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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THE URANIUM, TIN, AND COPPER DEPOSITS AT MAJUBA HILL, PERSHING COUNTY, NEVADA*

By

Ralph H. Thurston and Albert F. Trites, Jr.

December 1952

Trace Elements Investigations Report 171

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*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission

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By Ralph H. Thurston and Albert F. Trites, Jr.

ABSTRACT

Uranium is associated with copper and tin ores in the Majuba Hill area, Antelope mining district, in the central part of the Antelope Range, Pershing County, Nev. About 23,000 tons of copper and 200 tons of tin ore, a small quantity of lead-silver ore, and some arsenic-silver ore have been produced from the Majuba Hill mine, the Last Chance mine, and a mine in sec. 34, T. 33 N., R. 31 E.

Majuba Hill is a complex rhyolite plug of Tertiary age. The rhyolite can be divided into three types: (1) rhyolite porphyry, (2) quartz porphyry, and (3) porphyritic rhyolite. Five types of intrusion breccias and several fault breccias are associated with the rhyolites. The igneous complex intrudes and has slightly metamorphosed the surrounding argillites, quartzites, and impure limestones, all of Triassic (?) age. Both the igneous and metamorphic rocks near the plug have been partly sericitized, silicified, and tourmalinized.

The principal deposits of uranium, copper, and tin at the Majuba Hill mine occur in (1) veins, (2) disseminations in rhyolite and quartz porphyry adjacent to veins, (3) fault gouge, and (4) tourmalinized intrusion breccias. The primary minerals are chalcopyrite, cassiterite, arsenopyrite, and pyrite. Chalcocite, cuprite, bornite, brochantite, azurite, and malachite have been formed by supergene enrichment. No primary minerals of uranium have been found, but the secondary minerals, zeunerite, torbernite, and metatorbernite, are locally abundant.

The uranium deposits in the Majuba Hill mine range in grade from 0.016 to 0.30 percent U_3O_8. The presence of radon in some of the other workings suggests the existence of additional, but concealed, deposits. The grade of the tin reserves ranges from 0.10 to 0.60 percent; the highest-grade copper deposits range from 0.30 to 12.7 percent copper.

INTRODUCTION

Majuba Hill is in the Antelope (or Cedar) mining district, Pershing County, Nev., in the central part of the Antelope Range. About 20 miles east is Imlay, Nev. (fig. 1) which is on the main line of the Southern Pacific Railroad and on U. S. Highway 40.

The Antelope Range is near the western margin of the Great Basin, about 150 miles east of the Sierra Nevada. The range trends slightly east of north and is flanked on the east and west by deep, alluvium-filled valleys. Majuba Hill, a prominent landmark in the range, is centrally located and rises to an altitude of 6,886 feet.

The principal known ore deposits at Majuba Hill are in sec. 2, T. 32 N., R. 31 E. Mount Diablo base and meridian (fig. 2), in the vicinity of the Majuba Hill mine. The deposits contain tin, copper, and uranium. A prospect in sec. 34, T. 33 N., R. 31 E., yielded some arsenic-silver ore during the early 1920's. Lead-silver ore has been produced from the Last Chance mine of the Majuba Fresno Mining Company, in sec. 1, T. 32 N., R. 31 E.

The tin deposit at the Majuba Hill mine has been studied by Smith and Gianella (1942), Gilluly and Page (unpublished report), and Wiese (unpublished report) for the U. S. Geological Survey. The U. S. Bureau of Mines conducted a development program of diamond drilling and drifting on this deposit in 1943 (Matson, 1948). A brief reconnaissance examination of the mine was made for uranium in 1948 by Wyant of the U. S. Geological Survey (unpublished report). Between January and June 1949 the writers made a more detailed study of the uranium occurrences in the area as part of the program of uranium investigations carried out by the U. S. Geological Survey on the behalf of the U. S. Atomic Energy Commission.

The geologic map and section by Smith and Gianella (1942), on a scale of 1 inch equals 1,000 feet, were used as a base (fig. 2), and only the main intrusive area was remapped. A network of triangulation stations was established as a base for resection, stadia, and pace surveys. The underground workings were mapped on a scale of 1 inch equals 20 feet using Brunton bearings and chained distances. The geologic maps and sections (figs. 2-8) were prepared by Thurston, assisted by Trites; most of the petrographic, mineralogic,

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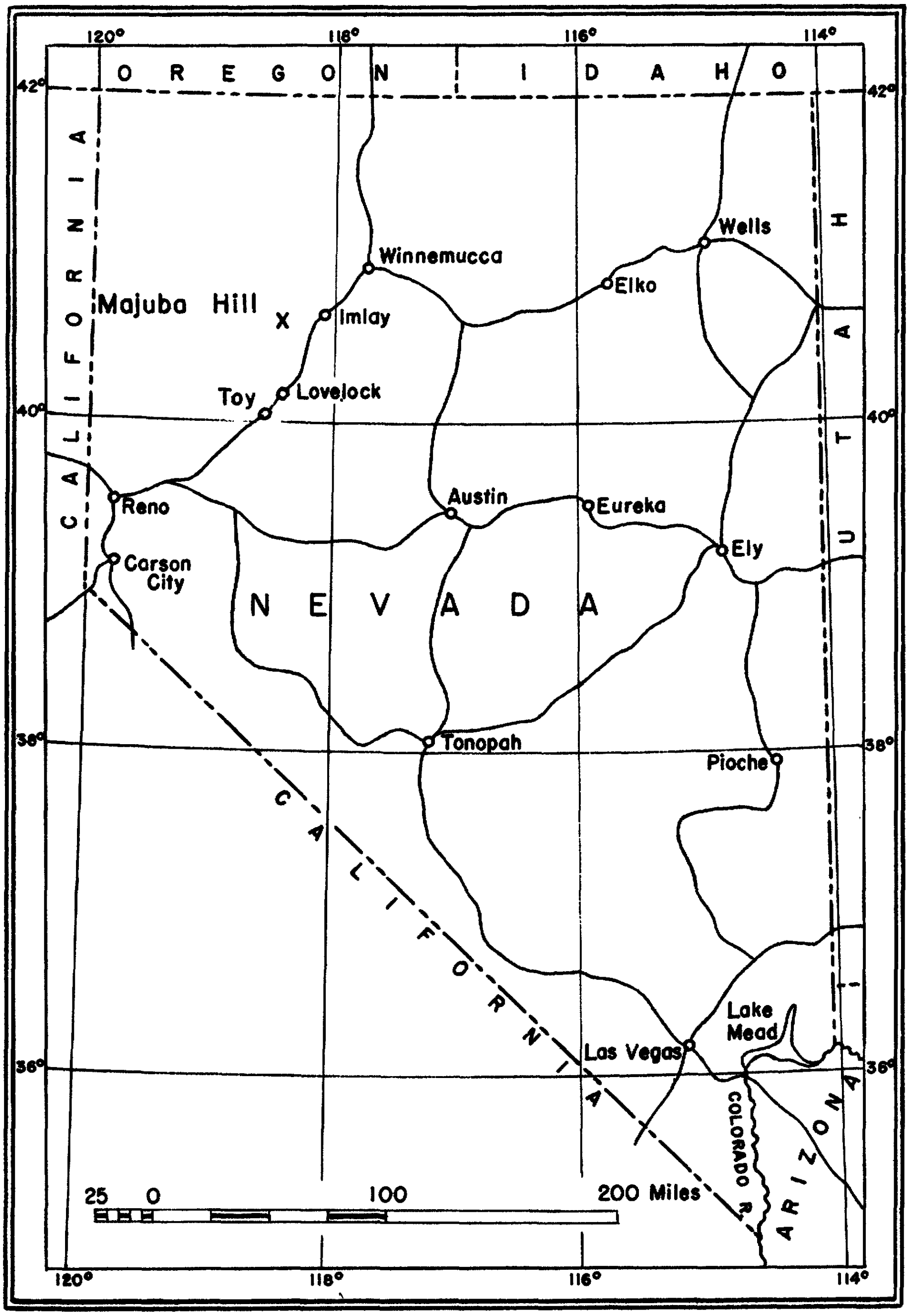

FIGURE 1.-INDEX MAP SHOWING LOCATION OF MAJUBA HILL, PERSHING COUNTY, NEVADA.

and radiometric studies were made by Trites.

The writers are indebted to Mr. E. J. Myler, owner of the Majuba Hill mine, for many favors and assistance during this study.

History and production

Tin and copper minerals have been known at Majuba Hill since about 1907. Cassiterite-bearing float was found in that year although its source was not discovered. In 1917 the Mason Valley Mines Company discovered a tin deposit underground during a search for copper ore. This company has done most of the exploration work at the Majuba Hill mine, and between 1916 and 1918, produced about 4,000 tons of ore that contained 12 percent copper.

The Mason Valley Mines Company ceased work in 1918, and the Majuba Hill mine remained idle until early in 1941 when it was optioned to the Freeport Sulphur Company by C. A. Copley and A. L. Gilmet, who apparently held the mine under arrangement with Harvey Reber, the owner. The Freeport Sulphur Company continued prospecting for tin until October 1941, when the mine again became idle.

E. J. Myler acquired the property from Reber under a bond and lease arrangement in May 1942. In October of the same year, after doing development work, Myler assigned a lease to J. O. Greenan and George Kerr of Reno, Nev.

The principal uranium deposit at the Majuba Hill mine was exposed during the mining of copper ore from the Copper stope between 1942 and 1945. No uranium ore has been shipped from the mine. Between October 1942 and May 1945, Greenan and Kerr mined about 23,000 tons of ore that averaged about 4 percent copper. This ore was purchased by the American Smelting and Refining Company smelter at Garfield, Utah. Greenan and Kerr also mined about 200 tons of ore that yielded between 10 and 15 tons of metallic tin. This ore was milled at a tungsten concentrating plant at Toy, Nev., and was sold to the Metals Reserve Company at Battle Mountain, Nev. Greenan and Kerr relinquished their lease in May 1945. From May 1945 to May 1949, Myler did development work which produced a small quantity of copper ore.

Mine workings

The Majuba Hill mine workings are on three adit levels (figs. 4 and 5). The Lower adit is at an altitude of 5,774 feet and is 2,000 feet long; the adit crosses the Majuba shear zone about 1,550 feet from the portal. The Middle adit workings, at an altitude of 6,250 feet, have a total length of about 2,000 feet. This level follows the Majuba fault, and crosscuts have been driven into both walls of the fault. Essentially all of the ore produced to 1949 has come from this level. The Upper adit is at an altitude of 6,451 feet and is about 100 feet long. It is connected to the Middle adit by a raise.

ROCK UNITS

The Antelope Range is made up of a thick section of argillite, limestone, and quartzite of Triassic (?) age that are intruded by: (1) stocks and plugs of rhyolite and granite, (2) sills and dikes of andesite, dacite, latite, and diorite, and (3) veins of quartz. The andesite, dacite, latite, and diorite are all older than the rhyolite of Tertiary (?) age. Lavas occur locally as erosion remnants on the flanks of the range. The quartz veins are generally barren and concordant with the bedding. In places the argillite has been altered to slate, phyllite or hornfels, and some limestone has been altered to zoisite-bearing rocks near the intrusive rocks; the rocks within the intrusive area have been intensely silicified and tourmalinized.

Majuba Hill, a prominent peak in the Antelope Range, is a complex plug approximately 5,000 feet in diameter that is composed of intrusive rhyolites and many diverse types of intrusion breccias. Repeated igneous intrusion and possibly explosive activity have produced a very complex sequence of rocks. Irregular dikes of rhyolite extend for several thousand feet into the sedimentary rocks that surround the plug.

Sedimentary and metamorphic rocks

The oldest rocks of Majuba Hill are metamorphosed sedimentary rocks of Triassic (?) age that consist, for the most part, of argillite and a few beds of quartzite and impure limestone. No fossils have been found in the sedimentary rocks; a Triassic age is inferred on the basis of lithologic similarity to Triassic rocks in the

Eugene Mountains, the next range east of the Antelope Range.

Argillite

Argillite crops out over most of the area, and is in contact with, or forms inclusions in, the intrusive rhyolite and breccias on the flanks of Majuba Hill. The argillite is thin bedded and ranges in color from dark blue to light gray. It is composed principally of clay minerals and quartz, and subordinately of mica and scattered crystals of pyrite. In places the argillite has been altered to brown or red slate, phyllite, and hornfels for distances as much as 100 feet from intrusive rocks, and the argillite is locally crumpled. The slate and phyllite are characterized by seams of granular quartz, alternating with thin seams of schistose sericite and quartz. Sericite, epidote, chlorite, and zoisite are widespread alteration minerals. Quartz, tourmaline, and fluorite have been added locally. The writers do not differentiate the metamorphic facies of these rocks on figure 2.

Quartzite

Lenticular beds of brown to buff, finely granular, metamorphic, micaceous quartzite constitute less than 1 percent of the sedimentary rocks. Individual beds range in thickness from a few inches to 6 feet and are seldom traceable along the strike for more than 100 feet. The beds weather to a reddish buff color and may be distinguished easily from other rocks of the vicinity. No evidence of hydrothermal alteration was seen in the quartzite.

Limestone

A few beds of gray, medium-grained argillaceous limestone, as much as 3 inches thick, were intersected in the Lower adit level of the Majuba Hill mine. One 6-inch bed of calcite-epidote rock near a quartz porphyry dike is believed to represent an altered limestone bed.

Igneous rocks

The igneous rocks at Majuba Hill (fig. 2), consist of: (1) the pre-rhyolite dikes and sills, and (2) the Tertiary intrusive rhyolites. The rhyolites are divided into three types and are-- from oldest to youngest-- (1) rhyolite porphyry, (2) quartz porphyry, and (3) porphyritic rhyolite. The areal distribution of these rocks is shown in figure 2.

Pre-rhyolite dikes and sills

Dikes and sills of fine-grained porphyritic to coarse-grained granite, andesite, dacite, latite, and diorite are abundant east and south of Majuba Hill, although they are found on all sides of the hill. They form short lenticular sills that range in length from 1 to more than 100 feet, and have an average thickness of 15 feet. Fresh surfaces of these rocks are grayish green or green; weathered surfaces are light tan or brown. A blocky to slightly platy jointing is well developed in them. Sericite, chlorite, calcite, and quartz occur as alteration products in many of these rocks. These rocks are all believed to be older than the rhyolitic rocks of the Majuba Hill plug and fragments of them are contained as xenoliths in some of the rhyolites and many of the breccias of the plug.

Rhyolites

The Tertiary (?) rhyolites, in the order of their intrusion, are: (1) rhyolite porphyry, (2) quartz porphyry, and (3) porphyritic rhyolite. The distinguishing features of the three types of rhyolite are given below:

	Grain size of groundmass (mm)	Phenocryst size (mm)	Abundance of phenocrysts (percent)
Rhyolite porphyry	0.1	0.25-4.0	2-10
Quartz porphyry	0.2	2.0-5.0	20-40
Porphyritic rhyolite	0.05	0.5	2-10

All of the rhyolites have been sericitized and silicified; the rhyolite porphyry and quartz porphyry commonly have been tourmalinized in the central and southern parts of the Majuba Hill plug.

Rhyolite porphyry. --Rhyolite porphyry, the oldest and most widespread rock of the Majuba Hill plug, constitutes about 75 percent of the exposed rocks in the plug. The three adits of the Majuba Hill mine penetrate rhyolite porphyry, and large outcrops of this rock form the crest of the hill.

The rhyolite porphyry contains inclusions of the sedimentary rocks. It is cut by the other two rhyolites and by breccias containing fragments of quartz porphyry. The rhyolite porphyry occurs as inclusions in the other two rhyolites and as fragments in most of the breccias.

The rhyolite porphyry is light gray on fresh surfaces and weathers light tan or brown. Quartz and sanidine phenocrysts, that range from 0.25 to 4 mm in diameter, constitute from 2 to 10 percent of the rhyolite porphyry; the larger phenocrysts occur near the center of the plug. The matrix has an average grain size of 0.1 mm, and is made up of quartz, sanidine (?), and plagioclase. Flow structures are found mainly near the intrusive contacts where they strike roughly parallel to the contact, and dip nearly vertically.

Much of the rhyolite porphyry has been intensely sericitized, silicified, and tourmalinized. Fine-grained sericite and quartz have replaced the feldspar phenocrysts and the groundmass, leaving quartz phenocrysts in a matrix of sericite and quartz. Such intense alteration is noted most commonly in the rhyolite porphyry on the north and northeast sides of Majuba Hill and in many of the breccias. Much of the rock has been altered by the addition of black tourmaline that occurs both in veinlets and as aggregates partially filling cavities formerly occupied by feldspar phenocrysts. The color of the altered rock depends largely upon the proportion of alteration products present; intensely sericitized and silicified rock is white or cream colored, and intensely tourmalinized rock is mottled gray.

Quartz porphyry. --Quartz porphyry forms an irregular mass within the plug of Majuba Hill where it constitutes about 15 percent of the total igneous rock exposed. Sills and dikes of the same rock occur in the surrounding shales. Some of the larger dikes (fig. 2) that extend into the shales have a tendency to widen at their ends.

The contacts of the quartz porphyry with the rhyolite porphyry are sharp, and the quartz porphyry shows only a slight amount of chilling. These contacts are irregular and dip vertically or steeply to the southeast. The contacts of the quartz porphyry with the shales are also sharp. Where the quartz porphyry is in contact with some of the larger masses of breccia, it fingers into the breccia, forming an irregular contact zone.

The quartz porphyry contains xenoliths of shale, rhyolite porphyry, and rhyolite-bearing breccias. A few quartz porphyry dikes are separated from the older rhyolite porphyry by rims of rhyolite-bearing breccias. The quartz porphyry occurs as xenoliths in the younger porphyritic rhyolite and in some of the breccias, and is cut by porphyritic rhyolite. The quartz porphyry is cut by some breccias containing fragments of rhyolite porphyry, argillite, and quartz porphyry in a matrix of quartz porphyry.

Phenocrysts of quartz, sanidine, and oligoclase, ranging from 2 to 5 mm in diameter, comprise from 20 to 40 percent of the rock. These same minerals make up the groundmass, which has an average grain size of 0.2 mm. The quartz phenocrysts are bipyramids and tend to occur in double crystals.

Most of the quartz porphyry has been altered, although the alteration is not uniform in distribution or type. Sericitized and silicified rocks are widespread; tourmalinized rocks are more restricted.

Porphyritic rhyolite.--The porphyritic rhyolite is the youngest of the three rhyolites. The main body of porphyritic rhyolite crops out over a large area along the southeastern margin of the rhyolite porphyry plug, but has not been penetrated in the Majuba Hill mine workings. All observed contacts of the porphyritic rhyolite dip 80° or more. The rock is generally white or cream colored on both fresh and weathered surfaces, although iron staining locally has produced a tan or brown color. The main body of the rock is lighter in color on the outcrop than other rocks in the area and is easily distinguished.

The porphyritic rhyolite has much smaller phenocrysts and a finer groundmass than either the quartz porphyry or rhyolite porphyry. The phenocrysts are of quartz, sanidine, and oligoclase. They average 0.5 mm in diameter and constitute from 2 to 10 percent of the rock. The groundmass has a grain size of about 0.05 mm.

Much of the rock has been altered to sericite; secondary quartz has been introduced locally, but silicification is less characteristic of the porphyritic rhyolite than of the two older rhyolites. Although tourmalinized xenoliths occur in the porphyritic rhyolite, the porphyritic rhyolite has not been tourmalinized and is, therefore, thought to be younger than the latest tourmalinization.

Breccias

More than twenty varieties of breccia were distinguished at Majuba Hill (fig. 2) and these are classified according to their origin as intrusion and fault breccias. Intrusion breccias, the most common kind, contain many of the known ore deposits. The fault breccias are barren.

Intrusion breccias

The intrusion breccias typically are chaotic mixtures of rubbly material, and characteristically they contain fragments of all pre-existing rock types. Component fragments of rhyolitic rocks are commonly rounded, whereas those of argillite are sharply angular. These breccias occur chiefly as dike-like bodies, although some have irregular shapes at the intersection of two or more breccia dikes. Some of the irregular bodies shown on figure 2 are of this type. Five main types of intrusion breccia have been distinguished.

The five types of intrusion breccias, classified according to included rock fragments are: (1) argillite breccia, (2) rhyolite porphyry breccia, (3) argillite-rhyolite porphyry breccia, (4) rhyolite porphyry-quartz porphyry-argillite breccia, and (5) rhyolite porphyry-quartz porphyry breccia. In the multicomponent breccias the relative abundance of individual components within a single body may range from zero to nearly 100 percent.

Except for the argillite breccias, which are confined to small areas near the margins of the plug, the distribution of the intrusion breccias is so complex that the individual types could not be mapped at the scale of the surface geologic map (fig. 2). The intrusion breccia bodies in the vicinity of the Majuba Hill mine are shown on a detailed geologic map (fig. 3).

Argillite breccia.--Argillite breccia occurs as discontinuous segments, as much as 100 feet wide, around the margins of the rhyolite porphyry plug. This breccia, which is believed to be the oldest intrusion breccia at Majuba Hill, is composed principally of argillite fragments with minor amounts of quartzite, limestone, and prerhyolite quartz veins and igneous rock fragments. These fragments are sharply angular, ranging in size from half an inch to 12 inches and having an average size of 3 inches. They tend to be tightly packed, and are cemented by rhyolite porphyry near the contacts with the rhyolite porphyry of the plug. Alteration has produced abundant sericite and less abundant quartz and tourmaline.

Rhyolite porphyry breccia.--A breccia composed entirely of fragments of rhyolite porphyry occurs near the northeast part of the summit of Majuba Hill. This breccia has been intensely silicified and sericitized but apparently has not been tourmalinized.

Argillite-rhyolite porphyry breccia.--The argillite-rhyolite porphyry breccia, the most abundant and widespread intrusion breccia at Majuba Hill, forms dikes that cut argillite at the Majuba Hill mine and form an interconnecting network that cuts the rhyolite porphyry plug. The breccia dikes range in width from 5 to 40 feet and dip from 70° to 90°.

The argillite-rhyolite porphyry breccia is composed of fragments of argillite and rhyolite porphyry, in varying amounts. Rhyolite porphyry xenoliths are as much as 8 feet in diameter, but average about 6 inches; argillite fragments are as large as 8 inches in diameter, but average about 2 inches. The matrix of argillite-rhyolite porphyry breccia is rhyolite porphyry, quartz porphyry, or quartz and tourmaline. Prominent flow banding is common in the rhyolite porphyry matrix, but is unusual in the quartz porphyry matrix.

The argillite-rhyolite porphyry breccias with a quartz porphyry matrix contain quartz and tourmaline throughout, whereas the breccias with a rhyolite porphyry matrix contain quartz throughout, and tourmaline only locally. All of the breccias contain sericite.

Rhyolite porphyry-quartz porphyry-argillite breccia.--Rhyolite porphyry-quartz porphyry-argillite breccias constitute the widest breccia dikes in the region, and are present in all the stopes of the Majuba Hill mine. The dikes trend from north to northeast and dip from 70° to 90° east or southeast. A prominent outcrop of rhyolite porphyry-quartz porphyry-argillite breccia just north of the portal of the Upper adit is approximately 190 feet long and as much as 75 feet wide. This exposure of breccia is bounded on all sides by faults (fig. 3).

The rhyolite porphyry-quartz porphyry-argillite breccia is estimated to consist of 10 to 85 percent rhyolite porphyry, 15 to 85 percent quartz porphyry, 2 to 5 percent argillite and as much as 1 percent other rocks. The rhyolite porphyry fragments have a maximum diameter of 48 inches and an average of 8 inches; the quartz porphyry 30 inches, averaging 5 inches; and the shale 3 inches, averaging 1 1/2 inches.

The matrix of the rhyolite porphyry-quartz porphyry-argillite breccia is either quartz porphyry or quartz and tourmaline. A large body of breccia with a quartz porphyry matrix crops out about 1,300 feet N. 18° W. of the Middle adit portal.

Sericite, quartz, and tourmaline are common in all of these breccias. Tourmaline is much more abundant in this breccia than in the others.

Rhyolite porphyry-quartz porphyry breccia.--Rhyolite porphyry-quartz porphyry breccia, which crops out near the center of the plug, has an irregular shape and an outcrop area of approximately 2,500 square feet. The fragments are well rounded and range in diameter from 1 1/2 to 20 inches. Because of the lack of an igneous rock matrix, the rhyolite porphyry-quartz porphyry breccia weathers to a rubble of rounded fragments. The breccia has been silicified and tourmalinized.

Origin of the intrusion breccias

An adequate understanding of the arrangement and continuity of the ore deposits at Majuba Hill depends on the correct interpretation of the form and origin of the intrusion breccias. The relative ages of most of the breccias can be determined by the crosscutting relationships and by the types of rhyolite fragments and matrices contained in them. A complete discussion of the formation of these breccias involves considerable speculation; the known facts are given below.

1. The intrusion breccias occur both as regular and irregular dikes, and as irregular masses at dike intersections. The dikes range in length from 10 to 1,100 feet and in width from 4 inches to 60 feet.

2. The intrusion breccia dikes trend in diverse directions and dip nearly vertical. Some of the dikes, especially those near the outer rim of the plug, have an arcuate or circumferential pattern. The breccia

dikes near the center of the plug have a predominant N. 30°-40° W. trend, and are parallel to subparallel to the Majuba fault zone, a large postrhyolite structure exposed in the workings of the Majuba Hill mine. Other breccia dikes within the plug trend N. 5°-15° E., roughly at 45 degrees to the major trend.

3. The intrusion breccias contain a heterogeneous assemblage of well-rounded to angular fragments of all rocks cut by them. The longer axes of the fragments are oriented parallel to the dip of the contact.

4. The contacts of the breccia dikes range from regular to very irregular; they are gradational where the breccia is in contact with postbreccia rhyolite and relatively sharp where the breccia is in contact with prebreccia rhyolite.

5. Several rock types--rhyolite porphyry, quartz porphyry, and quartz and tourmaline--constitute the matrices of the intrusion breccias; a few breccias have no matrix.

6. At least three, and possibly as many as five, different ages of intrusion breccias have been determined. The formation of all, except perhaps the last, of these breccias accompanied the injection of rhyolitic rocks.

The intrusion breccia dikes are believed to have been formed by the intrusion of the rhyolitic rocks in the plug. A large number of the dikes are believed to represent material that was pushed ahead of advancing rhyolite. Some breccia selvages along rhyolitic dikes have apparently been dragged along by flowing rhyolite. Other breccia dikes may be explosion breccias that resulted from the near-surface release of superheated steam along fractures. The vertical direction of flow and explosive activity is indicated by the vertical orientation of xenoliths along the edges of rhyolite dikes and by the nearly vertical walls of the breccia dikes.

The arcuate fractures around the circumference of the plug are thought to be the result of pressures developed in the cylindrical zones of shearing set up by the intrusion. These fractures might also result from a release of such pressure by the crystallization of the rhyolitic rocks of the plug. The intrusion breccia dikes that trend N. 30°-40° W. and N. 5°-15° E., are believed to reflect the regional fracture system; they do not occupy fractures that are inherent to the plug.

The discontinuous rim of argillite breccia that partly surrounds the plug may have resulted from a prerhyolite explosion that formed a vent that is now filled by rhyolitic rocks. The absence of volcanic ejecta around the plug suggests that such volcanic action was not intense.

Somewhat similar breccias of rhyolite porphyry in a matrix of either rhyolite porphyry or pulverized material have been described by Williams (1929) at Marysville Butte, Calif. Williams believes that the brecciated porphyry, lubricated by water vapor, was forced into the sediments under high pressure. Michel-Levy (1890) considered the pépérites massives of the Auvergne and the Limagne to be due to the expulsion of gases and water vapor from the margins of the dikes into weak sediments. Williams (1929) noted that brecciation at Marysville Buttes resulted only where the rhyolite porphyries were intruded under weak sedimentary rock rather than under the massive rocks such as the andesite of the laccolith.

Lovering (1949, pp. 11-13) has described pebble dikes from the East Tintic district, Utah, which have no visible connection with igneous rocks. He ascribed most of these dikes to intrusions of fragmental material in a nearly dry state, although he recognized that some formed by drag along the margins of viscous magma and others by explosion beneath a thin cover.

Explosive action associated with igneous stocks has been described by Emmons (1938), Daly (1938), Chace (1948), Lindgren (1906), Walker (1928), and Turneaure (1935). Many examples of the association of ore deposits with explosion breccia pipes and dikes are known. Among these are the Cresson blowout, Cripple Creek, Colo. (Loughlin and Koschmann, 1935, and Koschmann, 1947); Ollie Reed, Josie, St. Louis, and Eureka pipes, Leadville, Colo. (Emmons, 1927); Red Mountain district, Colo. (Burbank, 1941); Yellow Pine, Logan, and Lou Dillon mines, Boulder County, Colo. (Lovering, 1941); and the Bull Domingo mine, Custer County, Colo. (Emmons, 1896). Those in other countries include Cananea, Sonora, Mexico, (Perry, 1933); Braden, Chile (Lindgren and Bastin, 1935); Llallagua, Bolivia (Turneaure, 1935); and Oruro, Bolivia (Chace, 1948).

Fault breccias

Breccias that range in thickness from 1/4 inch to 6 feet, and that contain fragments of all the rocks cut by the faults, occur along many of the faults at Majuba Hill. Individual breccia fragments range in diameter from 1/16 to 8 inches, and most of the fragments are sharply angular. Sericite and kaolinite are commonly abundant in the gouge associated with the breccia; quartz and tourmaline have been introduced locally.

STRUCTURE

The dominant structural feature at Majuba Hill is the rhyolitic plug (fig. 2) of Tertiary (?) age that intrudes argillites of Triassic (?) age. The plug is roughly 5,000 feet in diameter and is composed principally of rhyolite porphyry, the oldest of the rhyolites. Dikes and irregular masses of younger intrusion breccias and quartz porphyry cut the rhyolite porphyry. The quartz porphyry dikes cut across the plug and extend to the northeast and southwest beyond the margin of the plug. Younger porphyritic rhyolite occurs as an irregular body along the southeast margin of the plug.

The Triassic (?) sedimentary rocks strike N. 45°-90° E. and dip 60°-90° N., although locally they are highly crumpled and overturned near igneous-rock contacts. The shales are intruded by all the igneous rocks and contain some concordant quartz veins.

Faults

The two main fault systems--the Majuba shear zone and the No. 211 fault (fig. 4)--are exposed in the Majuba Hill mine. The Majuba shear zone, approximately 100 feet wide, is a series of faults that strike N. 30° W. and dip 54°-85° SW., and includes the large structure called the Majuba fault by Smith and Gianella (1942). The No. 211 fault strikes N. 5° E., dips 45° SE; it has about 1 foot of gouge between the walls. These faults do not extend into the sedimentary rocks that surround the plug.

Several diversely oriented smaller faults, with small displacements, are widely distributed within the plug. A few of these faults can be traced beyond the periphery of the plug, but they do not extend for more than 100 feet into the surrounding shales.

Majuba shear zone

The Majuba shear zone is a series of faults that are exposed in the Lower adit level of the Majuba Hill mine (fig. 5); in the Nos. 201-N, 201-S, and 202 drifts, in the Middle adit level in the Nos. 213, 214, 215, 216, 217, and 218 crosscuts (figs. 4-8); and in the Upper adit level (fig. 4). Many cross faults are present between individual faults in the zone, indicating that differential block adjustments occurred along the entire zone.

The fault beneath the Tin stope and the fault beneath the Copper stope on the Middle adit level have been mapped by Smith and Gianella (1942) and by Gilluly and Page (unpublished report) as one structure, the Majuba fault. The present writers have designated the fault beneath the Tin stope as the Tin stope fault and have retained the name Majuba fault for that part of the fault beneath the Copper stope.

According to Smith and Gianella (1942, p. 48), the displacement along the Majuba fault is between 30 and 150 feet. They say:

> "In the drift that extends northwestward along the fault from the end of the west crosscut on the lowest level ..... flutings show that the hanging wall moved obliquely downward and southward at an angle diverging 35° from a line pointing straight down the dip. The amount of displacement in this direction is certainly over 30 feet but probably less than 150 feet, as indicated by the contact between slate and rhyolite porphyry that is exposed in the footwall on the east side of the drift."

The writers noted that flutings on the fault at the Middle adit level rake down the dip. This apparent difference in the direction of flutings may be due to a difference in strike of the Majuba fault between the points where the flutings were noted. The displacement could not exceed 350 feet if the movement was down dip.

A fault, called the Myler fault, approximately parallel to the Majuba fault, was observed in the footwall of the Majuba fault in the Middle adit level (figs. 4 and 6). This fault has approximately 4 feet of gouge and breccia. Where exposed, the hanging wall is intrusion breccia and the footwall is nonbrecciated quartz porphyry. As the Myler fault does not occur in the No. 211 crosscut, the fault is inferred to end against the No. 211 fault about 30 feet above the No. 211 crosscut (fig. 6, sec. c-c').

The Majuba shear zone is believed to have been formed before the introduction of copper, tin, and uranium minerals, because primary sulfides have been found in the gouge along the fault. Unbroken crystals of tourmaline appear to substantiate this premineralization movement along the fault.

No. 211 fault

The No. 211 fault strikes nearly north and dips 40°-45° E. It is exposed in the Middle adit level about 390 feet from the portal, about 20 feet east of the adit in the No. 211 crosscut, and at the head of "G" raise about 53 feet above the adit. The fault on the floor of the Copper stope on the footwall side of the Majuba fault appears to be the westward and upward extension of the No. 211 fault.

URANIUM DEPOSITS

The highest-grade uranium deposit in the Majuba Hill mine is in a copper- and tin-bearing vein exposed in the Copper stope. Lower-grade uranium deposits are in the rhyolite and quartz porphyry adjacent to the uraniferous vein, in fault gouge, in tourmalinized intrusion breccia, and in rhyolite and quartz porphyry adjacent to uraniferous breccia.

Mineralogy

Zeunerite, torbernite, and metatorbernite are the most abundant uranium-bearing minerals; autunite and gummite have been reported. Pitchblende and uraninite have not been found. The secondary uranium-bearing minerals occur with sooty chalcocite, pyrite, and arsenopyrite in the uraniferous vein in the Copper stope; with chalcocite, malachite, and pyrite in the rhyolite and quartz porphyry adjacent to the uraniferous vein; with cassiterite and secondary copper minerals in the intrusion breccia; and with iron oxides in the fault gouge.

The only hypogene minerals observed were chalcopyrite, arsenopyrite, and pyrite. The primary deposits of copper have been leached near the surface and enriched by supergene processes beneath the leached zone, which extends less than 60 feet below the surface.

Secondary copper minerals--chalcocite, cuprite, bornite, brochantite, azurite, and malachite--are very common and are widely distributed in the mine. No secondary tin minerals have been noted. Table 1 is a compilation of the minerals identified by various investigators. The formulae given are from Dana's system of Mineralogy (1946 and 1951) and from Dana's textbook of Mineralogy (1948).

Most of the copper arsenates are found in the Copper stope where they occur with the other secondary copper minerals. Yellowish green prismatic crystals of olivenite occur with black tourmaline in many of the intrusion breccias, commonly associated with cassiterite. Some olivenite, with tourmaline, forms a filling of feldspar phenocrysts in altered quartz porphyry.

The secondary minerals of silver, cerargyrite and (?) embolite, are very sparse and were not found by the writers. One mass of native silver from the Middle adit dump was seen.

Pale lavender fluorite is a common filling with quartz in veins cutting quartz and rhyolite porphyry, especially in the Lower adit. The fluorite is in cleavable masses less than half an inch across.

Euhedral crystals of brown cassiterite, less than 1/10-inch across, are concentrated in tourmalinized intrusion breccia in which many of the crystals rest on tourmaline prisms between poorly cemented breccia fragments. Some pores left in rhyolite and quartz porphyry fragments by the leaching away of the feldspar phenocrysts are partly filled by cassiterite and tourmaline.

Iron oxides, hematite and limonite, are common in the ore bodies and in much of the gouge along faults. The outcrops contain large amounts of iron oxides.

Needle-like crystals of epidote and zoisite are found in metamorphosed limestone beds near rhyolitic rocks, and are believed to have been derived by the alteration of the impure limestone. Fine-grained muscovite and sericite replace much of the groundmass and many of the feldspar phenocrysts in altered rhyolite and quartz porphyry. In addition to phenocrysts in the porphyries, quartz fills veins cutting rhyolite porphyry and quartz porphyry. Quartz crystals as much as an inch long were found in veins in the Lower adit, and some phantom growths were noted in the quartz crystals.

Table 1.--Minerals at Majuba Hill mine

	Arsenates
Chalcophyllite	$(Cu_{18}Al_2 (AsO_4)_3 (SO_4)_3(OH)_{27}. 33\ H_2O)$
Clinoclase	$(Cu_3 (AsO_4) (OH)_3)$
Cornwallite	$(Cu_5 (AsO_4)_2 (OH)_4. H_2O)$
(?) Euchroite	$(Cu_2 (AsO_4) (OH). 3\ H_2O)$
Conichalcite	$(Ca\ Cu (AsO_4) (OH))$
Leucochalcite	$(Cu_2(AsO_4) (OH). H_2O(?))$
Olivenite	$(Cu_2 (AsO_4) (OH))$
Pharmacosiderite	$(Fe_3 (AsO_4)_2 (OH)_3. 5\ H_2O)$
Pitticite	$(Fe_2 (AsO_4) (SO_4) (OH). nH_2O)$
Scorodite	$(Fe, Al) (AsO_4). 2\ H_2O)$
Tyrolite	$(Cu_5\ Ca (AsO_4)_2 (CO_3) (OH)_4. 6\ H_2O (?))$
Zeunerite	$(Cu (UO_2)_2 (AsO_4)_2. 10\text{-}16\ H_2O)$
	Carbonates
Azurite	$(Cu_3(OH)_2 (CO_3)_2)$
Malachite	$(Cu_2 (OH)_2 (CO_3))$
	Chlorides
Cerargyrite	$(AgCl)$
(?) Embolite	$(Ag (Br, Cl))$
	Fluoride
Fluorite	(CaF_2)
	Native metals
Copper	(Cu)
Silver	(Ag)

Table 1.--Minerals at Majuba Hill mine--Continued

	Oxides
Cassiterite	(SnO_2)
Cuprite	(Cu_2O)
(?)Gummite	($UO_3 . nH_2O$)
Hematite	(Fe_2O_3)
Limonite	($FeO (OH) . nH_2O$ or $HFeO_2 . nH_2O$)
Tenorite	(CuO)
	Phosphates
(?) Autunite	($Ca (UO_2)_2 (PO_4)_2 . 10\text{-}12\ H_2O$)
Pseudomalachite	($Cu_5 (PO_4)_2 (OH)_4 . H_2O$)
Metatorbernite	($Cu (UO_2)_2 (PO_4)_2 . 8\ H_2O$)
Torbernite	$Cu (UO_2)_2 (PO_4)_2 . 8\text{-}12\ H_2O$
	Silicates
Chlorite	(Hydrous iron-magnesium silicate)
Chrysocolla	($CuSiO_3 .\ 2\ H_2O$)
Epidote	($H_2O . 4CaO . 3(Al, Fe)_2O_3 . 6SiO_2$)
Muscovite	($2H_2O . K_2O . 3Al_2O_3 . 6SiO_2$)
Oligoclase	($nNa\ AlSi_3O_8 . m\ CaAl_2\ Si_2O_8$)
Quartz	(SiO_2)
Sanidine	($KAl\ Si_3O_8$)
Sericite	($2H_2O . K_2O . 3Al_2O_3 . 6SiO_2$)
Tourmaline	($H_9Al_3 (B . OH)_2 Si_4O_{19}$)
Zoisite	($4CaO . 3Al_2O_3 . 6SiO_2 . H_2O$)

Table 1.--Minerals at Majuba Hill mine--Continued

	Sulfates
Brochantite	$(Cu_4(SO_4)(OH)_6)$
Chalcanthite	$(CuSO_4.5H_2O)$
Cyanotrichite	$(Cu_4Al_2(SO_4)(OH)_{12}.2H_2O)$
Kalinite	$(KAl(SO_4)_2.11H_2O(?)$
Spangolite	$(Cu_6Al(SO_4)(OH)_{12}Cl.3H_2O)$
	Sulfides
Arsenopyrite	(FeAsS)
Bornite	(Cu_5FeS_4)
Chalcocite	(Cu_2S)
Chalcopyrite	$(Cu_2Fe_2S_4)$
Covellite	(CuS)
Pyrite	(FeS_2)
(?) Tetrahedrite	$((Cu, Fe)_{12}Sb_4S_{13})$

Tourmaline is abundant and widespread at Majuba Hill, both in intrusion breccia and in rhyolite and quartz porphyry near intrusion breccia. The tourmaline occurs in dark-green to black slender needles, less than 1/4 inch long.

Most of the primary metallic minerals at Majuba Hill are believed to be essentially contemporaneous. As cassiterite and tourmaline crystals line cavities in breccias that contain chalcopyrite and arsenopyrite, the cassiterite is believed to be slightly younger than chalcopyrite and arsenopyrite.

Hydrothermal alteration

Hydrothermal alteration at Majuba Hill seems to be unrelated to major fractures, veins, breccias, dikes, and rock contacts; however, it is confined to the rocks in the plug and to the argillites and metamorphic rocks immediately surrounding the plug.

Sericite is the most abundant alteration mineral. It comprises 30 to 60 percent of the matrices of many of the altered rhyolites, and is common in intrusion breccia and in the metamorphosed shale adjacent to rhyolitic rocks. Sericitization is believed to have been the first and most widespread of the alteration processes, for sericite is cut by veinlets of quartz and tourmaline.

Secondary quartz has been deposited in most of the rocks; many of the altered rhyolites have a groundmass of introduced granular quartz that ranges from 0.05 to 1.5 mm in diameter.

Tourmaline is abundant in the quartz porphyry and in the intrusion breccias, less abundant in the rhyolite porphyry, and apparently absent in the porphyritic rhyolite. Irregular grains, needles, and rosettes of tourmaline as much as 2 mm in diameter incompletely fill the voids left in the rhyolites by leaching of the feldspar phenocrysts. A mixture of quartz and tourmaline completely fills some of these voids. The tourmaline in the volcanic breccias has a coarse texture and forms grains and rosettes as much as 5 mm in diameter.

URANIUM RESOURCES

The principal known uranium resources at Majuba Hill are exposed in the south part of the Copper stope (figs. 4 and 9) where they are contained in a 3-foot vein and in the quartz porphyry adjacent to the vein. The vein is estimated to have an average grade of 0.30 percent U_3O_8; the wallrock, for a width of 15 feet, is estimated to have an average grade of 0.1 percent U_3O_8. The vein contains, in addition to the uranium, 0.47 percent tin and 12.7 percent copper.

A 3-inch fault-gouge zone exposed in the No. 216 crosscut (figs. 4 and 9) contains an average of 0.016 percent U_3O_8 and traces of tin and copper.

The No. 215 crosscut contains radon during periods of low barometric pressure. This gas, which probably enters the crosscut through the fault near the face (fig. 9), is believed to indicate the presence of an appreciable quantity of uranium in the vicinity of the No. 215 crosscut. Radon is found also near the end of the Lower adit.

Tin- and copper-bearing breccias in the mine contain from 0.002 to 0.008 percent U_3O_8 (fig. 9).

TIN AND COPPER RESOURCES

Tin-bearing rock that contains on the average 0.01 to 0.10 percent tin is abundant in the Majuba Hill mine. Higher-grade rock, having an average content of 0.10 to 0.60 percent tin, is exposed in the Tin, No. 211, and Copper stopes on the Middle adit level.

The highest-grade copper deposits are exposed in the Copper, Myler, No. 153, and No. 211 stopes; these deposits contain from 0.30 to 12.7 percent copper.

All samples collected at the Majuba Hill mine contained some gold and silver. The gold content was invariably low, ranging from a trace to 0.05 oz. per ton; the silver ranged from 0.10 to 11.08 oz. per ton in individual samples, the higher-grade silver-bearing rock being the quartz porphyry-rhyolite porphyry-argillite breccia exposed in the No. 211 stope. Spectrographic analyses of samples are shown in table 2.

SUGGESTIONS FOR PROSPECTING

Some areas in the Majuba Hill mine are favorable for a small exploratory program for uranium. This exploration could be done either by diamond drilling or by drifting and crosscutting. The following suggestions for prospecting in the mine are presented:

1. The area south of the No. 202 drift on the Middle adit level (fig. 3) appears favorable for finding the downward continuation of the uraniferous vein exposed in the Copper stope. This vein is believed to contain reserves of tin and copper in addition to the uranium.

2. The ground northeast of the face of the No. 215 crosscut may contain a uranium deposit responsible for the radon in the crosscut. Additional reserves of tin may also be discovered by exploring this area, especially along the fault.

3. The area west and northwest of the No. 216 crosscut may contain a uraniferous deposit, as suggested by the uranium minerals in the 3-inch fault gouge in this crosscut. The fault could be exposed to the northwest of the crosscut.

4. The area near the end of the Lower adit might be explored for the source of the radon.

Table 2.--Semiquantitative spectrographic analyses of samples, Majuba Hill mine, Pershing County, Nevada 1/

Field number	Location	Material	Type of sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ag	B_2O_3	Bi_2O_3	Co_3O_4	Cr_2O_3	Cu	MnO	MoO	PbO	SnO_2	TiO_2	V_2O_5	ZnO	ZrO_2
RHT-5	Chute from No. 211 stope	Tin-bearing rhyolite porphyry-quartz porphyry-argillite intrusion breccia	Grab	10	10	10	0.1	1.0	0.1	1.0	0.01	---	-----	1.0	0.1	0.001	---	0.1	0.1	0.01	-----	0.1
-6	do.	do.	do.	10	10	10	0.1	1.0	0.1	1.0	0.01	---	-----	1.0	0.1	0.001	---	1.0	0.1	0.01	-----	0.1
-7	No. 211 raise	do.	do.	10	10	10	0.1	0.1	0.1	1.0	0.01	---	-----	1.0	0.1	0.001	---	1.0	0.1	0.01	0.001	0.1
-8	Southwest wall of No. 202 drift	Uranium-bearing argillite	6-foot channel	10	10	1.0	0.1	1.0	0.01	1.0	0.001	---	0.001	0.1	0.1	-----	---	0.01	1.0	0.1	0.001	0.1
-9	do.	Copper- and uranium-bearing quartz porphyry	12-foot channel	10	10	1.0	0.1	1.0	0.01	1.0	0.001	---	-----	0.1	0.1	0.001	---	0.1	1.0	0.01	-----	0.1
-10	Southeast wall of No. 202 drift	do.	14-foot channel	10	10	10	0.1	1.0	0.01	1.0	0.01	---	-----	1.0	0.1	0.001	---	0.05	1.0	0.01	0.001	0.1
-11	Southwest wall of No. 202 drift	do.	8-foot channel	10	10	10	0.1	1.0	0.01	1.0	0.01	---	-----	1.0	0.1	0.001	---	0.01	1.0	0.001	0.001	0.01
-12	South wall of No. 216 crosscut	do.	6-foot channel	10	10	10	0.1	1.0	0.001	1.0	----	---	0.001	0.1	0.1	0.001	---	0.01	1.0	0.01	-----	0.1
-13	Northwest wall of Myler stope	Copper-bearing rhyolite porphyry-quartz porphyry-argillite intrusion breccia	Bulk	10	10	10	1.0	1.0	0.01	0.1	----	0.01	0.01	1.0	0.01	0.01	0.01	0.01	0.1	0.001	-----	0.01
-14	Southeast wall of No. 211 stope	Tin-bearing rhyolite porphyry-quartz porphyry-argillite intrusion breccia	8-foot channel	10	10	10	---	1.0	0.1	0.1	0.001	---	-----	1.0	0.01	0.001	---	0.01	0.1	0.001	-----	0.01

1/The table gives visual estimates and indicates no more than the relative order of magnitude. (10) 10 percent or more; (1.0) 1 to 10 percent; (0.1) 0.1 to 1 percent; (0.01) 0.01 to 0.1 percent; and (0.001) 0.001 to 0.01 percent. A dash indicates that the element was not detected. No thorium was observed in any of the samples. Analyses by Trace Elements Section Washington Laboratory, May 1949.

Table 2.--Semiquantitative spectrographic analyses of samples, Majuba Hill mine, Pershing County, Nevada 1/--Continued

Field number	Location	Material	Type of sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ag	B_2O_3	Bi_2O_3	Co_3O_4	Cr_2O_3	Cu	MnO	MoO	PbO	SnO_2	TiO_2	V_2O_5	ZnO	ZrO_2
RHT-15	Southwest wall of No. 211 stope	Copper-bearing quartz porphyry	15-foot channel	10	10	10	---	1.0	0.001	0.1	---	0.01	0.001	1.0	0.01	0.001	---	0.01	0.1	0.001	---	0.01
-16	South wall of Myler raise	Copper-bearing rhyolite porphyry-quartz porphyry-argillite intrusion breccia	5-foot channel	10	10	10	0.1	1.0	0.01	0.1	---	0.01	-----	1.0	0.01	0.001	---	0.01	0.1	0.001	---	0.01
-17	do.	do.	6-foot channel	10	10	10	0.1	1.0	0.001	0.1	---	----	-----	1.0	0.01	0.001	---	0.001	0.01	-----	---	0.01
-18	South wall of Copper stope	Copper-bearing quartz porphyry	3-foot channel	10	10	10	0.1	1.0	0.001	0.01	---	----	-----	1.0	0.01	-----	---	0.001	0.01	0.001	---	0.001
-19	South wall of Copper stope	Copper-bearing quartz porphyry	10-foot channel	10	10	10	0.1	1.0	0.001	0.01	---	----	-----	1.0	0.01	0.001	---	0.001	0.01	-----	---	0.001
-20	do.	do.	12-foot channel	10	10	10	---	1.0	0.001	0.01	---	----	-----	1.0	0.01	0.001	---	0.001	0.01	-----	---	0.001
-21	do.	Copper- and uranium-bearing vein	3-foot channel	10	10	10	---	1.0	0.001	0.01	---	----	-----	1.0	0.01	0.001	---	0.001	0.01	0.001	---	0.001
-22	Northwest wall of Copper stope	Copper-bearing rhyolite porphyry-quartz porphyry-argillite intrusion breccia	10-foot channel	10	10	10	---	1.0	0.001	0.01	---	----	-----	1.0	0.01	0.001	---	0.001	0.01	0.001	---	0.001
-23	South wall of No. 218 crosscut	Quartz porphyry	9-foot channel	10	10	10	0.1	0.1	-----	0.1	---	----	-----	0.1	0.01	0.001	---	0.001	0.01	0.001	---	0.001
-24	Tin stope	Tin-bearing rhyolite porphyry-quartz porphyry-argillite intrusion breccia	Bulk	10	10	10	---	0.1	0.01	1.0	0.001	----	-----	1.0	0.01	-----	---	0.1	0.1	0.001	---	0.001
-25	East wall of No. 153 stope	Copper-bearing rhyolite porphyry-quartz porphyry-argillite intrusion breccia	Bulk	10	10	10	1.0	1.0	0.01	0.1	---	0.001	-----	1.0	0.01	0.01	---	0.01	0.1	0.001	---	0.01
-26	do.	do.	Bulk	10	10	10	0.1	1.0	0.01	0.1	---	0.001	-----	1.0	0.001	0.001	---	0.001	0.1	0.001	---	0.001
-27	Chute from K-raise	Copper-bearing quartz porphyry	Grab	10	10	10	---	1.0	0.001	0.01	---	0.001	-----	1.0	0.01	-----	---	0.001	0.01	0.001	---	0.001

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