ore averaging about 10.6 percent WO_3 to 1926. Minor operation at times since then. Worked in 1943 by A. H. Scruggs.

BOULDER FALLS—SUGAR LOAF AREA

EUREKA MINE

The Eureka mine is on the steep slope north of Middle Boulder Creek at the Narrows, about 2,500 ft southwest of Boulder Falls (pl. 1). The Eureka vein crosses several claims owned by Gold, Silver & Tungsten, Inc., but most of the workings are on the Amanda claim. A tunnel 1,000 ft southwest of the Eureka tunnel and about 565 ft higher has been called the Upper Eureka or Tip Top, although the Tip Top

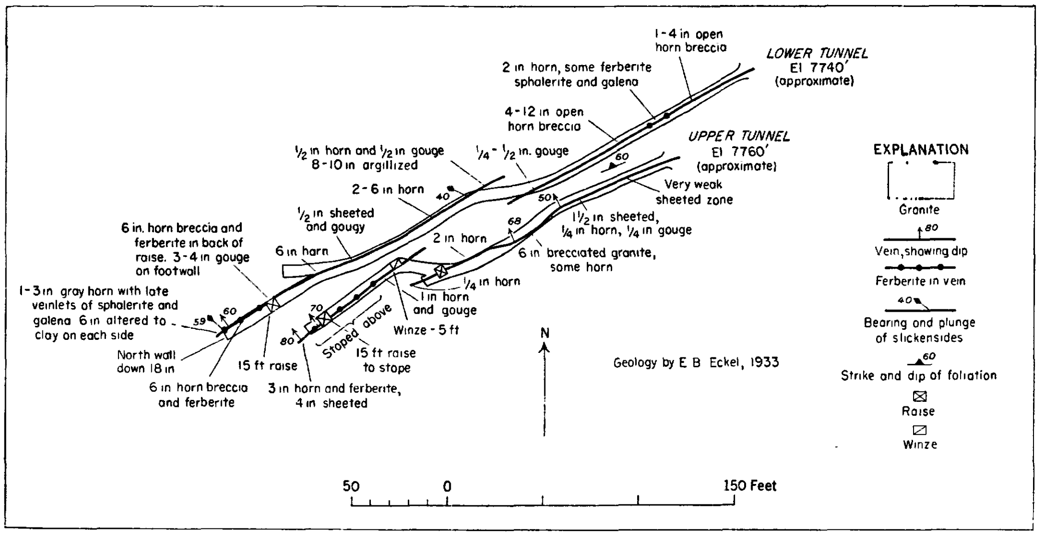


FIGURE 112.—Geologic plan of the Rogers No. 13 mine, Boulder County, Colo., including the Ruby tunnel.

claim is a few hundred feet farther southwest. The Eureka vein has been productive through a length of almost three-quarters of a mile and through a vertical range of about 900 ft, from an altitude of 7,950 ft on the Tip Top claim down to an altitude of about 7,050 ft at the bottom of the Eureka mine. This is the greatest vertical range of ore on a single vein known in the district. Most of the output has come from the Eureka mine, but the total output from many small tunnels and open-cuts is considerable. Only fragmentary production records are available, but even these show an output of more than 10,000 units of WO_3. The mine was operated prior to 1916, but no record of the early operations is available. It was operated in 1916–18 by Wilson and Adams, in 1927–31 by Miller & Co. and by Gilbert & Co., and in 1936–44 by Ben Newmann and associates, who did business as the Eureka Tungsten Co. From 1936 to 1943, the ore was concentrated in a mill at the mine, and in 1943–44, it was shipped to the Metals Reserve Company stockpile.

As shown in figure 113, the main mine comprises a crosscut tunnel and a drift about 500 ft long from which winzes have been sunk near the east and west ends. The eastern winze reaches a depth of about 150 ft, and two levels are turned from it. On the lower level a heavy flow of water was encountered in an open fissure a few feet east of the winze, and the Midway tunnel, whose portal is 1,200 ft east of the Eureka, was extended for several hundred feet to drain this flow. The western winze reaches a depth of 93 ft, and two short levels were turned from it. All the work below the tunnel was done by Newmann after 1936.

The Eureka vein strikes N. 55°–75° E. and dips 75°–85° N. in most places, though locally it swings through the vertical and dips 85° S. The movement of the premineral fault occupied by the vein is like that on most of the east-west veins in the southern part of the district; the south wall moved down and east at a low angle, and the angle of net displacement is probably 15° to 20°. As would be expected from this direction of movement, the ore occurs in the parts of the vein having a more northeasterly trend than the average; the right-hand wall of the vein moved forward, and the ore therefore tends to occur where the vein swings toward the left. Within the Eureka mine the dip of the vein decreases from west to east, and the character of the vein changes also. Near the western winze the vein dips 80° N. to vertically, or even steeply south, and at the edges of the ore shoot it is a single tight fracture or a narrow seam of horn quartz bounded on each side by about a foot of granite altered to clay minerals. Eastward, the vein grades into a sheeted zone that is 6 to 18 in. wide in most places but is 3 to 8 ft wide in the ore shoot near the crosscut tunnel. The wall rocks are argillized and cut by chloritic seams for 1 to 3 ft on each side of the vein.

The Eureka vein splits near the bottom of the eastern winze. A weak branch continues N. 65°–70° E. from the winze, and the Midway tunnel follows a zone of discontinuous small fractures that trends about N. 80° E. Veins in this zone were productive at the surface east of the Eureka mine, but they are practically barren in the tunnel.

Two ore shoots were worked in the Eureka mine. The eastern shoot raked steeply northeast and was stoped through a length of 135 ft on the tunnel level. The stopes above the tunnel can be seen extending to a height of at least 75 or 100 ft, and they are probably continuous up to a large open-cut at the surface, 225 ft

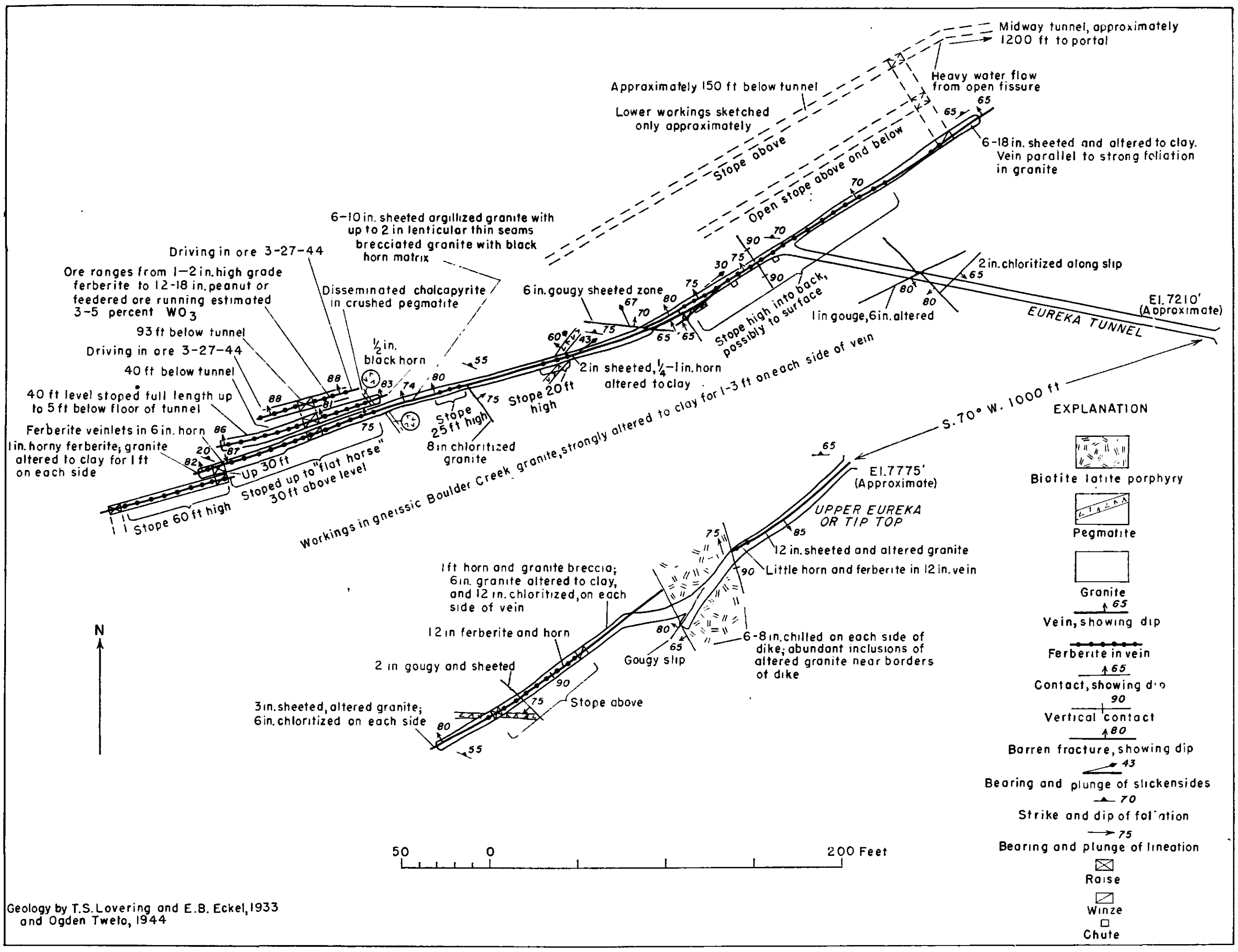


FIGURE 113.—Geologic plan of the Eureka mine, Boulder County, Colo.

above the tunnel. The shoot was also stoped down to the bottom level of the eastern winze. The sheeted granite in the vein above the tunnel was seamed by "peanut ore" consisting of fragments of granite and horn quartz in a matrix of ferberite and black horn, and the hanging-wall and footwall slips of the sheeted zone contained seams of high-grade ferberite. Ore of this type mined in 1916–18 averaged about 17 percent WO_3, presumably after sorting. The vein was 1 to 8 ft wide and averaged about 3 ft.

The western ore shoot was a blind shoot that was worked through a raise and sublevel to a height of 90 ft above the tunnel level and through the western winze to a depth of 93 ft below the tunnel. It was evidently localized by a slight turn to the left in the course of the vein, the strike of which swings from N. 75° E. northeast of the shoot to N. 71° E. within the shoot. Segments of the ore shoot above and below the tunnel rake about 80° NE., but 30 ft above the tunnel the shoot jogs 50 to 75 ft westward, making the average rake about 60°. The shoot had a stope length of about 90 ft on the tunnel level and first winze level, and the second winze level was being driven in ore in March 1944, about a month before the mine closed. As exposed on this level, the vein ranged from a single streak of high-grade ferberite 1 to 2 in. wide to a sheeted zone as much as 18 in. wide that was seamed by fine-grained ferberite, black horn, and fine-grained "peanut ore." The granite wall rock is argillized. The vein itself assayed 3 to 10 percent WO_3 through widths of 6 to 18 in., and the ore shipped from the drift averaged about 2 percent. According to Newmann and Bode, the ore shoot had not yet been entirely delimited above the tunnel in March 1944, and ore was present in the floor of the 93-ft level.

The upper tunnel (fig. 113) exposes more intensely altered granite and pegmatite than the lower tunnel and is remarkable for the presence of a biotite latite porphyry dike that is later than the vein fissure. The dike contains many fragments of altered granite close to its eastern border but is itself only slightly altered. It contains a little disseminated pyrite near the borders. As pyrite was not seen elsewhere, it is possible that the pyrite was derived from the porphyry and that the porphyry is later than the tungsten mineralization at this locality, but it seems more probable that the sulfide was introduced by tungsten-bearing solutions. The dike strikes N. 15° W. and dips about 65° W. It is nearly 50 ft wide where it is cut underground but is much narrower at the surface. The linear structure plunges steeply to the north.

The direction of movement along the vein is such that the southerly dip near the portal would not be favorable to the occurrence of ore, and there the vein is represented only by a zone of sheeted, altered granite. Just west of the dike, however, where the dip is to the north, the vein has been stoped to the surface. Where seen at the tunnel level, the vein has a maximum thickness of 1 ft and contains open vuggy horn quartz of the type generally found under ore shoots. Offset segments of a pegmatite dike near the breast of the drift show that the north wall moved west, but the angle at which it moved could not be ascertained. The stoped part of the vein is not as steep as the barren parts, and this occurrence of ore in the flatter, northward-dipping part of the vein is in harmony with the reverse-fault movement indicated in the lower tunnel.

LUCKIE 2 AND LOOKOUT MINES

The Luckie 2 and Lookout mines are a few hundred feet west and northwest, respectively, of the junction of Middle and North Boulder Creeks (pl. 1). The mines are owned by Gold, Silver, & Tungsten, Inc., and have been worked intermittently by many different operators since the early days of mining in the district. The output from the two mines is not known, but from the meager information available it is believed to exceed 10,000 units of WO_3. The mines were at the height of their productivity during the period of high tungsten prices in 1915–16, when the local price reached $90 per unit, and the value of their output thus exceeds that of most mines of comparable tungsten output. According to Oscar Hershey's report to the Primos Chemical Co. in 1914, the production from the Luckie 2 had an estimated value of about $25,000 up to that time, indicating a tungsten output of 2,500 to 5,000 units. The Luckie 2 was operated in 1927–31 and 1936–42, but the Lookout appears to have been idle most of the time since 1918 except for minor operation in 1942–43.

The two mines each comprise several tunnels and open-cuts (fig. 114). Most of the workings were inaccessible when the writers examined the mines in 1933 and 1943, and only the lower tunnel level of the Luckie 2 mine has been mapped geologically. The crosscut tunnel on this level extends northwestward for 970 ft and cuts the Luckie 2 and the Lookout veins.

The Luckie 2 vein, which is intersected 270 ft from the portal, strikes N. 55° E. and dips 50°–85° NW. It has been stoped extensively northeast and southwest of the crosscut. The vein is a sheeted zone 1 to 4 ft wide in most places; seams of gouge follow the hanging wall and the footwall, and the rock between is crushed, sheared, and altered granite. Both walls are strongly argillized for more than 10 ft from the main fissure. The vein follows a premineral normal fault, along which the north wall moved 3 ft down and west at about 10°. At the point where the crosscut intercepts the vein a branch vein extends northeastward from the hanging wall; it rejoins the main vein about 100 ft east of the crosscut tunnel. This hanging-wall split dips 50° NW. and carried most of the ore at this locality. It has been stoped extensively. A thin seam of high-grade, open, vuggy tungsten ore was found in a short crosscut from the Luckie 2 drift about 200 ft southwest of the crosscut tunnel, but this vein is not exposed in the tunnel, nor was its junction with the Luckie 2 vein discovered. It is probably the upper part of a small hanging-wall vein which may carry ore at its junction with the main vein below. Much of the ore mined from the Luckie 2 vein came from the upper tunnels, and some was apparently obtained also from a winze level 70 ft below the lower tunnel.

The Lookout vein is cut 810 ft from the portal of the lower tunnel of the Luckie 2. West of the tunnel it strikes about N. 80° W. and dips 65° N., but to the east the strike swings to due east for a short distance and then turns to about N. 80° E. A little farther east the vein turns northeast, as indicated by the workings of the Lookout mine (fig. 114). It continues in this direction to North Boulder Creek, where it turns east-northeast and is followed by the Good Friday tunnel, where it is known as the Pleasant Dream vein. The fissure occupied by the Lookout vein has been the site of repeated faulting. The earliest movement caused the north side to move west almost horizontally, but the later movements were nearly vertical and the north side dropped down. The vein is most open and best mineralized in the northeastward-striking portions. In the lower tunnel of the Luckie 2 it consists of brecciated and sheeted granite with 2 in. of gouge on the footwall west of the crosscut, and east of the crosscut it is a 5-ft sheeted zone with three seams of pyritic quartz 1 to 2 in. wide.

The Lookout vein is barren in the Luckie 2 tunnel, but it was productive at the surface and in all the Lookout tunnels. Tungsten ore was mined in a trench almost 500 ft long above the Lookout tunnels, and

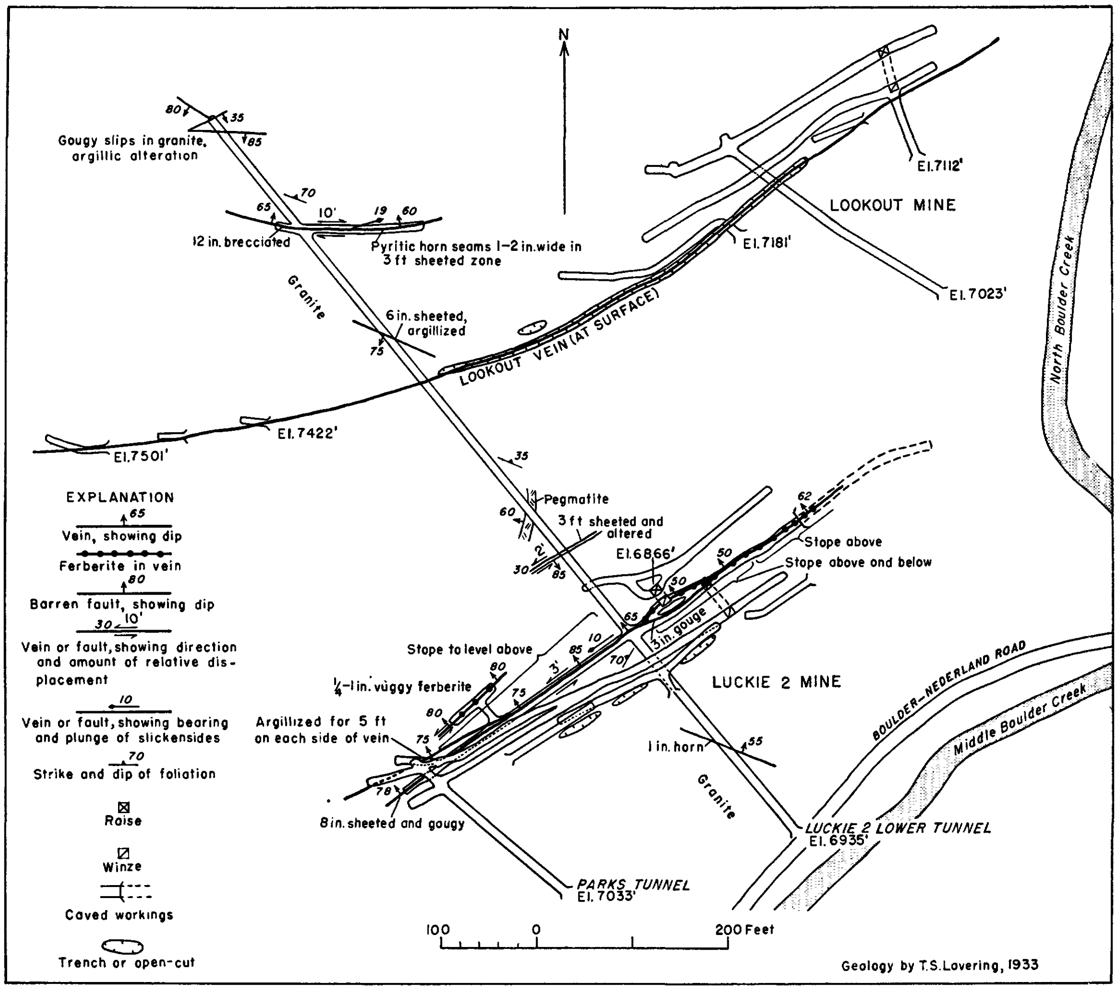


FIGURE 114.—Plan of the Luckie 2 and Lookout mines, Boulder County, Colo.

judging by the location of the tunnels, the ore plunged northeast. The vein has also been extensively "gophered" for several hundred feet west of the Lookout mine and was presumably productive at places at least in this area.

GOOD FRIDAY MINE

The Good Friday mine is on the east side of North Boulder Creek near Boulder Falls (pl. 1). It has been opened by several tunnels and shafts, but in 1943 it was accessible chiefly through the April Fool shaft, about 1,100 ft east-northeast of Boulder Falls, and through the lowest tunnel, the portal of which is on the creek bank 300 ft north of the falls. The mine is owned by the Star Tungsten Corp. and was leased for several years prior to 1945 by H. R. Meyer, who sublet it at various times to Earl Craig and associates, the Fortuna Mining & Milling Co., and to George Jump. It has been highly productive, and the single large ore shoot shown in plate 23 has the largest area of any ore shoot in the district, but no record of the early history and production is available. A large area is known to have been stoped before 1917, and there was apparently some production between 1917 and 1921 and around 1931. According to figures furnished by Meyer, the output from 1937 to 1944, inclusive, was about 12,500 units of WO_3, and the early output must have been considerably greater.

At one time the mine comprised four main levels, three of which were tunnels, and three inclined shafts, but by 1943 most of these workings had disappeared in open stopes. At that time the lower tunnel, which is about 1,400 ft long and about 320 ft below the collar of the April Fool shaft, was still completely accessible, and the first two levels above the tunnel were accessible for a few hundred feet eastward from the April Fool shaft (pl. 23). The Good Friday and April Fool shafts have been sunk 75 and 80 ft, respectively, below the lower tunnel level, but only short drifts have been turned from the bottoms of the shafts.

The Good Friday vein—or the April Fool vein, as it is sometimes called—extends northeastward from the vicinity of the Good Friday shaft on the lower tunnel level. A few feet south of this shaft it joins the eastward-trending Pleasant Dream vein (pl. 23). The Pleasant Dream is an early pyritic quartz vein that was reopened after the pyritic quartz was deposited, and moderately coarse grained ferberite was deposited as a filling in a breccia of quartz and granite fragments. The tunnel follows this composite vein from the junction near the Good Friday shaft southwestward to the portal. West of North Boulder Creek the vein is known as the Lookout. From the vicinity of the Good Friday shaft on the lower tunnel level, the line of junction between the Good Friday and Pleasant Dream veins extends about S. 45° W. and up at about 45°. Thus the lower western part of the ore shoot shown in plate 23 is on the Pleasant Dream-Good Friday composite vein, and the remainder is on the Good Friday vein. At the surface the Pleasant Dream vein lies about 225 ft south of the Good Friday shaft, which is on the outcrop of the Good Friday vein. South of the April Fool shaft the Pleasant Dream vein splits; the northern branch, which trends northeast, was worked in the Little Lester mine, and the southern branch continues eastward for half a mile to the vicinity of the Roosevelt mine.

In the lower tunnel of the Good Friday mine the Pleasant Dream vein strikes about N. 75° E. and dips 50°–60° N. at most places. The movement on the vein was not determined with certainty. The meager evidence suggests that the north wall moved down and east at 40° to 50°, although farther west, in the Lookout and Luckie 2 mines, the north wall seems to have moved west almost horizontally. Through most of the distance between the portal of the lower tunnel and the Good Friday shaft, the vein contains a tungsten-bearing hanging-wall streak separated from a footwall streak of pyritic horn quartz by 1 to 5 ft of sheeted and locally silicified granite. The walls of the vein are moderately chloritized and argillized. The chloritic alteration is the older and more widespread. It evidently accompanied the pyritic quartz, and the younger, hydrothermal clay-mineral alteration was superposed on it during a stage of the tungsten mineralization.

The drift turns off the Pleasant Dream vein at the junction with the Good Friday vein, about 700 ft from the portal of the lower tunnel. A short distance east of this junction a minor vein known as the Spur vein branches northeastward into the hanging wall of the Good Friday vein. The Good Friday shaft is on this vein. According to Meyer, the Spur vein was cut in the shaft between the so-called 100- and 200-ft levels, and the shaft was sunk on it in the belief that it was the Good Friday vein. A short distance below the level, the Pleasant Dream vein crosses the shaft, and according to Meyer, the Spur vein was not found below it. Meyer says that from the bottom of the shaft, 75 ft below the tunnel level, a crosscut was driven northward through the Pleasant Dream vein to the Good Friday, which was followed for a short distance. On the tunnel level the Spur vein shows a displacement of only 2 in., but it contained several inches of good ore in a stope above the tunnel level. The ore exposed in a pillar mined by George Jump in 1943 consisted of 4 to 10 in. of granite and horn quartz breccia heavily cemented by medium-grained ferberite. The Spur vein may end to the northeast against the unexplored vein that apparently branches westward from the Good Friday near the April Fool shaft (pl. 23).

The Good Friday vein strikes about N. 60° E. and dips 63°–88° N. It records two periods of movement. The hanging wall first moved down and west at about 60° and then moved up and west at 40°; as a result, it is displaced about 5 ft to the west and 3 ft downward relative to the footwall. The vein is a sheeted zone 2 to 4 ft wide and is characterized by moderate argillic alteration, which contrasts with the chloritic alteration along the Pleasant Dream vein. Most of the ore is vuggy, medium-grained ferberite and associated dark quartz which form the matrix of a granite breccia that is cut by white horn quartz seams. In some parts of the vein the ore consists of seams of ferberite and black horn in sheeted granite. Almost no pyrite was observed in the vein, but close to the point where it diverges from the Pleasant Dream vein it carries some dark pyritic horn that is cut by later ferberite-bearing quartz. Oxidized ore at the outcrop of the Good Friday vein is reliably reported to have carried free mercury, which would seem to indicate the presence of coloradoite, the mercury telluride.

On the tunnel level the Good Friday vein is stoped for much of the distance between its junction with the Pleasant Dream and the breast of the tunnel (pl. 23). Some ore has been mined from the April Fool shaft below the lower tunnel level, but the location and extent of the stopes is not known to the writers. The best ore occurs in the steeper parts of the vein and where the trend is northeast of the average course. Some of the small barren pillars are bounded on one side by minor northwestward-striking cross fractures. Minor movement on these fractures probably caused some segments of the vein to open wider than others.

Dikes of biotite latite intrusion breccia are exposed east of the April Fool shaft on the three levels shown in plate 23 and in the Little Lester mine a few hundred feet to the south. The intrusion breccia is clearly younger than the pyritic quartz in the Little Lester vein and younger than some of the horn quartz in the Good Friday vein. On the lower tunnel level the Good Friday vein weakens to an almost imperceptible crack where it crosses the dike, and it displaces the dike only 1 to 2 in., with the right-hand side ahead. On the level above, the walls of the drift show the dike displaced about 2 ft, with the right-hand side ahead. The back is stoped, so that the character of the vein in the dike could not be seen, but in a drift on a branch vein at this locality the dike cuts a vein of dark horn quartz. Late slips, parallel to the dike, fault a flat slip that displaces the dike. On the next level, the vein displaces the dike about 1 ft with the left-hand side ahead. The dikes on all three levels dip 45°–90° W., but their locations are incompatible with a single dike having this dip. Either the dip of the dike must change markedly between levels, or there is a series of discontinuous dikes arranged in an echelon pattern vertically. On both levels of the Little Lester mine dikes of intrusion breccia cut sharply across pyritic quartz in this strong branch of the Pleasant Dream vein and displace the vein slightly with the right side ahead. The Little Lester vein, like the Pleasant Dream, was reopened after the early pyritic mineralization and was mineralized with ferberite. On both levels the vein contains ferberite right up to the dike on the southwest side, but none has been found in the short distances for which the vein has been explored northeast of the dike. In the Little Lester the dike is intensely altered on both sides of the vein, but in all three occurrences in the Good Friday it is relatively fresh on the hanging-wall side of the vein and strongly altered on the footwall, suggesting that the alteration within the dike was caused by the solutions that deposited ferberite.

As ore has been stoped almost continuously for 1,400 ft in the back of the lower tunnel of the Good Friday, it is very probable that ore is present in some of the virtually unexplored ground below the tunnel. The Good Friday and April Fool shafts were not notably productive below the tunnel, but the lower workings exposed only a small part of the vein. Some ore was found in the April Fool, but the workings are on a segment of the vein that is very weak, both on the lower level and on the tunnel level directly above. In 1943 the Bureau of Mines drilled three shallow holes east of the Good Friday shaft (pl. 23); all the holes cut ferberite below the tunnel level, and two of them seemed to indicate minable ore. The two eastern holes cut the vein about 40 ft below the tunnel level and almost vertically below it, suggesting that the ore may be in a footwall split of the vein followed in the lowest April Fool level or in a parallel footwall vein.

The Pleasant Dream vein has not been explored east of the junction with the Good Friday vein except in shallow workings at the surface. Ore at the surface and in the Little Lester mine proves that the occurrence of tungsten in the Pleasant Dream vein is not restricted to the segment west of the junction with the Good Friday, and further exploration of this strong vein is warranted.

SMALLER MINES

CATASTROPHE MINE

Location: Altitude about 7,500 to 7,625 ft; on east slope of Comforter Mountain, 1,350 ft west of Boulder Falls.

Workings and geology: See figure 115.

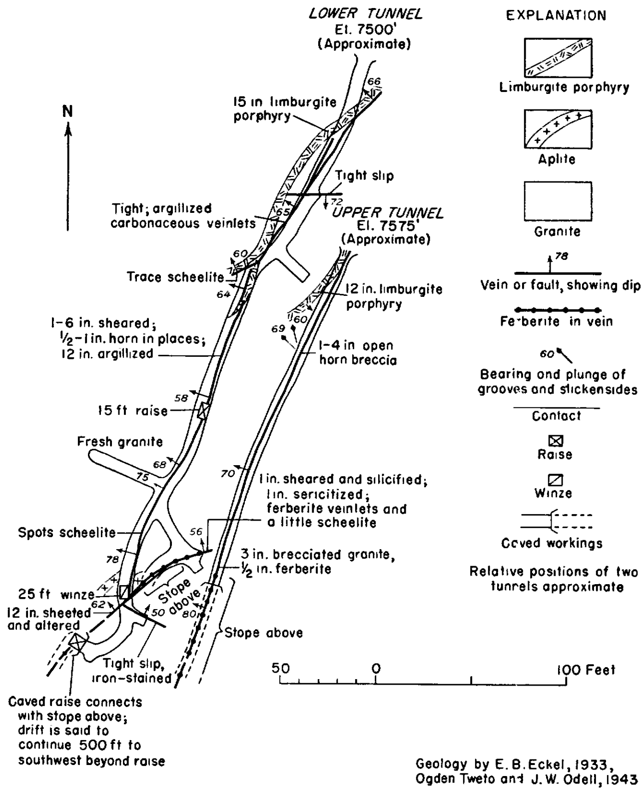


FIGURE 115.—Geologic plan of part of the Catastrophe mine, Boulder County, Colo.

History and production: Mine owned by Henry Lawerence, who says it produced about $40,000 worth of ore during World War I. Worked on minor scale since then; small production by Walter Laisch in 1943.

HERALD MINE

Location: Altitude, 7,680 ft; on north side of North Boulder Creek, about 1,000 ft N. 66° W. of Livingston mill.

Workings and geology: See figure 116. Gold mine.

Ore: Gold telluride minerals in horn quartz accompanied by accessory ferberite in places. Practically all ore west of shaft.

History and production: Gold production substantial; no tungsten produced. Mine operated in 1938 by Earl Craig, who said he shipped ore ranging from 0.26 to 2.42 oz of gold per ton.

MIAMI AND PINESHADE MINE

Location: Altitude, about 7,500 ft; 600 ft north of North Boulder Creek and 850 ft N. 40° E. of Livingston mill.

Workings and geology: See figure 117. Gold mine.

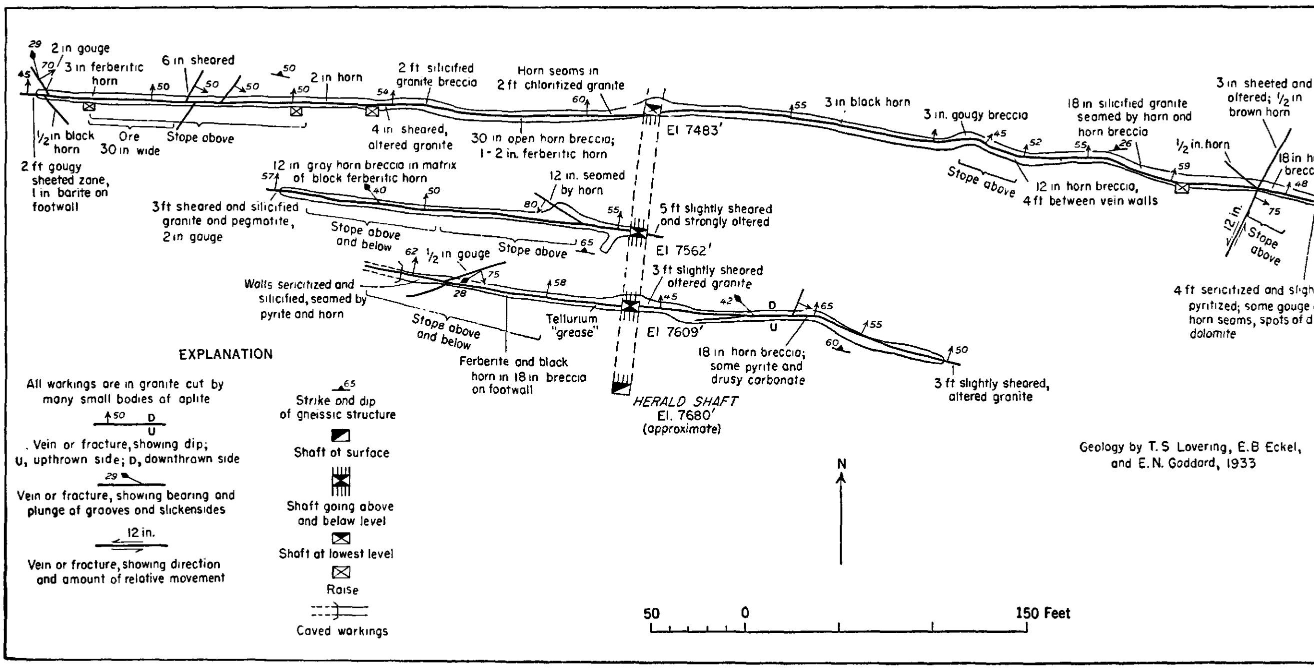


FIGURE 116.—Geologic plan of the Herald mine, Boulder County, Colo.

History and production: Judging by stopes, moderate production of gold ore, mostly long ago. Some of ore said to have assayed as high as 18 oz of gold per ton. Mine worked in 1933 by E. W. Webb.

FRANKLIN MINE

Location: Altitude, 8,075 ft; 2,250 ft N. 84° W. of Sugar Loaf Post Office.

Workings and geology: See figure 118. Gold mine.

Ore: Most of production from stopes above first level; small ore shoots plunged northeast. Gold tellurides and accessory mercury (from coloradoite, the mercury telluride) occur in thin veins of horn quartz.

History and production: Moderately productive gold mine. Stope at shaft on first level said to have produced $16,000 worth of ore. Next stope to southwest yielded ore rather low in grade. Mine owned by a Mrs. Washburn, of Sugar Loaf, in 1933; then being worked by Hurlburt and Vant.

MAYFLOWER MINE

Location: Altitude, about 8,070 ft; 325 ft east-northeast of Franklin shaft.

Workings and geology: See figure 119. Gold mine.

Ore: Vein follows seam of biotite latite intrusion breccia which is silicified and contains gold telluride near contact with biotite latite porphyry dike. Pocket of rich ore next to dike on level 25 ft below surface said to have yielded $14,000 worth of ore.

History and production: Mine was worked chiefly by Washburn, the original owner. Worked in 1933 by Hurlburt and Vant.

WILD TIGER WORKINGS

Location: Tunnel at altitude of 7,300 ft on north bank of North Boulder Creek, 3,500 ft S. 15° W. of Sugar Loaf Post Office. Shaft 500 ft north-northwest of tunnel.

Workings and geology: For tunnel, which is a gold mine, see figure 120. Wild Tiger shaft (not shown in fig. 120) on tungsten vein that strikes N. 60° E. and dips 55°–80° NW. Shaft 60 ft deep; stope above drift that extends 30 ft to northeast at depth of about 40 ft. Also open-cut at surface.

History and production: Many years ago, rich gold ore, both telluride and native, taken from discovery shaft on Wild Tiger gold vein, about 300 ft east of portal of tunnel. This ore pinched out at fault, apparently predating mineralization, at depth of about 30 ft. Most of ore mined from tunnel came from eastern workings on northern vein; this ore said to have been rather low in grade. Small production from tungsten shaft.

BALMORAL MINE

Location: Altitude, about 7,325 ft; 900 ft east of Boulder Falls.

Workings: See figure 121.

Geology: Balmoral vein strikes east-northeast and dips 70° NW.; crosscut to north on third level reaches Smith vein, which strikes east and dips 80° N. Both veins in granite. Some suggestion of location of ore on Balmoral vein given in projection on figure 121. Smith vein also worked through several shallow shafts.

History and production: Balmoral apparently worked chiefly before 1918; a little work at times since then. Various shafts on Smith vein worked on small scale at times up to 1943. Production not known; probably fairly substantial. Mine owned by the Colorado Tungsten Corp.

LITTLE LESTER MINE

Location: Altitude, 7,325 ft; 500 ft S. 80° E. of Good Friday shaft.

Workings and geology: See figure 122.

Ore: Rather horny ferberite in small streaks and veinlets in early pyritic quartz in branch of Pleasant Dream vein (see description of Good Friday mine).

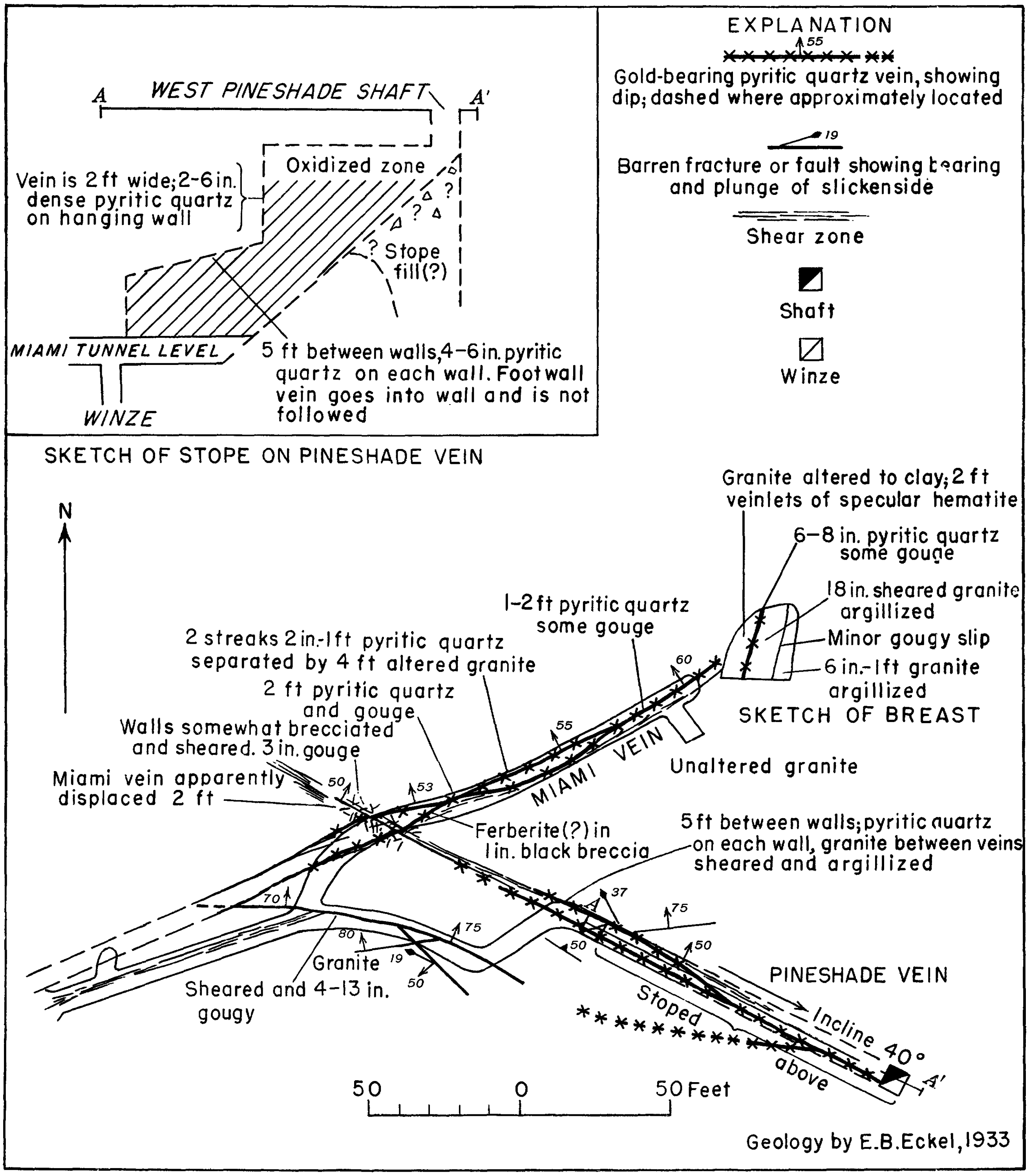


FIGURE 117.—Geologic plan of the Miami and Pineshade mine, Boulder County, Colo.

History and production: Mine said to have produced about $50,000 worth of ore in 1916–17. Production since then apparently a few hundred units of WO_3. In 1943 mine owned by G. R. Anderson, of Waterbury, Conn.; leased for a few years by A. B. Pace. Worked in 1942 by H. Cobb and in 1943 by Allen and Stern.

APRIL FOOL SHAFT

See description of Good Friday mine.

EASTERN PART OF THE DISTRICT

DOROTHY AND KATIE MINES

The Dorothy and Katie mines are the chief mines in Millionaire Gulch, a tributary of Bummer Gulch, at

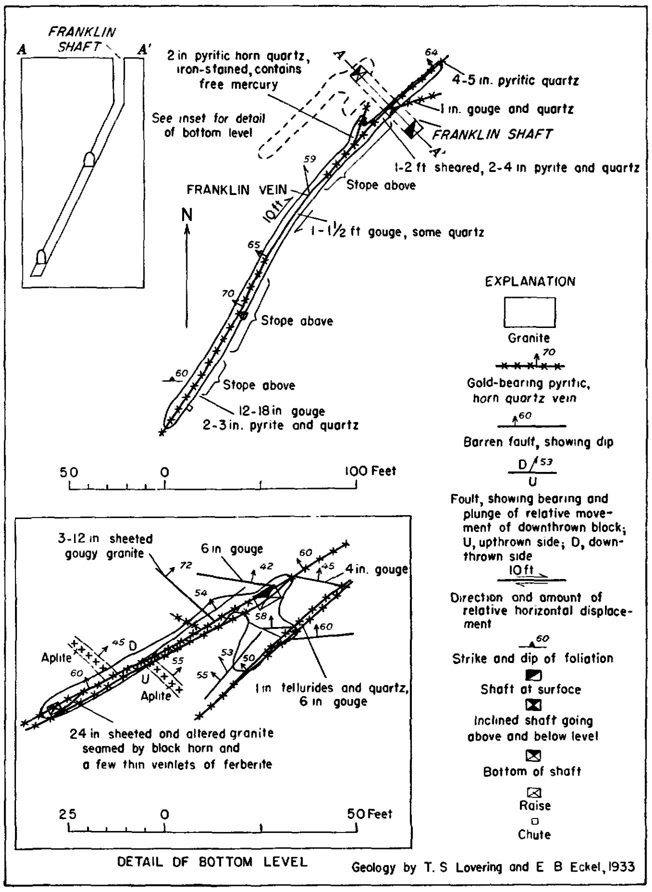


FIGURE 118.—Geologic plan of the Franklin mine, Boulder County, Colo.

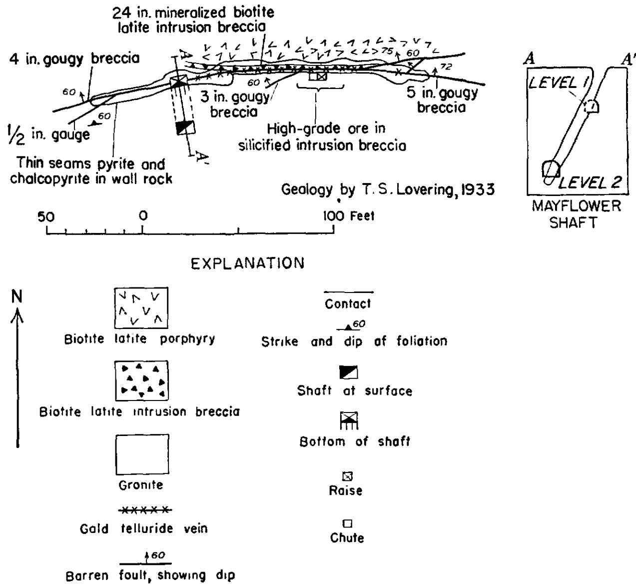


FIGURE 119.—Geologic plan of the second level of the Mayflower mine, Boulder County, Colo.

the east edge of the district (pl. 1). Several productive veins have been worked in the gulch, as shown in plate 24. The Dorothy mine comprises an inclined shaft whose collar is at an altitude of 6,930 ft and three levels at vertical depths of 100, 184, and 281 ft. The Katie shaft is 1,120 ft north-northeast of the Dorothy shaft, at an altitude of 6,809 ft. The shaft dips northwest, and four levels at vertical depths of 79, 136, 195, and 248 ft are turned from it. The second level of the Dorothy and the first level of the Katie are connected by an irregular winze. The second level of the Katie connects through a short winze with the first level of the Princess Eulalia shaft. Several veins east of the Dorothy shaft have been worked extensively at the surface and underground in the Crete and Crackerjack tunnels. Most of the workings in Millionaire Gulch are on claims owned by George Teal, but the Gold Coin claim, which includes the northern part of the Dorothy mine, and the Princess Eulalia claims are owned by Homer Pennock.

The veins in Millionaire Gulch were first worked on an extensive scale from 1915 through 1918, and more than half the total output dates from this period. The Dorothy was worked by a leasing company in 1926–27 and was worked by Teal from 1940 to 1945. The Katie has been operated only on a minor scale since 1918. It was operated in 1942 by Syd West.

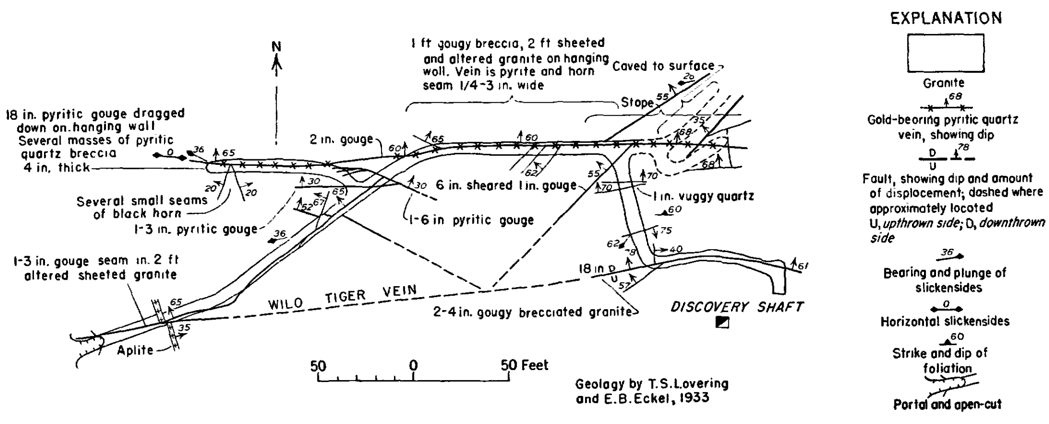


FIGURE 120.—Geologic plan of the Wild Tiger tunnel, Boulder County, Colo.

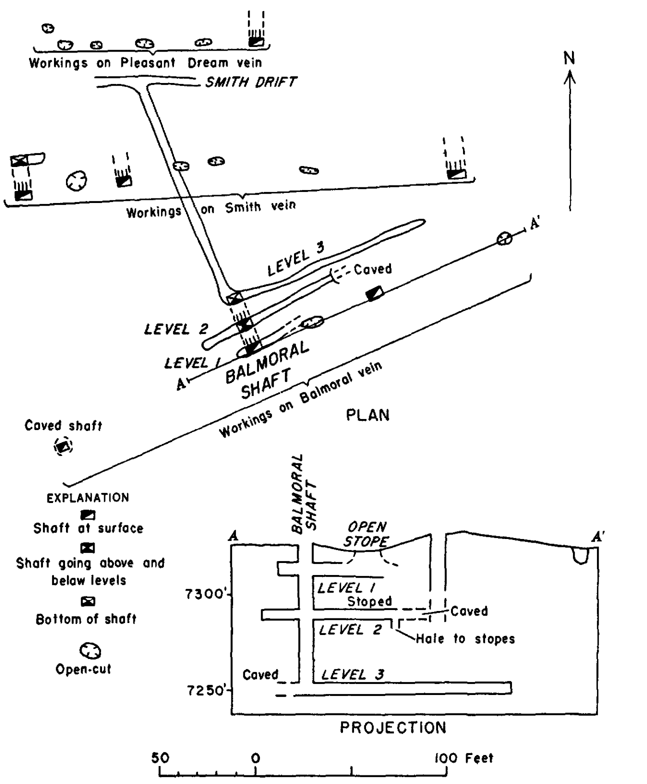


FIGURE 121.—Plan and projection of the Balmoral mine, Boulder County, Colo., in 1918 (after H. S. Sanderson).

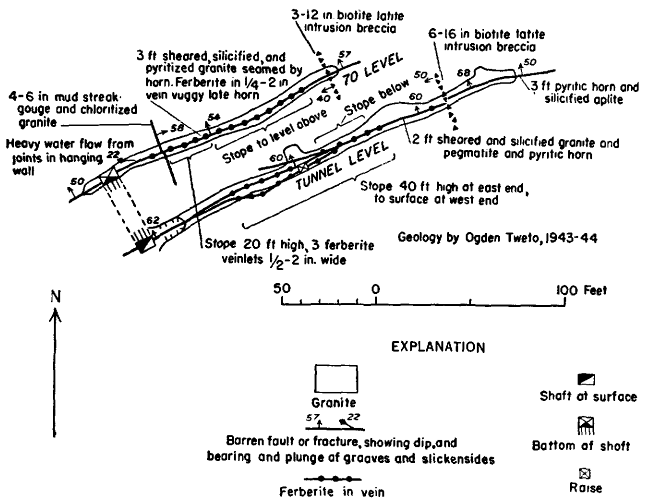


FIGURE 122.—Geologic plan of the Little Lester mine, Boulder County, Colo.

The Princess Eulalia mine was last worked on an extensive scale in 1938. Most of the underground workings on the Crete vein were driven in 1943, when the mine was operated by Messrs. Ralston, Tenhaeff, and Lowery. According to Teal, the output from the Dorothy mine was about 13,000 units of WO_3 through 1944, and the Katie production was about 7,000 units. The output from the several smaller mines and extensive surface workings in Millionaire Gulch is unknown, but the total is probably fairly large.

There are two well-defined sets of veins in Millionaire Gulch (pl. 24). The Dorothy, Crete, Crackerjack, and Princess veins trend about N. 30° E., and except for the Princess, all dip southeast. The Katie, Peter, Nile, Tungsten, and High Tungsten veins trend about N. 60° E.; veins of this group dip both southeast and northwest. The veins trending N. 30° E. are the older and are faulted by the veins trending N. 60° E., but later movement on some of the older veins has displaced slightly the veins trending N. 60° E. The veins are in coarse-grained, moderately gneissic Boulder Creek granite that is cut by several dikes of aplite and pegmatite. The dikes all trend northeast, and most of them dip northwest. Much of the granite in the gulch is stained red by iron oxide. This granite is weakly sheeted, and much of it is slightly granulated. Many of the tungsten veins contain reddish gouge at places, and some of them are characteristically red wherever they have been exposed. The main zone of reddish rock and red veins extends down the center of the gulch, along the line of the Crete and Princess Eulalia tunnels. This is a minor breccia-reef fracture zone that trends north-northeast. Its location suggests that it is a cross fracture between the Hoosier and Livingston breccia reefs, but it may end against other cross-fracture zones that trend about due east between the two main reefs.

The Dorothy vein strikes about N. 30° E. and dips 60°–85° SE. in most places, but locally it is vertical or dips steeply northwest. The hanging or east wall of the premineral fault that is followed by the vein moved 2 to 5 ft south almost horizontally. The vein is a well-defined single fissure on the first and second levels of the Dorothy mine, but below the second level it splits up and is locally very weak (pl. 25). The main drift in the southern part of the third level follows a northwestward-dipping vein that joins the Dorothy vein about 30 ft above the level near the crosscut from the shaft. The Dorothy vein steepens sharply and becomes weak and barren below this junction. The junction plunges gently northeast and is exposed in the drift about 275 ft northeast of the shaft station. Near this point several veins branch into the walls of the drift, and a hole drilled down and northeast was in a red, iron-stained fracture zone through most of its length. Near the northeast end of the second and third levels the Dorothy vein splits and the drifts follow the stronger, ore-bearing, right-hand branch, which trends about N. 45° E. This branch is evidently a younger fracture that connects the Katie and Dorothy veins, and the branch that continues northward is the older Dorothy vein (pl. 24).

The Katie vein strikes about N. 45° E. and dips

55°–65° NW. near the Katie shaft, but farther southwest, near the junction with the Dorothy, it turns N. 60° E. The vein occupies a fault fissure whose hanging wall moved up and southwest at about 30° for about 5 ft. The Katie and Dorothy veins intersect about 400 ft north of the Dorothy shaft at the surface. The Dorothy vein has not been traced on the covered hill slope north of the intersection, and the Katie vein is not exposed southwest of the intersection, but the Katie vein is known to continue to the southwest in the Dorothy mine. The intersection of the Katie vein and the younger branch of the Dorothy vein is exposed in a stope near the north end of the second level. There the Katie cuts the Dorothy and displaces it about 1 ft, with the northwest side down, and it is probable that the Katie displaces the older branch of the Dorothy a few feet more.

The Katie vein splits near the Katie shaft, and the branch that strikes in a more easterly direction has been followed in the Princess mine. Some ore was obtained from it near the surface and in the southwestern part of the Princess mine. In 1942 West mined some ore from a winze near the southwest breast of the Princess, but a heavy flow of water forced him to stop work there. The hanging-wall branch of the Katie vein is a wide sheeted zone that contains a few veinlets of ferberite on the first level of the Katie, but it apparently has not been explored beyond the junction.

Two main ore shoots have been worked in the Dorothy mine, and one large irregular shoot was worked in the Katie (pl. 24). The southern and larger ore shoot in the Dorothy extended from the surface down to about 30 ft above the third level. Although the shoot was irregular in shape, it had a general rake to the northeast at about 60°. The stope had a length of about 200 ft on the second level. On the first level the richest part of the shoot had a similar stope length, but lower-grade ore was later mined for about 175 ft northward from the edge of the older stopes. These later workings were inaccessible in 1942. The ore shoot was localized in a segment of the vein whose strike was a little more easterly than the average. The vein exposed near the edges of the old stopes consists of 6 to 18 in. of sheared silicified granite seamed by veinlets of gray and black horn quartz and find-grained ferberite, but relatively rich ore is said to have been found in widths of as much as 4 ft at places in the ore shoot. The Dorothy ore is typically fine-grained "steel ferberite," some of which contains considerable intergrown fine-grained quartz. Sulfide minerals and hematite are locally present in minor quantity, and a few lenses of galena are said to have been found in the large ore shoot. A photomicrograph of fine-grained Dorothy ore is shown in figure 45.

The northern ore shoot had a stope length of about 75 ft and extended from the intersection of the Dorothy and Katie veins, about 35 ft above the second level, down to and below the third level. The shoot raked steeply northeast, and its localization appears to have been influenced both by an aplite dike and by the eastward turn in the vein. Teal says that the vein in the stope above the second level was about 3 ft wide and averaged about 2½ percent WO_3. This stope is on the Dorothy vein up to the junction and then follows the Katie vein upward for a few feet. Near the junction the Dorothy consists of gray horn and ferberite veinlets in 2 ft of silicified sheeted granite. The Katie consists of 6 in. of gray and brown horn quartz and ferberite. Ferberite seams occur in both the gray and brown horn, but some of the brown horn appears to be later than the ferberite. The Dorothy vein has not been explored above the junction, and the Katie has not been explored below it except that one flat diamond-drill hole was drilled toward the Katie vein from the second level. This hole cut shattered iron-stained granite in which no definite vein was discerned.

As exposed on the third level early in 1944, the ore in the northern shoot ranged from 6 to 36 in. in width and comprised seams of "peanut ore" up to 3 in. wide and veinlets of ferberite in sheeted and locally brecciated sericitized granite and aplite. This ore assayed more than 3 percent WO_3. The ferberite was finely crystalline but was not so dense as the ore from most parts of the mine. Teal says that the ore continued to the bottom of a 30-ft winze, but the phosphorus content increased rapidly and the concentrates assayed as high as 0.60 percent phosphorus. The fine-grained ore itself may contain some phosphorus mineral, but it is probably significant that the aplite in which the ore occurs is abnormally rich in apatite. A thin section of green, sericitized aplite adjacent to a ferberite seam in the drift on the third level contains an estimated 5 percent apatite by volume. At least a part of this apatite was introduced during the period of wall-rock alteration. The altered rock also contains a few minute grains of scheelite.

In 1943 a little low-grade ore was obtained from an eastward-striking vein near the shaft on the third level. The vein is ore bearing where it crosses a small aplite dike, but several feeders split from the vein and follow the dike, and the vein weakens on the east side of the dike, where it turns to a N. 70° E. course. Several small hematite-stained fractures are present in the walls of the vein, and the stope was in reddish, iron-stained granite. This vein is correlated with the one that crosses the Crete vein and displaces it slightly in the Crete tunnel 310 ft from the portal; it is probably a branch of the Nile vein. The Nile vein was worked south of the Dorothy shaft at the surface and on the first level. At the south end of the first level it faults the Dorothy vein a few feet.

The Katie ore shoot lay southwest of the shaft, along the part of the vein that trends in a more northerly direction. The ore thus occurred where the vein turned to the left, as might be expected of a vein whose right-hand wall moved ahead. The best ore came from the first level and is said to have been 3 to 4 ft wide and to have assayed 5 to 9 percent WO_3 after the coarse waste was sorted out. Much of the ferberite was a filling in moderately open breccia, and judging by ore fragments on the dump, it was somewhat coarser grained than most of the Dorothy ore. At places feeders in the hanging wall of the Katie vein were abundant enough to mine, and the resulting stopes were several feet wide. Most of the Katie workings have been inaccessible for many years; the two upper levels end in open stopes, and the lower levels are under water.

LOGAN MINE

GENERAL FEATURES

The Logan mine is in the extreme northeastern part of the area shown in plate 1 and is accessible from the north over a good automobile road via Four Mile Creek. As shown in figure 123, it is opened by a number of adits between altitudes of approximately 6,900 and 7,500 ft.

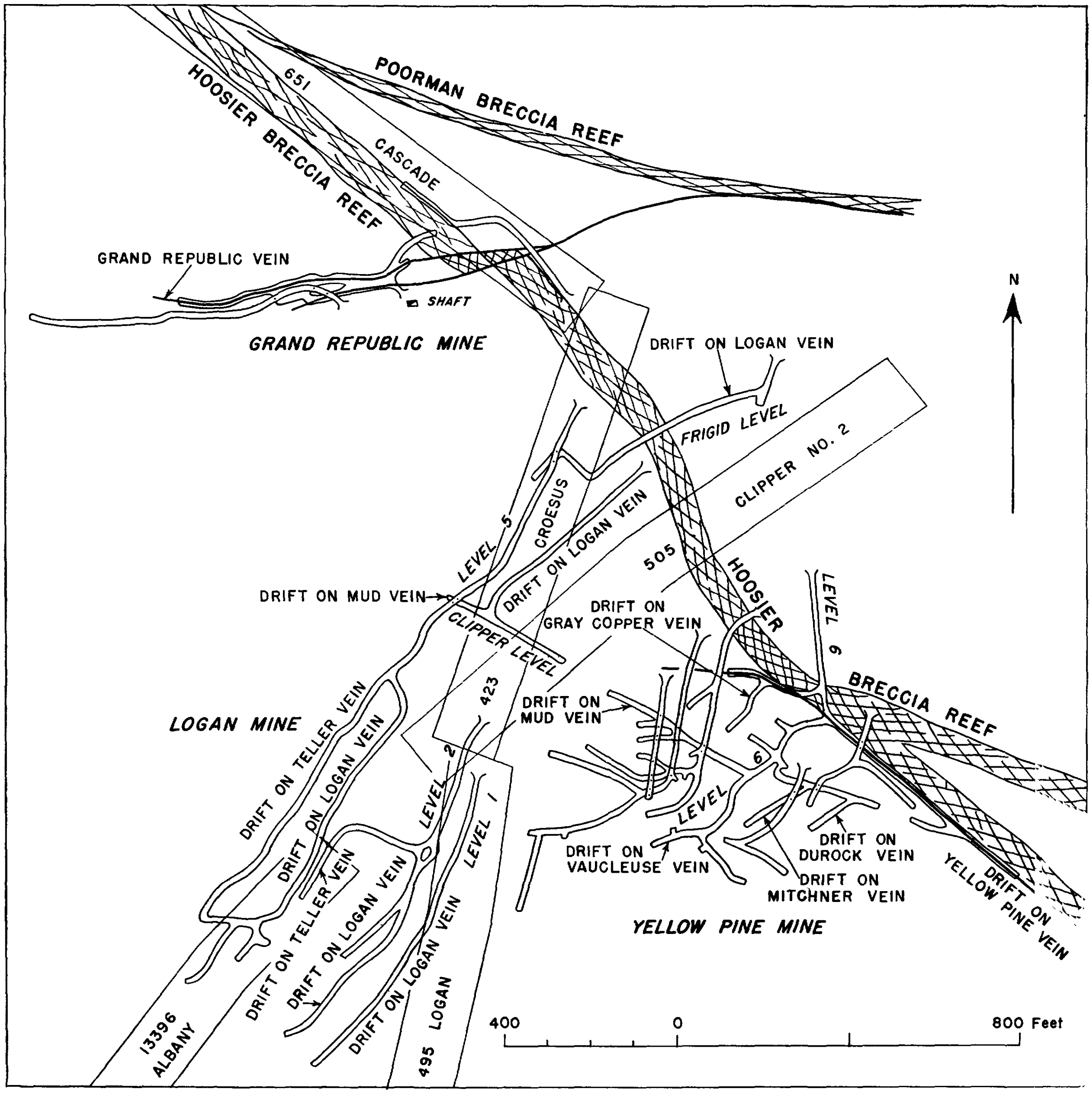


FIGURE 123.—Sketch plan showing breccia reefs and principal veins and mine workings in the vicinity of the Logan and Yellow Pine mines, Boulder County, Colo.

The mine is primarily a gold mine, but silver occurs locally and has contributed materially to the output, and some tungsten ore was found in the lower levels. About $80,000 worth of tungsten ore is said to have been taken from the single stope in which tungsten ore was mined separately from the gold and silver ore. The total production of the mine is unknown but must have amounted to several hundred thousand dollars worth of ore. Records of the Boulder Sampler show that the many small lots received from the mine from 1878 to 1892 amounted in all to about 65 tons and carried gold and silver valued at $6,195. Much of this ore assayed between 1.5 and 6 oz of gold and 1 to 5 oz of silver per ton.

The predominant country rock at the mine is Boulder Creek granite, but it is cut by many dikes of pegmatite and aplite and a few of biotite latite porphyry and biotite latite intrusion breccia. The most conspicuous structural feature of the area is the Hoosier breccia reef, which strikes northwest and is nearly vertical. It is explored by the Grand Republic mine, a few hundred feet northwest, and by the Yellow Pine mine, a short distance to the east (see pl. 1 and fig. 123 and description of the Yellow Pine mine). Some of the fractures found in the Yellow Pine mine extend into the Logan, but the productive veins of the Logan mine are not present in the Yellow Pine workings.

The production from the Logan mine has come chiefly from two branching systems of veins known as the Teller vein and the Logan vein. Both veins strike northeast and dip about 70° NW. in the lower workings, but the Logan vein, which lies about 200 ft southeast of the Teller vein, flattens conspicuously in the upper levels. Crossing these veins nearly at right angles are two premineral faults, 600 to 700 ft apart, that dip gently north at angles of 20° to 45°. The northeastern fault is called the Mud vein and the other the Flat vein. Both faults strongly influenced the localization of the ore in the Logan and Teller veins.

LOGAN VEIN

The Logan vein has been most productive between the Flat vein and the Mud vein, but in the lowest, or Frigid, tunnel (pl. 26), a tungsten ore shoot about 60 ft long and 80 ft deep was found several hundred feet northeast of the Mud vein and very close to the intersection of the Logan vein and the Hoosier reef. Northeast of the tungsten ore shoot the vein is chiefly a gougy sheeted zone 6 in. to 2 ft wide in gneissic granite. At many places this sheeted zone contains seams of dark horn quartz 1 to 2 in. thick. The tungsten ore shoot is like those of many tungsten mines and consists of fragments of wall rock and the earlier fine-grained pyritic horn quartz embedded in a matrix of ferberite and horn quartz.

Southwest of the tungsten ore shoot the vein contains 1 to 2 ft of pyritic quartz which apparently contains too little gold and silver to be mined. Both the vein and its wall rocks are silicified where the vein crosses the Hoosier breccia reef. A few feet southwest of the reef a dike of biotite latite porphyry enters the drift from the north, and the northeastward-plunging roof of the dike is exposed in a small crosscut. The lineation in the porphyry plunges steeply north and indicates that the porphyry was intruded from this direction. The dike turns abruptly southwest at the vein and is displaced by a right-hand movement in which the northwest wall of the vein moved about 2 ft southwest, but most of the movement along the vein fissure took place before the intrusion of the porphyry. A few seams of intrusion breccia follow the walls of the dike and branch off into the country rock at low angles. Several seams of latitic intrusion breccia are exposed in the crosscut to the Teller vein near the end of the Frigid tunnel, and a thin seam of intrusion breccia cuts into the Teller vein just south of a small stope where the crosscut from the main tunnel enters the vein.

The Clipper tunnel, about 87 ft above the Frigid tunnel, follows the Logan vein from the portal, just south of the Hoosier reef, to the junction with the Mud vein, 500 ft to the southwest. The biotite latite porphyry dike found in the lower tunnel is present in the Clipper tunnel, but it is less continuous there and is accompanied by a much larger proportion of intrusion breccia than in the lower tunnel. The biotite latite porphyry apparently did not extend far above the level of the Clipper tunnel, but the intrusion breccia, a more mobile fraction, rose higher in the mine. About 200 ft from the portal of the Clipper tunnel a dike of intrusion breccia with a thin central seam of biotite latite porphyry swings westward out of the drift and breaks across to the Teller vein, in which it appears on the next level above the Clipper (pl. 26).

The Logan vein throughout the Clipper tunnel is small and nearly barren. Only a 20-ft stope about 250 ft from the portal suggests a mineral deposit of commercial interest. The dip of the vein is very erratic, ranging from 45° to 70° NW. The vein is broken by many small cross fractures, and the movement along it was probably distributed over a wide fracture zone in which, at this level, none of the individual fractures are strong near the Mud vein. The direction of movement indicated by grooves and displaced segments of veins and dikes indicates that the north wall moved down and west[2] at 50° for approximately 3 ft. As will be shown, repeated movements occurred along the Logan vein, though none of them was large. The Logan vein is not readily distinguished south of the

[2] This direction differs from that observed south of the Mud Vein.

Mud vein on the Clipper tunnel, but is represented by the small quartz vein about 100 ft west of the point where the crosscut tunnel enters the Mud vein; it is made up of several thin stringers of horn quartz in gougy seams one-fourth to one-half inch wide. The zone as a whole dips about 80° E.

The fifth, or Croesus, level, the most extensive in the mine, follows the Teller vein to its intersection with the Mud vein, and a drift to the south along the Mud vein cuts the Logan vein. The northern segment of the Teller vein apparently was offset about 15 ft westward by the Mud vein. The late age of the intrusion breccia is shown by the relations at this intersection, where intermittent movement followed first one vein and then the other and the breccia is cut only by the youngest fracture, (fig. 20).

On the fifth level, the Logan vein is exposed north of the Mud vein only in a short stub drift. Here the Logan vein consists of about 20 in. of sheeted and somewhat pyritized granite. Grooves and striations on the wall plunge about 40° SW., about as on the lower level. Although no latitic breccia is found on this level, a small amount is present at the junction of the Mud vein and the Logan vein on the third level 180 ft above. It is probable, therefore, that this material rose along the Logan vein at a low angle from the north and connects with that in the Clipper tunnel. No intrusion breccia was found above the third level. As shown in figure 124, an ore shoot on the second and third levels roughly parallels the course of the breccia. The ore found in this shoot on the third level was comparatively poor, but it was richer on the second level and still richer on the first level. The possible genetic relation of the ore to the intrusion breccia has been discussed on page 73.

On the second level the Logan vein is characterized by many branch veins that appear to diverge southwestward as the vein is followed to the south. One of these, known as the Hanging Wall vein, has been stoped from the third level to well above the first

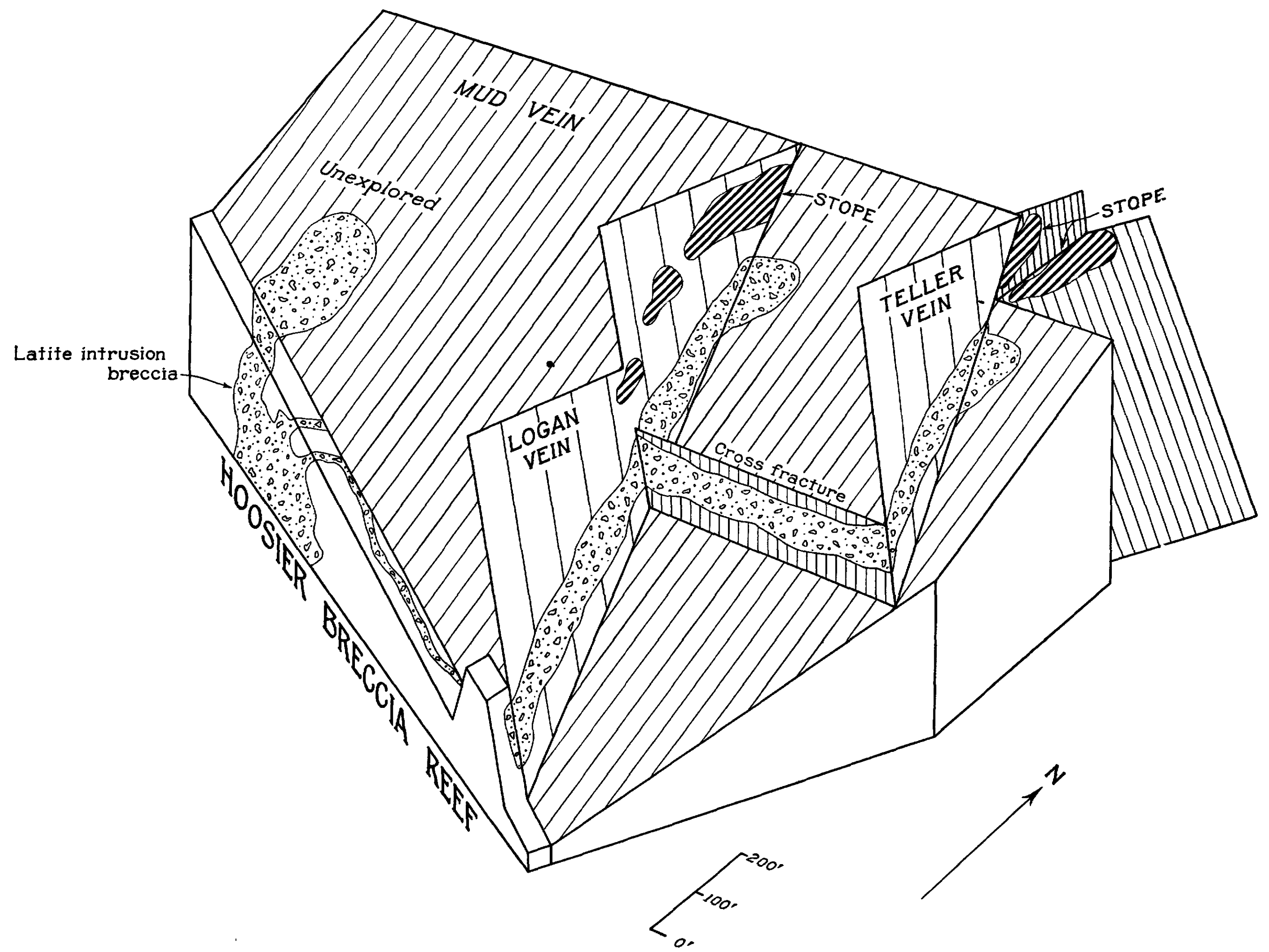


FIGURE 124.—Block diagram showing the relation of the biotite latitite intrusion breccia to veins and breccia reef in the Yellow Pine and Logan mines, Boulder County, Colo.

level. The main Logan vein in this part of the mine is known as the Footwall vein.

The direction of movement on the Logan vein, as shown by its intersection with the Mud vein on the third level, indicates that here during several periods of recurrent movement the predominant displacement was of the reverse-fault type. The grooves and striations found on the walls in different places consistently indicate that the hanging wall moved up and southeast. The horizontal component of the movement is such that in most places the right-hand wall moved ahead, so that open spaces would tend to be formed, where the vein swings to the left and where it flattens. Most of the stopes are in places where one or both of these conditions are fulfilled; much of the ore was found where the dip of the vein is less than 50° and very little where it is as much as 60°.

About 850 ft from the portal of the second level the main Logan vein turns sharply west and merges with a broad sheeted zone that dips about 40° N. On the third level this sheeted zone, which is there known as the Flat vein, extends eastward beyond the main Logan vein as if it were a fault against which the Logan vein ends. It is evident on the second level, however, that this is not so. Because of the direction of displacement along the vein, the abrupt swing to the west nullified the favorable effect of the flattening in dip and an unfavorable situation for ore deposition was created. Some of the movement that resulted in the splitting and continuation of the Flat vein east of the Logan vein junction on the third level was taken up by an eastward-trending slip, which leaves the main Logan vein about 650 ft from the portal of the second level. This slip is of interest because ferberite and horn quartz occur where the Silver vein joins it 50 ft northeast of the Logan vein, with which ths Silver vein is parallel. The ferberite is later than the pyritic quartz vein following the slip, which appears to branch from the Logan vein.

The unstoped parts of the Hanging Wall and Footwall veins on the second level indicate that they consisted of about 24 in. of highly mineralized sheared granite between walls altered to sericite and some clay. Both veins are made up of thin seams of black or dark-gray horn quartz strongly impregnated with pyrite. At a few places, as in the easterly split mentioned and in certain parts of both the Hanging Wall and Footwall veins, especially those near their junction, a small amount of ferberite is associated with the horn quartz, and in such places pyrite is scarce.

Along the southern part of the segment of the Logan vein that lies between the Flat vein and the Mud vein, stopes extend from the fifth level up to the first level, and the character of the ore was similar throughout these stopes. At a fork in the Logan vein 20 ft south of the Mud vein on the fifth level, however, a short segment of the Logan vein shows evidence of an entirely different type of mineralization. Here the vein is 6 to 24 in. wide and is predominantly a galena-tetrahedrite-sphalerite vein that carries 50 to 150 oz of silver per ton. The fork in the vein probably represents a fracture opened from the main Logan vein to its displaced segment by one of the recurring movements along the Logan vein during a period of quiescence on the Mud vein. In the Clipper tunnel, 60 ft below, these two parts of the vein have been cut, but their identity has not generally been recognized. On this level the earlier, or original, Logan vein is called the Parker vein. The later, southward-striking fork has not been named previously but is here called the Logan(?) vein. The intersection of the two veins would lie about 160 ft west of the breast of the drift on the Parker vein. The position and dip of the exposed parts of these two veins indicate that they will probably be steep at their intersection, but because of the course of the Logan(?) segment it is possible that late movement along it and the main Logan vein south of the fork opened the fissure enough to allow the deposition of ore there.

MUD VEIN

On the Clipper and fifth levels the average strike of the Mud vein is N. 60°–65° W. and its average dip about 22° N., but dips of 18° to 35° are found. Grooves and striations suggest that in much of the movement the hanging wall of the Mud vein moved up and S. 37°–40° W. This would be nearly straight up the dip in those parts of the vein where the strike is N. 50 W., but where its course was more westerly, as it is in most places, the evidence would mean that the right-hand wall moved forward.

The Mud vein has not been cut on the lowest, or Frigid level. On the Clipper tunnel level the vein is a wide sheeted zone marked by many gouge-filled seams under a seam of slightly pyritic silicified breccia in the hanging wall. This breccia contains a little gold for about 50 ft on either side of the point where it is cut by the main Clipper tunnel. Farther east and farther west the mineralization was weak, the fault apparently being too gougy to allow much movement of ore solutions. The Mud vein steepens eastward, and as it is a reverse fault the steepening did not favor the formation of open spaces. In the upper levels mineralization along the Mud vein is very meager, and nowhere has the vein been stoped above the Clipper level. Near its intersection with the Logan vein on the second level, the Mud vein probably breaks into a series of echelon fractures having nearly the same strike as the main Logan vein. The first level was inaccessible in 1933, but the mine map indicates that if the Mud vein is present there, it was not important enough to explore.

TELLER VEIN

The Teller vein, which is about 200 ft northwest of the Logan vein, strikes about N. 37° E. and dips 60°–80° NW. Grooves and slickensides along the vein show two principal directions of movement. One set of grooves plunges 20° SW., and another plunges 45°–60° N. It is probable that the hanging wall first moved down and southwest at an angle of 20° and later moved up and south at angles of 45° to 60°. In this compound movement the right-hand wall moved ahead, so that a swing toward the left would tend to open the vein and make space for the deposition of ore. Both normal and reverse faulting occurred, but as the reverse faulting is apparently the latest movement, a gentle dip would in general be more favorable to mineralization than a steep one.

Although the Teller vein has not been so extensively stoped as the Logan vein, there are some large stopes on the second and third levels (pl. 26). In 1933 some high-grade gold telluride ore was being mined just beneath the intersection of the Teller vein and the Mud vein on the third level. Gold tellurides and free gold occurred close to the intersection of a minor vein known as the Albany, which enters the hanging wall from the southwest, and the ore extended along both this and the main Teller veins. The high-grade ore (fig. 25) was only 2 to 6 in. wide, but ore of shipping grade occurred through a thickness of about 3 ft on each vein. No intrusion breccia was observed in the Mud vein where it is cut on the third level, and if the relation between the intrusion breccia and the gold ore on the Logan vein is not fortuitous, an ore shoot may exist on the Teller vein north of the Mud vein on the third level in ground that had not been explored in 1933.

At the south end of the fifth level, the Flat vein is displaced slightly by the Teller vein, along which the northwest, or hanging, wall moved southwest at a low angle. The Flat vein is mineralized where it swings right to a more easterly strike than the average. Mineralization was also more prominent where the dip flattens. These relations suggest reverse fault movement along the Flat vein. The ore is similar in appearance to that of the Teller vein, and the wall-rock alteration is nearly identical in both veins.

YELLOW PINE MINE

GENERAL FEATURES

The Yellow Pine mine is on the northeast slope of Logan Mountain, near the head of Sunbeam Gulch, in the extreme northeast corner of the tungsten district. It is accessible over 7 miles of good automobile road from Boulder, the nearest shipping point. The mine is developed through six adits, an underground shaft, and several winzes (fig. 123). It has been one of the outstanding producers of silver ore in Boulder County, and a little rich free-gold ore is said to have been mined from the upper levels. The production figures are incomplete, but the output from some of the chief stopes is shown in figure 125. The many small lots of ore from the Yellow Pine vein sent to the Boulder Sampler from 1878 to 1892 totaled 477.3 tons and contained silver valued at $71,996. Hardly any of this ore contained gold, and only one lot assayed as much as 0.8 oz gold per ton. The shipments to the Boulder Sampler of ore from the Gray Copper vein of the Yellow Pine mine during this same period totaled about 31 tons and contained gold and silver valued at $8,209. Much of this ore was also barren of gold, but a few lots contained 0.7 to 3 oz of gold per ton. The silver content of the ore from both veins ranged between 100 and 300 oz per ton.

GEOLOGY

The predominant country rock at the mine is the Boulder Creek granite, with some pegmatite and aplite. In a few places these rocks are cut by dikes of biotite latite porphyry, associated with biotite latite intrusion breccia. The most conspicuous structural feature of the area is the northwestward-striking Hoosier breccia reef, which, as shown in plate 1, is not a simple shear zone here, as it is in many other places, but has a braided structure and splits near the top of Arkansas Mountain into two prominent subparallel branches connected by a westward-trending cross vein. The southwest branch is the one known locally as the "Hoosier dike" and is the only part that is well shown in the mine workings. The general relation of the veins of the Yellow Pine mine to the Hoosier reef, and to the veins in the nearby Logan mine, is shown in figure 123. The relations of the northwestward-striking Yellow Pine vein, the Hoosier breccia reef, the west-northwestward-striking Mud vein, and the northeastward - striking Grey Copper, Northern Vaucleuse, Southern Vaucleuse, and Mitchner veins are shown in more detail on a map of the sixth level (pl. 27), the only level accessible in 1933.

The Hoosier breccia reef, which is exposed on the sixth level about 240 ft from the portal, where it is 50 ft wide, strikes N. 40° W. and is nearly vertical. The Yellow Pine vein, to which most of the production of the mine is credited, follows the southwest edge of the Hoosier reef for several hundred feet. Boulder Creek granite, pegmatite, and aplite within the reef are brecciated and somewhat silicified in most places. The reef

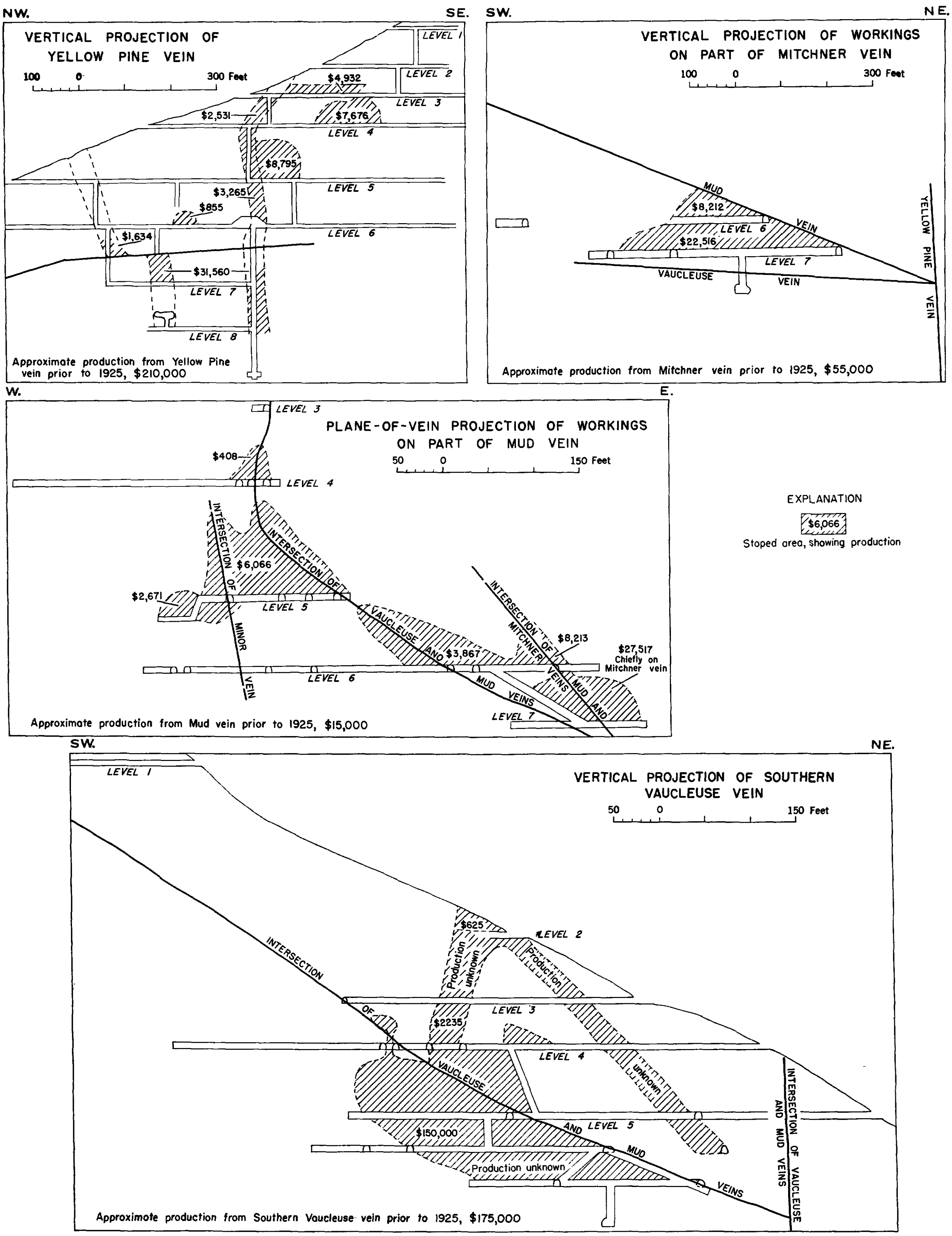


FIGURE 125.—Longitudinal projections of veins in the Yellow Pine mine, Boulder County, Colo. (after F. A. Fair, 1925).

is crossed by many seams of gouge, parallel or diagonal to its strike. Grooves, striations, and displacement along the northeast side of the reef show that the rock to the northeast moved down and southeast at an angle of 65°. Northwest of the locality where the Yellow Pine vein diverges from the reef, striations and displacement indicate that the wall rock on the southwest side of the reef also dropped at a steep angle. Thus it appears that the reef is essentially a long narrow horst. Late, nearly horizontal movement along the Yellow Pine vein obscures this relationship where the vein follows the wall of the reef. Biotite latite porphyry and the associated latitic intrusion breccia extend out from the Hoosier reef along late fractures and occur within the reef itself in the late, irregular fractures. The porphyry and the adjacent country rock are strongly altered in most places, but both the porphyry and the intrustion breccia are later than the silicification and later than most of the movement within the breccia reef. The horstlike movement of the breccia reef itself suggests that some of the brecciation between the two walls is due to the upward push of an underlying magma that follows the general course of the reef; it may be likened to a structural shadow of an underlying intrusive body, probably older than the biotite latite porphyry.

The Yellow Pine vein follows the southwest wall of the breccia reef for more than 1,000 ft, but just west of the portal of the fifth adit the vein swings northwest from the reef and feathers out. It has not been observed in the Logan mine on the projection of its strike.

The right-hand wall of the Yellow Pine vein moved forward almost horizontally, and the displacement did not exceed 6 ft. Argentiferous gray copper-galena ore occurred in nearly vertical chimneys 50 to 100 ft in stope length and several hundred feet in pitch length. The stope seen on the sixth level is coextensive with an area of pegmatite in the wall of the vein. At this place the vein dips steeply northeast, but throughout the barren section of the vein on the sixth level it dips steeply southwest.

The Mud vein strikes west-northwest, dips about 35° N., and intersects the Hoosier reef 700 ft from the portal. The Mud vein itself is productive only locally, but most of the ore in the Southern Vaucleuse and Mitchner veins was found just below their intersections with the Mud vein. Throughout the productive portion of the Mud vein on the sixth level it is a gougy sheeted zone 1 to 10 ft wide that contains one or two seams of intrusion breccia. Several periods of movement have affected it. The net movement has been that of a reverse fault whose south wall, or footwall, moved down and northeast. The direction of striations and grooves observed ranges from N. 65° E. to N. 30° E. The northeastward-striking veins, such as the Vaucleuse and Mitchner, are much stronger below the Mud vein than above it. The displacement of these veins by the Mud vein shows that much of the movement along the Mud vein took place after the northeastward-striking veins were formed, but the weakness of the displaced vein segments in the hanging wall suggests that the Mud vein fissure was formed before the northeastward-striking veins and that these veins broke only to the Mud vein fracture or slightly beyond it. Such an alternating recurrence of movement on intersecting veins has been found in the Logan mine.

A light-gray felsite is exposed close to the hanging wall of the Mud vein, between its intersections with the Mitchner and Southern Vaucleuse veins. To the east the felsite grades into an intrusion breccia which at places is almost indistinguishable from the gray gouge that makes up most of the Mud vein, suggesting that a substantial amount of the gouge observed in this vein resulted from attrition of this intrusion breccia during late movement along the fault. As shown in figure 19, the felsitic intrusion breccia is cut sharply by the later biotite latite intrusion breccia and has been affected much more by the repeated movement along the vein. That portion of the Mud vein in which the felsitic intrusion breccia is recognized coincides with the zone of strongest lead-silver mineralization, and it is possible that the magma from which the lead-silver minerals were derived is closely related to the felsite porphyry. The biotite latite intrusion breccia is in the hanging wall of the Mud vein, and its relation to the lead-silver ores could not be ascertained. The ore in the Mud vein close to its intersections with the Southern Vaucleuse and Mitchner veins is said to have been galena-gray copper ore very similar to that found in these cross veins. To the east of the Mitchner vein, however, it was more similar to the pyritic gold ore found in the Logan mine.

The Southern Vaucleuse vein follows a sinuous southwesterly course and dips 25°–40° SE. (pl. 27). The vein follows a reverse fault whose southeast, or hanging, wall moved up and west, thus opening the ground where the dip flattens or the vein swings to the right. Close to its intersection with the Mud vein, both the course and the dip are favorable, and the greatest production came from this place. The localization of the ore is apparently related to the intersection of the Mud vein as well as to the spaces created by the movement of the walls, for the tenor of the ore decreased with distance from the intersection, and so far as known, the vein is barren beyond a point 300 ft southwest of the Mud vein.

The Mitchner vein occupies a steep premineral fault along which the northwest side moved down and northeast at about 65° for approximately 20 ft. The vein dips northwest in some places and southeast in others.

It can readily be seen that the widest open spaces would occur where the vein dips southeast, and it is there that the ore shoots occur. In this vein, as in the Southern Vaucleuse, the best ore was found close to the intersection with the overlying Mud vein.

In both the Southern Vaucleuse and Mitchner veins, the ore was found through a width ranging from 6 in. to 3 ft. In many places in the Southern Vaucleuse, the ore is frozen to little-altered pegmatite, but the country rock adjacent to the Mitchner vein is strongly sericitized.

The Northern Vaucleuse vein on the sixth level is a seam of gouge 12 to 16 in. thick which dips 30°–50° E. The vein is apparently unproductive even in its upper levels except close to its intersection with the Gray Copper vein. The Gray Copper vein on the sixth level is a small tight fracture which does not persist far southwest of the breast of the drift in which it is exposed, and it was not recognized in the wall of the Mud vein 150 ft to the southwest. Where seen, the Gray Copper vein consisted of 1 to 6 in. of sheared rock containing a maximum of 3 in. of gray copper ore frozen tightly to the walls.

The ore minerals found most frequently in the specimens of silver ores from the Yellow Pine mine studied by Lovering are galena, sphalerite, pyrite, freibergite, stromeyerite, and stephanite (fig. 35). All these minerals were found below the sixth level, in the Southern Vaucleuse and Mitchner veins, under the Mud vein, and are believed to be hypogene. However, some veinlets of supergene bornite were present even there, and it is believed that much of the rich silver ore mined on the higher levels was supergene. An analysis of nearly pure stromeyerite from the Yellow Pine is given by Headden (1925, pp. 41–42), but the information regarding its occurrence is meager.

SUGGESTIONS FOR PROSPECTING

If the relation of the latitic intrusion breccia to the gold ore noted in the Logan mine is significant, there is a distinct possibility that gold ore may be found in the unexplored parts of the Mud vein above the latitic intrusion breccia (fig. 124).

COPELAND MINE

The Copeland mine is about 3½ miles south of the east end of the tungsten district. It is at an altitude of about 7,100 ft, in the bottom of a gulch a few hundred feet northwest of South Boulder Creek, and is about 1¾ miles west of the Walker ranch. The mine is of interest because it is on a tungsten-bearing breccia reef, and the deposit was probably the largest in Boulder County, although the ore was relatively low in grade, siliceous, and refractory. The mine has achieved a moderately large output but has not been especially profitable.

Tungsten was evidently discovered on the Copeland reef shortly after the first discoveries were made in the main tungsten district, and the Wolf Tongue Mining Co. worked the deposit in 1903 or 1904, when it first entered the tungsten field. The siliceous and fine-grained ore was too refractory to be worked profitably, and apparently little work was done at the Copeland from 1904 until the Primos Chemical Co. took it over a short time before 1914. The Primos Co. built a large mill at the mine in 1916 and operated it until the spring of 1918. The mine and mill were served by a wagon road leading to the Crescent station on the Denver & Salt Lake Railroad, high on the slope south of South Boulder Creek. The mine at that time was also accessible via Magnolia, but in 1943 it could be reached only by means of the Flagstaff Mountain road from Boulder to the Walker ranch and then by a very poor, steep road from the ranch to the mine. Since 1918 the Copeland deposit has been worked only infrequently on a minor scale at the surface. In 1943 Perl and Ray Pherson were reworking the dumps and shipping ore that assayed about 3 percent WO_3. They also mined some ore that assayed 3 to 4 percent WO_3 from a pit at the surface. If the City of Denver builds a dam and storage reservoir on South Boulder Creek as contemplated, the site of the Copeland mine will be flooded.

The available records show an output of about 15,000 units of WO_3 from Copeland mine, and the total is presumably somewhat larger. Most of this output was contributed by the Primos Co. from May 1, 1917, to March 31, 1918, the only period for which records of the Primos operations are available.

According to a map made early in 1917 (fig. 126), the mine comprises a vertical shaft 260 ft deep and three levels at depths of 50, 145, and 240 ft. However, the mine is generally reported either to be 400 ft deep or to have four levels; so it seems probable that an additional lift was sunk after the map shown in figure 126 was made. The mine was completely inaccessible from 1929 to 1946. The main stopes came to the surface in the gulch bottom, and a stream in the gulch has filled the stopes and upper workings with debris.

The Copeland breccia reef extends west-northwestward for several miles from the mountain front near South Boulder Creek almost to Tungsten Post Office (pl. 3). The Copeland mine is on a segment that strikes N. 80° W. between the Livingston and Rogers breccia reefs. Near the mine the reef is a shear zone 25 to 50 ft wide which is accompanied by smaller shear zones as much as 15 ft wide and as much as 125 ft from the main zone. The reef zone is mostly in Boulder Creek

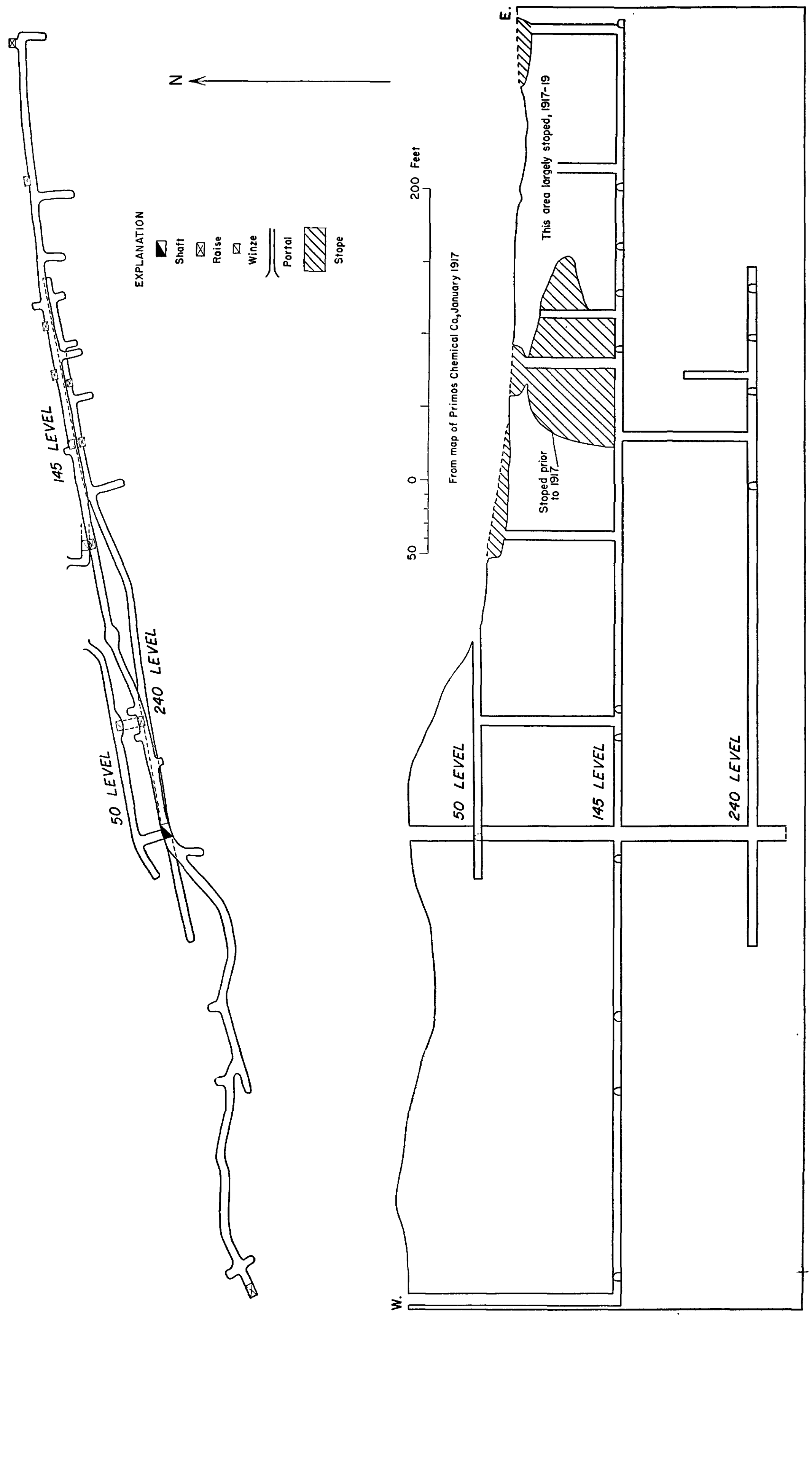


FIGURE 126.—Plan and projection of the Copeland mine, Boulder County, Colo., as of January 1917 (from a map of the Primos Chemical Co.).

granite, but it follows and includes several small dikes of aplite and a few of pegmatite. The rock within the reef is granulated or brecciated, stained red by hematite, and partly silicified. This material is cut by veins and veinlets of white to black and reddish horn quartz. The main tungsten streak is in about the center of the strongest part of the reef. The tungsten occurs chiefly as horny ferberite and black, ferberite-bearing horn quartz, but relatively pure, finely crystalline ferberite occurs in thin veinlets and local lenses, and some scheelite is scattered throughout the reef. The scheelite is dirty white or reddish, and as it resembles both whitish horn and bleached, altered feldspar fragments, it is inconspicuous. It occurs in small veinlets, as fine grains disseminated in the sheared rock, and as scattered larger nodules as much as 1 in. in diameter. It is most abundant in the ferberite-bearing part of the reef, and occurs chiefly in close association with the late crystalline ferberite. The sheared rock near the tungsten ore is cut by veinlets and seams of white clay-bearing horn quartz as much as 6 in. wide. The subsidiary shear zones contain scattered small lenses of horny tungsten ore and are cut at places by small veins of relatively high-grade ferberite that extend obliquely across the areas between the shear zones.

Tungsten ore has been found at intervals for at least 3,000 ft along the Copeland reef, but most of the production has come from an ore shoot under the gulch. The location of the shoot is indicated by the small stoped area shown in the section in figure 126, but the stope is much more extensive than it appears. Most of the recorded production from the mine came after the section was drawn. A substantial amount of ore was evidently recovered from several cuts, shafts, and tunnels about 1,000 ft east of the Copeland shaft. The ore at this locality was finely crystalline and occurred in veinlets in sheared argillized granite and as a filling in seams of siliceous breccia.

The Copeland mine was examined by O. H. Hershey in 1914, when it comprised two levels. In his report to the Primos Co., his references to the vein evidently refer to the main tungsten streak within the reef and not to the reef as a whole. Part of his description of the mine follows:

The Copeland mine * * * has a vertical shaft * * * which at 50 feet is connected by a short cross-cut with a 180-foot tunnel driven on the vein. At the 150-foot level a drift extends west 30 feet in vein matter with a little mineral and about 310 feet east along the vein. The vein has a course about east and generally dips south 75 degrees, though in a few places it becomes vertical or even slightly overturned. It follows a large dike which varies from ordinary pegmatite to fine-grained alaskite, type of rocks favorable for ore bodies. The vein was formed originally as a barren quartz vein of relatively small size. This was reopened and fractured, making a breccia of fine-grained quartz and fragments of pegmatite and alaskite. This open breccia was then cemented by ferberite and quartz of unusually fine grain. It ranges in composition from a gray quartz stained by ferberite to a nearly pure ferberite. There are a few very small vugs lined by quartz and ferberite crystals. Some black streaks that, at first glance, suggest slate are composed of nearly pure ferberite in very fine grains. The ferberite quartz where present at all along the vein is usually confined to a width of 1 to 5 feet, but in a cut on the eastern part of the ranch it is scattered through a thickness of 50 feet.

A third movement along the vein brecciated the zone and made a gouge. This is very prominent on the lowest (145-foot) level in the mine and varies from an inch or two of light colored crushed rock to 6 to 12 inches of red gouge largely silicified to rock. * * * The vein matter near it has been brecciated and re-cemented by barren quartz. In places this breccia embraces the entire width of the vein. * * * Where the fracturing involved ore, fragments and even boulders of the latter are scattered through the otherwise barren cemented breccia. Thus in places what may have been 6 inches of good ore has been scattered through 5 feet of breccia, making a large body of material doubtfully of commercial grade. That is the condition of a large part of the vein exposed in the lower level within 150 feet of the shaft. Beyond that the condition of the vein improves, the ore becomes less broken and of better grade and at and near the face there are 2 to 4 feet of fair-grade ore. This is about 310 feet from the shaft. In the No. 1 tunnel good ore up to a maximum width of probably 5 or 6 feet extends from near the mouth to the vicinity of the shaft. This suggests that the ore shoot pitches eastward and that much more ore would be found on the lower level by driving it ahead. Ore such as makes up the shoot extends or at least is exposed in a few surface cuts to at least 550 feet east of the shaft, suggesting the possibility of a much greater length to the ore shoot than is exposed underground. West of the shaft ore is exposed in two cuts but the showing is not very promising. East of the cuts containing the good ore mentioned above, small bodies of ore have been dug on in shallow cuts, but nothing of much promise is in sight in that direction. A small vein on the south of the main vein had at least one bunch of high grade ore for it has yielded some good float that is scattered on the hillside. * * *

Mr. Teal estimates that there is in sight in the mine about 3,600 tons of 5% ore. * * *

SMALLER MINES

ROOSEVELT TUNNEL AND ANNIE L. SHAFT

Location: Roosevelt tunnel at altitude of about 7,535 ft; 3,400 ft N. 72° W. of mouth of Black Tiger Gulch. Annie L. shaft 900 ft west-southwest of Roosevelt, at altitude of about 7,565 ft.

Workings and geology: Several shafts and tunnels on Roosevelt vein. See figure 127 for Roosevelt tunnel. Also a caved tunnel, about 50 ft lower, and a 150-ft shaft (Egle shaft) with three levels about 300 ft west of Roosevelt portal. Tunnel near this shaft connects through winze with tunnel level of Annie L. Annie L. shaft at portal of latter tunnel. About 120 ft deep; two levels are turned eastward from it. Vein stoped at places in all these workings; most productive in upper part of Annie L.

History and production: Mine owned for many years by Joseph Rafter, of Sugar Loaf; worked in block leases. Chief production in 1916–18; records covering 4 months in 1916 show output of about 1,500 units of WO_3. Annie L. worked in 1943 by Thayer and McClellan; Roosevelt worked in 1943–44 by H. K. Glancy. A few hundred units produced at this time.

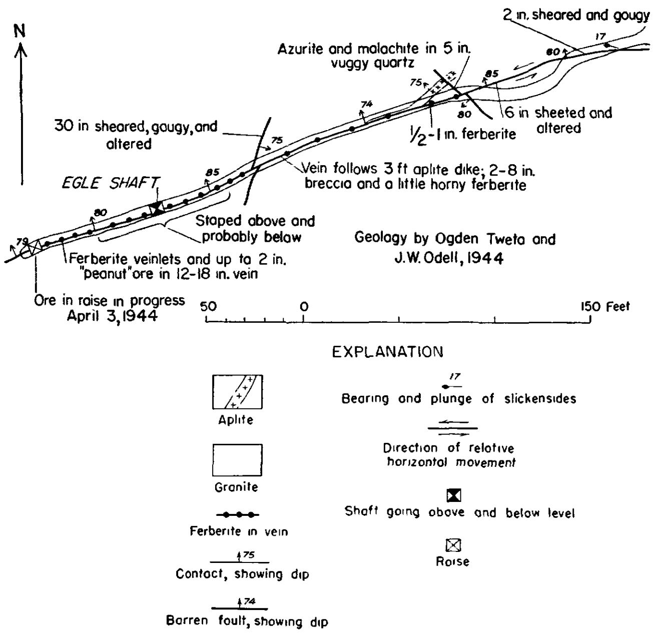


FIGURE 127.—Geologic plan of the Roosevelt tunnel, Boulder County, Colo.

BLACK PRINCE MINE

Location: Four tunnels at altitudes of about 6,725, 6,870, 6,955, and 7,000 ft on southwest side of Black Tiger Gulch about 1,500 ft from mouth.

Workings and geology: Tunnels follow strong shear zone of breccia-reef type; younger and generally small tungsten veins within this zone. See figure 128. Most of ore found between second and third levels.

History and production: Most of production in 1916–18. In 1943–44 mine worked on the second and fourth levels by M & P Leasing Co.; a few hundred units in ore assaying slightly more than 1 percent WO_3 produced.

MILAN MINE

Location: Altitude, about 6,975 ft; in bottom of Black Tiger Gulch.

Workings: In 1933 shaft was 140 ft deep; three short levels turned at depths of 50, 100, and 140 ft; possibly some work done later. Gold mine.

Geology: Vein that strikes west-northwest and dips about 65° N. was productive where it crosses Iron dike but is barren in granite.

Ore: Gold telluride in horn quartz seams cutting Iron dike. Vein 2 to 6 ft wide. Most of ore assayed $6 to $12 worth of gold per ton (price of gold, $20 per ounce), but thin streak as much as 8 in. thick on footwall near surface assayed as high as 9 oz of gold per ton.

History and production: Chief production about 1870 or 1880. Small production at times since then. Milan mine and Melbourne, a few hundred feet to north, have been most productive of small gold mines in Black Tiger Gulch.

LITTLE BELLE AND WESTERN EXTENSION MINES

Location: Tunnels at altitudes of about 7,070 and 7,050 ft in Black Tiger Gulch, 3,500 ft from mouth.

Workings: Little Belle comprises 60-ft crosscut tunnel and 100-ft drift on Western Extension vein. Western Extension tunnel is 300 ft to southwest and comprises 170-ft crosscut tunnel and short drift on minor vein. Gold mines.

Geology: Eastward-striking Western Extension vein faults Iron dike 240 ft. Part of Little Belle workings in dike; offset segment north of vein is north of Western Extension work-

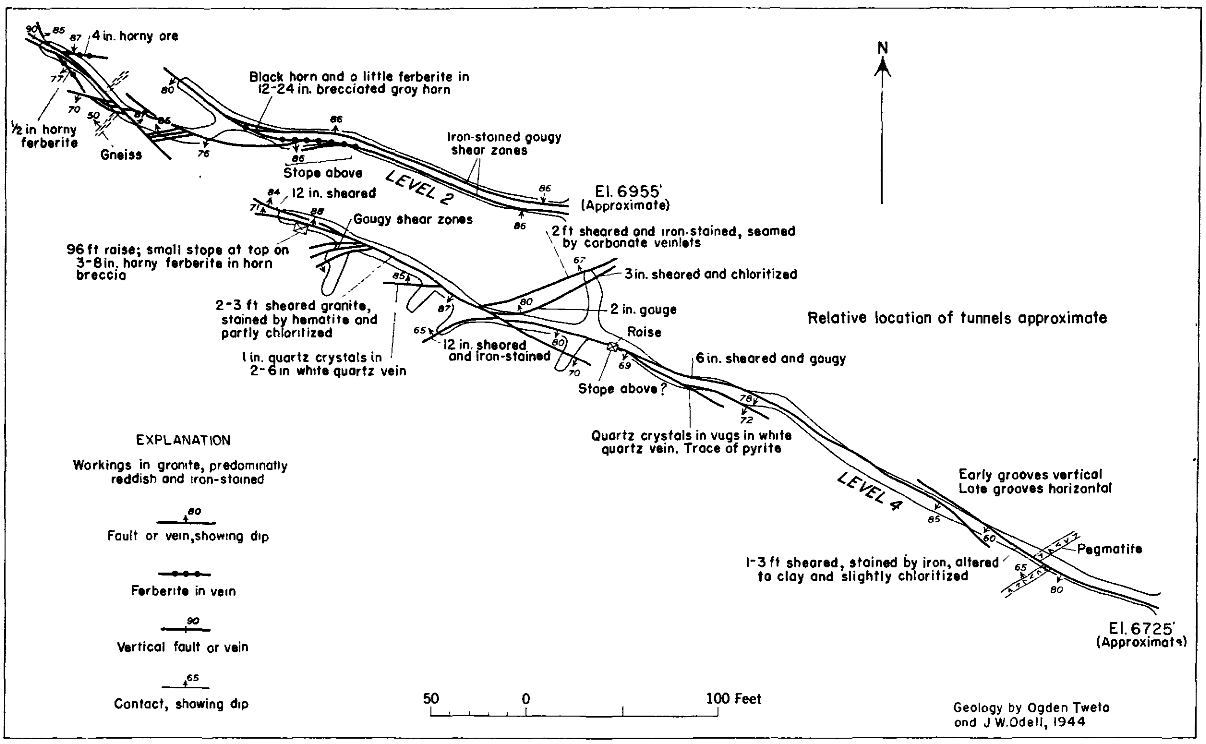


FIGURE 128.—Geologic plan of the second and fourth levels of the Black Prince mine, Boulder County, Colo.

ings. In Little Belle mine Western Extension vein contains 2 ft of dark pyritic horn quartz. Western Extension crosscut does not reach this vein.

History and production: Mines apparently have produced only minor amount of gold ore; some of ore said to have assayed about one-half ounce of gold per ton.

SUCCESS MINE

Location: Altitude, about 7,160 ft; in bottom of Black Tiger Gulch, near head.

Workings and geology: See figure 129. Gold mine.

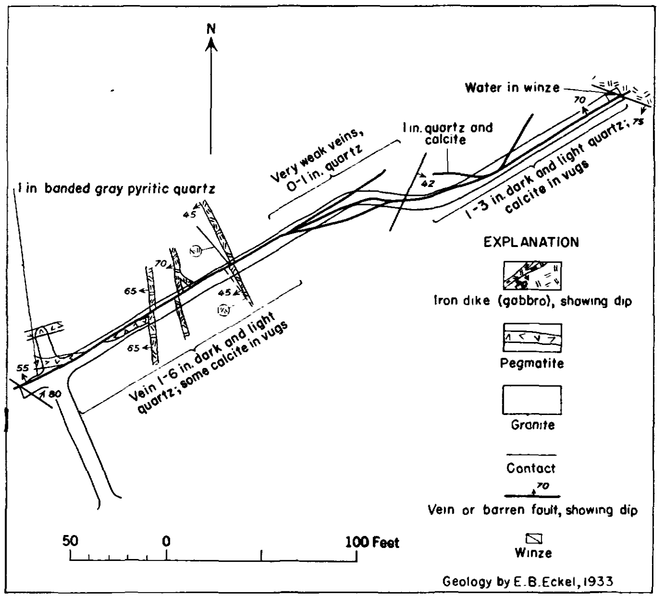


FIGURE 129.—Geologic map of the Success mine, Boulder County, Colo.

History and production: Apparently no production from tunnel. Vein contains gold ore of good tenor at several places farther northeast; may have been productive at intersection with Melbourne vein, 50 ft northeast of workings shown in figure 129. Melbourne workings inaccessible in 1933.

SPARKLING JEWEL MINE

Location: Altitude, about 7,430 ft; on ridge at head of Black Tiger Gulch, about 400 ft west of southwest corner of section 30.

Workings: Ninety-foot shaft; level at 50 ft; drift 40 ft to northeast and 50 ft to southwest. Gold mine.

Geology: Drift northeast of shaft on vein that strikes N. 55° E. and dips 40°–60° NW. This vein stoped above and below level; contains streaks of sylvanite-bearing quartz in 6 to 36 in. of brecciated gray horn. Drift southwest of shaft on branch vein that strikes N. 25° E. and dips 45° NW.; this vein contains small pockets of high-grade ore in 1 to 3 ft of brecciated gray horn.

History and production: Mine owned in 1933 by Ben Culver, according to whom ore assays as high as 1 oz of gold per ton through widths of as much as 3 ft. Pockets assaying several ounces of gold per ton mined.

GOLDEN EAGLE TUNNEL

Location: Altitude, about 7,300 ft; on north side of ridge at head of Black Tiger Gulch, 500 ft northeast of southwest corner of section 30.

Workings and geology: See figure 130. Gold mine.

History and production: Apparently only small production.

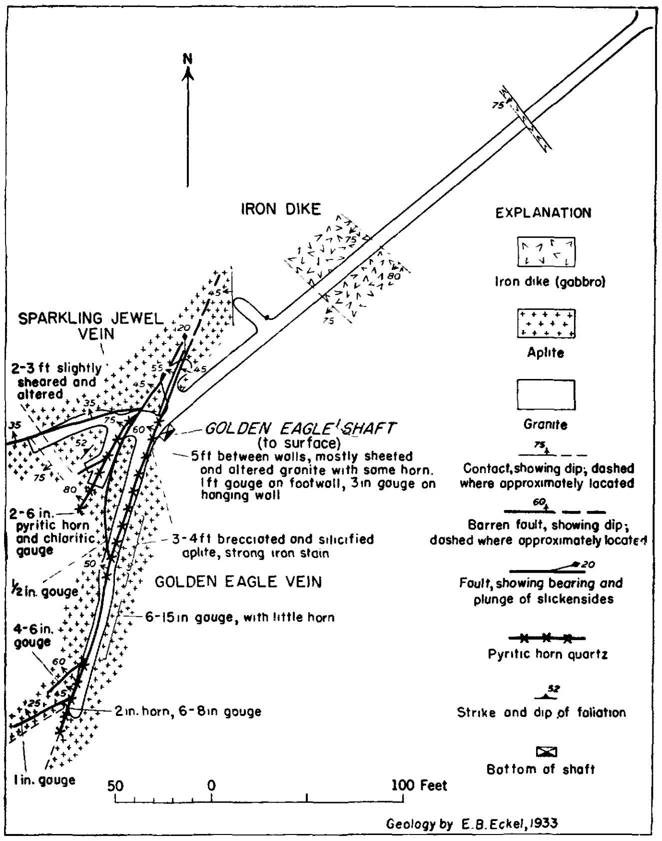


FIGURE 130.—Geologic map of the Golden Eagle tunnel, Boulder County, Colo.

PUEBLO BELLE MINE

Location: Tunnel at altitude of about 6,625 ft in bottom of Black Tiger Gulch, 1,100 ft from mouth. Shaft at altitude of 6,725 ft; 300 ft east of tunnel portal.

Workings and geology: See figure 131.

Ore: Most of ore dense and relatively horny; some finely crystalline. Production chiefly from surface cuts east of shaft and from ore body below tunnel west of shaft.

History and production: Ore said to have value of $49,000 produced from open-cuts in 1915–17. Mine operated and greatly extended by Southwest Shattuck Chemical Co. in 1939–44. Known to have produced more than 5,000 units of WO_3, largely in 1939–44; total output may be somewhat greater.

EMPRESS MINE AND POST BOY TUNNEL

Location: Portal of Post Boy tunnel at altitude of about 6,500 ft in bottom of Black Tiger Gulch, 600 ft southeast of Pueblo Belle tunnel; Empress shaft about 200 ft west of Post Boy portal.

Workings and geology: See figure 132. Post Boy tunnel is first level of Empress shaft.

Ore: In Empress mine small streaks of rich gold telluride ore occur in and are limited to Iron dike. Post Boy tunnel not productive except in vicinity of Empress shaft. Veins at inner end of tunnel contain trace of tungsten; are part of Pueblo Belle vein system.

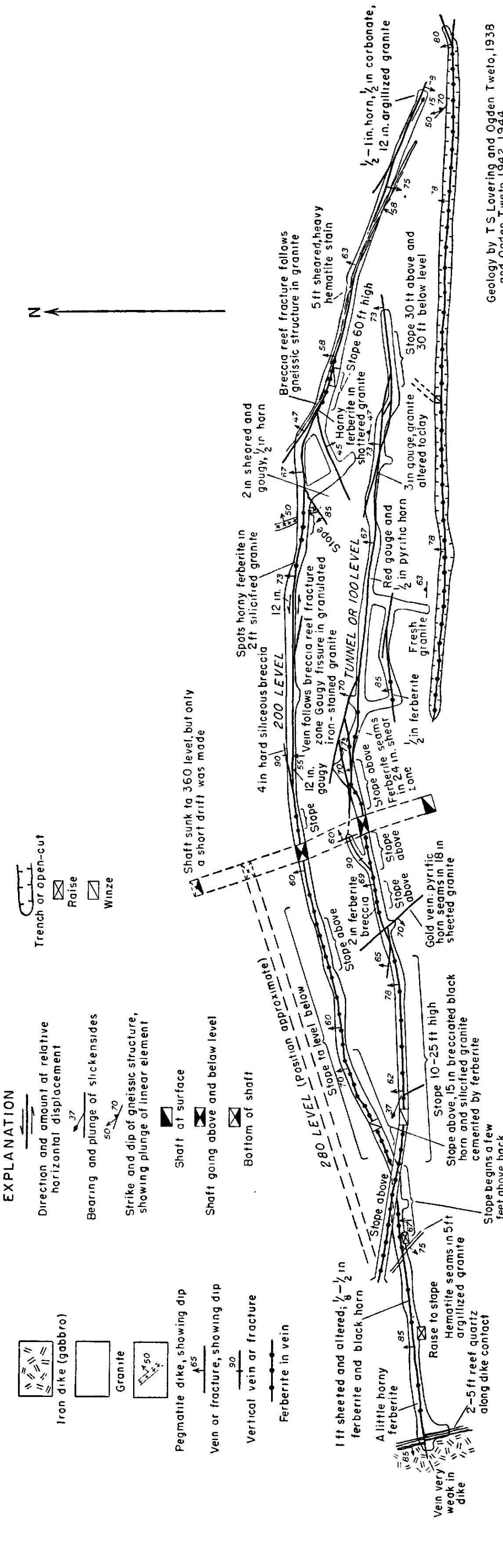


FIGURE 131.—Geologic map of the Pueblo Belle mine, Boulder County, Colo.

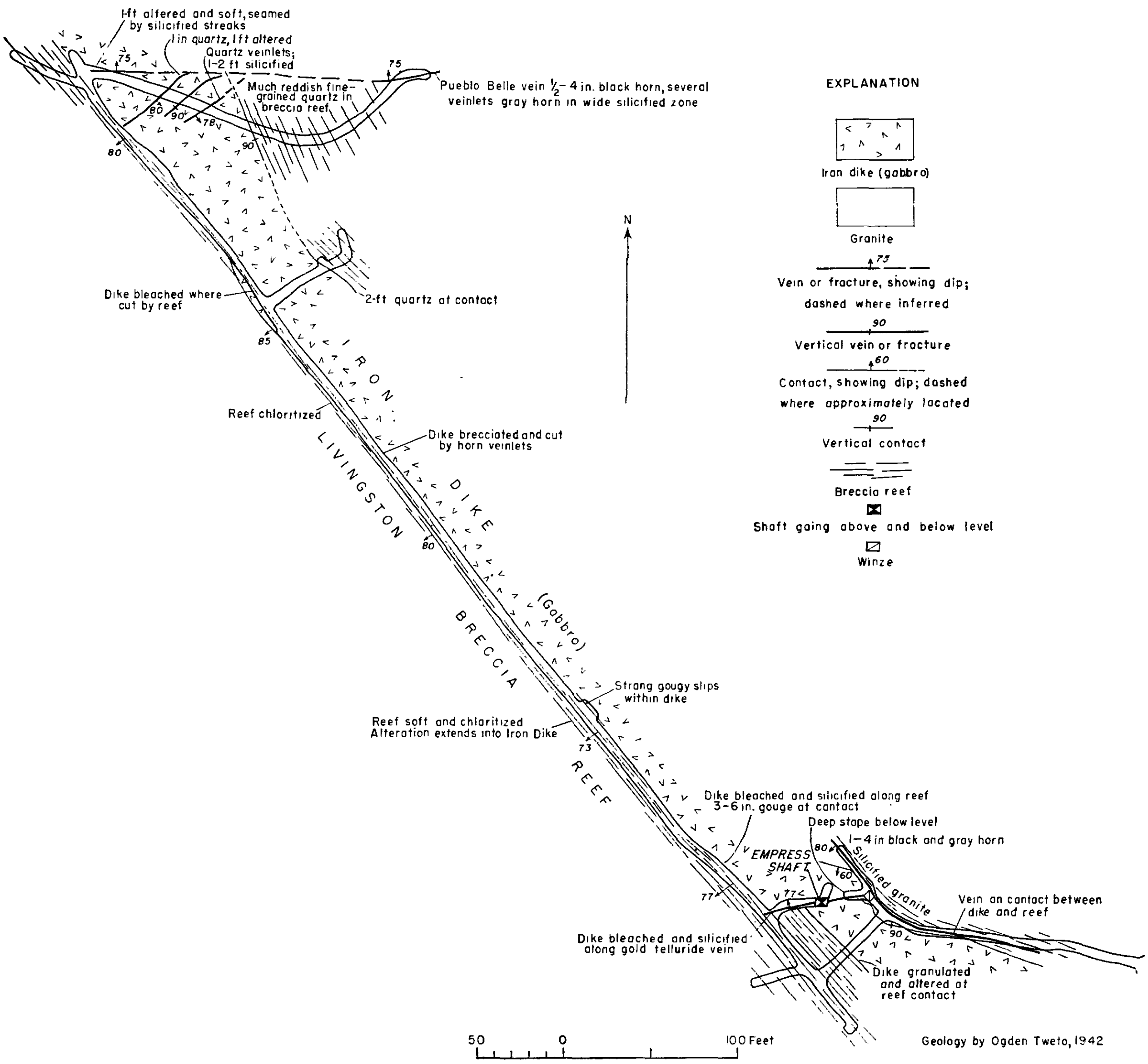


FIGURE 132.—Geologic map of the Pcst Boy tunnel and part of the Empress mine, Boulder County, Colo.

History and production: Empress operated at times by many different lessees; moderately large output of relatively rich gold ore.

WHEELMAN AND PAYMASTER TUNNELS

Location: Altitude, 6,350 ft; at edge of main Boulder-Nederland road, 1,600 ft east of mouth of Black Tiger Gulch.

Workings and geology: See figure 133.

Ore: Paymaster vein worked chiefly for gold telluride ore; a little tungsten ore also produced. Chief production from surface cuts above upper, or Paymaster, tunnel and east of Wheelman crosscut tunnel and from stope in caved workings west of crosscut tunnel.

History and production: Mine not worked in recent years. Substantial output of gold earlier.

RED SIGNE MINE

Location: Altitude, about 6,325 ft; on east bank of Middle Boulder Creek, at extreme east edge of district.

Workings and geology: See figure 134.

Ore: Red Signe has produced both tungsten and gold ores in substantial quantities. Tungsten ore occurs chiefly in western and lower part of mine; is finely crystalline to dense and horny and occurs as filling in breccia in larger veins and in veinlets in many small sheeted zones. Gold ore is gray pyritic quartz that contains both free gold and gold tellurides; concentrated chiefly in upper and eastern part of mine. Tungsten clearly later than pyritic gold quartz; vein as whole follows early breccia-reef fracture zone.

History and production: Red Signe worked before 1914 for tungsten; probably worked much earlier for gold. Tungsten production probably about 3,000 units of WO_3. Considerable part of this produced in 1943–44, when mine was operated by Cleveland and Horton. Gold output not known; probably substantial. Mine owned by George Teal in 1945.

CRETE, CRACKERJACK, AND PRINCESS EULALIA MINES

See description of Dorothy and Katie mines and plate 24A.

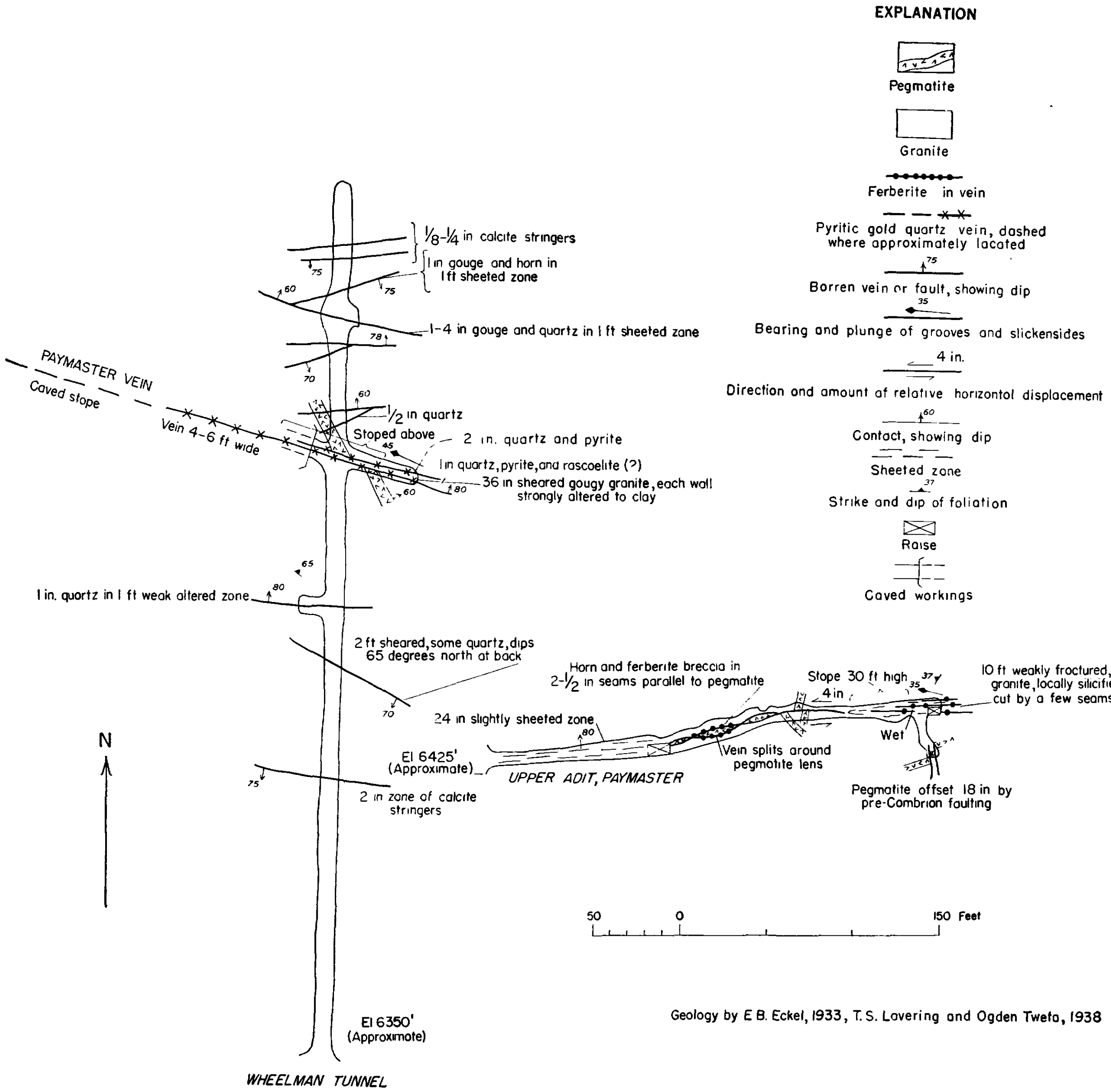


FIGURE 133.—Geologic map of the Paymaster and Wheelman tunnels, Boulder County, Colo.

OHIO MINE

Location: Altitude, about 6,950 ft; on ridge south of Bummers Gulch, just east of area covered by topographic map (pl. 1) and about 3,000 ft east-southeast of Dorothy shaft in Millionaire Gulch.

Workings and geology: See figure 135; also lower tunnel about 60 ft below main, or upper, tunnel and glory hole; many cuts and small shafts above upper tunnel.

Ore: Mine on strong shear zone that branches westward from Hoosier breccia reef; ore occurs as veinlets in stronger fracture zones and in intervening shattered rock, forming so-called blow-out 30 to 60 ft wide. In addition to ferberite, some of material in blow-out contains considerable scheelite.

History and production: Ore first mined from glory hole apparently relatively high in grade. Hershey reports that output to 1914 was 500 tons averaging 8 percent WO_3 (4,000 units of WO_3). Small output at times from 1920 to 1942, when Harrison Cobb discovered scheelite in material left as waste during earlier operations. In 1943–44 shipped more than 2,000 tons of ore assaying about 1 percent WO_3. About one-third to one-half of tungsten in this ore in scheelite; rest in ferberite. Recorded output of Ohio mine about 7,000 units of WO_3; total may be somewhat greater. Mine owned by Vanadium Corp. of America in 1945.

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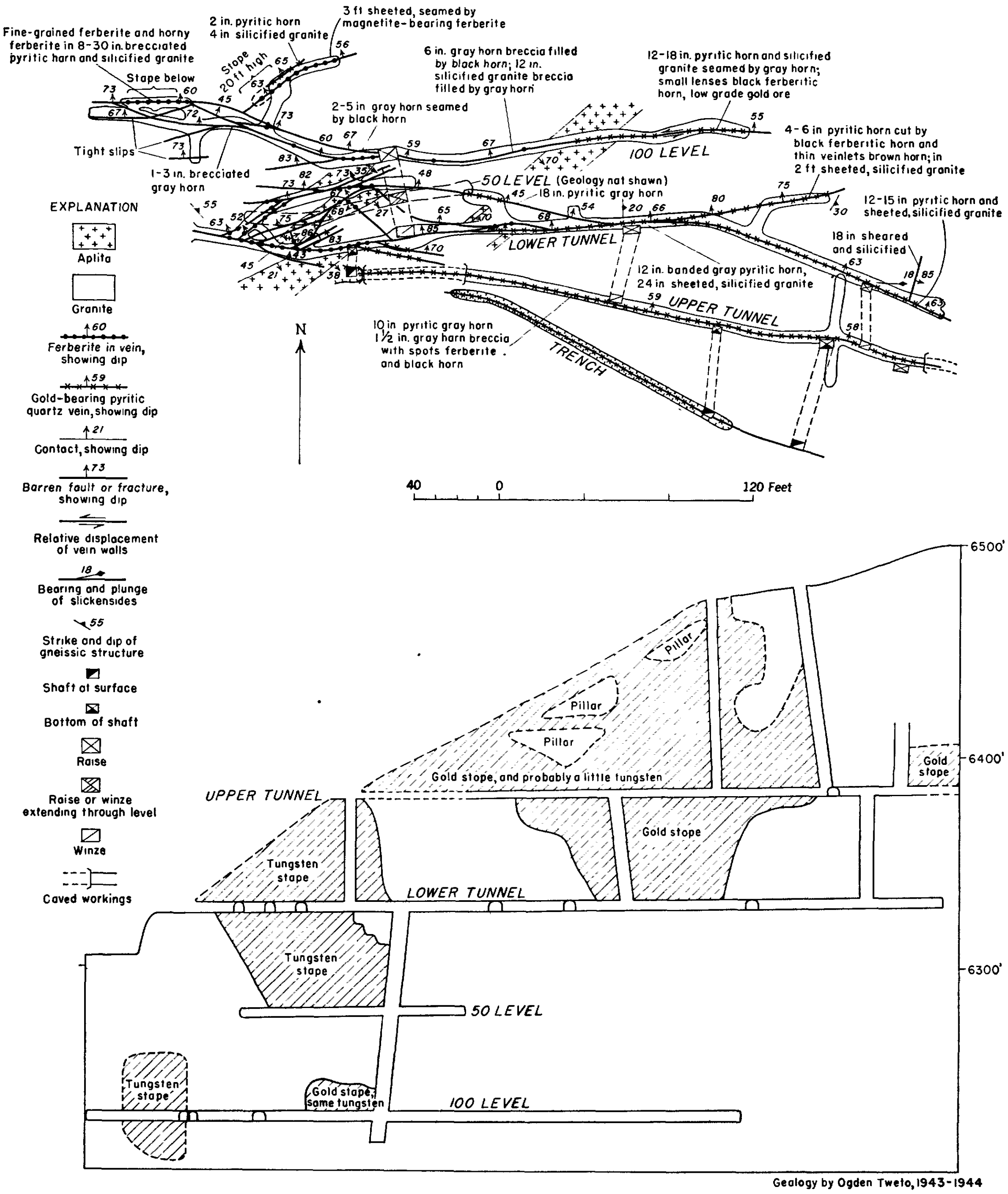

FIGURE 134.—Geologic plan of the Red Signe mine, Boulder County, Colo., and projection in plane in vein.

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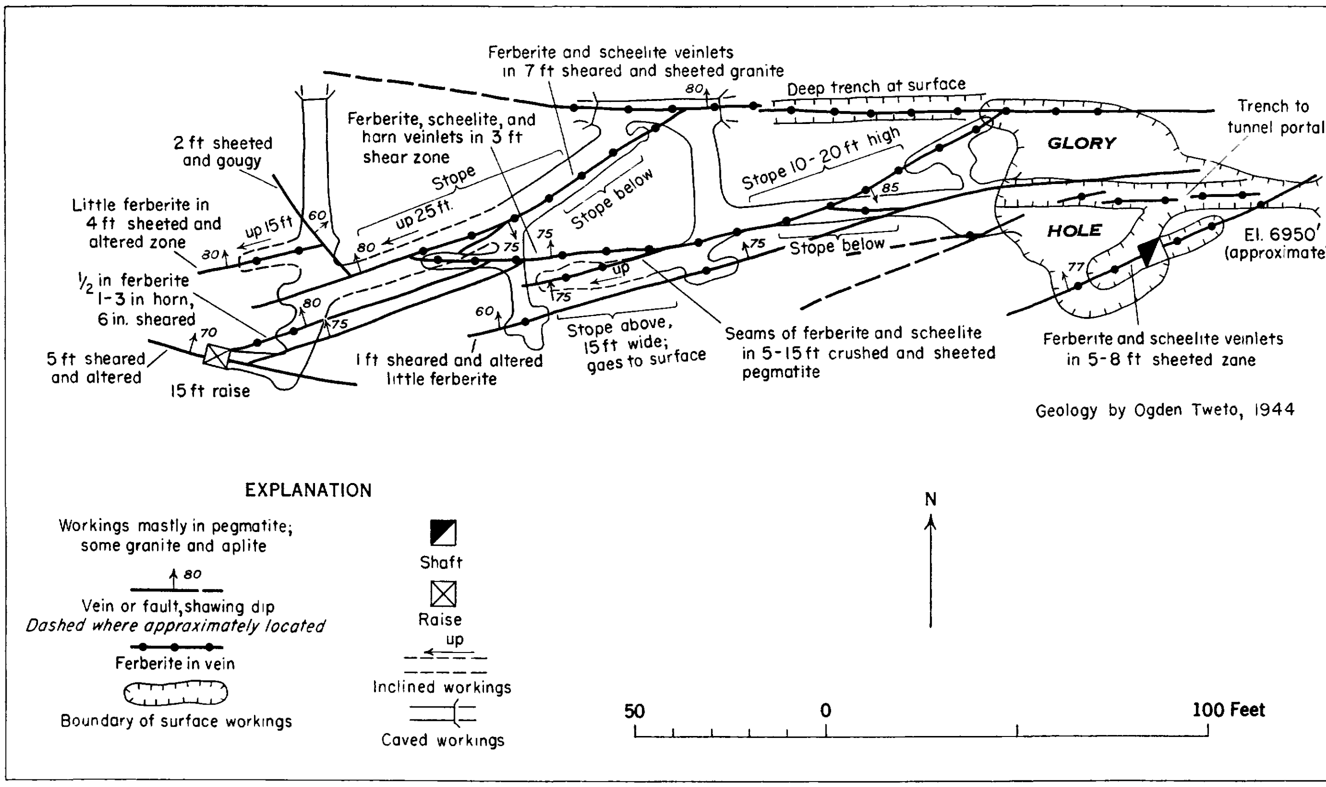

FIGURE 135.—Geologic plan of the upper workings of the Ohio mine, Boulder County, Colo.

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