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COPPER-ZINC DEPOSITS OF THE PENN MINE

CALAVERAS COUNTY, CALIFORNIA

By G. R. Heyl, M. W. Cox, and J. H. Eric

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ABSTRACT

The Penn mine deposits in Calaveras County, Calif., are in slightly metamorphosed Jurassic volcanic rocks and intrusive quartz porphyry. Bedding, schistosity, and cleavage strike northwest and dip steeply northeastward. Two main types of faults are present: high-angle schistosity faults, and younger low-angle reverse faults. There are six main alteration zones, in which rocks have been sericitized, silicified, and pyritized.

The ore bodies are sulphide replacement deposits either at contacts of alteration zones, or along faults within these zones. The ore bodies are steeply pitching lenses. Their pitch length ranges from 150 to 1,000 feet; breadth, from 100 to 400 feet; width, from 4 to 30 feet. The ore is a mixture of pyrite, sphalerite, chalcopyrite, and a little bornite and tetrahedrite. Gangue minerals are barite, calcite, and quartz.

Reserves are estimated to be 245,100 tons of mining-grade ore, and from 913,000 to 973,000 tons of low-grade ore. Two types of areas favorable for exploration are listed: (1) extensions of known ore bodies, and (2) locations considered geologically favorable for the existence of ore bodies. If warranted by the demand for copper and zinc, exploration of these areas is recommended.

INTRODUCTION

Location

The Penn mine is in northwestern Calaveras County, Calif. (pl. 1); however, the area studied (pls. 2 and 4) extends across the Mokelumne River into Amador County, and lies in secs. 3 and 4, T. 4 N., R. 10 E., and sec. 33, T. 5 N., R. 10 E., Mount Diablo base and meridian.

The area is traversed by gravel roads connecting with a surfaced road at Campo Seco, a mile to the east. Valley Springs, about 3½ miles southeast of the mine, is the closest rail shipping point.

Topography and drainage

The area is in the low foothills of the Sierra Nevada, close to the eastern edge of the San Joaquin Valley, at an altitude of 200 to 450 feet. Maximum local relief within the area is about 270 feet. The higher hills are capped by flat-lying Tertiary gravel, but the hill slopes below the gravel are commonly steep and locally precipitous.

The Mokelumne River, a trunk stream of the western slope of the Sierra Nevada, flows through the area from northeast to southwest and insures an ample supply of water. On the east the river flows through a canyon, but to the west it is in a graded valley with a narrow flood plain. The chief tributaries are Oregon Gulch, Mine Run, and Hinckley Run, intermittent streams in steep-sided valleys. In many places the upper reaches of these tributaries and the higher hill slopes are covered with gravel washed from the Tertiary beds by hydraulic mining.

Ownership and development

The Penn mine is owned by the Penn Mining Co. and consists of four patented claims, the Satellite, Little Satellite, Campo Seco, and Hecla, and, adjoining these claims to the east and west, mill sites, a smelter site, and other lands held in fee simple (pl. 2).

Southeast of the Penn mine lies the Constellation or Borger group of three patented claims owned by the Constellation Mining Co. The Jean group of claims, which covers part of the area east of the Penn mine, is held by location by L. W. Thayer of San Francisco, who also owns the mineral rights to the land north of and flanking the Hecla claim. North of the Jean claims and east of the Penn mine is an area owned by the heirs and assigns of James Gallager. The wedge-shaped plot shown on plate 2 east of the Thayer property and north of the Penn Mining Co. land is owned by the Pacific Gas & Electric Co. The Amador County portion of the area is held in fee simple by L. W. Thayer, by the Penn Mining Co., and by H. G. Kreth.

The Penn mine workings extend along a distance of three-quarters of a mile and to a depth of 3,300 feet, but in 1944 only a small part of these workings was accessible. The workings total about 55,000 feet, of which 42,000 feet is drifts and crosscuts, and 13,000 feet is shafts and raises, as shown in plan on plate 3. The accessible parts are shown on plates 8, 9, 15, and 16.

For convenience the portions of the mine near the two accessible shafts are designated No. 2 shaft area and No. 3 shaft area respectively.

The Constellation group of claims is explored by the 400-foot vertical Borger shaft with lateral workings at four levels, and by a 45-foot shaft. These workings are inaccessible.

The other properties are explored only by shallow shafts and short adits, apparently excavated for prospecting or assessment work.

History and production

In 1861 three copper deposits were discovered near Campo Seco, and named the Campo Seco, Lancha Plana, and Copper Hill claims.1/ The Lancha Plana is the present

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1/ Browne, J. R., Mineral resources of the States and Territories west of the Rocky Mountains (for 1866): U. S. Treasury Dept., pp. 146-147, 1867.

Satellite claim and comprises the No. 2 shaft workings; the Campo Seco is still known by that name and comprises the No. 3 shaft workings; the location of the Copper Hill is unknown, but it may be the present Hecla claim, on which the No. 5 shaft is located. The period 1861-68 was one of great activity, which was ended by a fall in the price of copper. During this interval the three claims were operated as separate properties, and no ore was shipped that ran less than 15 percent copper. Their production to the end of 1865 is as follows:2/

2/ Browne, J. R., op. cit.

Campo Seco..........	1,300	tons of ore
Lancha Plana........	250	" " "
Copper Hill.........	1,500	" " "
	3,050	" " "

In 1865 a Welsh-type furnace was erected at a cost of $30,000. It had a smelting capacity of 8 tons and produced a 35-percent copper matte. The ore smelted ranged from 6 to 10 percent copper, and contained an average of 40 percent iron and 45 percent sulphur.3/

3/ Browne, J. R., Report on the mineral resources of the States and Territories west of the Rocky Mountains (for 1867): U. S. Treasury Dept., 1868.

In 1883 the Satellite mine was reopened by H. D. Ranlett,4/ and a tunnel was

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4/ Aubury, L. E., The copper resources of California: California Min. Bur. Bull., vol. 50, p. 239, 1908.

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driven to shaft No. 1 (pls. 4 and 5). About three years later the property was sold to the San Francisco Copper Co., and for a time was operated by the Peyton Chemical Co. of Spenceville, Calif.

About 1887 the Penn Chemical Co., predecessor of the Penn Mining Co., was organized and acquired the Satellite, Campo Seco, and Hecla claims and adjoining property, which were merged into an operating unit known as the Penn mine. From September 1899 to April 1919 a smelter producing blister copper was operated continuously; it was closed in 1919 because of the unfavorable copper market that followed World War I.5/ During this period no attempt was made to recover zinc.

5/ Julihn, C. E., and Horton, F. W., Mines of the southern Mother Lode region, Pt. 1, Calaveras County: U. S. Bur. Mines Bull., 413, p. 112, 1938.

From the smelter operation, gross returns, including gold and silver, were $7,362,562, and dividends amounted to $3,007,888.6/

6/ Argall, G. O., Personal communication.

The Penn Mining Co. continued underground development until March 1921, and the mine was kept pumped until June 1926. Early in 1926, J. Kruttschnitt, Jr., sampled the mine for the American Smelting & Refining Co.

In 1928 the Mateo Mining Co. leased the mine and unwatered shaft No. 2 to the 700 level; only a small amount of ore was mined before operations ceased. A similarly short-lived project was undertaken in 1937 by the Penn Copper & Zinc Mining Co.

In 1943 the Eagle Shawmut Mining Co. leased the property above the 1,400 level and in July began unwatering it. By December 1943, the company was stoping ore from the 500 level, No. 2 shaft area, and since then regular ore shipments have been made. This operation was restricted to rehabilitation of some of the workings down to the 1,100 level, No. 2 shaft area and to the 1,000 level, No. 3 shaft area, and to extracting blocks of ore left by earlier operators. In February 1945 stoping was limited to the 700, 1,000, and 1,100 levels, No. 2 shaft area.

Ore from the Penn mine is hauled by truck about 70 miles to the flotation mill of Eagle Shawmut Mine near Chinese Camp, Calif. The two mill products, a copper-lead concentrate and a zinc concentrate, are shipped by rail from Chinese Camp to the International Smelting & Refining Co's smelter at Tooele, Utah.

A summary of the production of the Penn mine is given in table 1. The production of the Borger mine and other properties in the vicinity of the Penn mine is unknown.

The Constellation group of claims is said by local people to have been located by C. H. Borger about 1890; by 1908 the existing shafts had been sunk,7/ and since

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7/ Aubury, L. E., op. cit., p. 242.

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that time the workings have been flooded. In 1943 the United States Bureau of Mines put down a 665-foot drill hole on this property (pl. 4).

Field work and acknowledgments

The copper and zinc deposits of the foothill belt have been studied by the Geological Survey since 1942 as part of a wartime program of mineral resource investigations. Field work has been directed by G. R. Heyl, assisted at various times by G. L. Quick, J. B. Hadley, M. W. Cox, M. H. Staatz, D. G. Wyant, and J. H. Eric.

Areal mapping at the Penn mine was begun in November 1942 by Heyl, aided at first by Quick, and later by Hadley. Late in 1943 mapping was resumed and continued intermittently until November 1944 by Heyl, Cox, and Eric. A triangulation system was established by Staatz, Cox, Wyant, and Heyl to tie together the plane-table surveys. Control in the southernmost portion of the area was established by a transit traverse run by Cox and Eric.

Underground workings were mapped by Heyl, Cox, Eric, Staatz, Wyant, and Hadley during the period December 1943 to February 1945, as rapidly as rehabilitation of the mine permitted. Data for inaccessible workings have been obtained from a map of the Penn Mining Co., from the report made by J. Kruttschnitt, Jr., in 1926, and from published sources.

The report is necessarily based on field observations as only a few thin sections and no polished sections have been studied.

The authors acknowledge the many courtesies and valued aid extended to them by the Penn Mining Co., by the Eagle Shawmut Mine, and by Mr. L. W. Thayer.

GENERAL GEOLOGY

The Penn mine is within a mile of the western edge of the Sierra Nevada foothills, where Paleozoic and Jurassic metamorphic rocks of the range are overlapped by early Tertiary sediments. The metamorphic rocks consist of a thick sequence of metavolcanic and metasedimentary rocks and are invaded by various igneous rocks. The area in the vicinity of the mine is underlain by the Mariposa slate and the dominantly volcanic Amador group of Taliaferro, both of Jurassic age.

Bedding and primary layering dip steeply northeast and strike northwest. In general, schistosity and cleavage are parallel to bedding. The geologic map of the Jackson quadrangle 8/ suggests that the area studied probably lies on the west limb of an overturned southward-plunging anticline. However, this anticline is probably

8/ Turner, H. W., U. S. Geol. Survey, Geol. Atlas, Jackson folio (No. 11), 1894.

complicated by faults, by intrusions, and possibly by subsidiary folds.

At the Penn mine area on many of the higher hills Tertiary auriferous gravel rests on an unconformity that dips gently westward; below the unconformity the pre-Tertiary rocks are thoroughly decomposed by weathering to a depth of 20 to 25 feet.

In addition to recent river alluvium, there is another gravel, generally auriferous, interbedded with volcanic ash, which lies on benches developed in relatively unweathered rock. This gravel usually is less than 100 feet above the present river level, and was considered by Turner 9/ to be of early Pleistocene age.

9/ Turner, H. W., op. cit.

STRATIGRAPHY

Mesozoic sedimentary and volcanic rocks

In the Penn mine area the stratigraphic section consists of at least 500 feet of slate, which crops out along the western side, and approximately 2,700 feet of metavolcanic rocks, which underlie the remainder of the area. The lithologic character of the slate is such that it is considered to be Mariposa, which is in accordance with the earlier correlation by Turner.10/ The volcanic sequence, which

10/ Turner, H. W., op. cit.

Turner included in his "amphibolite schist" unit, is tentatively correlated by the writers with the lithologically similar Amador group of Taliaferro,11/ of upper and

11/ Taliaferro, N. L., Geologic history and correlation of the Jurassic of southwestern Oregon and California: Geol. Soc. America Bull., vol. 53, pp. 89-90, 1942.

possibly middle Jurassic age. The distribution of formations within the area is shown on plates 4 and 5.12/ The contact between the Amador and the Mariposa is

12/ Plate 4 is an interpretation of the hypothesis of a normal stratigraphic sequence with simple homoclinal structure, whereas plate 5 is an interpretation of the alternative hypothesis that certain formations are repeated by isoclinal folding.

conformable, and coarse-grained pyroclastics grade upward through 10 to 15 feet of fine-grained well-cleaved greenish-brown tuff into typical slate. Graded bedding, observed at two places, indicates top to the west; the sedimentary rocks, therefore, are probably overturned.

Although the portion of the Amador group exposed in the area has a fairly constant stratigraphic thickness, within the group several units show marked changes in thickness, and in some places pinch out. These variations are shown in columnar section (pl. 6). The most striking change is the gradual increase in width of felsic rocks outcropping along the strike from north to south.

Mariposa slate

The Mariposa slate (Jm, pl. 4) consists predominantly of dark blue-gray slate, in some places laminated or thin-bedded, and weathers to pale olive brown. Within the formation are several fine-grained arenaceous zones. A 25-foot zone of buff arkosic sandstone, showing graded bedding, is exposed on the right bank of the Mokelumne River near the west edge of the area. The slate, but not the sandy beds, generally has a well developed cleavage, locally folded or crenulated.

No attempt has been made to determine the thickness of the Mariposa slate, but at least 500 feet is present and the total thickness may be several times greater.

Amador group

Meta-andesite and metadacite pyroclastics.—The uppermost unit of the volcanic rocks correlated with Taliaferro's Amador group is a sequence of metamorphosed coarse- and fine-grained andesitic and dacitic pyroclastics (Jap, pl. 4). Much of this rock consists of coarse agglomerate with angular and subangular fragments, as much as 18 inches in diameter, in a green chloritic matrix. Coarse- and fine-grained tuffs are less common. Abundant chlorite gives this rock a light- to dark-green color. Epidote is very common, and quartz fragments and quartz grains within rock fragments are present.

The individual beds range in thickness from less than an inch in the finer-grained tuffs to 4 feet in the coarse agglomerate.

Within this unit near the Mokelumne River is a 20-foot zone of more mafic rock (m, pl. 4) that may represent a basaltic flow. Several thin zones of light-colored tuffs that contain small subhedral quartz crystals are also differentiated on the map (ct, pl. 4).

Metarhyolite tuff.—Underlying the meta-andesite and metadacite pyroclastics is a thin but persistent zone of metarhyolite tuff (Jar, pl. 4). This rock is pale green to white and commonly weathers buff. It is generally schistose, and consists of a matrix of altered feldspar, quartz, sericite, and chlorite, with larger fragments of quartz and altered feldspar scattered through it. The thickness is 50 to 65 feet, but about 400 feet northwest of shaft No. 5 it lenses out into the meta-andesite and metadacite pyroclastics.

Metafelsite pyroclastics.—Below the metarhyolite tuff is a sequence of metafelsite pyroclastics (Jaf, pl. 4), in which are several extensive flows of metabasalt (ma, pl. 4), thin beds of coarse agglomerate with prominent white fragments (ag, pl. 4), and small lentils of metarhyolite tuff (rt, pl. 4) similar to the overlying unit. In the southern part of the area the thickness is approximately 1,050 feet; northward it interfingers with the underlying meta-agglomerate and metatuff, so that near the northern end of the area it is 125 feet thick or less.

The bulk of the unit is made up of light green or pale greenish-gray rocks carrying abundant grains of quartz and, locally, feldspar. The finer-grained tuff contains abundant sericite and chlorite, whereas the coarser pyroclastics are characterized by fragments of felsite and quartz porphyry. As in most of the volcanic rocks, weathering accentuates whatever schistosity is present.

The flows are massive or moderately schistose, medium to dark green, and weather dark reddish brown. They consist mainly of chlorite, epidote, and altered feldspar. Amygdules are present as calcite or ankerite, as clear or white quartz, or as clusters of darker green chlorite metacrysts. Pillow structure (pl, pl. 4) is well developed at several places; the pillows are generally 1 to 3 feet in diameter, and commonly have characteristic red chert in the interstices.

Meta-agglomerate and metatuff.—Underlying the metafelsite pyroclastics at the north and interfingering with them toward the south is meta-agglomerate and metatuff (Jav, pl. 4), a sequence of coarse- and fine-grained pyroclastics predominantly of intermediate composition. This unit also includes felsitic tuff and agglomerate, as well as zones of dark green chloritic lava in places containing quartz and calcite amygdules. In the northern part of the area the estimated thickness is 800 feet, but the unit thins southward and lenses out in the southern part of the area.

The greater part of the pyroclastics of this unit is moderately schistose, medium to pale green, and weathers brown. These schists are composed of chlorite, epidote, and altered feldspar. In the agglomerate are fragments ranging in diameter from 4 to 6 inches, and scattered bombs as much as 2 feet in diameter.

The felsitic pyroclastics within this unit are pale gray and weather buff. Minerals present are feldspar, quartz, sericite, and probably chlorite. Tuff predominates, but zones of 1- to 4-inch fragments are not uncommon.

The thicker lava zones within this unit have been differentiated on the areal map (ma, pl. 4). In some places crudely developed pillow structure (pl, pl. 4) is present in these flows.

Metabasalt.—Underlying the predominantly intermediate meta-agglomerate and metatuff is metabasalt (Jab, pl. 4). Toward the north this unit has a thickness of 325 feet or more, and consists of well developed pillow lavas (Jabp, pl. 4). To the south pillow structure is absent, and a large, composite lentil of metafelsitic tuff (Jabf, pl. 4) occurs within the mafic rocks.

The metabasalt is medium- to dark-green chlorite-epidote schist and greenstone that weathers dark reddish brown. Also present are altered feldspar and sericite. Amygdules of white calcite and clear or white quartz are common. Numerous intercalated zones of coarse (4- to 10-inch) fragments are present; this rock is generally mafic, but locally includes fragments of pale-gray quartz porphyry and felsite, Pillow lava has the characteristic red chert masses between pillows, and individual pillows generally are 1 to 3 feet in diameter, though larger ones exist. This unit is particularly well exposed in the canyon of the Mokelumne River.

Metafelsite volcanics.—Underlying the metabasalt is a thick sequence of metafelsite tuff, agglomerate, and lava (Jafv, pl. 4), of which only the upper portion falls within the mapped area. Included in the unit are several lenticular areas of mafic rock, probably flows, which are differentiated on the areal map (m, pl. 4).

These volcanics are typically pale greenish gray or pale bluish gray, and weather to pale brown, buff, or white. Quartz, feldspar, sericite, and probably chlorite are the chief minerals. Bedding or layering is evident, particularly in the coarser rock which generally consists of fragments 1 to 6 inches in diameter. Most of these volcanics are aphanitic, or have small laths of white plagioclase in an aphanitic matrix, and some show a well-developed flow banding.

Tertiary and Quaternary sediments

Because the Tertiary and Quaternary gravels, ash beds, and alluvium have little effect on the bedrock geology, other than to conceal it, they are not described in this report.

INTRUSIVE ROCKS

Quartz porphyry

The most widespread intrusive rock within the mapped area is quartz porphyry (qp, pl. 4). It forms sills and lens-shaped bodies of considerable size, whose contacts in detail cut across contiguous volcanic rocks. It has abundant phenocrysts of clear vitreous quartz that in some places are euhedral and show the bipyramidal form of beta-quartz. Less common are phenocrysts of feldspar. The groundmass is gray-green to pale greenish white, and the rock weathers to brown or buff. Weathering brings out a schistosity which on many freshly exposed outcrops is not evident. The margins of some of the bodies, as well as narrow zones within them, are brecciated (qpb, pl. 4); the largest of these breccia zones is shown on the areal maps (pls. 4 and 5).

The feldspar consists of about equal amounts of orthoclase and sodic andesine, and occurs both as phenocrysts and in the groundmass, as does quartz. Usually the ferromagnesian minerals have been altered to chlorite, though some green biotite is seen under the microscope. Magnetite is a common accessory mineral. Sericite, epidote, chlorite, and leucoxene are common alteration products. The rock is quartz latite-porphyry.

Where this rock has undergone intense hydrothermal alteration its appearance is greatly changed; it is strongly schistose, and the groundmass consists largely of sericite or white cryptocrystalline quartz or both.

Felsite

Scattered throughout the area are small sills and lenticular bodies of pale-gray felsite (f, pl. 4) that weathers buff or white. In places minute phenocrysts of quartz and feldspar can be discerned, and some felsite bodies have cores of quartz porphyry, suggesting a common origin. Although some of these felsite bodies may be flows, or possibly very fine-grained tuffs, probably most of them are intrusions.

Greenstone

Two bodies of greenstone (gn, pl. 4), probably of intrusive origin, are present. The larger lies in the southern portion of the area, and extends beyond the limits of mapping. It is a fairly massive, medium-green rock that weathers pale grayish green. It contains abundant subhedral or rounded small white masses of altered feldspar that may represent phenocrysts, as well as numerous dark-green crystals, probably uralite. The groundmass consists of altered feldspar, chlorite, sericite, and some secondary quartz. In the south fork of Oregon Gulch, beyond the southern boundary of the mapped area, the contact of this greenstone locally cuts across adjacent felsite agglomerate, which suggests that the greenstone is intrusive.

The other body of greenstone lies about 500 feet southwest of shaft No. 3. It is lithologically similar to the southern mass, except that light-colored, altered feldspar is considerably less abundant and the rock weathers to a darker green.

Mafite

Three small bodies of dark fine-grained to aphanitic rock crop out about 500 feet northwest of shaft No. 2 (mf, pl. 4 and Tb, pl. 5). The rock is drab brown or greenish brown, and weathers reddish brown to purple. In those varieties where grains can be discerned, the rock seems to be made up largely of altered feldspar and an interstitial green mineral, and has irregular reddish brown to black spots scattered through it. Cubic pseudomorphs of limonite after pyrite occur sporadically in the rock. It is given the field term mafite. The rock has an unsystematic, closely spaced, smooth fracture, so that it breaks on weathering into small, more or less equidimensional chunks.

Relative age of the intrusions

With the exception of the mafite, which is massive, the intrusive rocks have a schistosity that is generally parallel to the foliation of the surrounding volcanic rocks and slate. Thus these intrusions antedate the regional orogeny, and possibly they are slightly later manifestations of Amador vulcanism. The fine-grained character of the intrusive felsite in particular, corroborates this, for it suggests emplacement at shallow depth, before a thick section had accumulated.

The mafite intrusions are later than the quartz porphyry, because they intrude it. The absence of foliation suggests they may have been emplaced after the major regional stresses had been relieved. Although the mafite intrusions are considerably altered, they are possibly of Tertiary age. A careful regional study, including known Tertiary igneous rocks, might solve this problem.

ROCK ALTERATION AND QUARTZ VEINS

Hydrothermal alteration

Along certain belts and in small lenticular areas the effects of sericitization, silicification, and pyritization have been superimposed on the low-grade metamorphic rocks. The sulphide ore bodies are restricted to these zones of alteration. Near the Penn mine the altered rocks are distributed in six main zones shown on plate 7. These zones are as much as 225 feet wide and 2,850 feet long; their downward extent appears to be at least as great as their length, and is probably greater. They have been called "veins," "dikes," and "lodes."

The West alteration zone is confined almost exclusively to a sill-like body of quartz porphyry; the other zones are developed mainly in fine-grained felsitic rocks. By and large, the alteration is in felsic rocks, as shown on plate 7. The Hecla zone, which appears to be surrounded largely by intermediate or mafic rocks, actually is developed in a narrow belt of felsic rock, as shown on plate 4. At the few places where alteration has extended into mafic rocks, the zones are short and narrow. In the Mariposa slate hydrothermal alteration has not been observed.

The transition from unaltered to altered rock is gradual within felsic rocks, but alteration generally ends abruptly at the contact between felsic and mafic rocks. Also within the alteration zones the transition from sericitized to silicified rock is gradual in many cases.

Sericitized rock includes sericite schist and quartz-sericite schist, and contains as much as 5 percent pyrite. Silicified rock consists dominantly of cryptocrystalline quartz with poorly developed parting, and contains as much as 20 percent pyrite. In some places folia of sericite are crossed by minute veinlets of silica, and appear to be partially replaced by them. In quartz porphyry, sericite folia wrap around vitreous quartz phenocrysts, which persist in all but the most intensely silicified rock. In many places sericitization has been more extensive than silicification. Not uncommonly areas of alteration have cores of silicified rock, with silicification becoming less intense outward, and have margins of sericitized rock. This is well shown by the southern part of the East alteration zone, and by parts of the Borger and West alteration zones.

Northward and southward from shaft No. 2 four narrow areas, within or adjacent to the West alteration zone, are underlain by red hematitic jasper having a poorly developed schistosity. Locally this rock is cut by many veinlets of clear quartz, and near shaft No. 2 it appears to be partially replaced by sericite.

Finely disseminated magnetite is locally abundant along the contact between the West alteration zone and felsitic schists, about 450 feet southwest of shaft No. 3.

Quartz veins

Veins of milky quartz are present throughout the area, and locally occur as swarms. They range from a fraction of an inch to several feet in thickness; the larger ones are shown on plates 4 and 5. Epidote is abundant in these veins, particularly in those that cut epidote-rich rocks. Chlorite and calcite are less common, and in places copper staining or a few grains of pyrite are present.

The relative age of these veins has not been determined with certainty. They apparently were introduced after the regional metamorphism, for in many cases they follow the schistosity. In parts of the West alteration zone they are folded and brecciated, indicating that some deformation occurred after their formation.

STRUCTURE

Schistosity and cleavage

Schistosity or cleavage is present in nearly all types of rock, but varies considerably in intensity. This schistosity is most pronounced in alteration zones, particularly where the rocks have been sericitized; in the more massive greenstone, it is little more than incipient. This is due in part to the large quantity of sericite in altered rock, but it seems not unlikely that the greater fissility of the altered rock predates the entrance of hydrothermal solutions. In general, schistosity strikes parallel to bedding, and dips eastward, parallel to or 5°-15° more gently or steeply than the bedding, possibly indicating the presence of minor folds. Plates 10 and 11 show trends of schistosity in underground workings.

Shear cleavage is developed in altered rock in the West and Hecla alteration zones, and in adjacent metafelsite breccia. This cleavage consists of closely spaced shear planes which are nearly parallel to major low-angle reverse faults. Minor reverse movements also occurred on the shear cleavage, displacing schistosity planes a fraction of an inch. The strike of the shear cleavage ranges from about parallel to schistosity to as much as 40° more east or west, and the dip is generally less than 50° E.

Lineation

Linear elements consist of crinkles in cleavage in altered rock, and of long axes of fragments and pillows in unaltered rock, in addition to slickensides and mullions on faults. These linear elements pitch steeply, generally nearly down dip. Some of the lineation may be due to intersections of schistosity and shear cleavage, but most of it is probably a result of either strike-slip rolling along schistosity, or dip-slip stretching. Fragments or pillows, where distorted, show flattening in the plane of foliation, and maximum stretching along axes approximately parallel to the dip; this deformation seems to be the consequence of regional compression.

Folds

Minor folds in bedding were observed in a few places; the most pronounced are in the Borger alteration zone northwest of the Borger shaft. Fold axes plunge from 60 S. through vertical to 85 N., and non-folded schistosity is parallel to axial planes of folds. The irregularities in the contact between metabasalt pillow lava (Jabp, pl. 4) and metafelsite volcanics (Jafv) in the northeast part of the area may be due to folding, although equally plausible hypotheses are that they are caused by cross-faulting, or interfingering. Most of the other irregularities in stratigraphic contacts that appear in plates 4 and 7 are probably due to interfingering, although in plan many resemble plunging folds.

Locally the schistosity itself is folded on a small scale, and randomly plunging minor folds in schistosity are developed in shear zones either within alteration zones or along contacts between different kinds of rock. In addition there are many small drag folds in schistosity adjacent to faults.

In general, bedding folds are probably a result of the regional orogeny, for in them schistosity is undeformed. Schistosity folds are associated with faults, shear zones, and other zones of later movement.

Faults

Faults can be grouped into three categories: (1) generally steeply dipping faults that strike northeast and have little effect on ore bodies; (2) relatively low-angle reverse faults that strike N. 30° W.-N. 30° E. and dip 25°-55° E., with a few complementary west-dipping faults; and (3) high-angle faults along certain schistosity planes or at contacts.

The steep northeast-trending faults dip 60°-85° eastward, but locally are vertical or dip westward. They range from tight structures to open, breccia-filled fissures as much as 30 inches wide, generally with a small amount of gouge. These faults extend only a few feet along the strike, and displacement, where it can be observed, as in the 700-level stope, No. 2 shaft area, amounts only to a strike-slip movement of 2 to 9 feet. In the 700-level stope, ore occurs at the intersection of these faults with the greenstone footwall of the West alteration zone, thus the faults here antedated the ore deposits. However, much of the movement along these faults occurred later than low-angle reverse faulting and ore deposition.

The second type, low-angle reverse faults, are by far the most significant. These pre-ore faults are one of the chief structural controls of ore bodies, although post-ore movement along some of them has displaced ore. Four major faults of this type have been recognized at the Penn mine: the Satellite, 1,000-level, Campo Seco, and 1,400-level faults. The Satellite fault crops out at the surface, where it has been mapped for a distance of 1,200 feet (pls. 4 and 7), and is present in the upper workings, No. 2 shaft area (pls. 12, 13, and 15). The 1,000-level fault was seen in the 1,000 and 700 levels, No. 2 shaft area (pls. 9 and 20). The Campo Seco fault has been observed at the surface (pls. 4 and 7) and in shaft No. 3 between the 1,000 and 1,100 levels (pls. 16 and 19), where it is marked by 1 to 2 feet of breccia. From company maps it is inferred that the 1,400-level fault lies in the deepest workings, No. 2 shaft area (pl. 20); it may be the southward extension of the Campo Seco fault, but, if not, the Campo Seco fault lies below this fault.

The Satellite fault consists of a main branch, which near the surface is the hanging wall of ore body 1, and several footwall spurs. It has an average strike close to north, and dips about 45° E., but locally trends N. 20° W. to N. 20° E. and ranges in dip from 25° to 75°. At the 200 level, No. 2 shaft area, the fault forms the hanging wall of ore body 1a, and in the south stope on the 500 level, it forms the hanging wall of ore body 1b. If movement along the Satellite fault is assumed to be rotational, with little or no displacement at the northernmost surface exposure, the dip-slip at the collar of shaft No. 1 is about 170 feet. This figure is obtained by determining the dip slip (about 300 feet) near the southernmost surface exposure, where the strike slip is known. The dip-slip at any point is then proportional to the distance from the northernmost exposure.

According to Julihn and Horton 13/ the Campo Seco fault strikes N. 12° W. and

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13/ Julihn, C. E., and Horton, F. W., op. cit., p. 114.

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dips 29° E. A cross section by Tolman 14/ shows it with a dip-slip of about 1,000

14/ Tolman, C. F., The foothill copper belt of California: XVI Internat. Geol. Cong., Copper resources of the World, vol. 1, pp. 247-250, 1935.

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feet (pl. 19). The writers question Tolman's interpretation, mainly because no fault of requisite magnitude was observed at the surface. If Tolman's interpretation is correct, his West "dike" below the fault should be the downward continuation of the alteration zone developed in quartz porphyry, and the 1,400 level footwall and hanging wall crosscuts would not extend into other alteration zones. These critical locations were not accessible to the writers. If the writers' interpretation (pl. 19) is correct, the fault has a dip-slip on the order of 30 to 90 feet, and shaft No. 3 workings partially explore three alteration zones: the West (in quartz porphyry), the East, and the Hinckley; unless the West zone pinches out with depth, all three should be present on the 1,400 level. The importance of determining the amount of displacement along the Campo Seco fault cannot be overemphasized, for if the displacement is small, as the writers believe, considerably more ground below the fault is favorable for exploration.

These low-angle faults commonly are fault zones, and generally consist of many closely spaced en echelon faults. Mullions pitch down dip, and drag in schistosity indicates reverse movement. Because sulphide stringers follow along these faults and their associated drag folds, low-angle reverse faulting is believed to have occurred before the introduction of sulphides. However, later movement on these faults has actually brecciated ore, for example the ore in a short raise near the south end of the 500 level, No. 2 shaft area.

The high-angle faults developed along certain schistosity planes or contacts are indicated by fairly coarse mullion structure, by schistosity drag folds, and by prominent surfaces with strongly developed lineation. These faults antedate those of the other two classes, and are believed to represent a type of failure common in the felsic rocks of the area, which may be a reason for the localization of sericitization and silicification in belts of these rocks.

ORE BODIES

General features

The ore bodies at the Penn mine are sulphide replacement deposits in alteration zones of sericitized, silicified, and pyritized schist, derived from felsitic volcanic rocks and intrusive quartz porphyry. In general the intensity of silicification and pyritization decreases away from the ore, which is typically a fine-grained mixture of pyrite, chalcopyrite, and sphalerite. The ore bodies strike and dip essentially parallel to the schistosity and have a lenticular form, with long axes pitching down dip, or steeply northward or southward.

The metasomatic origin of the ore bodies is indicated by the following features: (1) banding in the ore and strong relict schistosity, parallel to foliation of country rock, in the pyritic envelope surrounding ore; (2) retention, in sulphides and gangue, of drag folds in schistosity and of minor faults; (3) oriented residuals of schist within ore and the pyritic envelope; and (4) the gradational contact of at least one wall, and in some cases both walls, of the ore bodies.

Except for the ore body at shaft No. 5, the known ore bodies are shown in plan, section, or projection on plates 7-9, 12-18; for convenience in reference, they are designated by number. Ore bodies 1a, 1b, 2, 3, 4a, 4b, 5, and 6 are in the West alteration zone, 7a and 7b in the East alteration zone, and 8a and 8b in what is probably the downward extension of the Hinckley alteration zone. The ore body at shaft No. 5, which is inaccessible, is in the Hecla alteration zone.

The ore bodies occur at either the hanging wall or footwall contact of alteration zones; or within these zones either along high-angle faults parallel to schistosity, or along younger low-angle reverse faults that crosscut and drag schistosity, and offset alteration contacts. The low-angle faults, some of which show post-ore movement, are readily recognized by slickensided surfaces and gouge. The older high-angle faults along certain schistosity planes or at contacts are less obvious, for evidence generally is limited to coarse mullion structure and strong lineation approximately down the dip of foliation. The intersection of a low-angle fault with an older high-angle fault is a locus particularly favorable for ore deposition (pls. 20 and 21). Both types of faults are present on a minute scale measured in inches, as well as on a gross scale measured in tens or hundreds of feet (pl. 20).

Another factor in the localization of ore, at least in some cases, is the large-scale gentle bowing of faults and schistosity normal to their strike (pl. 10). Within these buckled zones, which can be considered as steeply pitching chimneys, the schistosity is more intricately folded and faulted, and in places is steeper than normal or dips west. The geologic level maps (pls. 8 and 9) show in plan that ore bodies 1a, 1b, and 6 are concave westward, and ore body 7a is concave eastward (pl. 21). There is also a suggestion that the upper portion of ore body 5, the probable downward extension of ore body 2, and possibly deep ore bodies 8a and 8b, all of which are inaccessible, are concave westward.

In cross section the ore bodies show several typical forms which are controlled by one or more of the structural features mentioned above. The simplest type is an elongate body, pod-shaped in cross section, developed along or near a contact of an alteration zone (ore bodies 4 and 5, pls. 12 and 20), or along a zone of strong deformation within an alteration zone (ore bodies 2, 3, and the north part of 1a, pl. 14). A second type differs from the first in that its upper portion flattens and follows a low-angle fault (ore bodies 1b, the south part of 1a, and probably 6, pls. 12, 13, and 20). A third type is exemplified by ore body 7a (pls. 16 and 17), whose central portion follows an old fault at the footwall of an alteration zone, but whose upper and lower portions leave the footwall and follow steeper schistosity. These last two types, with their structural relationships, are shown diagrammatically on plate 21.

The ore bodies vary considerably in size. Ore bodies 7a and 7b were mined along a pitch length of about 1,000 feet; the original length was greater, for parts of the ore shoots have been removed by erosion, and, in addition, a faulted extension probably exists below the 1,100 level. Ore bodies 1a and 1b have known pitch lengths of about 825 and 700 feet respectively, and some ore has likewise been removed from these ore bodies by erosion. The deep ore body (8a) in No. 3 shaft area has a pitch length of at least 900 feet, and 8b, just to the south, at least 650 feet. Ore body 5 has a minimum down-dip extent of 300 feet, and its pitch length is probably considerably greater. Of the smaller bodies, ore body 3 has a pitch length of 150 feet or more.

Ore bodies 1a and 1b, where they merge in the upper levels, were stoped along a distance of 600 feet or more; at greater depth, the breadths of ore bodies 1a and 1b are respectively 400 and 325 feet. Ore bodies 7a and 7b have breadths, respectively, of 300 and 250 feet, and where they merge with depth were stoped for a distance of 400 feet or more. The two deep ore bodies (8a and 8b) have breadths of 175 and 250 feet respectively. Of the smaller bodies, Nos. 2 and 3 have breadths close to 100 feet.

In width the ore ranges from about 4 to 30 feet. Ore was 20 feet wide at places in ore bodies 1a, 1b, and 5. Most ore bodies have high-grade ore ranging in width from 5 to 12 feet.

Characteristics of the ore

In the Penn mine sulphides are present as (1) massive ore, which may be either uniform or banded, (2) stringers or narrow irregular masses, (3) disseminated grains, or (4) short veins or veinlets which cut the other types. The massive and the stringer ore is a fine-grained, intimate mixture of pyrite, sphalerite, chalcopyrite, and a small amount of bornite; gangue minerals, which are generally sparse, are calcite, barite, and quartz. The disseminated ore consists of fine grains of pyrite, sphalerite, and chalcopyrite scattered through the silicified, sericitized wall rocks. The ore in veins which range in thickness from a fraction of an inch to a foot and a half, is later than the other types. These veins have no systematic attitude. They are composed of pyrite, chalcopyrite, bornite, and some tetrahedrite, with white calcite and quartz gangue that in places contains a little chlorite.

The pyritic envelopes of the ore bodies are made up of abundant pyrite disseminated in altered wall rock. The pyrite is generally fine grained, and may be present as cubes, pyritohedrons, or anhedral grains. Within the envelopes certain streaks or bands of schist may show local concentrations of pyrite, but in a general way, pyrite becomes less abundant outward from the ore bodies. A striking feature of some ore is the presence of residual masses of silicified, sericitized schist and quartz porphyry in the sulphides. Some of these are schistose and elongate, and oriented parallel to the schistosity of the country rock; others are more rounded and massive, locally giving the ore a "cobbly structure." In a general way, these residual masses are more numerous and more closely spaced in the tapering ends of ore bodies and near gradational contacts. Possibly some of the residual masses represent fragments in fault breccias developed before ore deposition. If this is true, the sulphides probably selectively replaced finely comminuted rock, leaving the more impervious larger fragments as residual masses.

Julihn and Horton 15/ state that, in general, ore from the Penn mine contains

15/ Julihn, C. E., and Horton, F. W., op. cit., pp. 112-113.

0.03 to 0.10 ounce of gold and 2 to 4.5 ounces of silver per ton, and 3 to 6 percent copper, and 5 to 15 percent zinc. The ore mined during the current operation is not typical, because it comes only from ore bodies of the West alteration zone, and in addition only the higher-grade ore is being mined. There is a suggestion that ore in this zone contains more zinc and less copper than ore of other zones. Past records indicate gold and silver also are more abundant in ore from the West alteration zone.

Supergene enrichment and gossans

Because the upper workings were inaccessible, little was learned during the present study regarding supergene enrichment. On the 200 level, chalcocite was present as sooty coatings on primary sulphides. Aubury 16/ states that copper

16/ Aubury, L. E., op. cit., p. 241.

glance was found in the upper portions of the "vein," and that scattered copper glance and covellite occurred in the deeper parts of the mine, then 750 feet deep.

Throughout most of the Foothill copper belt the zone of enrichment lies within 30 to 60 feet of the surface. However, at the Penn mine oxidation and enrichment of the ore may have penetrated deeper than normal, for the present erosion surface in many places is close to the pre-Tertiary unconformity, which was developed during a period of intense and prolonged weathering.

The outcrops of ore bodies are marked by gossans, and between No. 1 and No. 2 shafts by copper carbonates as well. The gossans derived from ore commonly are brown or yellow-brown, and contain malachite, azurite, jarosite, limonite, and kaolin, in addition to residual quartz, sericite, and barite. The gossans derived from pyritic material are generally red-brown and usually more siliceous. The larger gossan areas are shown on plates 4 and 5.

Mineralogy and paragenesis

Pyrite is present as cubes and pyritohedrons or as anhedral grains disseminated in wall rock and occurring within sulphide bodies. It is generally fine-grained, though some cubes are a quarter of an inch on a side. The banded ore not uncommonly is delineated by narrow, regular, pyrite-rich bands, and some altered wall rocks have apparently been replaced selectively along certain layers.

Sphalerite is a dark-brown to steel-black variety that probably contains combined iron. It is typically fine-grained, for grains larger than one-tenth inch in diameter are rare. It is found intimately mixed as grains and streaks with pyrite, chalcopyrite, bornite, and gangue minerals.

Chalcopyrite occurs as anhedral grains and aggregates of grains that may form streaks in the ore matrix. In the calcite-quartz veins it occurs in coarser masses than in the massive ore. Bornite is locally intergrown with chalcopyrite, but is relatively rare except in the calcite-quartz veins. Tetrahedrite is also present in these veins, but was not observed in massive ore. Galena was not recognized during the present study, but it has been identified microscopically by Tolman,17/

17/ Tolman, C. F., op. cit., p. 250 ff.

and some shipments of lead-bearing ore are recorded.

Barite, commonly fine-grained and pale gray, buff, or white, is locally abundant along the margins of ore bodies of the West alteration zone. It is intergrown with sulphides, especially sphalerite, and replaces residuals of country rock within ore bodies. It may also replace wall rock, locally preserving schistosity as a relict structure. A common occurrence of barite is in axial regions of schistosity drag folds in altered quartz porphyry.

Fine-grained white calcite is generally sparsely present as gangue in massive ore, and coarsely crystalline calcite and milky quartz are abundant in sulphide-bearing veins that cut massive ore. Chlorite was observed in a few places intergrown with the milky quartz of these sulphide-bearing veins. Sericite folia are parallel to schistosity of the enclosing rock at ore boundaries, and in one case a thin layer of a sericitic mineral, probably damourite, was present as folia perpendicular to the margin of a bornite-calcite-quartz vein. Pale-gray to white cryptocrystalline quartz characteristically replaces the wall rock and in places is present in massive ore.

Selenite occurs as clusters of crystals and as masses coating mine workings, and it was also observed as cavity fillings in ore body 5. It is probably supergene. Small botryoidal and dendritic masses of native copper were observed at many places in mine workings, coating walls and replacing old pieces of steel. It was reported by Aubury 18/ in the upper portion of the "vein," where it was probably in

18/ Aubury, L. E., op. cit., p. 241.

the oxidized zone.

The paragenesis of minerals associated with ore deposits is given in table 2. As this table is based on megascopic evidence, it is tentative.

Summary of ore controls

The ore controls recognized at the Penn mine are summarized as follows:

(1) Ore is apparently restricted to belts of sericitized and silicified schist derived from quartz porphyry and felsitic rocks. Whether ore deposition favored these belts because of chemical selectivity, or because these rocks were deformed in a manner favorable for circulation of replacing solutions is not known, but the second hypothesis is preferred.

(2) Within the alteration zones and at their margins are areas of gentle bowing or buckling in a direction normal to schistosity. These areas of greater disturbance represent favorable loci for ore deposition.

(3) Within the alteration zones and at their margins, the intersections of high-angle schistosity faults with younger, low-angle reverse faults produce loci favorable for ore deposition.

(4) Small, tight, schistosity folds, unsystematically oriented and generally with amplitudes measured in inches, are specific ore controls, for in places along their axes pencils of sulphides or barite are developed.

Of these four controls, the first is useful in delineating belts of country in which ore bodies may occur. The second and third, used in combination, can be applied to locating specific areas where ore might be found. The fourth probably has little economic significance, for the size of the controlling structures precludes commercial ore bodies.

GEOLOGIC HISTORY

The geologic history of the area near the Penn mine is summarized as follows:

(1) During Upper and possibly Middle Jurassic time a thick sequence of volcanic and sedimentary rocks was deposited in a marine basin which included the Penn mine area.

(2) Quartz porphyry, felsite, and mafic rocks were intruded into these rocks.

(3) In late Upper Jurassic time these rocks were folded, faulted, and underwent low-grade metamorphism (Nevadan revolution).

(4) Certain belts of these rocks were affected by hydrothermal alteration, followed by faulting and associated folding, formation of sulphide deposits, then more faulting.

(5) During Cretaceous and early Tertiary time the region was subjected to erosion and weathering, followed by deposition of Tertiary sediments, and finally by canyon-cutting and deposition during the Quaternary.

ORE RESERVES

Measured ore has been restricted to blocks outlined and sampled on at least two sides; indicated ore, to extensions of sampled ore bodies within 50 feet of workings, or to shaft pillars, etc. Inferred ore has been extended to the probable geologic limits of ore bodies.

Mining-grade ore

Total reserves of mining-grade ore are estimated, as of January 1, 1945, at 245,100 tons distributed as shown by table 3. These are restricted chiefly to ore bodies 1b, 5, 8a, and 8b. The grade, and to a certain extent, the limits of ore are based on the Kruttschnitt samples of 1926, checked by samples taken by the Eagle Shawmut Mine of the ore bodies now accessible.

Because the ore bodies commonly have only one well-defined wall, and because they grade along the strike into slightly mineralized rock, the tonnage depends upon the cut-off grade assumed. Estimates noted in table 3 are based on a cut-off grade of 2 percent copper or 5 percent zinc, or an equivalent combination thereof. The Eagle Shawmut Mine, however, attempts to maintain a cut-off grade of 6 percent copper or 12 percent zinc, or an equivalent combination,19/ and if this higher

19/ Peacock, D. C., Personal communication. Mr. Peacock, manager of the mine, states that the ore they handle should have a minimum value of $12, based on the arbitrary valuation of $2 per unit of copper, and $1 per unit of zinc.

grade is used the tonnage in ore body 5 is reduced by 34 percent.

The few available assays do not permit estimation of tonnage with a lower cut-off, such as 1 percent copper, but it is not unlikely that a tonnage based on this figure would be about 30 percent greater than that in table 3.

Low-grade ore

The disseminations and stringers of sulphides present at the ends and in the walls of ore bodies comprise a large reserve of low-grade material, which, as noted in table 4, may total from 913,000 to 973,000 tons. Available sample data are largely restricted to those portions of the low grade ore which are visually estimated to be of higher grade, but it seems that the average grade of this material lies between 0.5 and 1.5 percent copper, and 0.5 and 4 percent zinc. The tonnage estimate is probably conservative, for it is based on areas scaled from vertical projections, and on widths from geologic maps of accessible workings which obviously make little attempt to explore these low-grade deposits. A much greater number of samples must be taken to approximate the average grade of such material available.

AREAS FAVORABLE FOR EXPLORATION

Areas considered favorable for exploration are listed below. The plate numbers refer to illustrations on which these areas are indicated. In the two cases where no plate number is given, positions of the areas can be approximated on the areal map (pl. 4).

(1) Extensions of known ore bodies.

<u>In West alteration zone, No. 2 shaft area:</u>

A. South extension of ore body 1 above 200 level (pl. 18).
B. Downward extension of ore body 3 (pl. 18).
C. Downward extension of ore body 6 (pl. 18).
D. Downward extension of ore body 1b (pl. 18).
E. Upward extension of ore body 5 (pl. 18).
F. Downward extension of ore body 4a (pl. 18).
G. Downward extension of ore body 4b (pl. 18).
H. South extension of ore body 5 (pl. 18).
J. Downward extension of ore body 5 (pls. 18 and 20).

<u>In Hecla alteration zone:</u>

K. Downward extension of ore body at shaft No. 5.

In Hinckley alteration zone:

L. Upward extension of ore body 8b (pl. 17).
M. Downward extension of ore body 8a (pl. 17).

(2) Areas, other than extensions of known ore bodies, based on geologic inference.

In West alteration zone, No. 2 shaft area:

N. Area beneath footwall spur of Satellite fault south of shaft No. 2 (pls. 13 and 20).
P. Area below the intersection of the 1,000 level fault with hanging wall contact of the West alteration zone (pl. 20).
Q. Areas below the intersections of the 1,400 level fault with footwall and hanging wall contacts of the West alteration zone (pl. 20).

In West alteration zone, No. 3 shaft area:

R. Area below gossans and disturbed zone extending from the Busey adit northward for 500 feet.
S. Area below intersection of the Campo Seco fault with the West alteration zone (pl. 17).

In East alteration zone, No. 2 shaft area:

T. Areas at the intersections of the Satellite, 1,000 level, and 1,400 level faults with footwall and hanging wall contacts of the East alteration zone (pls. 15 and 20).

In East alteration zone, No. 3 shaft area:

U. Hanging wall contact of the East alteration zone between the 500 and 1,100 levels (pl. 17).
V. Area below the 1,700 level (pl. 17).

In Hinckley alteration zone:

W. Area above the 1,400 level (pl. 17).

RECOMMENDATIONS

If the war demand for copper and zinc is such that exploration by a Government agency is expedient, it is recommended that some or all of the areas listed in this report be explored by diamond drilling or other appropriate methods.

March 14, 1945.

Table 1.—PRODUCTION DATA

Period	Source of data	Ore (tons)	Copper (pounds)	Zinc (pounds)	Lead (pounds)	Gold (ounces)	Silver (ounces)
1861-65	A	3,050	915,000	1/	1/	1/	1/
1866-67	A	1/	1/	1/	1/	1/	1/
1868-82	A	2/	2/	2/	2/	2/	2/
1883	B	1,000	300,000	1/	1/	1/	1/
1884-86	A	2/	2/	2/	2/	2/	2/
1887-98	A-B	1/	1/	1/	1/	1/	1/
1899-1902	C	81,000 3/	7,500,000 3/	1/	1/	6,357.05	173,751
1903-19	C	692,321	67,124,593	1/	1/	49,550.92	1,608,087
1920-Nov. 1943	C	3,083	820,096	1/	4,906	278.68	9,563
Dec. 1943-Dec. 1944	C	11,686	621,475	2,214,998	1/	798.	36,066
Totals		792,140	77,281,164	2,214,998	4,906	56,984.65	1,827,467

Average grade ore, 1903-19: copper, 4.85 percent; gold, 0.07 oz/ton; silver, 2.32 oz/ton.
Average grade ore, 1943-44: copper, 2.66 percent; zinc, 9.47 percent; gold, 0.06 oz/ton; silver, 3.08 oz/ton.
(No allowance for loss in treatment)

1/ No data.
2/ Mine believed to be inactive.
3/ Estimated from gold and silver production.

Source data:

A—Mineral Resources west of the Rocky Mountains, 1866-1876,
Mineral Resources of the United States, 1886-1898.
Copper production estimated by assuming minimum grade of 15 percent.
B—Copper resources of California, Bulls. 23 (1902), 50 (1908), Calif. State Mining Bureau. Copper production estimated by assuming minimum grade of 15 percent.
C—San Francisco office, Economics and Statistics Branch, Bureau of Mines.

Table 2.—PARAGENESIS OF EPIGENETIC MINERALS AT THE PENN MINE
(Based on megascopic evidence)

HYPOGENE			SUPERGENE
Rock alteration stage	Sulphide replacement stage	Vein-forming stage	
Sericite		Sericite or Damourite	
Cryptocrystalline quartz			
	Pyrite		
	Sphalerite		
	Barite		
	Chalcopyrite		
		Bornite	
		Calcite	
		Milky quartz	
		Tetrahedrite	
		Chlorite	
			Chalcocite
			Malachite
			Azurite
			Gypsum
			"Kaolin"
			"Limonite"
			Jarosite
			Native copper

Table 3.—RESERVES OF MINING-GRADE ORE 1/

Ore body	Measured ore Tons	Measured ore Percent Cu	Measured ore Percent Zn	Indicated ore Tons	Inferred ore Tons
1a (pl. 18)	6,000	2.7	1.4	——	—— 2/
1b (pl. 18)	4,000	2.3	7.1	11,000	66,000
2 (pl. 18)	——	No data		500	——
3 (pl. 18)	——	No data		1,600	3,000
4a (pl. 18)	Pillars	2.1	20.9	3,000	3,000
5 (pl. 18)	29,000 3/	3.1	12.9	17,000	56,000
6 (pl. 18)	——	No data		——	13,000
7a, b (pl. 17)	——	No data		——	——
8a, b (pl. 17)	32,000 4/	5.58	5.88	No data	No data
TOTALS	71,000 5/			33,100 5/	141,000
AVERAGE GRADE		4.1	8.3	TOTAL, ALL CLASSES	245,100

1/ Mining-grade cut-off assumed as 2 percent copper or 5 percent zinc.

2/ Includes 40,000 tons above 400 level, estimated by Kruttschnitt.

3/ Based on Kruttschnitt data, with Survey ore limits. Using operators' ore limits, reserves are estimated as 19,000 tons averaging 4.2 percent copper and 18.3 percent zinc.

4/ Kruttschnitt estimate to nearest 1,000 tons, ore blocks 1-6 inclusive.

5/ Kruttschnitt estimate (1926) is: 101,356 tons, averaging 3.96 percent copper, 9.3 percent zinc, 0.068 oz/ton gold, and 2.76 oz/ton silver. This corresponds to Survey measured and indicated ore. Since 1926, about 14,000 tons has been extracted.

Table 4.—RESERVES OF LOW-GRADE ORE 1/

Ore body	Indicated ore			Inferred ore
		Percent		
	Tons	Cu	Zn	Tons
1a (pl. 18)	—	—	—	450,000
1b (pl. 18)	9,000	1.6	3.3	240,000
4a, b (pl. 18)	—	—	—	10,000
5 (pl. 18)	10,000	1.3	3.3	50,000
7a, b (pl. 17)	4,000	No data		100,000 - 150,000
West vein, No. 3 shaft area 500' to 700' level.	—	—	—	40,000 - 50,000

TOTAL INDICATED AND INFERRED ORE 913,000 - 973,000 tons

ESTIMATED GRADE RANGE 2/ Copper, 0.5 - 1.5 percent; zinc, 0.5 - 4 percent.

1/ Low-grade ore includes the ends of minable ore bodies, and the stringers and disseminations of sulphides shown on plates 17 and 18.

2/ Assays available range from 0.3 to 2.7 percent copper, 0.2 to 5.1 percent zinc, across mining widths.

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