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# THE ORE-DEPOSITS OF COPPEROPOLIS, CALAVERAS CO., CALIFORNIA.

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## LOCATION.

The town of Copperopolis, in and near which lie the copper deposits to be discussed in this paper, is situated in Calaveras County, California, about forty miles east of the city of Stock-

ton. A branch railroad runs from the last named place to the town of Milton, from which it is fourteen miles by stage to the copper town. The locality is a portion of the copper belt of the foothill region of the Sierra Nevada, which extends for one hundred and fifty miles from southeast to northwest. This belt is in turn a part only of the larger copper belt of California, which is roughly four hundred miles long, paralleling the crest of the Sierra Nevada. Two other copper-producing mines lie to the north in Calaveras County the Penn Company property at Campo Seco, and the Poole Mine, nine miles distant on the stage road from Milton to Angel's Camp. A number of promising copper properties are also situated in the region just west. The middle belt of the famous Mother Lode system lies twelve miles to the east, and the west belt of the same system is two miles to the west. All these belts extend northwesterly and southeasterly for many miles. Supplies are brought in to Copperopolis from the railroad by team and traction engine; the oil used in smelting is delivered entirely in the latter way. It is merely a question of time until rails are laid directly to the mine.

The south bounding line of the Jackson sheet of the U. S. Geological Survey, to which other reference will be made, is only about two and a half miles to the north. The areal geology around Copperopolis has never been mapped.

## TIME OF EXAMINATION.

The examination of this copper deposit was begun in the spring of 1906, and completed by work at different times until September of the same year. The ore deposit as a whole is of the greatest interest, and some features are peculiar and rather novel. No geologic work of detailed nature has heretofore been done on this property, and this paper aims to compass two ends: first, to set forth the exact nature of the ore-deposit in a short paper; and, second, to show the possibilities and need of such work in the proper development of a mine.

This study has been made possible only through the courtesy of the owners of the mine and of the general manager, Mr. G.

one other sulphide, pyrite. No gold or silver are present. A second variety of pyrite, containing some gold values, frequently occurs with the copper ore. This pyrite is genetically connected with the latest intrusive rock, granodiorite. The gold veins of the western portion of the Sierra Nevada are connected with the series of acid intrusive rocks, which are of later age than the group of peridotites, or the ultrabasic intrusives. The copper ore is connected genetically with a hornblendite, an ultrabasic rock, and therefore is older than the gold-bearing quartz veins of the Mother Lode. The copper ore is of special scientific interest on account of its genetic relations and mode of formation. From all indications, together with the large amount of ore in sight in the workings, Copperopolis bids fair to become one of the largest copper producers in the west.



McM. Ross, whose thoughtfulness has been felt in every way possible.

## HISTORY.

The mines at Copperopolis were first located in June, 1861, on what was called the Reed lode, after the principal discoverer. Over 11,000 feet of lode were located, and in the excitement which followed claims were taken up for twenty miles north and south. The Napoleon mine, the oldest copper mine in the state, and the Quail Hill mine are on a parallel lode six miles to the west; the Campo Seco and Lancha Plana mines are on a line about three miles west. This large copper belt in Calaveras County can be traced by stains and gossan for more than thirty miles.

Of all these mines, the Union and Keystone, at Copperopolis, were most productive in the early 60's, as they were also the most important in the state at that time. The oxidized ores extended only to a depth of twenty-five to thirty feet below the surface. The rich sulphides below were shipped to Swansea, by way of New York, to Boston, and to Baltimore. With the lowering of the price of copper in 1868 the mines were closed, and remained idle till 1887. A second period of activity followed, in which a hundred-ton Orford furnace was erected, and some high grade matte was produced. In 1892 a second shutdown occurred. The properties remained idle until 1901, when, under the present management, unwatering was begun. Up to, and including, 1866, the Union mine is credited with 56,500 tons of ore containing over 15 per cent. copper, and the Keystone with 5,719 tons. The copper produced was noted for its purity, ranking in the market with, or close to, Lake Superior metal.

At the present a large up-to-date plant has been partially completed. A hundred-ton oil-burning reverberatory furnace is producing from six to ten tons of high grade matte per day, only rich ore now being smelted. With the completion of the plant the production will be increased many times, and Copperopolis will again rank as one of the most important copper properties in the west.[1]

[1] References: Calif. State Mining Bureau. Eighth Annual Report, 1888, p. 150. Bull. 23, 1902, p. 23.

TOPOGRAPHY.

The region, although the elevation is not high nor the relief very great, has a well characterized topography, which is the result of the differential erosion of the various rocks. Two well-defined rocky ridges run northwest and southeast through the country: Gopher Ridge, four and one half miles west of Copperopolis, the first ridge east of the great valley; and the Bear Mountain Ridge, five and one half miles east of the town, separating the copper belt from the middle belt of the Mother Lode system. The lower ground between these two ridges is composed of a succession of short ridges often arranged *en echelon,* separated by long, narrow valleys. In one of these valleys lies Copperopolis, at an elevation above sea level of 980 feet. The ore itself is found to the north in the bottom of the valley; to the south, as the rock becomes more and more resistant to erosion, it occupies the center and sides of a low ridge. This ridge increases in size from its beginning near the center of the town (see section *E–F,* Plate VII.) to south of the concentrator, where it terminates, as shown in Plate VII.

The maximum relief is only a few hundred feet; the average is much less. (See Plate VII.) The elevations decrease progressively from the Bear Mountains on the east to Gopher Ridge on the west. The Jackson Folio shows well these salient features.

The streams of the region are divisible into the two types of the physiographers: consequent and subsequent. The Stanislaus river is the master stream of this immediate area, which, like all of the main rivers draining the west slope of the Sierra, is a consequent stream, with a course at right angles to the range crest.[1] These rivers, with local exceptions, flow over all rocks alike, and are responsible for the deep cañons of the range. The secondary stream courses follow in part the outcrops of the softer rocks, and in so far are subsequent; in part they also flow southwesterly across the strike of the country, through the lower passes between the overlapping ridges, and are consequent. The

[1] Jackson Folio No. 11, U. S. Geological Survey.



Therefore, there can be but little doubt that the Copperopolis ores reach downward at least for several thousand feet.

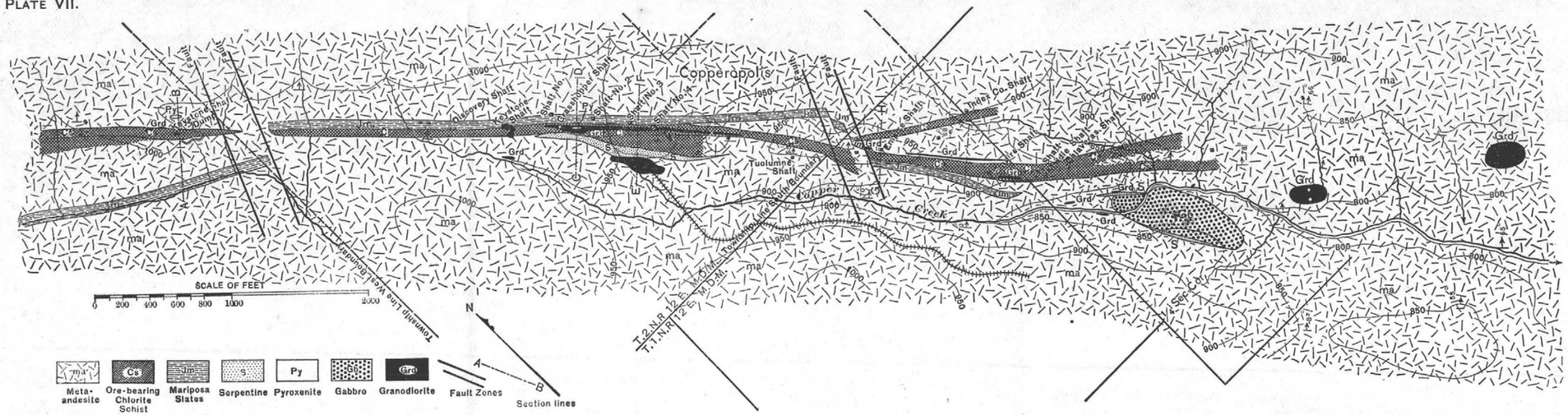
RELATIONS OF THE COPPEROPOLIS REGION TO THE MOTHER LODE.

The ore deposit at Copperopolis has been described as lying between the middle and west belts of the Mother Lode system. The truth of this statement is everywhere forced upon the observer in the country surrounding the copper deposits. Typical mariposite is found near Hodson, less than two miles to the west, in the vein formation at that point. Dikes of quartz and feldspar, so common along the middle belt of the Mother Lode, as noted by Ransome, are to be found in the slates west, north, and south of Copperopolis. Quartz veins with carbonates exist a few miles to the south. And on the Empire ground, as noted, some of the quartz veins above the granodiorite contain original calcite, showing the Mother Lode characteristics later than, and imposed upon, the copper deposits.

The Copperopolis ores are to be regarded as an early non-auriferous deposit in the great meta-andesite formation of the western Sierra Nevada, which has been surrounded and intruded by later gold ores of the Mother Lode type.

SUMMARY

The Copperopolis copper deposits may be finally described as consisting of a series of ore lenses of unknown depth, in part arranged *en echelon,* and in part serially along one line. In horizontal cross-section these lenses are from thirty to sixty feet wide and several hundred feet in length, with rich ore in the center changing into low grade pyrite at the periphyry. This change in the copper content of the ore appears to be due to the action of the chlorite schist as a septum, impervious to the copper, but permeable by the iron in solution. In the body of the ore lenses the value changes by the varying amounts of schist with the sulphides; from inside to outside the values change by the increase of the relative amount of pyrite. Chalcopyrite is the only copper ore in the unaltered zone, and is associated with but




Scale of sections, 1 inch = 200 feet.

Meta-andesite | Mariposa Slates | Serpentine | Serpentine | Granodiorite | Contact Phase Granodiorite | Pyroxenite

GEOLOGIC MAP AND SECTIONS OF THE COPPEROPOLIS DISTRICT, CALIFORNIA. BY JOHN A. REID.

drawn, therefore, that the earlier hornblendite has been responsible for the copper-bearing solutions, the magma from which the hornblendite came furnishing the copper. The gold-bearing non-cupriferous pyrite was derived from the acidic magma of the granodiorite.

In age the ore is earlier than the gold-bearing veins of the Mother Lode region. These veins are associated with the acidic intrusives of this part of the Sierra Nevada, which are distinctly later than the copper ore. Quartz veins of the Mother Lode type, with auriferous pyrite and free gold, occur in the Copperopolis region, some of which, at least, are associated with the granodiorite intrusions, and connected genetically with them. The series of basic intrusives, represented at Copperopolis by the hornblendite, is in all cases earlier than the acid rocks. The Copperopolis deposits are to be listed among the oldest ores of the Sierra Nevada.

### FUTURE IN DEPTH.

As a matter both of scientific and mining interest, the question of the permanence of ore with depth needs mention. There are a number of facts throwing some light upon this.

1. The ore occurs in veinlets, in the main interlaminated with the schists. These schists, from all mining work done in the great Sierra belt, and the deep cañons of the range, go downward unchanged to great depths.

2. The hornblendite, the source of the ore, undoubtedly extends downward in the form of thin intrusions to great depths.

3. The granodiorite, which is responsible for many quartz veins containing pyrite and gold, which veins lie *above* the intrusive rock, is later than the copper ore.

4. All mining developments throughout this country have always shown that ore values are present downward to the greatest depths reached.

5. Lastly, the ore at Copperopolis not only proceeds downward as far as exposed with undiminished values, but is slowly increasing in richness and volume.



hot, dry summers usually cause all small creeks to become dry during this part of the year, but springs are fairly plentiful in the hills. The only source of water power is the Stanislaus river, which runs about six miles southeast of Copperopolis. Timber is fairly plentiful, the trees furnishing fuel being the common or digger pine, the live oak, blue oak, and some white oak. Travel to and from Copperopolis is entirely by team, the roads following the valleys wherever possible.

## GENERAL GEOLOGY.

### OUTLINE.

The general geology of the Sierra Nevada is well known. At the close of Jurassic time an immense thickness of sedimentary rocks, chiefly muds, sands, and gravels, together with interbedded volcanic tuffs and flows, were intricately folded into a mountain range, compressed and thoroughly metamorphosed into slates, schists, and allied rocks. The isoclinal folds of the range strike in the main parallel to the range crest, N. 40° W., and all dips, with only local variations, are about 70° E. The whole was intruded by vast masses of igneous rocks, the axis of the range being a great granitic batholith. Other igneous rocks were intruded after the initiation of the folding and compression, but before all such movements had ceased. Thus a great complex of rocks has been produced, and has been given the name of Bedrock Series or Complex. During Cretaceous time the range was eroded to a peneplain, a few monadnocks, such as Bear Mountain, remaining above the general level. During Tertiary time the streams cut to a second base level or peneplain, a little distance below the first, due to some slight elevation of the range. Near the close of the Tertiary, the whole range suffered differential elevation as a single great block; a great fault occurred on the eastern flank, and the old erosional surfaces were tilted gently to the west. The higher portions of the range were covered with lavas, and the old river channels filled by flows downward from the summit. Since then active erosion has gone on, carving the range into its present form. There are thus two

groups of rocks, separated by a great unconformity: pre-Cretaceous, composing the body of the range; and post-Cretaceous, or post-Jurassic, which overlie the first. The rocks of the first only, the slates, schists, and intruded plutonics, occur in the vicinity of Copperopolis; the gravels and lavas of the latter group are here lacking, though they occur but a few miles away to east and west.

ROCKS.

The rocks in the vicinity of Copperopolis, which all belong to the Bedrock Complex, are both of igneous and sedimentary origin, with a great preponderance of the igneous. Two divisions of these may be made: those which are largely metamorphic tuffs and breccias, represented by the meta-andesite and amphibolite schist formations; and the intrusive plutonics, represented by serpentine and talc, hornblendite, gabbro, and granodiorite. The pyroclastics are the older, and with the slates, the oldest rocks in the area; the plutonics are younger. The Mariposa slates occur as a thin tongue through the center of the Copperopolis region. Both ridges on east and west of the town are composed of the harder varieties of meta-andesites, with the softer rocks of the same formation, with the slate, underlying the valley between. Two miles to the north, where the two ridges approach closely, as shown in Plate VII., the amphibolite schist area wedges out in the schists of the meta-andesite formation.

A most important modification of the schists in this region is found in the large occurrence of chlorite schist, both microcrystalline and coarse-grained, through the center of the area.

The Jackson folio shows near the center of the south boundary line, the broader relations of the rocks around Copperopolis. The broad belt of amphibolite schist shown, however, wedges out rapidly just south of the sheet.

The rocks will first be described individually and then their inter-relations discussed.

*Mariposa Slates.*—The Mariposa slates occur here as a long, narrow tongue or wedge, which is about six miles in length. The northern end of this tongue is clearly shown in the Jackson



such wall pyrite is due to the action of waters containing sulphides upon iron-bearing minerals, but much more is clearly not thus formed. Certain rocks at times appear to act as septa, impervious to some mineral substances and pervious to others. In the chlorite schists at Copperopolis the chlorite has acted as the septum, impervious to the copper in solution, but permeable by the iron.

Few references have been made by geologists to osmotic action in mineral deposits; it would appear that here is a promising field for investigation, particularly in a laboratory way. Becker[1] and Lindgren[2] have noted some suggestive occurrences, the former being the first to suggest the application of osmotic action to ore deposits.

GENESIS OF THE ORE.

The ore is peculiar in its small content of minerals present beside the chalcopyrite and pyrite. The small amount of silica is the only one which was deposited with the sulphides, and some of this may be original in the schist. The ilmenite and sphene associated with the ore have probably resulted from the alteration of titaniferous pyroxene, similar to that change of the augite in the augite porphyrite. The waters carrying the ore were probably essentially alkaline sulphide solutions carrying copper and iron with small amount of silica. Solutions of such simple character were rather rare in this portion of the Sierra Nevada.

The source of the solutions and their copper content is connected with the hornblendite. This rock contains original chalcopyrite, and is always found with the ore in the chlorite schists. Two samples of the sulphide-bearing hornblendite were treated chemically, and the sulphide determined to be pure, or nearly pure, chalcopyrite. The granodiorite, containing original pyrite, was tested from a number of localities, but was unvarying in its freedom from the merest traces of copper. The conclusion is

[1] G. F. Becker, "Quicksilver Ore Deposits." "Min. Res. of U. S.," 1892, p. 21; "The Gold Fields of Southern Alaska," Eighteenth Annual Report U. S. Geological Survey, Pt. III., p. 68.

[2] W. Lindgren, "Gold Quartz Veins of Nevada City and Grass Valley," Seventeenth Annual Report U. S. Geological Survey, Pt. II., p. 183.

(*b*), a later deposit of chalcopyrite around pyrite, or (*c*) a small film of chlorite on one or all sides.

3. Veinlets of pyrite, regular or irregular, separated from classes 1 and 2, by schist films and walls. Chalcopyrite, when it occurs with these veinlets, is always later in age, and either is in the pyrite in small veinlets recognizable only under the microscope, or as solid masses surrounding kernels of pyrite. Rarely, a specimen shows that the pyrite-bearing fissure has been opened to the rich copper solutions and the pyrite partially dissolved. See Fig. 43, *A*.

A subclass under class 3 might be made, to consist of the pyrite-bearing schist outside the ore lenses. Such pyrite is composed of cubes and pyritohedrons at times one half an inch in diameter, and occurs in the rock near the ore shoots. Such material, in mode of formation, is in no wise different from pyrite-bearing slates and schists forming the walls of the gold veins of the Mother Lode.

There is a fourth variety of ore, which might be placed in a subclass in a scheme of classification. This is the quartzose ore connected with the granodiorite intrusions, and is the only ore in which free silica can be seen by the unaided eye.

From all these facts concerning the ore, but one mode of formation is deducible. Both macroscopic and microscopic evidence point to the different osmotic pressures of the two sulphides in solution, exerted throughout a rather prolonged period of ore deposition, as the true cause. This is in keeping with many facts elsewhere observed. The presence of cubes of pyrite in apparently impervious rocks near ore deposits, the growth of which has displaced the rock itself, is very common, and in the clay gouges of vein walls cubes of pyrite can frequently be found forming at present, as on the Comstock. It seems hard to escape the conclusion that the iron in certain solutions has a great osmotic pressure sufficient to carry it away from other minerals, including gold. For in so many mineral deposits the vein and wall rock both carry pyrite of the same age, with the vein pyrite rich in gold and the wall pyrite very lean or barren. Some of



folio. The southern end is found just south of the town of Copperopolis, near the concentrator building of the mining company. With the exception of the three small breaks or faults on the mining ground, this slate area is continuous throughout. The most northern of these faults, which is about one half mile south of the Jackson area, cannot yet be conclusively proven to be a fault; it is inferred from those which are more clearly developed. If this be not a fault, the slate then occurs as two overlapping lenses of different lengths. In the copper area the slate lens is then usually less than one hundred feet thick, with a maximum thickness of one hundred and fifty feet.

In color the slates are a dark gray to black. They are finely fissile and homogeneous. Under the microscope the fissility is strikingly shown, the laminations being exceedingly thin. The rock is chiefly composed of isotropic kaolin, with a few very small grains of clear, low-polarizing silica. The rock is quite full of dark-colored dust, irresolvable by the highest powers of the microscope. Frequently small parallel veins of fine-grained silica cut horizontally across the slaty structure.

The amphibolite schists do not enter the immediate area of Copperopolis, as they wedge out about two miles north of the town. Detailed description therefore is not necessary. The Jackson and Mother Lode Special folios of the U. S. Geological Survey give all facts here necessary concerning them. The best exposures found just north of Copperopolis show a finely schistose greenish rock derived from a tuff. The strike and dip conform to the characteristics of the other formations.

*Meta-andesite.*—The formation of various rocks placed by Ransome under the one head of "meta-andesite" makes up by far the largest portion of the area. The topography is due, largely, though not entirely, to the differences in resistance to weathering among these rocks. There exists a gradation from the tuffaceous, clay-bearing, soft schists into the hard, massive, resistant augite porphyrites. Intercalated with these rocks, as an integral portion in the Copperopolis area, is a comparatively thin bed, or series of beds, of a basic chlorite schist. This

chlorite schist grades into the slates on the one hand and into the augite porphyrite tuffs on the other.

The harder rocks of this formation outcrop boldly on the higher ridges east and west, particularly to the east. The microscope shows the most massive rock to be an augite porphyrite, with augite phenocrysts in a groundmass of augite and feldspar. Much of the augite is altered to chlorite, especially the larger crystals. The feldspar in the slides examined is so far decomposed that identification is impossible. A small amount of clear, original quartz and some grains of magnetite are present. Not only does this massive phase of the meta-andesite occur on the higher ridges, but it is also found close to the chlorite schists in the valley at Copperopolis. One prominent outcrop is one hundred feet west of the new shaft, in the footwall of the ore. The rock here is fresher than the ridge outcrop and shows a finer grain and some clear feldspars. These feldspars show extinction angles of from 8° to 12° and belong to the oligoclase-andesines. This same facies of the augite porphyrite has been cut in the Index shaft near the outcrop. The porphyrite here shows less altered than the others and besides augite, which is all chloritized, and feldspar, considerable titanite and a little epidote appear. In the ninth level in the cross-cut east from the shaft to the main drift a small amount of the massive porphyrite occurs closely associated with the ore-bearing chlorite schist. Particular notice is made of this occurrence because of the relations of the decomposing augite and clear grains of titanite. The augite is largely decomposed. Clustered around many of these augites, as if derived from them, are irregular clear grains of titanite. The rock also contains some areas of quartz. The feldspars correspond to those of the other similar rocks.

The massive augite porphyrite grade into the tuffaceous facies through the more finely crystalline varieties. These tuffaceous rocks, the typical meta-andesites of the formation, are distinctly schistose, often finely so, and of a light, grayish-green when fresh. These rocks are best exposed underground in the east cross-cut on the seventh level. Such facies show broken crystals



phery the fissures are less open and more pyrite is present; on the outside no openings are present which connect inside and outside, and pyrite only occurs. Further, when a single small fissure in the schist, containing chalcopyrite, becomes closed temporarily by a film of chlorite, the same fissure continued on in the rock contains only pyrite. Or, as is often seen, small openings closed at both ends, close and parallel to a larger opening

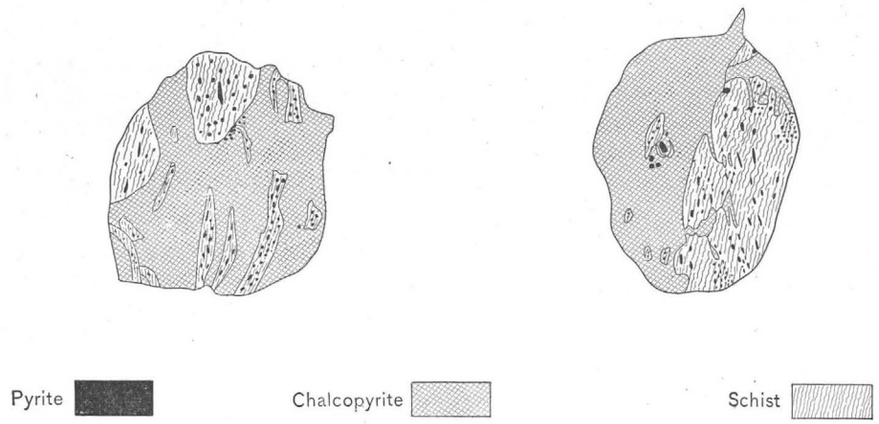



FIG. 48. Sections of ore showing relations of sulphides to schist.

containing chalcopyrite, is filled only with pyrite. Figure 48 shows such ore.

The ore may be divided into three quite distinct grades, varying as indicated. These are:

1. Veinlets of nearly pure chalcopyrite, in fully open fissures, with clear cut walls. A very small amount of pyrite is very intimately associated with the chalcopyrite, and visible only under a microscope.

2. Veinlets of chalcopyrite and pyrite intimately mixed; pyrite either fine or coarse; vein walls less perfect than in class 1; in less open fissures; and commonly separated from class 1 by a shattered wall of schist. Where pyrite is fine-grained the fissure has better walls and is more open to the man fissures. When pyrite is coarser it is due either to (*a*), less open fissures, or

tinuous from the shaft south to the creek south of the concentrator, and no doubt beyond; the west one is divisible into two. One of these is that developed by the Empire shaft; the other is to the south, exposed between the gabbro boss and the Empire tunnel, and outcropping best at the concentration. The tunnel cuts the north or upper portion of this south shoot. It is in this tunnel that the best specimens of hornblendite with chalcopyrite are found.

From the small granodiorite outcrop north of the Empire shaft two lines of intrusions radiate southward, approximately paralleling the ore shoots. The map and section *I–J* (Pl. VII.) show the relative positions of these. The face of the tunnel is almost to the westernmost, and the dome near the tunnel entrance marks the easterly. The one to the west can be followed by outcrops and in cuts to points on all sides of the gabbro boss and beyond. The east intrusion is the larger, and to the south half a mile exists in some large masses, forming low hills full of nearly horizontal quartz veins.

### RELATION OF ORE MINERALS.

It has been stated on a previous page that the two minerals, pyrite and chalcopyrite, are in general of the same age, but that some pyrite is older than some chalcopyrite. The full explanation for this fact is found in a marked peculiarity of the ore which has not yet been mentioned. It has also been stated that the ore lenses feather out into barren rock. Not only do the two sulphides both decrease in amount toward the exterior of the lenses, but also the relative amount of pyrite becomes greater from center to outside, eventually to the complete exclusion of the chalcopyrite. These facts hold true on all sides of an ore lens. Thus, an ore lens, in horizontal cross-section, is an elliptical mass, with rich chalcopyrite in the center and pyrite on the outside, with a zone of transition between. Careful examination reveals further that the change from chalcopyrite to pyrite is attendant upon the closing of the openings in the schist to mineralizing solutions. Where fissures are open, as in the inside of the lenses, there is nearly pure chalcopyrite; toward the peri-



of augite, feldspar and opaque dust, which is probably largely iron ore. In the tuffaceous meta-andesite in the ninth level crosscut, some traces of kaolin-like material occur, showing a transition to the clay slates. The transition is gradual, both microscopically (in the few slides examined) and macroscopically. In fact, the field transitions are strikingly apparent. The same holds true regarding the change from clay slate to chlorite schist. In the deep mine workings where the rocks are best exposed, it is often extremely difficult to distinguish the true clay rock from the slaty facies of the chlorite schist, and some specimens require the use of a microscope for identification. The tuffs, slates and the chlorite schists, in part at least, all seem to have been water-laid, and this relation of clay rock and pyroclastic may be a common characteristic throughout the meta-andesite formation.[1] Also coarse breccias, amygdalytes and conglomerates occur in thin beds in different portions of the formation. One bed of coarse breccia is worthy of particular mention. This has a thickness of from four to six feet and outcrops continuously for a hundred feet or so southeast of the concentrator. The rock fragments embrace coarse and fine grained hornblende-bearing granitic rocks, sometimes gneissic, with andesites and other related rocks.

The chlorite schists are briefly described by their name, the typical rock being composed of chlorite alone or with very small and varying amounts of sphene, magnetite, ilmenite, apatite, quartz and epidote. The color is commonly a dark grayish-black, varying to almost a jet-black in the more crystalline facies. The finer-grained rock is slaty in structure, with quite perfect cleavage. Under the microscope it is seen to be cryptocrystalline, showing many small spherulites between crossed nicols. A dusty kaolin-like substance isotropic between crossed nicols is also present in small amount, and at times in the rock near the slate crystals of andalusite occur. The coarser varieties assume an ordinary schistose structure and become almost massive in the coarser-grained facies. The variation seems to be due entirely to the

[1] J. D. Whitney, "Geol. of Calif.," Vol. 1, p. 254. A. Knopf, "Notes on the Foothill Copper Belt of the Sierra Nevada," p. 418.

change in size of the chlorite crystals. The coarsest grained phase is found in the North Keystone ground on the dump. In this rock the chlorite appears in apparently well-defined crystals. In all the varieties the most constant accessories are sphene, usually in clear, rounded grains, and ilmenite in platy crystals. A few well-formed crystals of titanite were found but are rare. The ilmenite is frequently associated with its alteration product, leucoxene. In some few localities, notably at the small incline on the Empire hill and from the footwall cross-cut on the seventh level south, magnetite in very perfect, small, octahedra occurs. Apatite with the usual characteristics is seen in rare crystals. Some clear quartz in rounded grains, or aggregations of grains, occurs in every slide examined. Epidote is quite common in certain portions of the chlorite schist, but is not usually noticeable to the unaided eye. The schist was probably derived from a basic augitic tuff, closely related to the augite porphyrites. An analysis of a specimen of schist is given below. The titanium was evidently calculated as $Al_2O_3$.

| | | | | | |
|---|---|---|---|---|---|
| $SiO_2$ | 36.30 | FeO | 17.52 | MgO | 3.40 |
| $Al_2O_3$ | 32.09 | CaO | 2.00 | $FeS_2$ | 1.02 |
| | | $H_2O$ | 6.85 | $CuFeS_2$ | trace |
| | | | | Total | 99.18 |

*Serpentine.*—The serpentine of the area occurs as a series of tongue-like intrusions all no doubt connected below the surface. A long, narrow area occurs to the north, on the area of the Jackson sheet, and it is the extension southward of this which forms the various occurrences at Copperopolis. Here it always lies to the west of the chlorite schist and ore. Its characteristics are the usual ones for serpentine in the foothills of the Sierra Nevada. Wherever exposed, the rock shows the effect of great lateral crushing. Under the microscope not sufficient structure remains to furnish exact data for determining the original constituents. Considerable calcite occurs in irregular areas and seams, and also numerous small crystals of iron ore. With the serpentine is always associated talc, usually schistose. The talc also occurs in separate dikes to the east of the serpentine areas.

*Hornblendite.*—The ultrabasic intrusives, other than serpen-



schist. From this fault two ore shoots proceed southerly: one to the east of the low ridge marking the ore ground; and one to the west. The easterly one can be traced on the surface to a point southeast of the concentration, where some very rich ore, much like that in the North Keystone, was mined. The westerly shoot has the richest outcrop on the property, with an abundance of cuprite veinlets near, and just north of, the concentrator building. The serpentine, while not appearing on the surface in more than the smallest traces, is continuous underground, and very near, this west ore shoot. A comparatively large amount of both talc and serpentine cut in the one hundred-foot incline just south of the Empire shaft, contains sufficient copper mineral in thin seams to constitute a concentrating ore. Fifty feet north of the Empire shaft the granodiorite comes to the surface in a small knob a few feet across. The comparatively large size of this tongue is no doubt due to its location in the broken and faulted zone existing here. The north and south sides of this intrusion pitch steeply downward. The action of this rock is finely exhibited in many specimens, and much rich siliceous ore has been taken from the Empire shaft. The unaltered ore near the intrusion can be seen gradually to change from the normal, with veinlets of sulphides, interlaminated with the schist, into a quartzose mass containing irregular spots of finely crystalline, greenish-black chlorite, with very irregular masses of recrystallized chalcopyrite. Some of the quartz contains well formed crystals of calcite, of the same age. Feldspar occurs in the quartz veins only quite near the main masses of the granodiorite.

From surface outcrops and shallow cuts, it is very probable that a second tongue of granodiorite is present still further west, as shown in section *I–J*, Pl. VII. In this southern section there is a great development of the various intrusive rocks, which increase quite regularly in volume from north to south. On the surface of the Empire ground this is not altogether apparent, but the Empire tunnel shows clearly the under-surface relations. The position of the two ore shoots is indicated on both sections, *G–H* and *I–J*. The east shoot seems to be con-

fact by itself would indicate that the ore shoots in this direction overlap *en echelon* southwestward, similar to those to the north. However, the serpentine approaches nearer the slate in this portion of the ground, so that there can be but little, if any, overlapping of the lenses. The individual shoots are from thirty to sixty feet wide and several hundred feet in length, in a horizontal cross-section. More work of exploitation must be done before a more careful statement of size can be made.

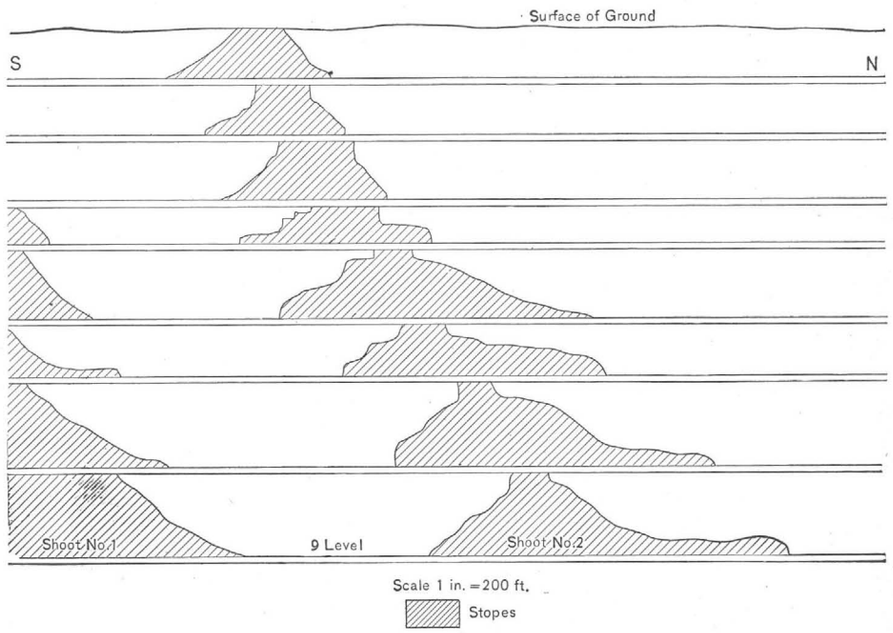



FIG. 47. Longitudinal section through ore bodies.

*Empire Section.*—In the third, or Empire section of the ore-bearing ground, no deep workings are now accessible, so that the geology of the depths is only to be inferred. The surface geology is given on the map, Plate VII., and sections *G–H* and *I–J* give the arrangements of rocks near the surface. The fault separating the middle and south sections is shown rather diagrammatically, as it is usually impossible to draw sharp contacts between slate and



tine, while not rare in the older rocks of the Sierra Nevada, are yet in small amount. Hornblendite, as a distinct species, has received no notice in either the Jackson or Mother Lode folios, or in Turner's[1] papers upon the rocks of the Sierra Nevada. There is, however, considerable development of hornblendite at Copperopolis, though the actual outcrops are few and very insignificant. It is mapped under the ultrabasic family name of pyroxenite, as its affinity with this group needs emphasis, because of the rock relationships in the Sierra Nevada. This rock shows on the surface at but four points, only two large enough to map. These two exposures are near the North Keystone shaft, east of the ore body, and near the present working shaft, Union No. 1, west of the main ore outcrop. One small boulder-like occurrence exists to the north, just off the map, Plate VII., and the fourth is in the ravine east of the concentrator. Underground the conditions are different, and a large mass of hornblendite is cut in the Empire tunnel. (See section I–J, Pl. VII.) Small dikes of the rock are found also at different parts of the mine workings, as shown in sections 2 and 3. These small dikes show much squeezing, and it is frequently possible to pick out detached fragments from the schists.

In color the hornblendite is black when fresh, with at times a mottled appearance, due to small amounts of feldspar. In grain it varies from coarse, with crystals often one inch across, to porphyritic, with large idiomorphic hornblendes set in a finer hypidiomorphic granular mass of hornblende and feldspar. The latter is the most common type. The coarse-grained rock has no feldspar except in traces; the other variety has a small amount, usually less than 10 per cent. Under the microscope the hornblende is seen to be of the common variety, strongly pleochroic, and partly altered to chlorite. Many crystals of hornblende show veinlets of nearly colorless chlorite parallel to the cleavage, and the whole blotchy with secondary products. Some shreds of bio-

[1] H. W. Turner, "The Rocks of the Sierra Nevada," Fourteenth Annual Report, U. S. Geological Survey, Pt. 2, p. 441 et seq. "Further Contributions of the Rocks of the Sierra Nevada," Seventeenth Annual Report, U. S. Geological Survey, Pt. 1, p. 529 et seq.

tite are also present. The feldspars are much altered, frequently saussuritic. The extinction angles range from 19° to 21°, corresponding to labradorite. The only accessory minerals beside biotite are a few grains of titanite and chalcopyrite. The chalcopyrite is intergrown with the hornblende, and in the hand specimens grains can often be seen entirely within the boundaries of large unaltered hornblendes. This sulphide is not evenly distributed throughout the mass of the rock, but varies irregularly from none to 1 or 2 per cent. Further, the grains may be either irregularly distributed or arranged roughly parallel to veins of colorless amphibole.

*Gabbro.*—Gabbro occurs in only one location in the Copperopolis area, as a small boss near the south end of the ore ground now being developed. See Plate VII. The roughly circular outcrop is bordered east and west by serpentine, and north and south by a facies of granodiorite. The color is a greenish white. The grain of the mass is medium, but some of the rock broken for smelting purposes is coarsely crystalline, the individual crystals being from one half to three fourths of an inch in diameter. Diallage and feldspar in about equal amounts, with a little accessory pyrite, make up the entire rock. The diallage exhibits no characteristics out of the ordinary, and the feldspar is so badly altered that precise identification is not possible in the slides examined. Much secondary calcite is present in irregular areas. The old term of saussuritic gabbro seems quite appropriate until more detailed study can be made. The following partial analysis, made at the mine, indicates the composition of the rock.

| | |
|---|---|
| $SiO_2$ | 45.50 |
| $Al_2O_3$ | 20.58 |
| FeO | 3.52 |
| CaO | 12.44 |
| MgO | 10.12 |
| $FeS_2$ | 1.11 |
| Alkalies | not determined. |
| Total | 93.27 |

The crystals exhibit some bending and fracturing, due to the strains to which the rock has been subjected.



faults is due entirely to the granodiorite and in part to the earlier hornblendite. This curving of the slate was present in some part, at least, before the introduction of the ore, for the arrangement of ore lenses is connected genetically with this form of the clay rock. The clay slate itself has exerted an influence upon the ore in two ways. First, because of its impervious nature, the mineralizing solutions did not penetrate it and therefore it acts as the hanging wall of the ore zone. Second, because of its toughness, it acted somewhat as a restraining force against the opening of the schist zone just before the introduction of the ore, for the ore lenses are now found to feather out as the slate is approached.

The ore occurs as a series of overlapping lenses, often arranged *en echelon,* each lens being composed of a complex series of bands or veinlets of chalcopyrite and pyrite deposited mainly parallel to the foliation of the schist. These lenses or shoots pitch downward to the north as shown in section 11. These lenses are not separated by barren ground, but ore of poorer grades laps across from one to another. By poorer here is meant that ore poorer in quantity of sulphides; it must be kept in mind that the ore varies in copper content in two ways: change in amount of sulphides present in the schist and change in the relative amounts of chalcopyrite and pyrite. These ore lenses, or shoots, as they are termed locally, have a rather definite arrangement. The lens or shoot worked in the early days, known as shoot No. 1 (see Fig. 47), lies close beneath the slate from the present working shaft extending a few hundred feet each way in the lowest workings. Further north and south the ore becomes poorer until finally it is no longer sufficiently high grade to win. Northward the main drifts on each level are extended partly as crosscuts. At the end of the shoot No. 1 on each level the drifts bend sharply to the west, cutting across the strike of the rock and ore.

To the south the ground is not opened up, but from the southernmost drifts the slate hanging wall is seen to be bending to the southwest, in prolongation of the curve concave westward. This

the mine, but contains an abundance of pyrite. The physical effects of this intrusive are of great importance, particularly in winning the ore. The ore, the inclosing schists, and to some degree the slate hanging wall, all exhibit a vast number of faults, of two general series. One of these is made up of a small number of nearly vertical faults cutting across the ore formation at about right angles, and dipping either north or south. In the few faults of this kind examined, the throw was always such that the wall nearer the granodiorite moved out. More mine development is needed before these can be studied fully.

The other fault series consists of a vast number of small, nearly horizontal, displacements, striking approximately with the vein and dipping slightly to the east. These have been dismissed on a previous page; here it becomes necessary to describe their effect on the ore. In a small way this effect causes the ore seams to be displaced to the east on the lower side (see Fig. 43, *B*) and apparently has no great value practically. In a large way, the aggregate of all these individually small displacements has caused the ore to dip eastward much flatter than the dip of the planes of schistosity. Or in other words, the ore makes toward the hanging with depth. The faults show some evidence of increasing in size and throw with depth, as a few small lenses of ore have been cut off at their bottom and found some feet to the east going downward.

This faulted structure is characteristic chiefly of the ground now actively being mined. The ground both north and south fails to show this in so marked a degree, the reason being the larger development of the intrusive rock in the central portion. (See Plate VII.) And this maximum effect has been exerted differently in the schists and the clay slates. The chlorite schist is thoroughly faulted; the slate, on the other hand, has been bent rather than broken, though locally sharp-cut small faults do occur, of the same strike and dip as those in the other rocks. Also, the faults are shown by broken but straight laminæ. Thus the slate is slightly concave to the west, with a decreasing easterly dip. The change in dip, due to the series of small flat-lying



*Granodiorite.*—The granodiorite outcrops in a series of irregular areas more or less parallel to the strike of the schists. These outcrops decrease in size from south to north, and eventually disappear. The most northerly exposure is near the North Keystone shaft. As with the hornblendite, much more of this intrusive is exposed in the mine workings, and no doubt can exist that the various exposures are all part of one large intrusion, whose top is exceedingly irregular. This top may be said to consist of a series of tongues extending upward approximately parallel to the foliation planes of the schists. A few of these tongues have been cut below ground. From all facts known concerning the granodiorite distribution, it is concluded that the main intrusive mass must be at considerable depth. The various sections and map show well the occurrence of this and other intrusive rocks.

On the surface the granodiorite is greatly altered; the fresh rock is developed only below the surface. The color is a light gray; and the grain medium fine. The texture is hypidiomorphic granular. The essential minerals are hornblende and biotite, now altered to chlorite, with both orthoclase and plagioclase and abundant quartz. The proportion of plagioclase to orthoclase is about as 2 is to 1, in the slides examined. The plagioclase is oligoclase, with extinction angles of about 9°. The chief accessories are sphene and pyrite. Some of the sphene and pyrite are associated with epidote, ilmenite and leucoxene, in chloritized hornblende, and may both be secondary in part. Other sections show both these minerals associated with clear original quartz and feldspar, and therefore original. The pyrite is in abundance. Strained and broken crystals show the effect of dynamic forces.

A different phase of the granodiorite is found on the Empire ground, both as outcrops and in the Empire tunnel. This is a white fine-grained rock, showing to the unaided eye glistening cleavage faces of feldspar and much pyrite in cubes. The microscope shows idiomorphic feldspar in a finer-grained mass of hypidiomorphic granular mass of feldspar and quartz. Quartz is not present in great amount. The orthoclase shows frequent Carlsbad twins; the plagioclase is identical with that in the

normal facies of the rock. Spots of chlorite represent the original ferromagnesian minerals. Pyrite is original, as in the common phase of the granodiorite.

Two other varieties of the granodiorite need mention. The small outcrop in the creek bed just west of the present working shaft, is a more acid facies. It shows chiefly orthoclase and quartz, with about one fourth plagioclase. Traces of biotite are present in shreds, with a very little chlorite and iron ore. The fourth facies is a basic modification which occurs in the Empire tunnel and elsewhere as a contact rock. The variation from normal in this appears to be in the greater amount of hornblende and the greater relative amount of orthoclase.

### RELATIONS OF THE VARIOUS ROCKS.

Although all the details cannot yet be deciphered, yet sufficient evidence is available to establish some definite relationships of the various plutonic intrusives, and by inference, the relative ages of the rocks can be made out quite satisfactorily. It has been stated elsewhere,[1] by the geologists of the U. S. Geological Survey, that the amphibolite schists and the meta-andesites are contemporaneous in part with the Calaveras slates and in part with the Maripose slates. At Copperopolis, there is most frequently a gradual transition from the very slaty facies of the finer tuffs to the true clay slates, and the whole series seems to be of one age. Thin beds of pebbly conglomerate at times are found with the transition rocks between slates and schists. These rocks may then be regarded as the oldest of the area, into which the later plutonics have been intruded. The serpentine, probably an altered peridotite, was the first of these. Besides its dike-like character other evidence of its intrusive nature is found north of the area mapped, near the south line of the Jackson folio. Here the slate strikes a few degrees more northerly than the serpentine, with the result that the two rocks come into close contact. At the contact the serpentine has pressed up beneath the slate with such force that

[1] Mother Lode, Special Folio, U. S. Geological Survey, Jackson Folio, U. S. Geological Survey.



ness of the mineralized belt. It has affected the ore both chemically and physically—in the first way, locally; in the second throughout large volumes. As is common with acid intrusions, it has not only intruded the schistose rocks but has also partly dissolved and recrystallized them along its periphery. The rock immediately in contact with the granodiorite and for a number of feet above the top of an instrusive tongue is invariably silicified and many small veins of white quartz seam the rock in the vicinity. The pegmatitic nature of such material is evident and its nature too well understood to require further comment. Where these quartzose veins cut ore, the quartz is often ore-bearing, where barren schist is cut, no sulphides are ever present. But the quartzose veins which traverse the ore are peculiar in that the sulphides in the quartz are on or near the schist walls and are not dispersed throughout. Where the ore in schist has been rendered quartzose, the sulphides show the dissolving and re-

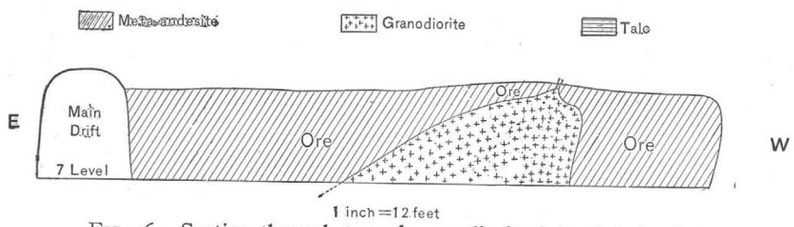



FIG. 46. Section through top of granodiorite intrusion, level 7.

crystallizing effect of the superheated solutions and are evenly dispersed. The finest example of the action of the pegmatitic solutions on the ore comes from the Empire ground. The development of this siliceous ore is a factor of considerable economic importance as there is great need for such material in smelting.

Figure 46 shows the top of a single granodiorite tongue. Ore is plainly seen above the intrusive rock in the schist. This ore is all siliceous, for two or three feet above the granodiorite. Also, the outer portion of this rock is a contact phase, representing the product of the fusion into the schists of the intrusion, and contains some scattered chalcopyrite. The body of the normal rock is absolutely devoid of copper, as tested chemically at

The influence of the various rocks upon the ore and the mine development forms a most interesting portion of the geology. Beginning with the oldest of the intrusive rocks, the serpentine, the effect of each upon the ore will be described. The serpentine is unquestionably older than the ore, for thin films and seams of chalcopyrite occur as coatings in the gliding planes of this rock. Only in a small portion of this intrusive does any ore occur, for the nature of the rock is such that mineralizing solutions cannot find ready circulation. The deposits of chalcopyrite and pyrite mark a peculiarly open portion of the mass. But there is no doubt that the serpentine and talc did act as the western wall of the ore solutions, and if ore is ever found west of the serpentine it will be because of an independent duplication of conditions.

The hornblendite at first appears to be a negligible factor. Where it is found in the underground workings it is associated

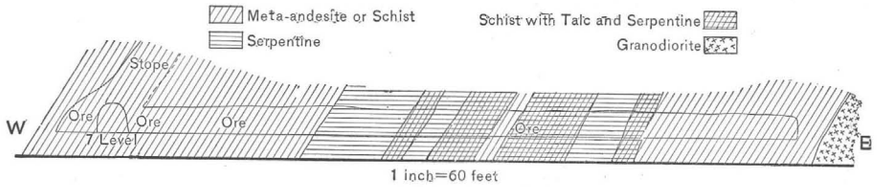



FIG. 45. Section in crosscut on level 7, south, showing ore in serpentine.

always with the ore-bearing schists and itself contains original grains of chalcopyrite. A few small squeezed and distorted dikes are to be located on careful search on the three lowest mine levels. All facts noted point to this intrusive as the one responsible, mainly at least, for the formation of the ore.

All the rocks thus far mentioned in this section, together with the slates, show evidences of much pressure and movement. All are likewise of earlier age than the ore, the hornblendite being in part also contemporaneous. The granodiorite, on the other hand, shows some, but comparatively little, evidence of the action of dynamic forces and is distinctly later in age. This rock as shown on the surface and developed under ground, exists as a series of tongue-like intrusions in, or bordering upon, the ore zone. Its presence here is no doubt due to the comparative weak-



the slate is very strongly bowed, convex eastward. Also, the serpentine is in comparatively large amount at this joint.

Intruded into the serpentine at two different places are granodiorite and gabbro. The granodiorite-serpentine contact shows perfectly the relative ages of the two rocks. The former lies to the west, and near the latter becomes fine grained, due to rapid cooling. To the east of the contact plane is first a foot of talc schist, followed by one and one half feet of talc somewhat schistose, with the normal serpentine farther east.

The serpentine and gabbro are usually considered as about of the same age. However, the distribution of the two suggests strongly an intrusive character for the gabbro, and the surface cut turns this into certainty by exposing the chilled finer grained periphery of the gabbro in contact with schistose serpentine. It is probable, however, that the relative difference in age is not great, on account of the close petrographic relations of the two, and their invariable close association wherever found.

No contacts of normal granodiorite and gabbro could be established, but exposures of quartz-feldspar veins in silicified schist exist near the gabbro, cutting the gabbro-serpentine contact, and of later age. This quartzose material can be traced into normal granodiorite at other points.

The hornblendite has as yet been found actually cutting no rocks except the schists. It is intruded by granodiorite in a very fine exposure in the Empire tunnel.

On chemical and petrographic grounds it is likely that the basic rocks, serpentine, gabbro, and hornblendite, are relatively of about the same age. The serpentine is without doubt the oldest. Of the other two, the hornblendite shows greater effects due to dynamic forces and is taken to be the older. These relative ages will be assumed until further facts disprove them. There is, then, the following succession of intrusive plutonic rocks, beginning with the oldest:

1. Serpentine, from peridotite.
2. Hornblendite, as type of pyroxenite.
3. Gabbro.

4. Granodiorite.

Turner[1] gives as the succession of pre-tertiary igneous rocks of the Sierra Nevada, the following:

1. Intermediate, effusive,—greenstones and diabases.
2. Basic, intrusive,—serpentine and pyroxenite.
3. Acid, intrusive,—granodiorite.

This in keeping with the Copperopolis area, although no distinction is made between the various ultrabasic rocks.

### STRUCTURAL MOVEMENTS.

Faults are not common on the west flanks of the Sierra Nevada, but the area under discussion shows a few which are well developed. Also, movements of a different character, small individuallv, but of the greatest importance collectively, are developed in the slates and schists, chiefly in the latter. Further, the movements producing schistosity in this region of weak rocks, have been long continued, as shown best by the ore. There are thus three distinct types of motion, and the results of each are vastly different. The largest movements are those of ordinary faulting, with a large horizontal displacement. The second type is shown best and perfectly in the ores, and consists of a vast number of reverse or thrust faults, each fault seldom having a throw of more than a few inches. The third type is that motion which has produced schistosity, and has resulted (1) by processes of dynamo-metamorphism, in the production of the slates and schists from ordinary sediments and volcanic extrusives; and (2) by long continued movement, in making the schists more schistose and the ore itself characterized by slickensided surfaces. More in detail, these are described as follows:

1. *Major Faults.*—There are three faults coming under the head of major faults, two of which are fairly well established and occur on the mining property. The third, or northerly, is yet problematical. The slate tongue described as occurring on the Jackson sheet comes to a sudden end about half a mile south of the end line of the mapped area, at the junction of the road

[1] H. W. Turner, "Age and Succession of the Igneous Rocks of the Sierra Nevada," *Jour. Geol.*, Vol. III., p. 414.



*Union Section.*—Shaft No. 1 is used as the working shaft and for detailed description the main interest centers here. The ore is not entirely confined to the chlorite schist, but is found also in some small amount as sulphide films in the gliding planes of the talc and serpentine. A similar occurrence will be noted for the Empire section, to the south. This ore in serpentine has not yet been sufficiently developed to become of economic importance, but should become of value in the future, for quite an amount of sulphides occurs in this manner. The walls of the ore zone are in the main well defined. This statement must not be taken to mean that all is ore between the walls of the ore-bearing ground. The clay slate is unequivocally the hanging wall of the ore in this section. Serpentine, when it occurs, as it usually does, forms the footwall, though commonly the workable ore fails to extend quite to this rock. A dike of talc, occurring a few feet east of the serpentine mass, often acts as the approximate footwall of the ore now mined. (See Fig. 44.) The

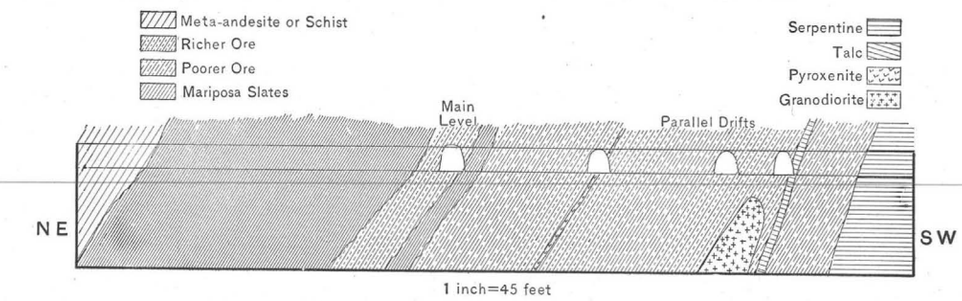



FIG. 44. Generalized section across ore on lower levels.

hornblendite is in the midst of the ore. The granodiorite is in no way connected genetically with the ore; to the south it often lies beneath the workable ore; to the north it is near the hanging wall slates; while in the center of the section ore occurs on both sides of and above it. Three sections show the ore zone and walls in cross-section; sections *C–D* and *E–F*, in Pl. VII., and Fig. 44, a generalized section in the lower mine workings. The more massive phases of the meta-andesite occur to east and west of the ore zone.

about six hundred feet deep. Here the ore occurs in the most massive variety of the chlorite schists, and from what ore and waste are on the dump appears, on the average, to be the richest on the property. The arrangement of the rocks in this portion of the ore-bearing ground is largely inferred from occurrences southward. Serpentine, as is common, is on the foot, with hornblendite on the hanging. A small intrusion of granodiorite is present between these walls, outcropping as a thin dike in the tunnel one hundred feet north of the shaft. (See Pl. VII., section *A–B*.) The influence of the slate is problematical. The main belt is too far to the westward to have exercised much control over the circulating waters, but there are some tuffaceous beds nearer the shaft which have probably acted as impervious walls. From the North Keystone shaft northward, the strike of the schists bears westward into the hill on the west of the valley. The slate belt, from field study alone, appears slightly concave eastward opposite the shaft, but changes its course to more westerly toward the north, paralleling the schist strike. Owing to the intimate relations to the clay slates and finer tuffs, only a careful microscopical study will suffice definitely to locate the true slates. Further to the north, outside the limits of the map, the ore-bearing schists come into close proximity to the slates, and the hornblendite is only about one hundred feet east of the clay rocks. Hence, northward it is to be expected that the slates act as the footwall of the ore.

The rock present on the North Keystone dump shows that the ore seams are arranged not only parallel to the foliation planes but also cut across the schistosity, forming a reticulated mass of roughly rhombic form. The ore is more slickensided, showing evidence of considerable pressure and movement. The main distinctive characteristic of the ore in the first section is its arrangement into an anastomosing series of veinlets. This structure is due to the more massive character of the inclosing schist, which made it nearly as easy to be broken across the schistosity as parallel to it. Nothing can now be stated regarding the ore in place.



from Copperopolis to Milton with the road to San Andreas. The strike here does not change, but is a direct continuation of the tongue to the north. The meta-andesite bounds the slate on the south, as well as on the other sides. This point is on the east side of the valley. Proceeding on a line southwest across the valley, another outcrop of slate is found in the bed of the creek at the west side of the valley. This is just north of the limits of the map, Plate VII. This occurrence of slate can be traced by exposures in and near the creek to a point southwest of the North Keystone shaft, where it disappears. The strike of the slate is the usual one, except toward the north near the supposed fault, it bends gradually to the west. The facts upon which the inference of faulting are based are in the main two: (1) Demonstrable faulting of like throw further south; and (2) the topographic and geologic details at the line in question. The following generalized sketch map illustrates the topography and geology at this point. The rather heavy erosion of the small creek just east of the point where the slates disappear is very suggestive of a line of weakness due to motion in the rocks.

The second slate lens is continuous, as above noted, to a point southwest of the North Keystone shaft. Further south the slate is found displaced to the east, to the line of the outcrops of gossan and copper ore. The further facts tending to prove the existence of faulting here are: (1) A large number of individually small faults in the bed of a small stream here flowing westward across the formation, at right angles to the creek; (2) the presence of perennial springs along this line; (3) the displacement of the western ridge to the west, north of this line, with correlative broadening of the valley; and (4) the cutting of the creek across the western ridge of harder schists at this line instead of continuing to flow southward over the softer schists and slates.

Following this next slate area south, it is found outcropping on the line of the main mine workings as far as the concentrator building. Careful search, however, reveals the presence of a third fault just north of the Empire shaft. Here the fault is proved not only by the evident displacement, but also by a very

fine example of a slate friction breccia. This is best exposed in a surface cut a few feet north of the shaft. From this exposure the slate is followed to a point just beyond the south end of the precipitation boxes, in the creek. See Plate VII.

*Small Faults.*—The second type of rock movements is shown best in the ore and ore bearing schists on the lower mine levels. Small thrust faults, of little throw, dipping steeply both east and west, and rather flat lying, easterly-dipping thrusts shown in the ore seams, compose the visible effects of this motion.

Obviously, the cause of this structure might be pressure from either west, or east, or both. In the upper levels these pressure phenomena are less noticeable, increasing in size and number as greater depths are reached. The first impression received is that a horizontal force from the east has acted to produce the motion. Further search, however, makes it certain that the motive force has come from the west and below, the force due to the intrusion of granodiorite.

The movements producing schistosity belong to the greater orogenic movements which have resulted in the formation of the range. Therefore they need no further notice in this brief paper. The details which it is necessary to discuss will be taken up further in the second part dealing with the ores.

## PART II.

### ECONOMIC GEOLOGY.

#### ORES.

*Nature and characteristics.*—The ore of the Copperopolis belt is notable for its few minerals and its great purity of copper produced. This character is strikingly different from the other copper ores of the region. The ore at Campo Seco contains much zinc, with both gold and silver; the Poole mine, eight miles northeast of Copperopolis is somewhat similar to Campo Seco in minerals present, but contains galena in addition; the Napoleon mine eight miles west of Copperopolis, contains galena in addition to zinc, with some gold values and some copper ore



and similar appearing occurrences of pyrite without copper. The outcrop of the copper ore is marked by a heavy gossan, so that any heavy limonite deposits or stains in the immediate vicinity of the copper ground may be taken to indicate the presence of copper below. But heavy iron croppings do occur near the vein, which are entirely free from copper. The granodiorite has been described as frequently heavy with pyrite, and often dense, nearly solid masses of this mineral were found overlying this intrusive and genetically connected with it. Such pyrite is not cupriferous, and carries some values in gold. This is in striking contrast to the same mineral in the ore.

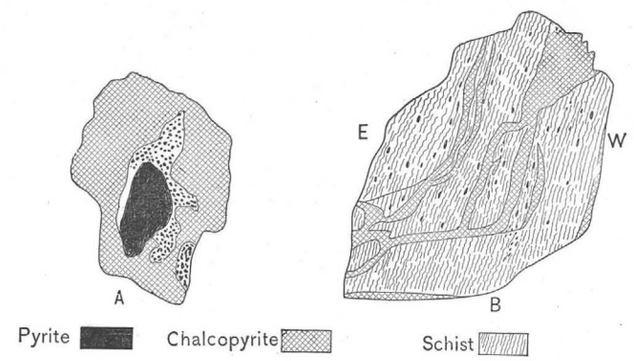



FIG. 43. *A*, pyrite inclosed in chalcopyrite; *B*, ore in schist.

For the sake of simplicity the ore bearing ground, at present only partly developed, will be divided into three parts, separated by the two faults discussed. See page 396. Beginning at the north, the first, or North Keystone section, lies north of the north fault; the second, or Union section, lies between the two faults; and the third, or Empire section, lies south of the south fault. In the second only has any deep underground examination been possible.

*North Keystone Section.*—In the North Keystone section the facts presented are based upon the surface geology, together with a few surface cuts, one short "grass-root" tunnel one hundred feet north of the North Keystone shaft, and the rather large dump at the shaft, which shaft is reported to be

no case is the ore pyrite found later than the chalcopyrite. At times eyes of pyrite occur partially dissolved and surrounded by nearly pure chalcopyrite. See Fig. 43, *A*. The bearing of these facts upon the ore genesis will be discussed later. It is sufficiently accurate to state that, in the great mass of the ore, the two sulphides are of the same age.

*Occurrences.*—In describing the ore occurrences and the ore bearing zone, general characteristics will first be given, followed by detailed description of the separate portions of the productive ground. The rock which incloses the ore is a chlorite schist. This rock constitutes the sole gangue with a few exceptions to be noted later. It occurs both thinly fissile, when it has much the appearance of the clay slates, and massively schistose, when it has a very rough uneven fracture. The more massive variety contains the richest ore. The other gangue minerals are quartz, quartz containing recrystallized chlorite, and quartz-calcite, or quartz-feldspar veins. All this material is relatively in small amount, and is genetically connected with the granodiorite intrusions in different parts of the ore zone. A few thin seams of sulphides may penetrate the slates, but in no sense can this rock be regarded as ore bearing.

While it is true, speaking from an economic standpoint, that the ore has no well defined walls, it is also true that the ore bearing zone has rather definite limitations, particularly in the ground at present being exploited. The slate, wherever it occurs, has acted as an impenetrable wall to the mineral solutions, forming either a foot or a hanging wall of the ore. In like manner serpentine, or talc, at times has acted as a barrier to the mineral bearing currents.

In general, the richer ores follow the foliation planes of the coarser schist, approaching only to, or near, the tougher, more fissile, fine grained tuffs or clay slates and the dense serpentine. The granodiorite, because it is of later age than the ore, is of no importance in the present connection. The hornblendite, where it occurs within the ore zone, may be regarded, like the schist, as ore bearing.

It is necessary here to distinguish the surface ores of copper,



from near Hodson, two miles west of Copperopolis, is rich in zinc. The unaltered copper mineral in all the ores is chalcopyrite, which at Copperopolis is associated only with pyrite and contains no gold or silver values. Published accounts[1] of the various copper properties of the foothill copper belt give grounds for believing that the Copperopolis deposits are different, in age and conditions of deposition, from all the others.

At Copperopolis the ores are divisible into the two usual classes, surface, or oxidized, and deep, or unaltered. The surface zone of oxidized ore is very shallow, thirty feet or less, and a zone of secondary enrichment is entirely lacking. This is no doubt due to the fact that the intense lateral pressure in the rocks has prevented the formation of a vadose circulation. The actual surface is characterized by extensive gossan, in which occur seams of malachite, often very rich, coating the schist. A very small amount of azurite occurs, particularly toward the south. In the Empire ground, south to the concentrator, cuprite is found. Some very rich ore of this kind has been mined within a few feet of the concentrator, to the north. In a small incline shaft a few feet south of the Empire shaft, cuprite appears as small flakes in the gliding planes of serpentine and talc. The ground to the south, from the Empire shaft to the gabbro boss, shows the largest amount of oxidized ore, due to the greater shattering of the rocks by the latest igneous intrusives.

Beneath this oxidized zone occur the original sulphides: chalcopyrite and pyrite in a gangue of country rock, the latter being usually chlorite schist. The richest ore is pure chalcopyrite; the copper content is lowered both by admixture of pyrite and of country rock. The presence of too much schist or other rock makes a low grade concentrating ore; too much pyrite produces eventually waste material. Both the sulphide minerals, which occur relatively in all proportions, are found in thin veinlets or bands in the foliation planes of the schists, with a small amount in the gliding planes of the serpentine and talc. These

[1] Calif. State Mining Bureau, Bull. 23. A. Knopf, "Notes on the Foothill Copper Belt of the Sierra Nevada," Bull. Geol. Dept. Univ. Calif., No. 17, Vol. 4.

bands vary in thickness from one sixteenth of an inch or even less, to three or four inches. Rarely masses of chalcopyrite two or three feet thick are found, though the richer ore, consisting of a series of rather thin veinlets, is almost solid sulphide. In the richest ore, the individual bands of chalcopyrite do not always follow the planes of the schists, but form a reticulated mass seaming the rock in all directions. The appearance of such ore is much as if the original veinlets were in two series crossing at right angles, which were later squeezed into approximate parallelism.

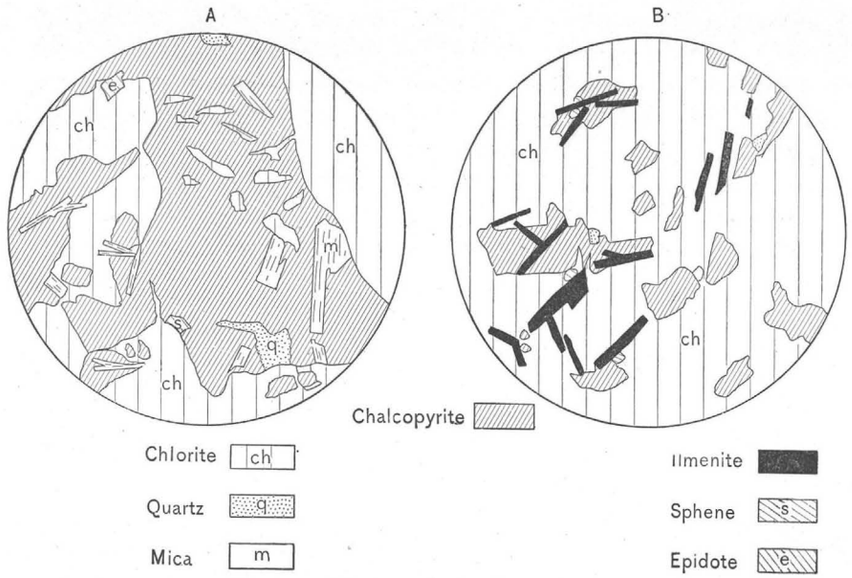



FIG. 42. Microscopic sections of ore.

Under the microscope the normal phase of the ore shows a few noteworthy characteristics. The sulphides are distinctly later than the chlorite, but are intimately associated with some of the other minerals present. Besides the chlorite, epidote, sphene, and ilmenite are present in small and varying amounts. In the interior of the ore seams the sulphides have no connection with any other minerals, but along the borders there is frequently an intimate association with ilmenite, sphene, and under some



conditions, epidote. The latter mineral is in part earlier than the ore and in part of the same age. The same holds true, in part, for the titanium minerals, though the ilmenite is almost always deposited with the sulphides. This association is probably due to the action of the original mineralizing solutions, which produced from the schists a portion of the epidote, sphene, and ilmenite, and dissolved and redeposited a large part of the remainder. The pyrite and chalcopyrite were deposited with these. The granodiorite has also had some effect upon the ore containing the epidote and titaniferous minerals. Some hematite has been produced from the ilmenite and all the minerals have been dissolved and reprecipitated with feldspar and quartz in addition. Some small amount of quartz, in microscopic grains, always accompanies the ore. In a few sections abundant plates of a micaceous mineral allied to muscovite are crystallized with the ore. Fig. 42 shows some of these characteristics.

Below is an analysis of a low grade, or concentrating, ore. No titaniferous mineral except traces of sphene are present.

ANALYSIS OF ORE.

| | |
|---|---|
| $SiO_2$ | 21.14% |
| $Al_2O_3$ | 14.10 |
| FeO | 13.91 |
| $Fe_2O_3$ | 11.51 |
| CaO | .69 |
| MgO | 8.50 |
| $K_2O$ | trace |
| MnO | trace |
| $P_2O_5$ | trace |
| $H_2O$ | 6.90 |
| $FeS_2$ | 9.10 |
| $CuFeS_2$ | 11.12 |
| Total | 96.97% |

*Paragenesis.*—In age the two sulphides are the same, although some chalcopyrite is later than some pyrite, for the deposition was continuous during considerable rock movement. Typical thick veinlets of ore, consisting of both chalcopyrite and pyrite show the two minerals crystallized in a most intimate mixture, each on the other. Other specimens can be found which show heavy massive pyrite cut by veinlets of pure chalcopyrite. In

~~Anchor Lode – // to above, 200 yds. W, wholly in rhyolite. 2/3 mi. long. ZnS increases with depth. Some malach. in gossan. Gangue barite.~~

~~Copper City – 4 mi. S Bully Hill. Ore-body mostly copper bearing ZnS. Gangue chiefly barite.~~

---

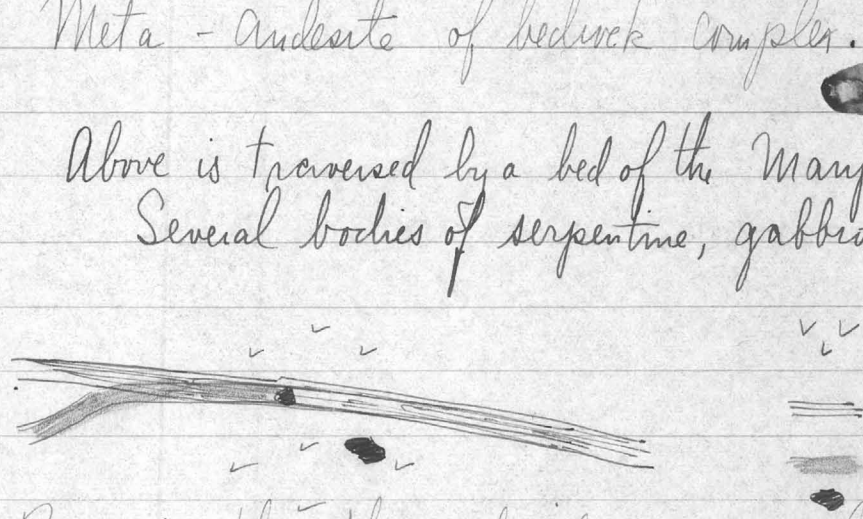
Sierran Foothill Cu. Belt. Fairly persistent N–S.

Copperopolis – 12 mi. from Angels.

Meta-andesite of bedrock complex. Prevailing rock.

Above is traversed by a bed of the Mariposa slates.

Several bodies of serpentine, gabbro, grano-diorite.



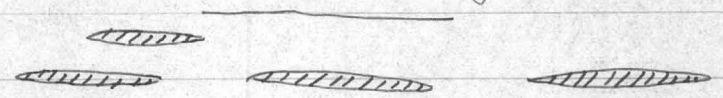

Running thru the andesite & associated with the slate is a belt of typical chlorite schist. This is the ore gangue. The ore is oxidized to a depth of 30' – carbonate & cuprite.

Chalcopyrite & pyrite are the S ores, occurring in varying proportion. There is no secondary enrichment, & this was to be expected from the presence of carbonates & cuprite instead of limonite.

The "rich ores" (direct smelting) occur (1) in lenses up to 3'; (2) in portions of the schist where the sulfides are reticulated thru the schist, & (3) in disseminated parts. The concentrating ore occurs as (3), in less proportion.

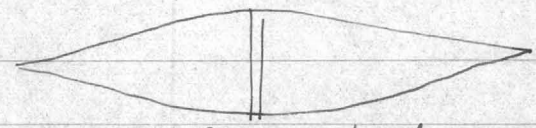
The ores minerals seem to be later than the schist, as they follow the schist foliations.

The minable ore bodies lie in lenses following each other or overlapping.



Plan.

The ore bodies may be 30-60' wide, & be mined for a distance of several hundred feet.



Plan

The max. Cu. content is in the thickest part, & the % decreases as the lens thins out.

Napoleon Mine. 6 mi. SW Cu-opolis.

Sep. from Cu-opolis by a mile wide belt of Mariposa slates. Prevailing rock is a massive quartz-porphyry, in contact with a hornblendic amygdaloidal meta-andesite, 100-500' thick. The quartz-porphyry shows a chilled edge against the andesite, indicating later formation. The andesite was a flow, as it is accompanied by tuffs. The country has been sheared along the contact line, & here the andesite → chlorite schist.

The qtz. porphyry has been changed into sericite schist along the contact — "talc schist."
Width of shear zone = 30'

⊥ N 75 W
62° S

Ore — Chalcopyrite with $FeS_2$, $PbS$, $CaCO_3$, in lenses in the schist.

HW — qtz porph.
FW Chlor meta-andesite.

Zn ore present in some places. The unchanged meta-andesite has been impregnated with sulfides on the margin of the shear zone.

---

Spenceville — Rock an amygd. meta-andesite, traversed by shear-zone belts of chlorite schist, 4' wide

⊥ NW
90°

Lenses of mashcaned rock in the midst of the schist.

Ore — $FeCuS_2$ in the schists, acc. by stilbite. Pinch out in depth.

---

Campo Seco, Calav. Co.

Black Mariposa slates ass. with tuffs, congl., greenstone schists of basic complex; a belt of qtz. porphyry, the Cu-bearing rock, in 2 belts separated by a belt of tuff (200' wide); the 2 porphyry belts converge finally.

The qtz. porphyry has been changed to a sericite schist, full of lenses of qtz; due to shearing.

Ore - $CuFeS_2$, in the sericite schist; there itself shows some shearing, showing that some ore was formed before process of shearing ended.

Ore in lenses 30' wide; 8 - 10 % Zn in some parts; Au $1-3; Ag $1-3 (50¢ avg)

Faults cut off the ore in the deeper levels, but careful cross-cutting & sinking have found it again.

REPORT ON HIGH-GRADE COMPLEX ORE, CALAVERAS CO.CALIF.
C.Erb Wuensch (PENN, NAPOLEON,QUAIL HILL & OTHER MINES).
Feb.22,1941.

ABSTRACT

Seeks deposits to exploit his sink and float process.

Favored central mill.

Properties under consideration aggregate 250,000 tons ore,ave.grade:

Au .07-.25 oz. Ag 3-10 oz. Cu 4-6% Zn 8-12% Pb ½ ¼-2%. Thinks over 1,000,000 tons additional can be developed.

Area SW of Copperopolis

Napoleon Mine.- 7 miles from Copperopolis.

Report by R.N.Dikcinson & J.H.Farrell, June,1928.

History: Discovered 1860,expoited,closed 1866.Unwatered 1887,worked intermittently until 1916,continuous operation, 1916-1919, Closed then,afte War I. By 1866 opened to depth 400',300-400' lateral development. Most of this early production from one shoot 65' long, 6-20 ft.wide. Authors estimate OB 10-50' in (horizontal) section would produce 12,000 tons at 10 cu.ft.per ton. This is haywire. Possibly 60' long x8' wide, x 250' depth - 12,000 tons. CEW says wrong,more than this shipped in sorted ore and concentrates,and more than this tonnage of milling ore on dumps. Says mining selective to get Cu,avoid Zn

Geology: CR greenstones,schists etc. Napoleon vein N75W,70-75° S;to E swings to N50W, 67SW.,but no UG work here. (Authrors could see only surface and lessees tunnels on W half of claim). Lines of regional schistosity trend N35-40W,dip 75-80,usually NE. Vein cuts across. Likely that ore deposition tended to follow these schist bands locally making off main vein,and that UG work consisted in part of drifting on these rather than along main shear zone. May be one reason why ore reporte erractic,since branches or lenses of this sort would pinch out on strike and dip away from main ore channel.(CEW:Imp.Their map shows definite displacement along shear zone.

Main zone offsets stratigraphic contacts,but little effect on ore. Width of vein zone as shown by parallel shearing 50-100'.OBs may be anywhere within this velt.

Rock formations: S of vein CR fg siliceous,probably QP. Under mike fg.GM qtz.,felds.phenos of orthoclase and qtz.Rhy porph. Possibly originally QDP,silicified by HT alteration. Main shoot where this rock forms HW. N of vein (FW) rock highly altered,kaolinized;mike shows DP. From both these rocks & possibly from seds.are developed schists of area. Schists highly sericitized near vein,pyritized,much 2ndary qtz.

Can't tell about ore shoots-original OC removed or covered by caved matter and waste dumps. By early accounts OC strong.FeOx with some CuOx & carbs. Better ore carries $3-10 Au,so its presence near surface indicate by panning;sure enough colors panned below OC;barite in pan also.As check, panned and assayed croppings of silicified schist. No significant Au or barite. Heavy pyritic parts of vein easily eroded,soil-covered,need

trenching. Not done. Oxide zone very shallow.

Ore of main shoot doubtless mixture of cuprif.py.,ccpy,blende with qtz., kaolin, barite. From massive sulphides to low-grade mill ore.

Shoot, 60-70' long, 6-20' wide,dip 70S and raked 70 to E in plane of vein. Mined,surface to below 250' level. Conlficting reports as to pinching with depth,going low-grade,faulted. Quit twice with low Cu prices. CEW: Penn Mine Campo Seco 3500';Copperopplis 1500',ore in bottom. Authors think ore should go down..

Chances for Ore: See plan. Apparent localization where schist belts in HW join main shear zone at acute angle. Authors: E of Vertical shaft thick s il covers OC;but 500' east is well-marked schist belt with traces of mineralization intersecting main shear zone. Should give conditions similar to those W of Vert.Shaft,where another schist belt intersects the vein from the HW and where good ore found. Do surface prospecting here.

Old-timers thought schist belt SE of 4000N, 6000E was main vein;NG. Thinks Fe-staining,some limonite but no Au,Cu traces in samples,near 4000N,6500E has some promise and recommends trenching;but is just outside property.

"The only part of the vein which may be rated as possibly productive & which may be easily prospected by surface workings is that toward the west end of the claim." Lesseees have started tunnel to go 280' west along vein from Oleson Shaft. This ground accotding to records never been prospected. Only 35' back max.but show explore top of sulphide zone .120' from entrance ( now in 60') should reach best part of vein as indicated by OC.

Conclusions:Thinks mine not thoroughly explored for downward extension of main OB. 250 ft.level lateral work far from conslucive on finding other shoots along strike of mineralized zone. Chances good for more ore both at depth and laterally. Trench supposed E extension of main vein. Prospect whole belt,ight find possibly productive area big enough to justify exploration and development on larger scale. Napoleon would make excellent starting point.

Wuensch Comments and Additions: Developed to 375' but bulk of production from above 250' level. 15,000 tons ore shipped,ave.:
Au .20 ($7),Ag 4.0 ($3.60) Cu 7% (about $17), Zn 12% (about $15),Pb 1%. (present liquidation value, March,1952,about $45).

Thinks 30,000 tons milling ore: Au .08 ($2.80),Ag 3.0oz ($2.70) Cu 1.5% (about $4.50), Zn 5% (about $6).(Present liquidation value about $15). Gives no evidence for all this.

~~Dennidxon Report,1/31/52~~

Calif.State Division of Mines,Bull.144,1948.

Plate 45,Geol.Map Napoleon areashows no such structural unity as Farrell plan. QP S of Napoleon zone more or less chacks;but diorite is mainly QP or Amador volcanics, elongated roof pendants in the big QP mass. Amador altered to greenstone,green schist. Most of F's schist areas are in Amador but some in QP and Heyl,Hadley & Gilbert show schistosity in QP as well.

# NOTES ON FOOTHILL COPPER BELT.

However latter workers admit they do not show the N shear zone.

Shear zone,mentioned only between vert.shaft and open cuts is in QP and felsite close to contact of these with Amador volcanics. Cuts across regional schistosity.

Mine 430' deep,4 main levels at 100,250,300,375.

1942*43 Mt.Copper Co. rehabilitated vert.shafy.280' deep. Drilled 10 holes from 250' level,as shown on plan. Two surface holes.Hole 4 cut small lens near collar,others blank. Main drift, 250' level,described as in sericitic schistose felsite width of drift,strong N or FW dips 75S, sparse Cu and/or ZnS

Ore a replacement deposit developed along "a shear zone",the latter having been formed close to the contact of a large body of intrusive QP and felsite. Ore shows intimately IG Cu,Zn,Fe sulphs,carry Au,Ag. Barite among gangue minerals,sericite WR alteration product.

Old maps,records show 3 irregular lenticular shoots,largest Discovery, 60-70' long,6-20' wide,mined down 250' or more. Below this,2 smaller lenses,between 250 and 375' levels.Lenses,indivudially and as a group pitch E 65-70°.

Donaldson,Report of 1/31/52, with Huseby consutling,affirms Mt.Cu Co.drilling disproved the mine. But if Farrell right on structure,and nothing in Gilbert et alii paper or maps to deny this,their drilling was nonsense. Surface Hole 2 started where F puts the OC,and went SW,presumably down,to test an NG schist belt. Hole 11,surface,started and ended in the FW,even according to Gilbert's map. On 250' level,all holes collared along or near the ore zone,and went N or S,up or down at flat to moderate angles. Nof a single hole cut the vein zone.

A lens averaging 12% Zn, 100 ft.long, 15 ft. wide and 300 ft. deep would contain about 10,000,000 lbs zinc or 10,000 tons of 50% concentrate

H.E.Bush Report on Napoleon Mine,Oct.20,1940. Made from old Seeley Mudd data.

Profitable small mine. 50 t/day. Mt.Copper did what he recommended, possibly on his urging, 2 yrs.later:unwatered vert.shaft,est.at $5000. But they did not clean out 250 ft.level to W,in stoped area.Only drilled for parallel lenses..

After 1860-1866 operation, Seeley Mudd and Peyton Chemical Co.of S.F. reopened;mined mostly shipping ore from old stopes. No zinc reported Shipped to Peyton Chem. on Bay where S 1st recovered for acid. 1906-07.

3rd period:1916-1919,D.D.Coughanour leased mine from Mudd and continued leasing from Edward H.Nutter who meanwhile bought ppty. Small flotation mill,bulk concentrates,Cu-Zn. Sold for copper,heavy Zn penalty. Fracaso. C told Nutter after closing there was perhaps 15 to 40,000 T Zn ore above 250.On fringes of his stopes,which were to 20-25' wide. Letter to Nutter,2/2/18:Stoping about ½ way between 250 and 150 ft.Levels have worked up on FW leaving HW in good shape to mine mill ore.Some ore in place,FW,10-20% Zn.

Apparently little or no stoping below 250, so this zincy ore described in this and similar letters ought to go below 250. Howevef,VLP furnished by Bush says on 375' level:6" to 20" high-grade streak for 160',HW. This apparently is from Seeley Mudd section or map.

Bull.144 Collier:1/2 mi.SE of Napoleon.probably on same general zone.Opened in 60's, gold found in gossan above OB.1917-18 shaft sunk to 58',56' level developed some sulphide ore shipped. 1942 development carried on by E.A.Vogt,regular shipments,May 43 to July 44. In this period 2 additional levels developed ,5613 tons ore produced. Ran:

Au .09 ($3.15);Ag 4 oz ($3.60);Cu 1.5%, Zn 11% (about $13,present)
Total liquidation value about $20)

Shaft 51°,levels at 56,124,167' on incline. Mine developed along flt. zone,which follows or is close to contact of intrusive QP with Amador Ju greenstones,bedded tuffs. OB a replacement sulpide lens which has on its FW the E-dipping high-angle flt. Thus main fault dips other way from Napoleon;but felsite still on SW,Amador on NE. Fault has many spurs in HW or NE block. FW flt,dips NE 44-70,ore formed where dip low,ore piches where dip steepend. Plunges N 45°. Ore IG ccpy,ZnS,Py,barite. Pyritization extend considerably along strike past pinching edge of lens. Oxides go down only 36'.

1944,USBM drilled 2 holes to explore below mine workings;2 more holes 825 and 975' to NW under shallow workings of Little Quail Hill. All found Zn,copper,gold,silver minerals but no ore. Presumably all holes drilled from surface. CEW says strong irreg.shear zone roughly paralellels that of Nap. Some good gossans.

Quail Hill.-About 2 mi.NE of Nap.Bull.144: Near N end of 5 mi.belt of Cu-Zn mines and prospects developed in Aamador volcanics and in QP,felsite intrusions.

Operated Sept.42 to Nov.44. 2 comp.vert.shaft 280',levels 70,170,205, 270. Open stopes,filled or allowed to cave. ~~Found Napoleon also but less gold there,but Nap.samples assayed 30% Cu.~~ ~~Shxredxearlyxproduxtixxxof~~
Quail Hill 1st mine located in foothill belt.1860. Gossan worked for Au. Same man found Nap.but panned less Au there.However assayed for Cu-30%. Nap and Quail Hill produced Cu together in 60s. Then no record of production until 1917,Quail Hill M.C.operated,mined ore 3 yrs. Mainly from above 170' level. 1938 brief activity,Bullion Gold & Silver M.C. Small production. March 43 until late 44,idel,renewed 1945.

Production,Zn lb.s,43-45: 2,064,071.Total Cu prodiction,1917-1945,905, 000 lbs. Amador volcanics; extending NW from mine body of felsite 1900' long NW, 1500' wide (extends farther NW) Cuts across volcanics. Both types meta to low-grade schists,greenstones. Schistosity NW,dip NE 50-70. Bedding dips NE less steeply than regional clravage.

Felsite NE contact dips steep E,cross-cutting.Shearing,brecciation along contact,localized at salients. Felsite emplaced before orogeny,at shallow depth.

Ore shoots pods,lenticular masses,formed by replacement of felsite breccua alogg faults & shear zones adjacent to intrusive contact. Pyritization hako around OBs.mincreasing in intensity with approach to ore. Contact mai

ore channel.

Main shoot a few ft, NE contact Shoot dips steep E,plunges 68 SE.

Mined above 170',War I.,extended 75' above that level,where it pinched as inverted keel,trending 20° E of N. Widens downward,below 170 gets more equant in horiz.cross-section,then tapers to funnel,pinches out at 240'. As a whole parallels adjacent felsite HW.

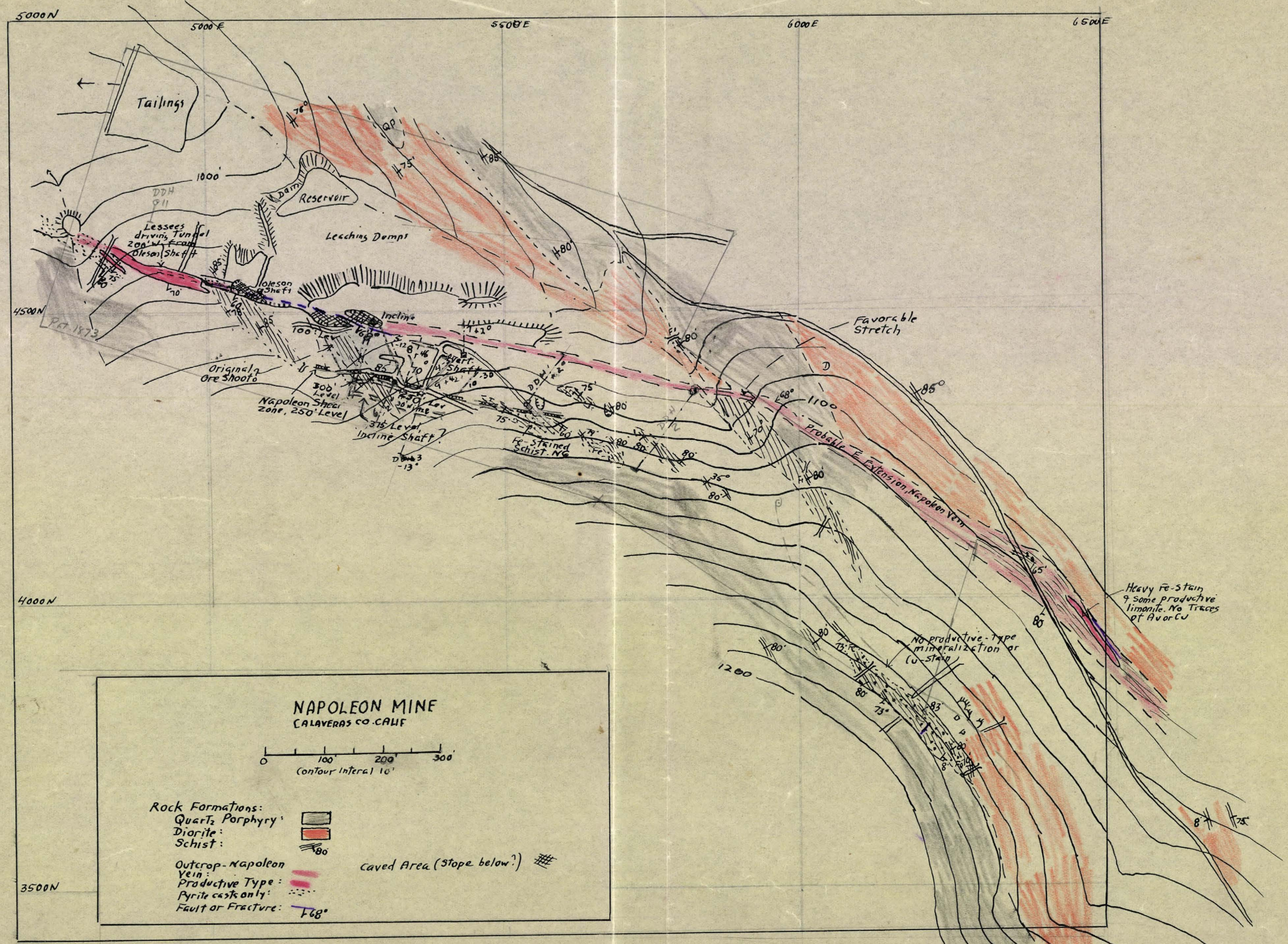
Whole shoot high-grade. War I 2622 T shipped Tacoma, 5.6% Cu,15.60% Zn,0.40 oz.Au,6.51 oz Ag. Later,lower ore similar grade.

Faults bounding parts of this and smaller shoots premineral,localizers. Ore like otjers,including barite/

DD from 270 shows zone of strong mineralization in which knwon OBs lie comtinues downward on established trend. No holes have explored full width of mineralized zone. Good chances at depth.

p.122: "In prospecting for additio al ore rserves,the most favorable ground is that lying along the trend of the downward extension of the strongly mineralized zone. The detailed mapping and examination of salients on the felsite contact exposed at the present eorsion surface,and the location by geophysical metjods of unexposed salients which may be present,are probably the most feasible methods for systematic prispecting at this locality."

Gopher Hill Bull.144. ½ mi.SE Quail Hill. Vert.shaft,2 short levels @ 40,80'. 1943 uneatered by Calaveras Consol.Cu Co.of Copperopolis,3 holes drilled from shaft bottom. Negative.Vlose to N ,argin of irreg. QP intrusion, 500 to 700 Diam. Intruded into Amador.Similar to Quail Hill. Strong NW steep shear zones developed in QP and adjacent gray felsite. Most intense within intrusion,close to margin. S.t. strong sericite. Pyritized, carry Au,Ag.but no Zn,Cu seen in place.


5000N
5000E
5500E
6000E
6500E
4500N
4000N
3500N
Tailings
1000'
DDH #11
Dam
Reservoir
Leaching Dump
Lessees driving Tunnel 200' W/ From Oleson Shaft
Oleson Shaft
Incline
Pat. 1873
Original? Ore Shoots
300' Level
Napoleon Shear zone, 250' Level
375' Level
Incline Shaft
Fe-Stained Schist. NG
Favorable Stretch
Probable E. Extension, Napoleon Vein
1100
1200
Heavy Fe-Stain & Some productive limonite. No Traces of Au or Cu
No productive-type mineralization or (U-stain)
NAPOLEON MINE
CALAVERAS CO. CALIF
0 100' 200' 300'
(contour interval 10')
Rock Formations:
Quartz Porphyry:
Diorite:
Schist:
Outcrop-Napoleon Vein:
Productive Type:
Pyrite casts only:
Fault or Fracture:
Caved Area (Stope below?)

Foothill Copper Belt -

See Notes on the Foothill Copper Belt of Calif.
A Knopf U. C., Dept. Geol. Vol. 4 No. 17,
411-23. Aug. 1906.

Replacements along shear zones in foothill greenstone
belt. Py - Cpy., S.T. with Gal - ZnS - Zeolites.

Nassau Copper Co., Calaveras Co., Calif.

Report by H.L.Huston to Hugh Rose,1/20/17.

Location.-One claim on Poole Ranch.sec.9 and 10,T2N R12E; 6 mi. W of Angels; 4 mi. from Copperopolis. Road from Angels to Cooperopolis passes with 200 yds.of mine.

Nassau Vein.-In belt of amphibolite and talc schist 80-100' wide trending regionally N29W,dip 67NE. Schist pyritized,and parts of belt, especially on W side,carry low-grade Cu and Zn. Nassau ore bodies occurred on E or HW side of belt,as solid siliceous vein 1.5' to 12' wide,with high Zn and enough Cu.Au, Ag to make shipping ore. Vein as stoped ave.3'. On 100' lev. shoot stoped 200' N of shaft,500' S with S face still in ore. Ave, analysis of ore from smelter receipts:

| | |
|---|---|
| Au | 0.25-0.30 oz. |
| Ag | 5-6 oz. |
| Cu | 6% |
| Zn | 13-17% |
| Pb | 3-3.5% |
| Fe | 5-7% |
| S | 22-25% |
| Insol | 50-55% |

2- comp. 280' vert.shaft,main levels at 95 and 200'. 95 lev. drift 200' N from shaft, 800' S. On 200,N drift 400', S drift 500'. Vein stoped practically to surface above 95 for 550'. Above this level the vein south of the shaft where the stoping was done is well exposed in the drift,and is still in place. On 200,vein stoped 200' N of shaft,250' S. Left on this level ground N and S of the shaft aggregating 250' opened up by S drift, now ready for stoping. Shaft sunk to 280',said to show 2' shipping ore. About 20,000 tons partly developed.

THE FOOTHILL COPPER BELT OF CALIFORNIA.

P 247-250

C.F.Tolman: from Copper Resources of the World, XVI Int. Geol. Congress, Washington, 1933.

Three types of Foothill copper deposits: massive lenticular pyrrhotite-copper deposits,with zinc and gold; massive lenticular pyrite-copper-lead-zinc deposits,with gold and silver; tabular pyritic copper-lead-zinc-gold-silver deposits. All three types formed by replacement of schistose effusive and intrusive members of bedrock complex.

Selective replacement of a favorable band of schist gives tabular ore bodies (fahlband);less selective replacement of more homogeneous schist forms large lenses of cupriferous pyrite and pyrrhotite.

The mines and prospects of central part of belt are aligned with outrops of favorable schist bands. Individual lodes or belts range from 1 to 20 miles long; en echelon . See Fig. 15.

Geology.- Detailed study limited to pyritic ores of main belts from Valley View to Copperopolis. Bedrock chieflt meta-volcanics, amphibolite, meta-andesite,greenstone. Main rocks meta-andesite,meta-rhyolite. These cut by irregular intrusive serpentine,gabbro, pyroxenite, and by sills parallel to layering of metavolcanics. Hard to distinguish these sills from the flows. Metavolcanics occur cheifly between the Calaveras (Carbonif.) and Mariposa (Jurassic) slates,and also interstratified with the Mariposa. Schistosity is parallel to layering of volcanics. Strike NW,dip 45-90E. Schistose formations form a synclinal block,closely compressed into secondary isoclinal folds,bounded on N,E & S by the Sierra Nevada batholith;interripted on the W near Ophir by cupola stocks,offshoots of the batholith.

Lodes and Shoots.-Metarhyolite ore layers metamorphosed into qtz-sericite-pyrite schist;basic ore layers, into chlorite-epidote-pyrite schist. These mineralized layers called lodes. Metallization far more restricted than mineralization,forming flat lenses or steeply plunging narrow ore shoots,

Outcrops.-The mineralized bands carry gossan and exposures of leached friable schist locally copper and iron stained. Some of these gossan being worked in 1935 as low-grade gold deposits. Ore not confined to any one schist type,although in mineralized meta-rhyolite in c central part of belt.

Mineralogy.- All tabular complex lead-zinc-copper deposits of central part of belt are very similar ~~in xxxxxxxxxxx~~ except Copperopolis. Ore minerals of the tabular group are intricately intermixed py,ZnS,rare tetrahedrite,ccpy,rare bornite and PbS. The more abundant minerals both include and are margined by the other minerals. Mutual bdries they the rule. Detailed study however shows prgressive deposition, minerals introduced as listed above. After extensive pyritization later minerals partly or completely replaced available residual gangue fragments, In complete replacement the replacing minerals occur as inclusions. The contact between the older sulphides and the gangue was vulnerable to attack by later minerals;hence marginal relations of the gangue sulphides around the older sulphides are common.

The massive pyritic lenses carry less ZnS and ccpy than the tabular deposits,galena is rare and bornite and tetrahedrite absent. Order of introduction was sphalerite, ccpy, galena.

Selective Replacement.- Shown by preservation of schistose layering in the banded ores.

Sulphide Enrichment.- Supergene white chalcocite,blue chalcocite (submicroscopic mixture chalcocite and covellite) covellite,cut the hypogene minerals in sharp reticulated veinlets. A central core filled with soft powdery minerals represents the original crack,and the 2ndary sulphides have eaten out into the various primary minerals. No enriched ore found more than 50' below water table. Enerichment materially increased copper tenor of ore only rarely.

Structure of Ore Shoots.-See pencil-shaped faulted Campo Seco shoot. Lode here quartz-pyrite-sericite schist. Note lack of exploration outside main shoot.

Origin of Deposits.- With the doubtful exception of pyrite accompanied by silificic.,sulphdes were introduced after metamorphism of CR. Mineralization and metallization not limited to basic facies of the schist nor related to local intrusives. Like S.N. gold deposits, copper mineralization of foothill belt was later than S.N. batholith intrusion and later than contact meta.connected therewith.Extraordinary similarity of foothill ores along a line parallel to Mother Lode for 100 mi.and a regional variation away from this line,toward the granite batholith in a similar fashion to the Au deposits indicate a similar genetic relation to the batholith.

Distribution of principal groups of gold-quartz veins of the S.N. shown on plan. Mother Lode mesothermal;mineral association of gold-bearing deposits shows a regional variation,changing to hypothermal types on the N, E and S, toward the batholith. The E lode contains such high-T deposits as pyrrhotite, arsenopyrite and magnetite,and some of the lodes are cut by dikes that represent the end products of batholithic intrusion. Mineral association also indicates higher-T ore deposits toward the N,toward Grass Valley,and to the S,in the CM schists caught up in the granite.

Similarly the foothill copper deposits show a regional variation in mineral composition,with higher T types toward and in the granite,where pyrhhotite takes the place of pyrite as the dominant sulphide.

Above facts suggest that both the gold-quartz deposits of the S.N. and the pyrite and pyrrhotitic base metal deposits (replacement) of the foothill belt are results of a widespread regional mineralization,an after-effect of the batholitic intrusion.

occur chiefly between the Calaveras (Carboniferous) and Mariposa (Jurassic) slates and also interstratified with the Mariposa. Schistosity is parallel to the layering of the volcanic rocks. The strike is northwest, and the dip is 45°–90° E.

The schistose formations constitute a synclinal block, closely compressed into secondary isoclinal folds and bounded on the north, east, and south by the Sierra Nevada batholith, and interrupted on the west in the vicinity of Ophir by cupola stocks which are offshoots of the batholith. (See pl. 15.)

*Lodes and shoots.*—The ore-bearing members have been mineralized into quartz-sericite-pyrite schist (mineralized phase of metarhyolite) and the more basic rocks into chlorite-epidote-pyrite schist. These mineralized layers are called lodes. Metallization and the resulting introduction of copper, zinc, lead, gold, and silver was far more restricted than mineralization, giving rise to flat lenses or steeply plunging narrow ore shoots. (See fig. 23.)

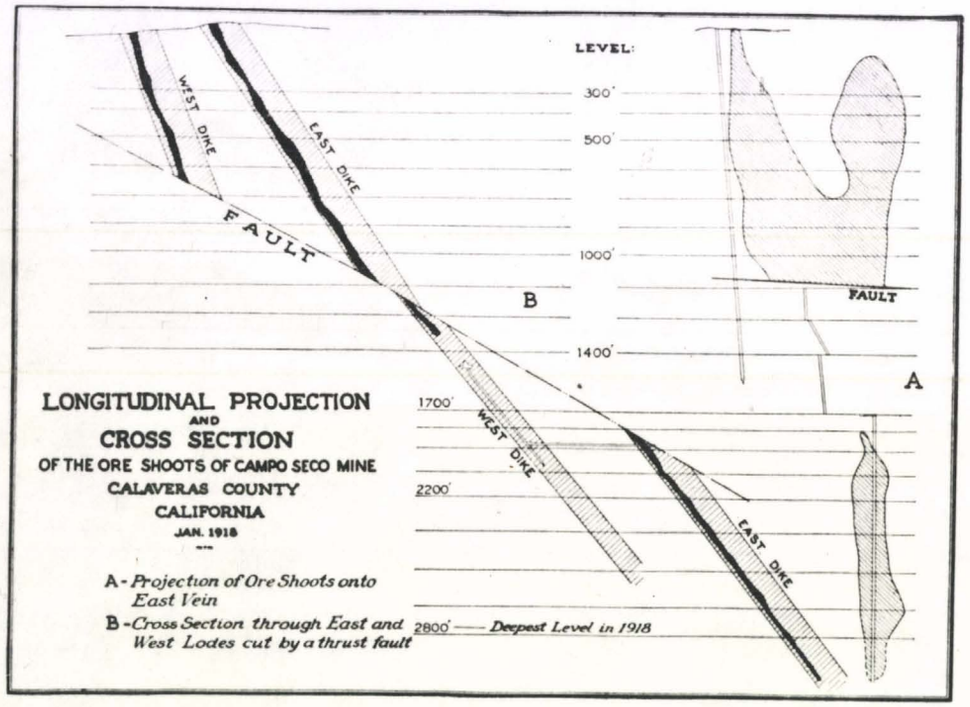


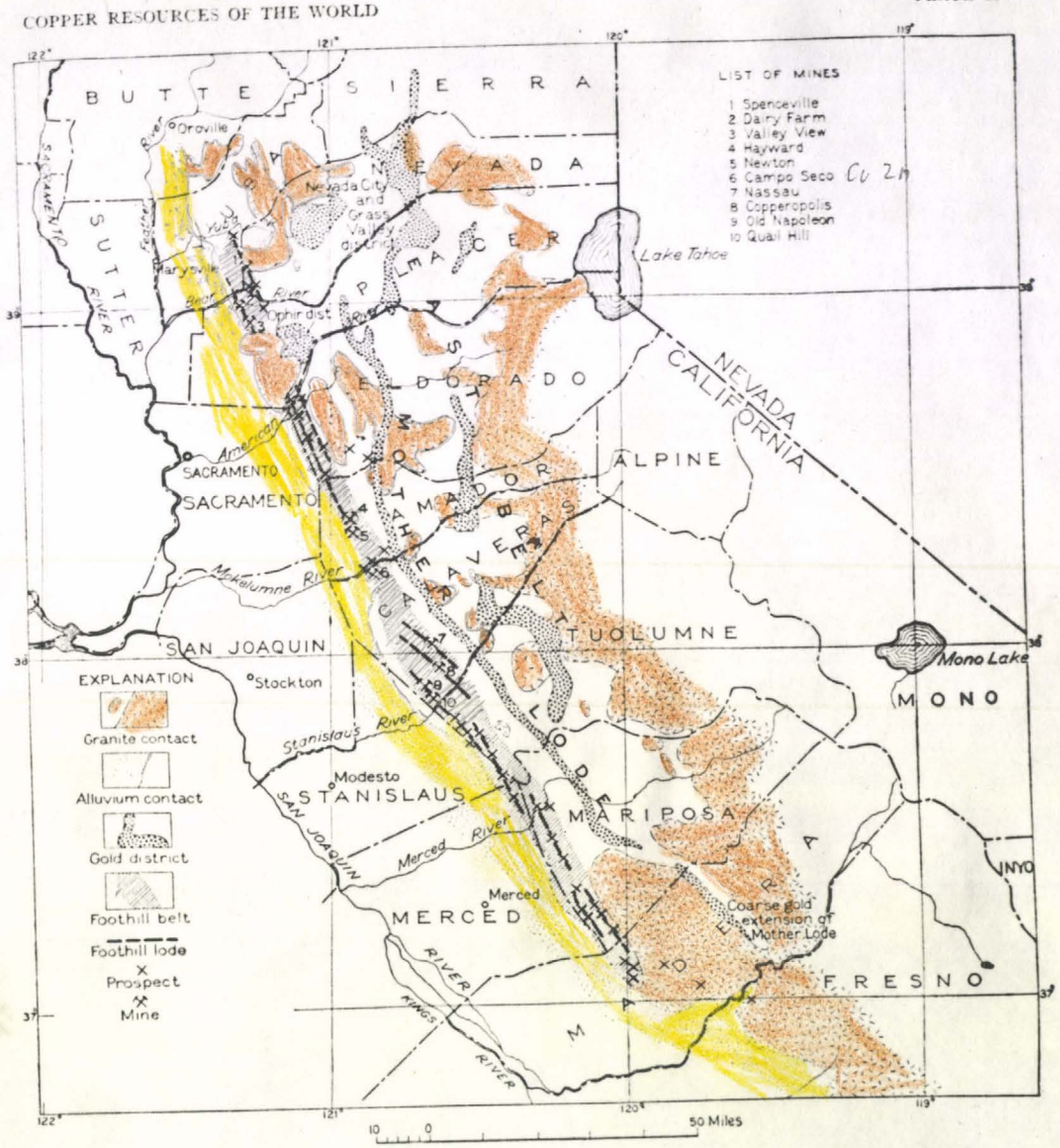

FIGURE 23.

*Outcrops.*—The mineralized bands are marked by gossan outcrops and exposures of leached friable schist locally stained with copper or iron salts. At a few localities soluble salts of copper, zinc, and iron occur as an efflorescence on the outcrops of the ore-bearing schist. Some of these gossans are now (1935) being worked as low-grade gold deposits.

The ore is not confined to any one variety of schist, although it commonly occurs in mineralized metarhyolite in the central portion of the region.

*Mineralogy.*—All the tabular complex lead-zinc-copper ore deposits of the central portion of the foothill belt are very similar in occurrence, mineral association, and accompanying rock alteration, with the one exception of Copperopolis.






MAP OF THE FOOTHILL COPPER BELT OF CALIFORNIA

Showing principal mines and prospects, the Sierra Nevada gold belt, the granite-schist contact, and the bedrock-alluvium contact.

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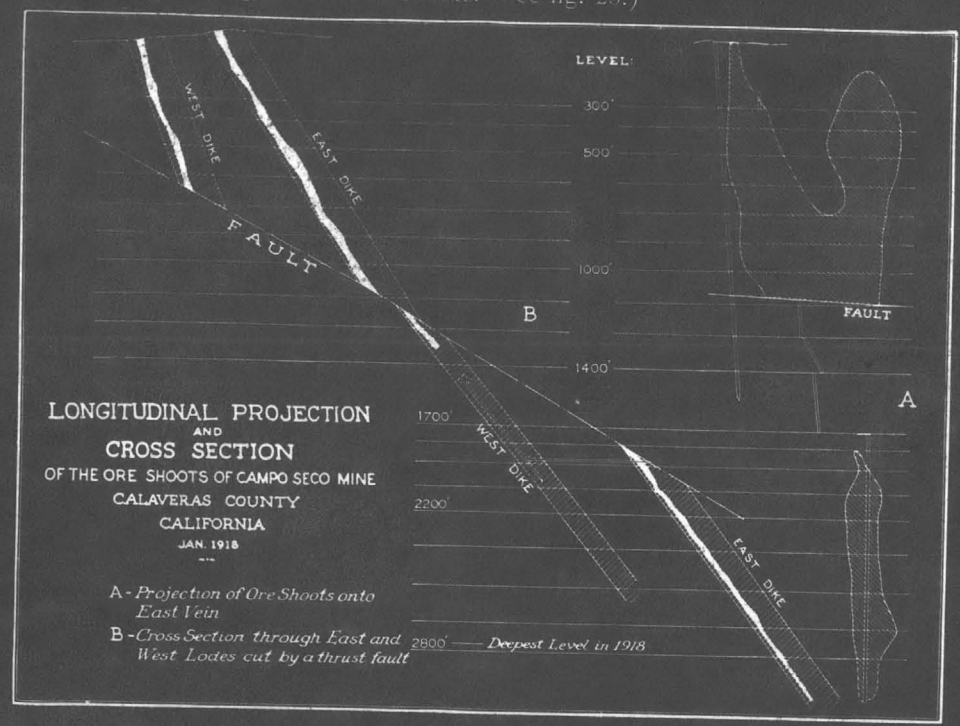


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XVI Int. Geol. Cong.

# FOOTHILL ZINC-COPPER BELT OF CALIFORNIA

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Prevailing rocks of the Foothill belt are meta-sediments and metavolcanics, ranging in age from Mississippian to Jurassic. These formations strike north-northwest (as does the Foothill belt and Mother Lode) and dip mainly steeply eastward. Basic and acid intrusions are numerous, many of the intrusions taking the form of sills conformable in attitude to that of the meta-sediments and meta-volcanics.

Copper, zinc-copper and zinc ore bodies occur as lenses, ranging in size from mere pockets to ore bodies 500-800 feet long and over 1000 feet deep (Penn mine). Mineralogy is simple, the chief ore minerals being chalcopyrite, sphalerite, and galena, with precious metals in moderate amounts. The ore occurs as replacements in schistose rock; at the Penn mine and elsewhere the country rock for the ore is schistose quartz porphyry or felsite, in zones carrying marked sericitic alteration, but at Copperopolis the ore occurs in chloritized slate and schistose greenstone.

Strong schistosity and hydrothermal alteration are useful guides for ore; structural control of ore deposition is often obvious.

Table I gives a notion of the highly variable size of the mines, and the grade of ore to be expected in any virgin ore deposits found. While most known deposits are small, grade of ore is apt to be high. A lens of zinc ore only 100 feet long, 15 feet wide and 300 feet deep, containing 12% zinc, would yield 10,000,000 pounds of zinc, or 10,000 tons of 50% concentrates. Such a lens would provide 100 tons of ore per day to a mill for well over a year.

The Blue Moon mine produced 13,000,000 lbs of zinc from a lens 200 feet long and less than 500 feet deep. Copper, lead, silver and some gold were also produced.

As Heyl stated in 1948 (Copper in California, Division of Mines Bulletin 144, P. 28-29):

"Very few portions of the Foothill copper-zinc belt have been adequately prospected in the modern sense of the term. Small-scale operations, allowing little or no funds for methodical exploration, have been the rule in the district, and in many of the mines even the mineralized zones that contain exploited ore have not been thoroughly tested by crosscutting or diamond drilling for additional ore bodies. Though ore shoots that do not extend to the surface are present in several of the mines, surface prospecting . . . has been almost entirely limited to the search for favorable gossans, accompanied by limited exploration of the ground in their immediate vicinity.

"Systematic geologic mapping delineating the structure of the rocks should disclose those portions of the belt particularly favorable to ore deposition. Within such areas, geologic work in greater detail, possibly aided by geophysical methods or aerial color photography, will in many cases be necessary to define specific localities where exploration by trenching, drilling, or other means is advisable. It is believed that a broad, methodical program, consistently carried out along such lines, would with little doubt disclose additional metal reserves.

"It seems reasonable to conclude, therefore, that the Foothill belt offers real opportunities for the discovery of untouched ore deposits, that can be profitably mined under favorable economic conditions."

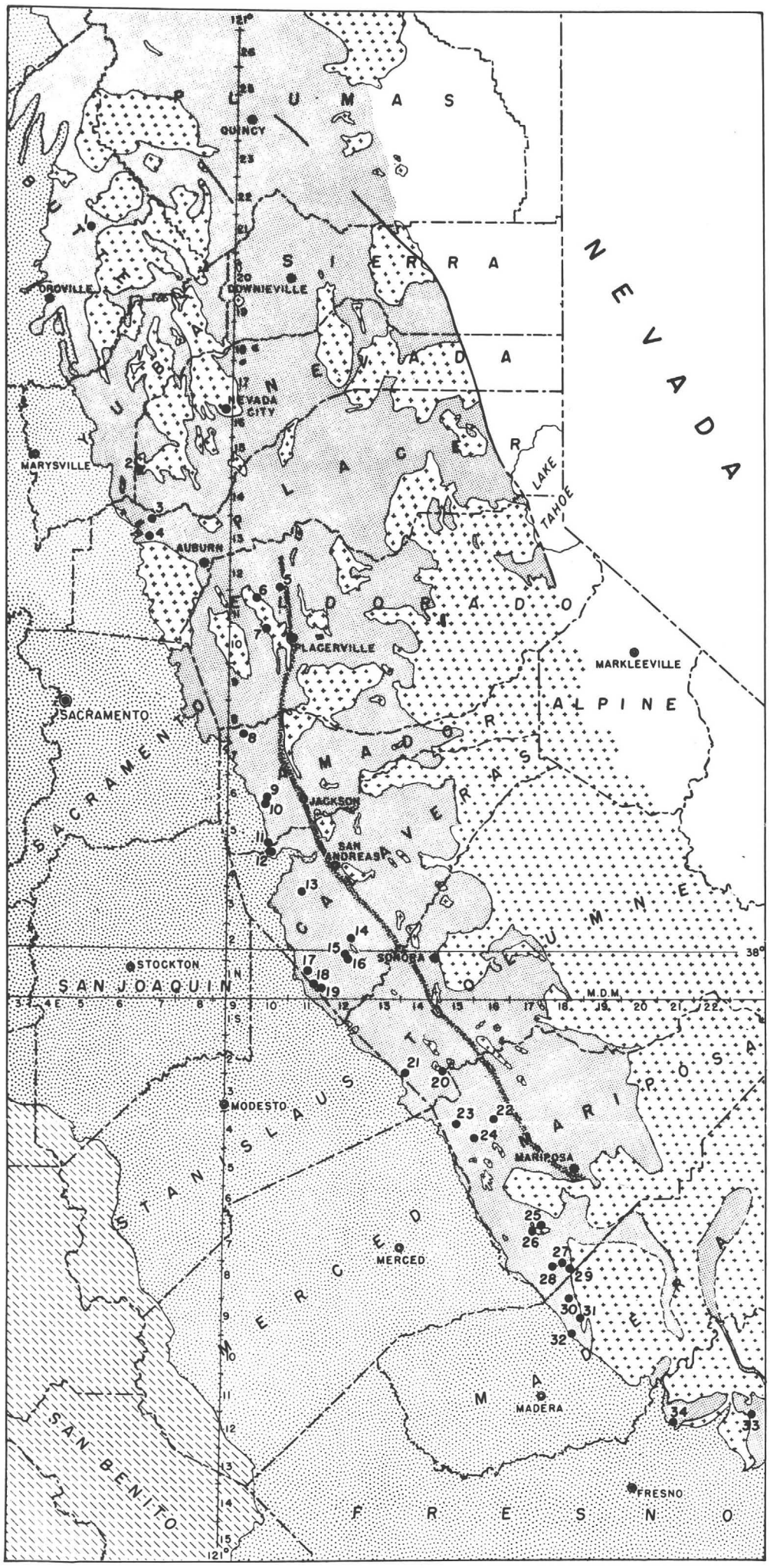
Only sporadic and very limited exploration has been done in the Foothill belt since this was written.

The ore bodies were deposited over a very large vertical range. The two main ore bodies at the Penn mine cropped out, but a third ore body was discovered which topped 1700 feet below the surface. There seems good reason for hope that somewhere along the belt where strong schistosity, strong alteration, and favorable

structure exist, sizable ore bodies may be found which top only a few hundred feet below the surface, and hence could readily be discovered by geophysical methods and drilling.

TABLE I

| Mine | Period | Tons Mined | Cu, lbs | Cu% | Zn, lbs | Zn. % | Pb, lbs | Pb% | Ag, 0z | Ag 0z/Ton |
|---|---|---|---|---|---|---|---|---|---|---|
| Penn | 1861-1953 | 977,000 | 82,590,000 | | 22,258,000 | | 235,000 | | 2,191,000 | |
| | 1943-1946 | 83,555 | 3,321,300 | 2.03 | 12,293,700 | 7.9 | 601,000 | 0.36 | 199,005 | 2.4 |
| Copperopolis | 1861-1946 | 1,188,906 | 72,600,000 | 3.05 | | | | | | |
| | 1944-1946 | 717,000 | 11,324,000 | 0.8 | | | | | | |
| Blue Mount'n | 1944-1945 | 55,000 | | | 13,000,000 | 11.8 | | | | |
| Newton | 1943-1946 | 41,200 | 4,759,300 | 5.75 | | | | | 30,800 | 0.75 |
| Big Bend | 1888-1945 | | 905,000 | | 2,064,000 | | | | | |
| | 1943-1945 | 8,187 | 480,773 | 3.0 | 2,064,000 | 12.6 | | | 41,859 | 5.1 |
| Quail Hill | 1943-1945 | 28,800 | 1,004,000 | 1.7 | 6,204,000 | 10.3 | | | | |
| Napoleon | Disc. 1860 | 15,000 | | 8.0 | | 10.0 | | | | |
| Collier | 1942-1944 | 5,613 | 130,330 | 3.5 | 1,188,970 | 8.0 | 83,161 | 0.5 | 20,614 | 5.0 |




## EXPLANATION

- Undeformed Upper Cretaceous, Tertiary and Quaternary deposits of the Great Valley of California
- Mother Lode gold-quartz vein system
- Granodiorite and related granitoid intrusives
- Strongly deformed, metamorphosed Mesozoic and Paleozoic rocks
- Folded rocks of the Coast Ranges

Note: Areas of Tertiary and Quaternary deposits capping granodiorite and metamorphic rocks in the Sierran Province are not differentiated

SCALE

0 25 50 75 100 MILES

## PRINCIPAL MINES AND PROSPECTS OF THE FOOTHILL COPPER-ZINC BELT

1 Big Bend
2 Spenceville
3 Dairy Farm
4 Valley View
5 Eldorado
6 Lilyama
7 Funny Bug
8 Copper Hill
9 Allen
10 Newton
11 Grayhouse
12 Penn
13 Caledonia
14 Nassau or Poole
15 North Keystone
16 Keystone-Union
17 Quail Hill
18 Napoleon
19 Collier
20 Salambo
21 Oak Hill
22 La Victoria
23 Akoz
24 Blue Moon and American Eagle
25 Pocahontas
26 White Rock
27 Lone Tree
28 San Jose
29 Green Mountain
30 Buchanan
31 Jesse Belle
32 Daulton
33 Copper King
34 Fresno

MAP SHOWING RELATIONSHIP OF THE FOOTHILL COPPER-ZINC BELT OF CALIFORNIA TO THE BATHOLITH OF THE SIERRA NEVADA

# PROPOSED EXPLORATION CAMPAIGN, FOOTHILLS COPPER BELT, CALIFORNIA

We propose a six phase program of exploration for massive sulphide orebodies of zinc and copper in the Foothills Copper Belt of California (see sketch map attached). The six phases are as follows:

Phase 1: Review of available data and an approximate delineation of the area of interest accompanied by a brief memo on the ore potential of the district. This step has been completed and the report plus map accompanies this brief. Cost - nil.

Phase 2: Detailed delineation of the area of interest utilizing all available information. We anticipate that this phase will require two to three months and should involve contributions by Ward Austin, Edward Wisser, F. H. Frederick, and Stanley H. Ward. Cost estimates for this phase should include the following:

| | |
|---|---|
| Wisser | $2,500 |
| Ward | 1,200 |
| Frederick | 750 |
| | $4,450 |

Sets of 1:250,000 scale overlays will be the product of this phase and these will contain sub area priority ratings, photogeology, known geology, flight patterns and elevation, known occurrences.

Phase 3: Reconnaissance field checking of the output of phase 2, with additional filling in of any notable gaps. We anticipate that this phase could be accomplished by Keevil personnel acting upon advise from Edward Wisser. About two months field time will be required and perhaps one week of Wisser's time. For this phase we recommend establishment of an office in Placerville which later can serve as headquarters for the airborne operation. For security purposes, we would recommend some subterfuge -- a syndicate or company might be formed to operate under a name such as Foothills Rock and Gravel. Cost estimates will need to include $1,000 for Wisser's fees.

Phase 4: Helicopter electromagnetic-magnetic surveying should commence at the end of the rainy season in April. We would recommend that this operation be under the direction of John May and Douglas C. Fraser with consultation from Stanley H. Ward. The duration of this phase will not be known until phase 3 has been completed, but $1,000 should be allocated for Ward's fees.

Phase 5: Ground followup and ground acquisition should be under the direction of John May and Douglas C. Fraser. Cost estimates should allow $1,000 for Wisser and $1,000 for Ward.

Phase 6: Drilling

General

We have recommended retention of Francis H. Frederick for five days at his normal fee of $150. Mr. Frederick has extensive physical knowledge of the Foothills Copper Belt and abundant office data. Wisser would propose to spend five days with Frederick in Phase 2 of the program.

Edward Wisser

Stanley H. Ward

September 27, 1965

September 5, 1965

Dear Stan:

Here is the brief memo as promised. It should of course be accompanied by Plate 1 of Bull.144. I think it is sufficient for an introduction to the Foothill belt.

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|---|---|---|---|---|---|---|---|---|---|---|
| Penn | 1861-1953 | 977,000 | 82,590,000 | | 22,258,000 | | 1,235,000 | | 2,191,000 | |
| | 1943-1946 | 83,555 | 3,321,300 | 2.05 | 12,293,700 | 7.9 | 601,000 | 0.36 | 199,005 | |
| Copperopolis | 1861-1946 | 1,188,906 | 72,600,000 | 0.05 | | | | | | |
| | 1944-1946 | 717,000 | 11,324,000 | 0.8 | | | | | | |
| | | | | | 13,000,000 | 11.8 | | | | |
| Blue Moon | 1944-1945 | 55,000 | | | | | | | 30,800 | 0.75 |
| Newton | 1943-1946 | 41,200 | 4,759,300 | 5.75 | | | | | | |
| Quail Hill | 1888-1945 | | 905,000 | | 2,064,000 | | | | 41,859 | 5.1 |
| | 1943-1945 | 8187 | 480,773 | 3.0 | 2,064,000 | 12.6 | | | | |
| Big Bend | 1943-1945 | 28,800 | 1,004,000 | 1.7 | 6,204,000 | 10.3 | | | | |
| | | | | 8.0 | | 10.0 | | | | |
| Napoleon | Disc. 1860 | 15,000 | | | | | 83,161 | 0.5 | 20,614 | 5.0 |
| Collier | 1942-1944 | 5,613 | 130,330 | 3.5 | 1,188,970 | 8.0 | | | | |

2

REPORT ON THE FOOTHILL COPPER DISTRICT OF CALIFORNIA AS BASED ON AN EXHAUSTIVE SEARCH OF THE LITERATURE

by H. C. Wells

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for Mr. Wasser

# A REPORT ON A SURVEY OF THE LITERATURE OF THE MINES, PROSPECTS AND GEOLOGY OF THE FOOTHILL COPPER BELT-CALIFORNIA

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REPORT SUBMITTED TO PROF. E. WISSER, DEPARTMENT OF ENGINEERING, DIVISION OF MINERAL TECHNOLOGY AT THE UNIVERSITY OF CALIFORNIA, IN BERKELEY, CALIFORNIA AS EVIDENCE OF WORK DONE IN THE COURSE OF MINING 299

Herbert C. Wells

June, 1950

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ILLUSTRATIONS in pocket

Map of California showing quadrangles.

Map of Foothill Copper Belt showing major deposites

Geologic map of the Foothill Belt of California

# A B S T R A C T

The Foothill Copper Belt is named after the comparatively lower hills lying to the west of the Sierra Nevada Mountain Range of California. The belt is about 250 miles long, and is a region of copper and zinc mineralization, lying in portions of Butte, Yuba, Nevada, Placer, El Dorado, Amador, Calaveras, Tuolemne, Mariposa, Madera and Fresno Counties, California. The region was discovered soon after the great California Gold Rush and contributed much of the copper used during the civil war. Since then much more copper as well as sinc, some gold silver and lead have been produced.

The rocks in the belt fall into two major groups, the older being quite complex faulted and folded, pre-Jurassic and Jurassic in age with a variety of intrusions; the younger being low dipping volcanic and sedimentary beds of Tertiary and Quaternary age unconformably overlying the older formations.

The valuable mineral deposits are lensoid beds, most of which developed by replacement along faulted zones in the older formations. The deposits are almost always associated with pyritization zones with chlorite, sericite, silica etc., having developed by

the same hydrothermal activity responsible for the ore minerals. The ore is characterized by abundant pyrite and occasional pyrrhotite, usually with much spahalerite and some gold and silver. On the basis of their primary mineral content they are classed in four groups.

Structural control of the deposites is often prominant. This is particularly true in intersecting and branching fault zones, at changes of attitude of fault surfaces and irregularities on contacts between rocks of markedly different competency, and the intersection of faults and such contacts.

The idea that the ore minerals were introduced after the regional orogeny, is shown by adequate evidence to be true. The concomitant metamorphism, the emplacement of the grannodiorite intrusions, and the spatial distribution of the deposites suggests that they are genitically related to the Sierra Nevada batholith.

## INTRODUCTION AND PURPOSE OF THE REPORT

From the Feather River Region in the North to the Kings River on the South and in the Foothills along the Western slope of the Sierra Nevada Mountains of California, there is a band or belt of mineralization rich in copper and zinc minerals, which developed in the Jurassic and older metamorphic and igneous rocks. This belt is about 250 miles long and includes portions of Butte, Yuba, Nevada, Placer, El Dorado, Amador, Calaveras, Tuolemne, Mariposa, Madera, and Fresno Counties. It is limited on the west by the alluvium and younger sedimentary formations of the San Joaquin and Sacramento Valleys.

There have never been any real attempts to limit the confines of this belt and many authors have considered it to extend into the Mother Lode gold belt which to be sure, contains related minerals to some extent and has a similar history. Arbitrarily then, the line dotted in on the map accompanying this report has left out some regions and included others. In general however, the foothill copper zinc belt lies at altitudes ranging from 200' to 2500' above sea level. The majority of the mines are at less than 1500' elevation.

Almost all of the precipitation in this region falls during the winter and the summer is characteristically hot and dry. This has lead to many problems in mining. There are some offsetting advantageous

such as the ready access to large population centers and excellent comunications by both railroad and highway, which are in the districts favor.

Some of the large copper producing mines in this region have been purposely omitted from this report. The reason for this is that most of those are large gold and/or silver producers and have been well studied and have much available literature. That literature has been referred to but the listing of mines has been restricted to those producing copper or zinc (or both) as their major metal.

The purpose of this report is primarily to study the literature available so as to find an area in which sufficient work has not yet been done, and then to do field work~~ing~~ in that area, especially if indications that this area is part of the foothill belt, are uncovered. Secondarily this report is to consolidate information about the entire belt on a slightly diferent manner than those comprehensive reports available on the region.

The search of the literature has been exhaustive and it is believed that everything of importance has been studied (if not everything written and published). Such a volume of material as was considered is too great to be condensed in a report but wherever specific references were used, they are listed by number corresponding to those in the Bibliography.

The majority of the work done in this region has

taken place during the various war periods that the United States has passed through since the first discovery of the belt. This is because few of the mines are of high enough grade to be economic in slack times, largely due to the lack of proximity to smeltering facilities.

Statistics have been omitted with a few exceptions because an adequate summary of the statistics of the region is available in the Bulliten of the California State Division of Mines #144 on "Copper in California". This reference was the most important single one for this work.

In general it has been found that the material available for so large and potentially important a district as the Foothill Copper Belt is insufficient especially in the southern region. Outlines on the accompanying map of California, showing the United States Geological Surveyed Quadrangles, are the maximum and minimum quadrangular limits of the district and those quadrangles which have been mapped or are on the process of being mapped are shown. About two thirds of the region has been mapped but most of these are on such a scale as to necessitate re-mapping (as is being done in some cases).

It is concluded that there is adequate room in the region for more work especially in the central and southern parts of the belt.

## HISTORY AND PRODUCTION

The first real discovery of copper within the strict limits of the foothill belt (exclusive of by-product copper from the few gold mines in the north-eastern part of the belt) was made in about 1860. This discovery began an intensive period in California Copper mining with discovery and exploitation of a number of deposites. The initial discovery was at Quail Hill by Hiram Hughes who had returned to California from the Comstock Lode. Hughes worked the gossan he had discovered, for it's high gold content but soon afterward when he discovered the Napoleon gossan, he neglected the Quail Hill for the copper reported in the Napoleon gossan, which due to it's low gold content he had sent to San Francisco for assaying. The gossan was some 30% copper, worth at the time $120 per ton. This news naturally brought many prospectors to the district.

This first boom continued throughout the Civil War years but within two years after the end of the war, almost all mines were closed. This was due largely to the post war recession and fall of copper prices in 1866. Browne [1] estimates that by this time more than 100,000 tons of copper ore valued at $5,000,000 had been taken out of California.

In 1875, the Spenceville mine was reopened by the San Francisco Copper Company and caused a mild reinterest

in copper during the next 10 or 15 years [2]. During that period the Campo Seco district, the Lancha Plana district, the Union Mine of Copperopolis and the Newton Mine near Jackson all reopened [3].

That period of activity ended in 1890 and it was not untill World War I that production really hit reasonable activity again although there had been increasing mining from the turn of the century untill then. Several of the mines tried leaching stock piles and smelting concentrates in local areas but with little economic success.

The end of the first World War brought another recession which again closed the mines although the Keystone Union Mine at Copperopolis was able to operate untill 1930.

It took World War II to bring new interest to the Foothill Belt and the Daulton, Victory and Jesse Belle Mines in Madera County, the North Keystone, Quail Hill, Collier and Penn Mines in Calaveras County, the Newton Mine in Amador County, the Lilyama Mine in El Dorado County and the Valley View Mine in Placer County all became signifigant producers of copper and/or zinc. The Penn and Newton Mines operated into 1946 and there is minor activity in the region today. Two new mines were opened during the war, these being the Blue Moon Mine in Mariposa County and the Big Bend mine in Butte County. Production from these mines may be found summarized in Table 1 opposite page 15 in the aforementioned Bulliten of the State Division of Mines #144, Copper in California.

Zinc became important in the Foothill Belt only comparatively recently but it was first produced in 1906 as a byproduct of copper. This early production was in limited quantities due to lack of developement of necessary techniques of seperation which made large scale production possible [4]. This situation was remedied before the war and during the war years some 35,000,000 pounds of zinc was produced as compared with only 22,000,000 pounds of copper.[5].

Total production as based on figures of the United States Bureau of Mines for the period since first discovery to 1946 show 104,500,000 pounds of copper and 50,400,000 pounds of zinc.

## GENERAL GEOLOGY

Regionally metamorphosed rocks Jurassic and older in age are characteristic of the Foothill Copper Belt and the Mother Lode Gold Belt in California. In both districts the older formations are often hidden by overlying Tertiary sediments and volcanics. Both districts follow the same general strike which is about N20°W.

The Paleozoic and Mesozoic formations in this region have been divided by the United States Geological Survey, into three groups. The oldest is the Calaveras, the youngest being Mariposa and the middle group, Monte de Oro.[6]

The Calaveras is generally considered to be Carboniferous in age but more recently authoritative studies show that it probably contains Permian beds also [7]. Many variations of the formation exist but within the Foothill Belt the important members are gray chert, red chert, blue gray recrystallized limestone and marble, gray clay slate and Phyllite, conglomerate, sandstone, quartzite and green schists derived from volcanic rocks.

Monte de Oro beds occur only in the part of the belt which lies northeast of Oroville where it is a cark carbonaceous clay slate with some conglomerate and sandstone. It contains a meager and poor fossil fauna but fair flora. Taliaferro has considered it to be Mid Jurassic in age [8].

The Mariposa is predominantly dark blue gray to

black clay slate which weathers pale green or olive brown and includes some light colored siltstone, sandstone graywacke and numerous conglomerate lenses although the later are not usually very thick. There are some thin beds of volcanics in some regions. Fossils through out are not abundant but are sufficient to place the age as upper Jurassic. Fossils include Belemnites, Aucellas and Ammonites.

Taliaferro has named a new sequence of rocks which underlie s the Mariposa in the Foothills. He calls the sequence the Amador group [9]. The base of the group he calls the Cosumnes formation [10]. but since this formation has not been positively identified in the region of the Copper Belt, it will not be discussed here. The upper member is the Logtown Ridge Volcanics and that name has been assigned to some volcanics found in and at some of the mines in the region. The Newton mine has some material around it which cannot be assigned to any of the above mentioned formations, but has been considered as possibly new members of the Amador group.

As the Jurassic time approached it's end, the Sierras were uplifted, strongly compressed, folded, faulted and dynamically metamorphosed. This period is called the Nevadan Orogeny and established the ancestral Sierras. Taliaferro's correlation [8] is most likely correct, dating the orogeny upper Kimmeridgian but pre-Portlandian [11].

The intrusive rocks of the belt present a variety of types. Some are older than the Nevadan Orogeny and as a result have suffered deformation and metamorphism along with the rocks into which they were intruded. The deep igneous equivalants of the Amador group are examples of such rocks.[12]

Plutonic rocks in the region included grannodiorite and genetically related granite, quartz diorite, gabbro etc. In the grannodiorite core the final emplacement probably came after the aformentioned deformation of the Jurassic and older rocks. This is evidenced by the fact that folds can be followed across regions of the intrusions even though the intrusives cut the folded rocks as dikes etc. [13].

Cloos [14] has found that much of the magma was guided by structural weaknesses in the older rocks especially in the fault structures while the faults themselves are not continous across the igneous rocks (and therefore obviously were a structural control).

Cloos has outlined the pattern and internal structure of the Sierra Nevada batholith or pluton and has shown that the main batholith had somewhat of a northward plunge so that erosion has cut more deeply into the southern part than the northern.

Strong thermal metamorphism resulted from the intrusion and immediately around it, with aureoles of hornfels and other contact metamorphic rocks, the presence of andalusite

and chiastolite being characteristic and common, especially in the central part of the belt.

Regional metamorphism has formed slate, phyllite, quartzite, greenstone etc. with abundant chlorite, epidote and a pale green amphibole throughout the foothill region. Such metamorphism took place during the same period of orogeny and is quite widespread. This metamorphism is characteristic of the epizone.

# ECONOMIC GEOLOGY

## Ore Deposites

The majority of the mineralization in the Foothill Belt has been in fault and shear zones with the formation of lenticular sulphide ore bodies. There are also some irregular and/or lenticular quartz bodies and veins which contain pyrite, chalcopyrite and other sulphides. The formation of the quartz bodies has been much the same as the formation of the larger bodies. There are also some occassional ore bodies found in close conjunction with the grannodiorite intrusion and because of their formation, mineral association, and other characteristics are conclusively pyrometasomatic in origin, the Lilyama and Pioneer deposites in El Dorado County being examples.

Almost all of the belts deposites are characterized by pyrite, less commonly by pyrrhotite and by minor amounts of chalcopyrite, Sphalerite, gold, silver, galena, tetrahedrite, bornite etc. are all minerals in the deposites. Heyl [15] has placed these deposites in four groups on the basis of their primary mineral content. These groups are as follows:

(1) Primary minerals being sphalerite, chalcopyrite, pyrite with small amounts of galena, usually economic amounts of gold and silver. Examples are the Big Bend Mine, Butte County; Penn Mine and Quail Hill Mine, in Calaveras County; and the Blue Moon Mine, Mariposa County.

(2) Deposites consisting mainly of pyrrhotite and chalcopyrite, with or without pyrite and sphalerite, and generally with some gold and silver. Examples are : Green Mountain Mine, Mariposa County; Buchanan Mine and Daulton Mine, Madera County; Fresno Copper Mine, Fresno County.

(3) Primary minerals of pyrite and chalcopyrite with practically no gold or silver or zinc minerals. Examples: Newton Mine, Amador County; North Keystone Mine and Keystone Union Mine, Calaveras County.

(4) Primary Minerals chalcopyrite, pyrite and quartz with or without sphalerite and pyrrhotite, and usually a little gold and silver. Examples: Eldorado Copper Mine, El Dorado County; La Victoria Mine, Mariposa County; Jesse Belle Mine, Madera County.

Species of Many other minerals are found in the region but in negligible quantities. Some of these are Bornite (which is found in some of the ore at the North Keystone Mine and in quartz calcite veinlets which cut the sulphide bodies in the Big Bend and Penn Mines). Tetrahedrite, Cobaltite, cubanite, arsenopyrite, stibnite and ilmenite, all being found sporadically.

According to Lang [16] the highest average gold content was 0.318 ounces per ton from the Quail Hill mine during the period from 1943 to 1945. This mine was one of the few which produced any gold during the war.

Gangue minerals are limited to quartz (almost entirely)

calcite, magnetite, hematite, green chlorite, epidote etc. in distinctly minor amounts.

It is interesting to note that the variations of minerals and the mode and characteristics of emplacements as well as the gangue characteristics etc. of the foothill belt are very similar to those of the Mother Lode Gold Region which lies in a belt trending in the same general direction and at a distance of between 20 and 75 miles to the east of the major part of the foothill belt. The main difference lies in the larger quantity of pyrite in the Mother Lode belt and it's higher gold content.[17] The variations between the two regions are little greater than the different parts of each belt and this is additional evidence of the common genesis of the two districts.

Special studies of some of the gangue minerals in minor quantities, have been made, especially of the green chlorite and the Epidote which is commonly found as large crystals and as groups of radiating crystals [18] in the ore from the North Keystone. Feldspar, muscovite, biotite etc are found occassionally. The most common and characteristic gangue other than the quartz and calcite is barite. It is this characteristic as much as any other which makes the Foothill belt different from the Mother Lode belt. This difference has been remarked on by the several authors who have made specific studies of both regions [19]. The Barite is most common in ores of the Type 1 mines.

Ores throughout the region are amazingly similar in

appearance. The most common appearance is that of any fine grained mixture of sulphide which is mainly pyrite, or phrrhotite and chalcopyrite. Sphalerite may or may not be present. The ores are most commonly massive but often banded. This later feature is caused by replacement of schistose country rock with retention of it's structure.

Certain ores, especially of Type 1, besides showing barite gangue in quantity, often show a crystaloblastic texture. This texture is characterized by pressure and strain shadows around pyrite crystals and augens of some of the minerals. The texture is indicative that there was at least some deformation after the major mineralization. Occassional slickensiding on the ore minerals offers verification.

The ore bodies are almost always located in regions of strong hydrothermal alteration and the dip and strike of the country rock is often imitated. The regional attitude of the faults in the Belt follows the structure. In short stretches, the ore may cut across the attitude but this is due to local conditions of the zones of weakness. The bodies appear as large fat lenses, long narrow lenses with stringers and veins around them, as a series of small lenses, or as several belts of combinations of these types. In size the bodies range from a few cubic feet to great volumes 200' wide and as much as several thousand feet long. The Copperopolis belt is over 9000' long and some belts are somewhat longer.

It appears that silicification was earlier than the sericitization where the two appear together while the introduction of pyrite came later than either of these two. It generally overlaps into the period of introduction of the ore minerals. Quite commonly there are several introductions of pyrite and silica during the mineralization. This is another characteristic that the region has in common with the Mother Lode Region.

## Structural Controls

In general the ore deposits of the foothill belt are formed along faults and shear zones especially where the breaking up of the rock has been intense. Because of this, fault zones, regions where formations of differing competency are in contact, in ruptured folds, etc, were favorable for the deposition of the ore. This is true with but two exceptions and those being a special case where there was limestone adjacent to a granodiorte stock and the proper conditions for ore deposition were present. The Lilyama and Pioneer mines in El Dorado County are examples of such conditions.

Ore searches have been greatly facilitated by searching out those places where the structure was favorable for ore deposition. Such control is obviously evident in many deposites usually each deposite having only one of the many possible types of control.

It is not the purpose of this report to give indivifual examples of structural controls but some of those which are prominant in the literature are discussed below.

In Butte County, the Big Bend Mine [20] has ore which developed between intersecting and curving high angle faults which bound a bulbous lensoid body in folded, sheared, crushed and fissured rock.

In El Dorado County, the smaller mines have a variety of characteristics but the two important mines, the Lilyama and the pioneer are characterized by replacement of limestone. This characteristic has been previously discussed.

In Amador County, the Bull Run Mine, the Chaparral Mine,[21, 22, 23] the Tussel Mine, the Thayer Mine and the several prospects of the Grayhouse region all have similar structural controls. Bedding in schistose replacements was observed in the southern part of the area. Small folds where the ore has replaced folded structure were observed in Barnett Gulch. High angle strike faults and low angle reverse faults were both found to have controlled the structure in this region.

The Newton Mine [21,22,23] is very close to the Gray house region but the structural control is limited to chimneys of crushed and sheared material.

In Calaveras County, the Collier Mine [24] shows characteristic sulphide deposition on the hanging wall of a large fault with the surface of the shear zone localizing the sulphides.

The Copperopolis Mines have variations through their length (covering quite a stretch) even though some are moderately close spaced [25, 26, 27]. In general there is a tendency for the ore in this region to form on the hanging walls of the major faults.

Also in Calaveras County are the mines of the Quail Hill region. The Quail Hill [28], Gopher Hill [28], Napoleon [28] and the Star Excelsior. The Collier mentioned previously is also in this group. All but the Collier have ore shoots along faults and shear zones near the contact with a relatively massive intrusive rock.

In Mariposa County, the La Victoria Group of Mines and Prospects [29] are in ore which is replacemnt in shear zones but restricted to material which strikes N15°W [30].

In Mariposa County, the American Eagle-Blue Moon district [31] have ore which was deposited in an active shear zone and therefore showsn slickensiding.

In Madera County at the Jesse Belle Mine the major ore Bodies occur at the intersections of shear zones.

## Supergene Enrichment

Toman [32] has found that secondary chalcopyrite is rarely present but that chalcocite is an important secondary sulphide in this district. The zone of supergene enrichment is shallow varying from 20 to 60 feet in depth but usually about 35'. It extends to about 160 feet maximum depths of 200 feet being reported.

Because of the relatively recent geologically uplifting of the Sierras and the rapid erosion and accompanying lowering of the water table at a rapid rate, the zone in the belt is somewhat thinner than would normally be found in this type of deposites. However, some of the mines have had supergene ores which were nearly twice as rich as the deeper ore. The supergene enrichment seems to be peculiar to copper minerals alone with no supergene zinc, gold or silver.

The oxidized zone of the Foothill belt generally extends from 10 to 50 feet with maximums at about 80 feet. Of the copper minerals in the oxidized zone, malachite, azurite etc. are commonist with minor amounts of native copper and some cuprite.

The origin may be briefly summarized by stating that it took place after the emplacement of the Sierran Batholith. The mineralization is directly related however, to that batholith. The fact that the mineralization came after the main diastrophism of the region is evidenced by the structural controls already discussed. However certain ores show that the movements had not ceased at the time of deposition even though continuations were minor.

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# INDEX TO PRINCIPAL MINES & PROSPECTS

| County | Mine | Section | Township | Range |
|---|---|---|---|---|
| BUTTE COUNTY | | | | |
| 1. | Big Bend | 8 | 21N | 5E |
| 2. | Bloomer Hill | 35 | 21N | 4E |
| 3. | Gold Bank | 5? | 19N | 6E |
| YUBA COUNTY | | | | |
| 1. | Ayer | 35 | 16N | 5E |
| 2. | Brady Ranch | 1 | 15N | 5E |
| 3. | Copper Crescent | 19 | 14N | 6E |
| 4. | Dempsey Ranch | 3 | 15N | 6E |
| NEVADA COUNTY | | | | |
| 1. | Arkansas Traveler | 13 | 15N | 6E |
| 2. | Berkeley | 6,7 | 16N | 8E |
| 3. | Big Bend | 25, 36 | 17N | 7E |
| 4. | Bitner group | 13 | 15N | 6E |
| 5. | Boss (San Juan) | 1, 12 | 17N | 7E |
| | | 6,7 | 17N | 8E |
| 6. | California | 12, 13 | 15N | 6E |
| 7. | Copper Claim | 25,26,35 | 15N | 6E |
| 8. | Gautier Ranch | 28, 29 | 14N | 8E |
| 9. | Green Lead | 1, 12 | 15N | 6E |
| 10. | Hibber | 32 | 14N | 7E |
| 11. | Imperial Paint | 26, 35 | 15N | 6E |
| | & Copper | | | |
| 12. | Last Chance | 12,13 | 15N | 6E |
| 13. | Letzen Ranch | 2, | 14N | 7E |
| 14. | Mammoth Gold Cu | 12 | 17N | 7E |
| 15. | Mineral Hill gp | 13, | 15N | 6E |
| 16. | Nickerson Ranch | 29 | 14N | 8E |
| 17. | Pine Hill | 12 | 14N | 7E |
| 18. | Spenceville | 25,26 | 15N | 6E |
| | | 27,35 | | |
| 19. | Wetteran Ranch | 34 | 15N | 7E |
| PLACER COUNTY | | | | |
| 1. | Algol | 9 | 13N | 7E |
| 2. | Bobtail | 18 | 13N | 7E |
| 3. | Casey | 10 | 13N | 8E |
| 4. | Dairy Farm | 27 | 14N | 6E |
| 5. | Davenport | 15 | 12N | 8E |
| 6. | Elder | 4 | 13N | 6E |
| 7. | Lakeview | 32 | 13N | 9E |
| 8. | Nevada Mining Co. | | | |
| | | 32 | 14N | 8E |
| 9. | Oest | 4 | 13N | 8E |
| 10. | Thomeau | 4,5 | 13N | 8E |
| 11. | Valley View | 12,13,24 | 13N | 8E |
| 12. | Van Giesen | 10 | 13N | 8E |

| County | Mine | Section | Township | Range |
|---|---|---|---|---|
| EL DORADO COUNTY | | | | |
| 1. | Agara | 19 | 8N | 9E |
| 2. | Alabaster Cave | 10,15 | 11N | 8E |
| 3. | Arizona | 24 | 12N | 10E |
| 4. | Baker | 28 | 10N | 11E |
| 5. | Barkledge & Miller | 13 | 12N | 10E |
| 6. | Big Buzzard | 29 | 11N | 8E |
| 7. | Big Canyon | 29 | 9N | 10E |
| 8. | Blue Cat | 18 | 9N | 11E |
| 9. | Boston | 18 | 11N | 9E |
| 10. | Breala | 2 | 8N | 9E |
| 11. | Bryant Ranch | 2 | 8N | 9E |
| 12. | Bunker Hill | 14 | 12N | 9E |
| 13. | Cambrian | 23 | 11N | 9E |
| 14. | Camel Back | 11 | 11N | 8E |
| 15. | Cosumnes | 24,25 | 9N | 12E |
| 16. | Cothrin | 29 | 9N | 9E |
| 17. | Costa Ranch | 12 | 11N | 8E |
| 18. | Copper Chief | 12 | 12N | 10E |
| 19. | Contraband | 24 | 12N | 10E |
| 20. | Doctor Wren | 7 | 9N | 11E |
| 21. | EE Copper | 18 | 9N | 11E |
| 22. | El Dorado | 34 | 12N | 10E |
| 23. | Funny Bug | 5 | 10N | 10E |
| 24. | Hale | 25 | 9N | 12E |
| 25. | Irland | 15 | 10N | 10E |
| 26. | Iron Crown | 13 | 12N | 10E |
| 27. | Larkin | 29 | 10N | 11E |
| 28. | Lilyama | 3 | 11N | 9E |
| 29. | Mt. Pleasant | 16 | 9N | 13E |
| 30. | Noonday | 18 | 9N | 11E |
| 31. | Pioneer | 9 | 11N | 9E |
| 32. | Revoir | 12 | 9N | 12E |
| 33. | Rip and Tear | 3 | 8N | 9E |
| 34. | Robert | 13 | 9N | 11E |
| 35. | Seven Bells | 10 | 10N | 10E |
| 36. | Woods | 4 | 8N | 9E |
| AMADOR COUNTY | | | | |
| 1. | Bull Run | 15 | 5N | 10E |
| 2. | Chaparral | 10 | 5N | 10E |
| 3. | Copper Hill | 34,35 | 8N | 9E |
| 4. | Forest Home | 9 | 7N | 9E |
| 5. | Hayward | 28 | 8N | 10E |
| 6. | Ione City | 3,4 | 5N | 10E |
| 7. | Ione Copper | 11 | 6N | 9E |
| 8. | Johnson Ranch | 24,35,36 | 6N | 10E |
| 9. | Moon | 3,9,10 | 5N | 10E |
| 10. | Mutual Life Insurance | 2 | 7N | 9E |
| 11. | Newton | 28 | 6N | 10E |
| 12. | Russell | 10 | 5N | 10E |
| 13. | Thayer | 23 | 5N | 10E |

| County | Mine | Section | Township | Range |
|---|---|---|---|---|
| CALAVERAS COUNTY | | | | |
| 1. | Bell Prince | 4 | 4N | 10E |
| 2. | Bonanza | 27, 34 | 5N | 12E |
| 3. | Bunds | 12 | 3N | 12E |
| 4. | Caledonia | 4? | 3N | 11E |
| 5. | Clothier & Cameron | 2 | 2N | 12E |
| 6. | Collier | 24 | 1N | 11E |
| 7. | Constellation | 3,4 | 4N | 10E |
| 8. | Copper Crescent | 26(aprx) | 1N | 11E |
| 9. | Copperopolis | 3 | 1N | 12E |
| | Mines | 34 | 2N | 12E |
| A. | Empire Mine | 3 | 1N | 12E |
| B. | Keystone Union | 34 | 2N | 12E |
| C. | North Keystone | 34 | 2N | 12E |
| 10. | Eureka | 33,34 | 5N | 11E |
| 11. | Gopher Hill | 10 | 1N | 11E |
| 12. | Holmes | 2,11 | 4N | 10E |
| 13. | Jackson | 23 | 1N | 12E |
| 14. | Josephine | 8 | 1N | 13E |
| 15. | Lightner | 18 | 1N | 13E |
| 16. | Little Quail Hill | 24 | 1N | 11E |
| 17. | Napoleon | 23 | 1N | 11E |
| 18. | Nassau | 10 | 2N | 12E |
| 19. | Penn | 3,4 | 4N | 10E |
| 20. | Quail Hill | 3, 10 | 1N | 11E |
| 21. | Shumate | 25 | 1N | 11E |
| 22. | Star & Excelsior | 24 | 1N | 11E |
| 23. | Telegraph | 26 | 1N | 11E |
| 24. | | | | |
| TUOLEMNE COUNTY | | | | |
| 1. | Adams | 16 | 3S | 15E |
| 2. | Chinese Camp | 9 | 1S | 14E (in town) |
| 3. | Donahue Ranch | 23 | 2S | 14E |
| 4. | Kahl Ranch | 6,7 | 1N | 14E |
| 5. | Mann | 27, 28 | 1N | 14E |
| 6. | Mariano Ranch | 4,5,8,9 | 1S | 14E |
| 7. | Oak Hill | 32 | 2S | 14E |
| 8. | Oak Mesa | 22 | 3S | 15E |
| 9. | Ohio Diggings | 21, 28 | 1N | 14E |
| 10. | Salambo | 30,31,32 | 2S | 15E |
| 11. | Shell Ranch | 17 | 1N | 14E |
| 12. | | | | |
| MARIPOSA COUNTY | | | | |
| 1. | A. C. Smith | 9 | 7S | 17E |
| 2. | Akoz | 9,10 | 4S | 15E |
| 3. | American Eagle | 30 | 4S | 16E |
| 4. | Barret | 29,29,32 | 3S | 16E |
| 5. | Blue Moon | 19 | 4S | 16E |
| 6. | Bruschi | 24 | 3S | 15E |
| 7. | Cavagnero | 9 | 4S | 16E |
| 8. | Cavan | 5 | 8S | 18E |
| 9. | Copper Hill | 14 | 6S | 16E |

| County | Min4 | Section | Township | Range |
|---|---|---|---|---|
| 10. | Copper Mountain | 33,34 | 7S | 18E |
| 11. | Copper Queen | 3 | 8S | 18E |
| 12. | Copper Queen | 19 | 5S | 19E |
| 13. | Cornett | 19 | 6S | 17E |
| 14. | Great Northern | 2,3,10,11 | 7S | 17E |
| 15. | Green Mountain | 3,4 | 8S | 18E |
| 16. | Heiser | 19 | 5S | 19E |
| 17. | Hotaling | 12? | 6S | 16E |
| 18. | Indian Peak grp | 19,20 | 7S | 18E |
| 19. | Klondike claim | 16 | 7S | 18E |
| 20. | La Victoria | 4,9,10 | 4S | 16E |
| 21. | Lone Tree | 4 | 8S | 18E |
| 22. | | 33 | 7S | 18E |
| 22. | Pocohontas | 1,12,14 | 7S | 17E |
| 23. | Toad | 31 | 7S | 18E |
| 24. | Ward | 34 | 6S | 19E |
| 25. | White Rock | 14 | 7S | 17E |
| MADERA COUNTY | | | | |
| 1. | Bach | 8? | 9S | 18E |
| 2. | Big Chief | 23 | 10S | 21E |
| 3. | Copper Queen | 15 | 9S | 18E |
| 4. | Daulton | 35 | 9S | 18E |
| 5. | Jesse Belle | 13 | 9S | 18E |
| 6. | | 18, 19 | 9S | 19E |
| 6. | Krohn and Ward | 23, 26 | 10S | 19E |
| 7. | Nelson | 25, 26 | 9S | 18E |
| 8. | Old Reed | 16 | 10S | 21E |
| 9. | Questo | 2 | 10S | 18E |
| 10. | Vignola | 2 | 9S | 18E |
| | | 35 | 8S | 18E |
| FRESNO COUNTY | | | | |
| 1. | Ackers | 10 | 12S | 24E |
| 2. | Anderson & Gist | 14,15,23,24 | 12S | 24E |
| 3. | Black Mountain | 36, 24 | 11S | 23E |
| 4. | Blackjack | 14 | 12S | 24E |
| 5. | Buck's Peak | 12 | 12S | 23E |
| 6. | Copper King | 3 | 12S | 23E |
| 7. | Fresno | 10 | 12S | 21E |
| 8. | Grubstake | 15 | 12S | 23E |
| 9. | Happy Camp | 6 | 12S | 24E |
| 10. | Hinkle | 25,26,27 | 12S | 24E |
| 11. | Mount Sterling | 10 | 12S | 23E |
| 12. | Neiper | 34 | 11S | 23E |
| 13. | Painter | 33 | 11S | 21E |
| 14. | Post Oak | 29 | 12S | 25E |
| 15. | Sunset | 35 | 11S | 23E |
| 16. | Wabash Mining Co. | 2,3,11 | 12S | 23E |