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University of Arizona Bulletin

ARIZONA BUREAU OF MINES

GEOLOGY AND ORE DEPOSITS OF THE MAMMOTH MINING CAMP AREA, PINAL COUNTY, ARIZONA

BY NELS PAUL PETERSON

A Thesis Submitted to the University of Arizona in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

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PREFACE

During recent years there has been a strong demand for molybdenum ore, and many articles descriptive of deposits of molybdenite (sulphide of molybdenum) have been published. Little has been printed, however, about the deposits of wulfenite (molybdate of lead) that occur in numerous places in the Southwest.

The Arizona Bureau of Mines considers itself fortunate, therefore, in being able to publish this description of the most productive wulfenite deposit in Arizona.

The author's suggestion that wulfenite may be a primary mineral that has been deposited in the oxidized zone by ascending solutions will doubtless be criticised by geologists who are unfamiliar with deposits of this mineral, but it is the only theory yet offered that appears to conform to observed facts.

Wulfenite has often been found associated with oxidized ore in Arizona, but there are no evidences that it is an oxidization product of molybdenum-bearing galena (if such galena exists) or of mixtures of galena and molybdenite. Indeed, it is a well-known fact that molybdenite oxidizes to molybdite (molybdenum ocher or oxide). When wulfenite deposits have been developed to sufficient depth to reveal the unoxidized, primary ore, the galena encountered has been found to contain no molybdenum.

If such conditions prevailed in only one mine, it would be logical to assume that a molybdenum-bearing galena that originally lay above some molybdenum-free galena had been oxidized, but, when the conditions mentioned exist in every place where development has been deep enough to uncover the unoxidized ore, this theory becomes untenable.

The origin of vanadinite (vanadate of lead), which is usually associated with wulfenite, is as much of a puzzle as is the origin of wulfenite. This wulfenite-vanadinite problem is certainly a perplexing one, and it is hoped that the publication of this bulletin will direct general attention to it and prove an aid in its solution.

June 1, 1938 G. M. Butler

Aguaya Prospect

The Aguaya prospect consists of an adit following a narrow vein along the footwall of a body of rhyolite in contact with granite. The vein dips steeply northeast, with clearly defined walls marked by gouge. At the northwest end of the adit the vein is lost in the jumbled structure along the hanging wall of the Mammoth fault. A thin basic dike lies along the footwall between the vein and the granite.

The vein matter consists of loose, quartz-filled breccia containing fragments of rhyolite and basic rock cemented by limonitic gouge. The vein has been partly mined between the adit and the outcrop. Gold occurs in thin films coating fragments in the breccia that are especially rich in iron.

This vein is probably the northwest end of the Dream vein.

Mohawk Extension Mine

The Mohawk Extension claims are southeast of the Mohawk and New Year claims. The mine was not examined, but it is understood to be on a narrow vein along the footwall of a rhyolite sill in contact with granite or arkose.

The Dream vein, projected to the surface, coincides closely with the vein in the Mohawk Extension workings.

Two crosscuts, driven into the footwall of the Dream vein to prospect for the Smith veins, show a thick stratum of arkose between the granite and the footwall of the rhyolite sill.

200-foot level (Pl. VII)

The structure of 391 vein on the 300-foot level carries through to the 200-foot level. At the southeast end of 391 stope (291 stope) the vein passes into intrusive breccia and contracts as on the level below. The vein structure continues to the northwest beyond the end of the stope, but there is not sufficient mineralization to make ore.

A crosscut into the hanging wall shows 200 feet of brecciated rhyolite and two poorly defined veins, one of which is 376 vein, the other is probably what is left of 491 vein. Several of the intervening fractures are also slightly mineralized.

The 100-foot level was not accessible. According to Vanderwilt,[29] it was limited to drifting and stoping along the vein which continues upward from 391 stope.

Smith Mine

The Smith Mine is on the Washington claim, 1,000 feet west of the Mohawk shaft. It consists of an adit and several hundred feet of drifts and crosscuts (Pl. IV). The outcrop shows two narrow veins, one on the footwall and one on the hanging wall of the rhyolite dike dipping steeply northeast. Granite arkose forms the footwall of the dike and a basic breccia the hanging wall. The dike appears to be cut off at each end by cross faults. The Mammoth fault must be close to the footwall of the dike.

Several small ore shoots have been mined from shafts sunk at intervals along the outcrops. The underground workings are 50 feet below the outcrop. The adit, evidently driven to crosscut the veins, completely missed the southeast end of the rhyolite dike but crossed a mineralized stringer which when followed to the northwest turned out to be the hanging-wall vein. A drift to the southeast goes into alluvium. The underground workings have served mainly for prospecting which was not very instructive. A little ore was stoped from the hanging-wall vein. The structure shown underground is more complicated than appears on the outcrop. The intense brecciation and complicated fracture pattern is characteristic of the hanging-wall side of the Mammoth fault.

The veins are not over 2 or 3 feet wide but were probably well mineralized. They are now completely oxidized and leached. Gold occurs in very thin films which are doubtless of supergene origin.

A crosscut was driven from the 300-foot level of the Mohawk Mine to prospect for the downward extension of these veins without success.

[29] John W. Vanderwilt, *Economic Geology of the Mohawk-New Year Mine*, private report, 1934.

TABLE OF CONTENTS

TABLE OF CONTENTS—*Continued*

ILLUSTRATIONS

550-foot level (Pl. X)

Both the 491 and 391 veins are developed on the 550-foot level, which is 13 feet lower than the 700-foot level of the Mammoth Mine. The intersection of the two veins is near section F-F′ (Pl. III), whence it plunges below the level to the southeast. At the northwest end of the level, 591 stope is on the main or 491 vein. At the southeast end 542 and 543 stopes are on the branch (391) vein.

As the Mohawk shaft passes through the Dream vein a little above the level, the vein crosses the shaft station a few feet northeast of the shaft. There the vein is narrow and poorly mineralized.

400-foot level (Pl. IX)

Both branches of the Mammoth vein as well as the Dream vein are explored on the 400-foot level. The intersection of 491 and 391 veins is near section E-E′ (Pl. III). The principal stopes on this level are on the 491 vein. The 391 vein is well defined but narrow and contains only one small stope. Beyond the northwest limit of 492 stope the vein contracts and at the end of the level is a practically barren fissure.

The Dream vein on the 400-foot level widens at the southeast end where the vein is cut by a series of cross-fractures which probably were effective in localizing the mineralization. A small stope was begun at this point, but apparently the results were not encouraging.

The 400-foot level is near the bottom of a large wedge-shaped mass of intrusive breccia included in the rhyolite sill.

300-foot level (Pl. VIII)

The structure on the 300-foot level resembles that on the 400-foot level. The two veins converge near the northwest limit of 391 stope, beyond which the mineralization ends abruptly. A northeast crosscut off 351W2 winze about 80 feet below the 300-foot level (section E-E′, Pl. III) shows the convergence of 391 and 491 veins a little above the 400-foot level.

At the southeast end of 391 stope (392 stope) the vein passes into intrusive breccia and becomes too narrow to mine profitably. The vein continues southeastward for 450 feet along a contact of rhyolite with intrusive breccia but without sufficient width to warrant stoping.

The top of 491 stope is a little above the 300-foot level. The upward continuation of the vein is said to have "feathered out," that is, mineralization became too dispersed to make ore.[28]

The Dream vein, which is explored for 650 feet along its strike, is well defined and mineralized but too narrow for profitable mining. As on the 400-foot level, a group of parallel cross-fractures appear to have caused a widening of the vein at the south end of the level where a little ore has been stoped.

[28] Carl Geib, oral communication.

Adit level (Pl. IV)

This level is 70 feet higher than the collar of the Mammoth shaft and 130 feet below the highest point of the vein outcrop.

The vein structure southeast of the Collins shaft is almost identical to that on the 60-foot level. The principal ore shoot has been stoped to the surface, leaving a large open cut or glory hole.

A drift southwestward into the hanging wall of the vein cuts 150 feet of brecciated rhyolite and closely sheeted andesitic breccia. The first 40 feet next to the vein is an andesitic breccia containing numerous thin stringers of quartz and cut by sheeted zones in which the laminations are commonly less than an inch wide.

All the rock on this level is intricately fractured and sheeted in zones that trend northwest and dip steeply southwest. The slickensides of some fractures suggest reverse movement.

A fairly large shoot of ore has been mined in a glory hole at the junction of the Collins east vein with a wide sheeted zone striking eastward.

Mohawk-New Year Mine

The Mohawk-New Year Mine explores three veins: the southern extension of the Mammoth vein (491 vein), a branch of the Mammoth vein (391), and the Dream vein. The branch vein dips northeasterly and intersects the footwall of the Mammoth vein. The intersection of the two veins plunges southeastward from above the 300-foot level at the north end of the mine to below the 550-foot level at the south end.

It is interesting to note that above the intersection of the faults, wherever the vein widens in one branch, the vein opposite contracts. Apparently when the ascending solutions reached the intersection of the faults they largely entered whichever branch offered the more open channel. The vein is widest in rhyolite and contracts where one or both walls are of intruded breccia. The country rock in the Mohawk-New Year Mine is almost entirely rhyolite with included bodies of intruded breccia.

The Dream vein follows the footwall of the rhyolite intrusive in which the other veins occur. The footwall of the Dream vein is a coarse arkose derived from the granite that it overlies. Only a very small amount of ore has been recovered from the Dream vein.

The mine is entered by either the Mohawk or New Year shafts, which are both vertical and are only 140 feet apart. The Mohawk shaft has three compartments, two of which are equipped with cages operated in balance by a double-drum electric hoist. The ore is hoisted in mine cars. The New Year shaft has a manway compartment and one hoisting compartment equipped with a skip. The collars of the two shafts are 10 feet higher than the 100 foot level of the Mammoth Mine.

GEOLOGY AND ORE DEPOSITS OF THE MAMMOTH MINING CAMP AREA, PINAL COUNTY, ARIZONA

INTRODUCTION

Field Work and Acknowledgments

This report is the result of four months of field work from February to May, 1937. Laboratory investigations and preparation of the report required most of the year following the field work.

A topographic map, with a scale of 300 feet per inch and a contour interval of 25 feet, was available for the part of the area that includes the mine workings and camp buildings. This map was extended westward to Tucson Wash, eastward to the alluvium, and southward to the limit of known mineralization. The Mammoth-St. Anthony co-ordinate system, with its origin near a U.S. Geological Survey bench mark at an altitude of 3,171 feet, was adopted as a base for the entire camp.

This report is concerned primarily with the mineralization and ore deposits of the Mammoth mining camp area. Time was not available for a study of the broader features of regional geology and their relations to local structures.

The writer wishes to express his appreciation to Dr. B. S. Butler and Dr. M. N. Short of the University of Arizona, for many helpful suggestions and criticisms during the preparation of this report. He is also indebted to Foster S. Naething, Manager of Mammoth-St. Anthony, Ltd., who made this work possible by granting the writer complete freedom in the camp and access to the maps and records of his company; to Carl Geib, Mine Superintendent of Molybdenum Gold Mining Company, for much helpful information especially concerning parts of the Mohawk and New Year mines that are now inaccessible; and to Sam Field and other members of the operating organizations who gave their assistance and co-operation wherever possible.

Bibliography

The following publications and private reports contain information concerning the geology and mining operations of the Mammoth camp area:

1896.—Rickard, T. A., Vein walls: *Am. Inst. Min. Eng., Trans.*, Vol. 26, pp. 214, 233, and 234. Contains a short description of the veins and mineralization in connection with a discussion of vein walls.

1901.—Blake, Wm. P., Report of the governor of Arizona: Annual report of the Department of Interior, 1901, pp. 188-90. Describes in some detail the mining operations as of 1901 and the years directly preceding.

1912.—Stewart, S. O., The Old Hat mining district, Pinal County, Arizona: *Mining and Eng. World*, Vol. 36, p. 952. A short rather sketchy description of the topography, geology, and the mines of the Mammoth area.

1924.—Hess, Frank L., Molybdenum: U.S. Geol. Survey Bull. 761, p. 15. Discusses the wulfenite mineralization and includes a few historical notes concerning the reworking of the early mill tailings.

1934.—Wilson, Eldred D., Arizona lode gold mines: Univ. of Ariz., Ariz. Bureau of Mines Bull. 137, pp. 170-74. Contains a short outline of the history, geology, and ore deposits of the Mammoth vicinity.

1934.—Naething, Foster S., and Murphy, Paul R.: Private report for Mammoth-St. Anthony, Ltd.

1935.—Vanderwilt, John W., Economic geology of the Mohawk-New Year mine: Private report for Molybdenum Gold Mining Company.

GEOGRAPHY

Location and Accessibility

Mammoth mining camp is in Pinal County, Arizona, 3 miles southwest of Mammoth, a small village on the San Pedro River, 21 miles south of Winkelman. In the early days the camp was known as Schultz.

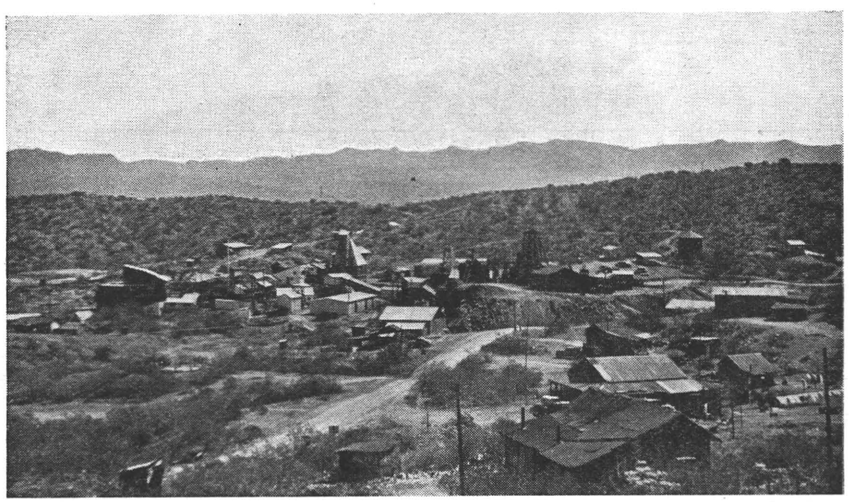

Plate XI.—Mohawk-New Year Mine at right, Mammoth-St. Anthony mill at left.

A good highway gives access to the camp from Tucson, about 50 miles to the southwest, and from Winkelman, the nearest railroad station, which is the terminus of a branch line of the Southern Pacific Railroad.

400-foot level (Pl. VII)

The drift northwest and southeast from the Collins shaft shows very little ore, but a crosscut recently driven northeastward passed through a mineralized zone, suggesting that the drift was driven entirely in the hanging wall of the vein. The relation of the ore to the rhyolite cut by the drift at co-odinate 1300 W. is doubtless the same as on the level below.

300-foot level (Pl. VI)

A crosscut southwestward from the northwest end of the 300-foot level of the Mammoth Mine passes through the Mammoth fault and intersects the Collins vein 280 feet east of the Collins shaft. A drift along the vein opened an excellent ore body. A little over a hundred feet northwest of the shaft, mineralization decreases below the limit of ore.

The gold content of the vein, which is almost negligible on the levels below, will exceed that in any of the remaining ore bodies. The copper content is much larger than on the levels below, whereas the zinc content is lower. Molybdenum and vanadium are high but probably not as high as in the ore just above the 520-foot level.

The vein has not been explored east of the point where it was encountered by the crosscut.

The slightly mineralized fault cut by the crosscut at co-ordinate position 900 W. is probably the Collins east vein (section A-A′, Pl. II).

60-foot level (Pl. IV)

The 60-foot level is 60 feet below the collar of the Mammoth shaft and 125 feet below the Collins adit level. For current operations access to this level is through an inclined shaft near the east portal of the adit level.

A large body of gold ore has been mined above the 60-foot level; but considerable vein material that is now ore was left along the foot and hanging walls and is now being recovered.

A narrow vein to the northeast, approximately parellel to the main vein, has recently been prospected, but the results were disappointing. This is doubtless the same vein that occurs in the short adit at elevation 3,370, or about 75 feet above the main adit level and a little to the northeast, and which also occurs on the 300-foot level at co-ordinate position 1100 N., 900 W. This vein crops out for 750 feet northwest from the east glory hole to its termination against the Turtle fault. It is known as the Collins vein, but in this report is called the Collins east vein.

In places the outcrop of the Collins east vein is well mineralized, as is shown in the Carbonate prospect, and further prospecting on the 60-foot level may be warranted. However, an adit driven to intersect this vein at approximately the elevation of the 160-foot level, 225 feet vertically below the outcrop, crosscuts 400 feet of intricately fractured rhyolite and granite but does not locate the vein.

below the contact of the Gila conglomerate with the intruded breccia.

Conditions at the south end of the level are shown on Plate IV. Development is almost entirely in rhyolite which is thoroughly brecciated and cut by numerous gouge-filled fractures. The complicated structure on this level is due partly to branching of the vein and probably also to postmineral faulting. The 204 stope ends just above this level at a gouge slip dipping 45 degrees SW, which may have displaced the top of the ore shoot toward the west. If this displacement occurred, the ore shoot in the extreme southwest part of the level is doubtless the top of 204 ore body. Similarly the small ore body 60 feet west of the shaft ends about 25 feet above the level at a slip dipping 45 degrees SW.

Collins Mine

The Collins Mine workings are limited largely to one ore shoot about 350 feet long, which strikes northwest, dips steeply to the southwest, and plunges northwest. The 300- and 700-foot levels are now connected with the Mammoth Mine. Prior to these connections, access to the various levels was through the Collins shaft, which extends from near the middle of the ore shoot on the 700-foot level to the west end of the shoot on the adit level with an average inclination of about 68 degrees.

At the present writing (1938), ore mined above the 60-foot level is hoisted through an inclined shaft.

700-foot level (Pl. X)

The 700-foot level has been described on page 55. Development on the levels above is confined to the west ore shoot. The country rock on the 700-foot level is granite, but the vein breccia contains abundant rhyolite fragments, especially at the east end of the shoot, which apparently have been dragged down from above.

650-foot level (Pl. IX)

On the 650-foot level the vein is less clearly defined than on the level below. The mineralization appears to be dissipated in a wide fractured zone in which cross fractures had a marked influence in directing the solutions. The minerals are mostly oxidized, but large masses of galena remain. The vein passes into rhyolite at the east end of the shoot.

520-foot level (Pl. VIII)

The structure on the 520-foot level resembles that of 650-foot level but is complicated at the east end by an irregular tongue of rhyolite intruded into the granite.

Oxidation is more complete than on the level below, and wulfenite and vanadium minerals are more abundant.

The vein between this level and the 400-foot level was partly mined out in 1918 for its molybdenum content. The ore recovered averaged 8 pounds of MoO_3 and 0.025 ounce of gold per ton.

The mapped area which forms a part of the Old Hat mining district is almost entirely in the W. ½ Sec. 26 and in the E. ½ Sec. 27, T. 8 S., R. 16 E. It lies on the east flank of the Black Hills, a low range north of the Santa Catalina Mountains.

Drainage and Relief

The Mammoth region is drained by the San Pedro River, which flows northwestward in a remarkably direct course and empties into the Gila River at Winkelman. The most important tributary in the vicinity of the mines is Tucson Wash, which forms the north and west boundaries of the mapped area. This wash rises near Oracle and drains a large territory but like most of the watercourses in this region is dry except after heavy rains. Its sandy bed provides a roadway over which much of the adjacent country is accessible.

The mapped area ranges from 2,800 to 3,500 feet above sea level. The Mohawk and Mammoth shaft collars are at altitudes of 3,107 and 3,225 feet, respectively.

The land forms of the area reflect the character of the outcrops. The granite, where not reinforced by rhyolite intrusions, weathers to low, rounded hills separated by relatively wide, shallow valleys. The lava areas are characterized by steep, rugged hills and ridges, dissected by narrow, steep-walled gulches. The position of hills and ridges is governed largely by dikes and irregular bodies of rhyolite which have a far greater resistance to weathering than any of the associated bodies of rock. So-called "blowouts" of rhyolite breccia stand out as knobs or high, sharp ridges flanked by talus of broken rock.

In the lava-covered area west of Tucson Wash the topography and drainage pattern were greatly influenced by faulting. The angular course of Cloudburst Canyon is largely due to faulting. Nearly vertical scarps of recent faults are common in the rugged hills on both sides of the canyon.

East of the camp the tilted Gila conglomerate is deeply dissected by recent watercourses which trend north and northeastward. The west banks slope gently, whereas the east banks are generally steep cliffs.

The regional topography is illustrated on the Winkelman quadrangle sheet, published in 1913 by the U.S. Geological Survey. This map is on a scale of about 2 miles per inch and a contour interval of 100 feet.

Climate and Vegetation

The temperature at Mammoth camp ordinarily ranges from 20 degrees F. to somewhat over 100 degrees F. December and January are the two coldest months, while June and July are the hottest months. The weather is pleasant during a greater part of the year, and even in midsummer the days are seldom oppressively hot.

The annual rainfall, probably 10 to 13 inches, occurs mainly in two periods, one in July and August and the other during the winter months. Very little snow falls in the area.

The vegetation is typical of the semiarid portions of southeastern Arizona. On the rocky outcrops saguaro, ocotillo, paloverde, prickly pear, and cholla are the most conspicuous plants. Creosote bush, canutilla, cat's-claw, and barrel cactus are common. Mesquite is rare and probably indicates underlying fault zones.

GEOLOGY

Rocks of the Area

ORACLE BIOTITE GRANITE

The oldest rock exposed in the Mammoth area is the Oracle granite, which outcrops in the southwest quarter of the mapped area. In Camp Grant Wash, about 10 miles north of the mines, it is unconformably overlain by the pre-Cambrian Apache series and by valley fill. It is separated from the Oracle granite of the Oracle area by a belt of alluvium 2 or 3 miles wide.

In the Mammoth and Collins mines granite is the most important host rock for ore. In the Mohawk-New Year Mine granite arkose forms the footwall of the Dream vein, but granite is almost entirely lacking in the formations cut by the main veins.

Surface exposures of the granite are a light buff color and coarsely granular in texture. Deeply weathered areas of the rock appear distinctly reddish, particularly when viewed from a distance.

The granite forms low, rounded hills whose slopes, covered by coarse granite sand, present a marked contrast to the rugged topography of the lava-covered areas. At higher elevations where precipitation is greater, as around Oracle, tops of the granite hills are covered by large rounded boulders, the valleys are filled with a thick mantle of granitic gravel, and the intermittant watercourses show deposits of magnetite sands derived from the granite.

The granite is prevailingly a coarse-grained, porphyritic rock with large pink or salmon-colored feldspars 1¼ or 1½ inches across that give it a pink and gray mottled appearance on fresh surfaces. The groundmass consists of uniform grains of clear white feldspar and glassy quartz, about 0.2 inch in diameter, with greenish black masses of biotite and magnetite.

In the vicinity of Oracle dark basic segregations are common in the exposed boulders of granite, but this feature was not observed at Mammoth.

In thin section the pink feldspar phenocrysts are seen to consist of microperthite with a little microcline; together they make up about 37 per cent of the section. The groundmass consists of well-formed crystals of oligoclase-andesine, $Ab_{70}An_{30}$, which constitutes about 28 per cent of the rock. Quartz forms about 28 per

400-foot level (Pl. VII)

Drifting southeast from the shaft follows the Mammoth vein. The vein is entirely in granite for 180 feet southeast of the shaft to where the hanging wall changes to rhyolite; 140 feet farther both walls are of rhyolite. On entering the rhyolite the vein fault contracts to a narrow fissure filled with white or pinkish gouge of kaolinized rhyolite. Beyond the south limit of 402 stope the volume of mineralization becomes too small for ore. Where both walls are rhyolite the vein is 3 to 12 inches wide or is entirely absent. Where the vein fault is not mineralized the breccia is slightly silicified and contains abundant clear, colorless calcite crystals.

A raise at the southeast end of the level connects with the 300-foot level of the Mohawk Mine 50 feet below.

The vein structure at the north end of the mine continues on this level and on the levels above, but there is a marked decrease in the volume of mineralization from east to west.

300-foot level (Pl. VI)

Development on the 300-foot level is similar to that on the level below. At the north end of the mine the west-striking segment of the vein is being mined in 303 stope. The vein ends at the west against a fault dipping 35 degrees W. This fault is probably later than the sulphide mineralization but is definitely earlier than the vanadium mineralization. The flat fault cut in the end of the short crosscut to the northwest from the end of the vein is of the same age and probably represents considerable movement, since the fault breccia contains fragments of intruded breccia dragged in from an unknown source.

At the south end of the mine the vein structure at the southeast limit of 304 stope is like that on the level below.

200-foot level (Pl. V)

The ore shoot southeast of the Mammoth shaft has been stoped to the 100-foot level where the ore ends abruptly at the footwall of a fault dipping 45 degrees SW. In places 204 stope attained a width of 35 to 40 feet. The ore carried 0.3 to 0.4 ounce of gold but was much leaner near the 100-foot level. Unlike other important ore shoots in the Mammoth Mine, this one was entirely in rhyolite although the hanging wall in the south half of the stope was basalt or basalt breccia.

The workings north of the caved section are reached by way of No. 2 shaft and consist of about 200 feet of drifting along the vein, which is well defined and mineralized but narrow. The west end of the vein reaches nearly to the 100-foot level; the east end is probably eroded much deeper and covered by Gila conglomerate.

100-foot level (Pl. IV)

The 100-foot level north of the cave consists of a waste drift driven northward from No. 2 shaft, partly above and partly ing wall side of the Mammoth fault wherever the fault is encountered underground.

The Collins vein was cut 430 feet west of the fault. Section C-C′ (Pl. II) is approximately on the line of this crosscut.

On the 700-foot level the Collins vein forms a broad arc, convex toward the northeast. The vein averages 5 feet wide and is composed of massive sulphides, mainly galena and sphalerite, surrounded by an envelope of quartz, specularite, and chlorite.

A winze 46 feet deep sunk to the water level started in ore containing 16.3 per cent lead and 9.5 per cent zinc, but bottomed in material containing only 0.8 per cent lead and 3 per cent zinc.

600-foot level (Pl. IX)

The workings on this level northwest and southeast of the Mammoth shaft are limited to drifting and stoping along the vein. Except for a small section in the shaft pillar, the drifts are caved and inaccessible.

The continuation of the vein northwest of the caved section is similar to that on the level below. Northwestward along the strike, the vein becomes too narrow and the mineralization too feeble to constitute ore, although there is no intruded breccia present to account for the change.

The ore shoot in the west-striking segment of the vein bottoms on a flat slip about 1½ feet above the 600-foot level at the extreme west end of the level. The Mammoth fault forms the west limit of the shoot. The sill floor of the stope (601 stope) is less than 50 feet long, but the length increases above the level to at least 180 feet on the 560-foot level.

560-foot level

The 560-foot level consists of a single drift 175 feet long driven along the vein. Both walls of the vein are of granite.

500-foot level (Pl. VIII)

The old workings along the main vein southeast and northwest of the shaft are caved and inaccessible. A drift in the granite footwall around the caved section provides access to the northwest end of the mine.

Although the westward swing of the mineralization northwest of the cave is clearly shown on this level, there is also a suggestion of the continuity of the vein fault on its original northwest strike. However, the extension of the fault has been well prospected by a crosscut and drift which show that the fault is not mineralized beyond its intersection with the west-striking segment.

The drift along the west-striking segment of the vein shows continuous mineralization up to its intersection with the Mammoth fault. A crosscut through the fault shows unmineralized rhyolite west of the fault.

cent, green biotite about 5 per cent, and titaniferous magnetite and apatite the remaining 2 per cent.

The samples studied were obtained from the 700- and 500-foot levels of the Mammoth Mine and appeared fresh in the hand specimens. Under the microscope, however, the plagioclase is seen to be largely altered to sericite. This alteration is confined almost entirely to the albite intergrowths.

The composition given above suggests that this rock should be classed as quartz monzonite rather than granite. Plagioclase amounts to 43 per cent of the total feldspar, which is well above the 33⅓ per cent limit set for granite.[1] Also the plagioclase is more calcic than is characteristic for granite.

APLITE

The Oracle granite is intruded by numerous dikes and small, irregular bodies of aplite which do not invade the later formations. The dikes range from a few inches to 10 feet in width, strike irregularly, and dip steeply. A few masses of aplite, roughly circular in outline and generally less than 100 feet in diameter, are present.

The aplite is a uniformly medium-grained, sugary, pinkish-gray rock whose grains of pink orthoclase, white plagioclase, quartz, and brownish specks of mica can be recognized with the aid of a hand lens.

In thin section the aplite is seen to consist of interlocking, nearly equidimensional grains of quartz and feldspar. The feldspar grains average 0.03 inch and the quartz 0.016 inch in diameter. The composition of the section is approximately 60 per cent feldspar, 36 per cent quartz, 2 per cent muscovite, 1 per cent biotite, and 1 per cent magnetite with a little apatite. The feldspar is about half microcline and half oligoclase of the composition $Ab_{87}An_{13}$. The plagioclase grains are in general a little larger than the microcline grains.

ANDESITE PORPHYRY

Intruding the Oracle granite and the aplite are abundant dikes and irregular bodies of andesite porphyry. These masses tend to be larger than the aplitic intrusives.

The andesite porphyry shows laths of altered white feldspar, up to 0.4 inch long, and hexagonal prisms of green mica, up to 0.08 inch across, within a dense grayish groundmass that constitutes about 60 per cent of the rock. Viewed microscopically, the feldspar is seen to be completely altered to sericite and epidote, but some ghosts of original albite twinning remain. The mica has been completely chloritized and sericitized. The groundmass consists of sericitized laths of plagioclase, about 0.004 inch long, together with interstitial limonite and chlorite derived from

[1] F. F. Grout, *Petrography and Petrology*, 1932, p. 47.

augite or hornblende. Some accessory magnetite and apatite are present.

AGE OF THE ORACLE GRANITE AND ASSOCIATED ROCKS

Stratigraphic evidence for the age of the granite is lacking in the Mammoth area. About 10 miles farther north, however, similar granite is overlain, apparently with depositional contact, by the pre-Cambrian Apache group. This contact is exposed in Camp Grant Wash, 2½ miles west of Arivaipa School and 11 miles south of Winkelman. Here, the Scanlan conglomerate and Pioneer shale, which are the two lowest members of the Apache group, contain fragments of the underlying granite. As the basal strata show no evidence of metamorphism, the granite in Camp Grant Wash is clearly older than the Apache group. Microscopically, this rock is similar to the Oracle granite, but it has not been proved to be part of the same intrusion.

Pending further study of this problem, it appears safe to assume that the Oracle granite is older than the Apache group.

GRANITE ARKOSE

Before the extrusion of the lavas the surface in this area was one of low, rounded hills and shallow valleys. The relief was probably little, if any, more than is now seen in the granite area farther south. The decomposed granite of the hilltops was washed into the depressions where it accumulated as granitic sand or gravel. The pressure exerted by later volcanic rocks consolidated these sands into an arkose that, especially in surface exposures, may easily be mistaken for granite.

The two west crosscuts into the footwall of the Dream vein on the 300-foot level of the Mohawk Mine show a thickness of about 130 feet of this arkose between the granite and the rhyolite sill. Small boulders of granite and rounded fragments of aplite and andesite ranging from about ½ inch to 3 inches in diameter occur in the arkose along the granite contact. Farther north the arkose is thin or entirely lacking. Apparently the southern part of the area was a valley in the old granitic land surface, and the area occupied by the Mammoth and Collins workings was a hill or ridge. Decomposed granite was eroded from the hills and deposited in the valley where it accumulated to a thickness of 130 feet or more.

The arkose is a dark, chocolate-colored rock studded with pink and white feldspar, quartz, and granite fragments. On weathered surfaces the matrix has worn away faster than the included material so that the larger fragments protrude as much as half their diameter beyond the average surface of the rock.

Microscopic examination shows that all the constituents of the arkose were derived either from the Oracle granite or the aplite and andesite. The angularity of the fragments suggests that the material was not transported far from its source.

shaft located about midway in the productive section of the vein. The shaft was begun in the hanging wall but crosses through the vein into the footwall granite at the 300-foot level. At the 700-foot level the shaft is 120 feet from the vein in the footwall.

The shaft is equipped with two 1½ ton, self-dumping skips, operated in balance by an electric hoist. The ore is trucked from a bin at the collar to the mill.

The general strike of the vein in the Mammoth ground is about N. 40 degrees W., but 400 feet north of the shaft the vein turns abruptly to a nearly due west strike. The upper part of the vein dips 75 to 80 degrees SW but flattens somewhat below the 500-foot level. The dip between the 600- and 700-foot levels is about 60 degrees SW. Coincident with the change in strike at the north, the dip steepens to nearly vertical.

A large ore shoot directly north of the shaft was mined prior to 1901. Due to inadequate support, the ground caved, first above the 400-foot level and later from the 750-foot level to the surface. Most of the early production up to 1901 came from this ore body, which in places was 60 feet wide. Fortunately the shaft was protected by a substantial pillar.

Number 2 shaft was sunk to give access to the mine workings north of the caved section where several good ore shoots remained. Drifts were driven around the footwall side of the cave on the 300-, 500-, and 700-foot levels.

750-foot level

This level is flooded and inaccessible. The workings are not extensive and are probably confined to drifting and stoping on the vein north and south from the shaft.

700-foot level (Pl. X)

A crosscut southwest from the shaft intersects the footwall of the Mammoth vein at 120 feet. The vein has been stoped south of this point and northward for 300 feet, but the sill floor on both sides is caved and inaccessible. The continuation of the vein north of the cave is now being stoped. The mineralization ends at the north near a body of intruded breccia. Attempts to locate the east-west segment of the vein beyond this point were not successful. The country rock between the end of the ore and the Mammoth fault consists of granite and small bodies of intruded rhyolite, much broken by small faults and fractures.

A narrow vein crosses the shaft station on the 700-foot level. This vein, known as the Schultz vein, is followed northwestward by a drift that also passes around the cave. The Schultz vein is mineralized for several hundred feet northwest from the shaft but is too narrow to be considered ore. It is unknown on higher levels but was doubtless present on the 750-foot level.

The crosscut southwestward from the shaft connects with the Collins Mine. It passes through 200 feet of intensely fractured, brecciated granite and crosses the Mammoth fault 250 feet from the vein. Similar brecciated zones are characteristic of the hang-

CLASSIFICATION OF DEPOSITS

The Mammoth mineralization cannot be readily fitted into Lindgren's classification. The mineral associations indicate a long range in temperature of deposition.

The loose, open brecciation in the fault fissure is evidence that the fractures were formed near the surface. The fine, intricate banding of the quartz and abundance of vugs and open spaces, are indicative of near surface precipitation. In general, the texture is fine-grained as is characteristic of shallow deposits where solutions reach supersaturation and precipitate minerals rapidly by loss of heat and included gases; but changes from fine to coarse and from coarse to fine textures occur, due probably to changes in permeability of the channel and to loss of heat and lowered concentrations during ebbing stages of magmatic activity.

Hydrothermal alteration of the wall rocks does not ordinarily extend more than a few feet from the vein, and replacement is of far less importance than deposition in open spaces. Both conditions indicate near-surface deposition.

The mineralogical associations and shallow depth of formation suggest that the deposits are of the class of high-temperature, shallow deposits recently discussed by Buddington[26] and by Butler.[27]

UNDERGROUND WATER

The mine workings above the water level are remarkably dry. The permanent water table in the mines is at an altitude of 2,495 feet or 730 feet below the collar of the Mammoth shaft and about 160 feet higher than the level of the San Pedro River at Mammoth.

While operations were in progress on the 750-foot level the water was handled by a pump with a capacity of 385 gallons per minute. Later the shaft was deepened to 835 feet at which point an inflow of water was encountered that was greater than the capacity of the pump, and the water rose to its present level. In 1938 water was being pumped from the Mammoth shaft for domestic and metallurgical purposes at the rate of about 150,000 gallons per day.

DESCRIPTIONS OF THE MINES

Mammoth Mine

The Mammoth Mine explores the north end of the Mammoth-Mohawk vein from its intersection with the Mammoth fault south to the barren section of vein between the Mammoth and Mohawk mines. The mine is developed from a three-compartment vertical

[26] A. F. Buddington, "High-Temperature Mineral Associations at Shallow to Moderate Depths," *Econ. Geology*, XXX (1935), 205-22.

[27] B. S. Butler, Discussion of the above paper, *Econ. Geology*, XXXI (1936), 115-18.

VOLCANIC ROCKS

Volcanic rocks occupy the entire portion of the mapped area north of the Turtle fault and also outcrop for about 3 miles west of Tucson Wash to a fault which brings them in contact with the granite. North and east of the area they are covered by Gila conglomerate and alluvium.

The volcanic rocks consist of basalt, flow breccia, and agglomerate, interbedded with conglomerate, arkose, and possibly tuff. All are tilted 45 to 65 degrees northeastward and strike N. 30 to 45 degrees W., with the older units at the west.

The total thickness of the volcanic series has not been determined. Measured eastward from Tucson Wash to a point where the lavas are covered by alluvium and Gila conglomerate, a thickness of 3,600 feet is exposed. They may extend eastward for some distance under this cover. West of Tucson Wash the structure is so complicated by late faulting that their extent westward cannot be determined without further detailed study and mapping. It is probably safe to assume that the total thickness is well over 5,000 feet and perhaps much more.

The earliest basalt lavas picked up much of the coarse, granitic sand and conglomerate that mantled the granitic land surface. At first the flow of lava that reached this particular area was small and interrupted by erosion which dissected the lava surface. The deposits of erosional debris that accumulated were covered and indurated by subsequent flows or picked up to form agglomerates. Some of the earlier flows, such as the series of basalts at co-ordinate position 1800 N. and 800 E., probably followed narrow valleys. Small lenses that occur with the lower members of the main series of flows possibly represent intrusions.

The basal member of the volcanic series is probably represented in the outcrop 800 feet east of the Mammoth shaft. This outcrop is also completely isolated by alluvium, but underground data indicate that basal member to be the hanging wall of the rhyolite sill that was intruded along the contact between the granite and the overlying lava (sections E-E′ and F-F′, Pl. III). This member is an agglomerate composed chiefly of varicolored basalt fragments together with abundant granitic material. The outcrop strikes N. 45 degrees W. and dips about 65 degrees northeast. The abnormally steep dip is probably due to tilting caused by the intrusion of the rhyolite sill. As this member dips under the alluvium, the next member of the sequence and the relation to the flows north of the Turtle fault cannot be determined.

The first member represented north of the Turtle fault and just east of Tucson Wash is a dark-gray basalt or andesite flow breccia composed of angular fragments in an altered basaltic groundmass.

Next follows a series of about 600 feet of alternating basalt flows and clastic rocks composed of material derived from the basalt and from granite. The clastic layers are 60 to 150 feet thick; the basalt is generally a little thicker. The basalt is dark gray and fine-grained, whereas the intervening strata are dark brown with a sandy texture. The Mammoth fault is believed to form the east boundary of this series.

In thin section the clastic rock resembles fine-grained arkose of quartz, sericitized feldspar, and grains of magnetite and hematite in a nearly opaque matrix of limonite, epidote, and chlorite. Areas of secondary quartz are common throughout the section.

The unit next above owes its position at least partly to faulting, and its stratigraphic relation to the rocks above and below is uncertain. It is made up of clastic material that ranges widely in character but contains a large proportion of dense, gray fragments characterized by glassy feldspar phenocrysts and plates of dark biotite. As no quartz is present, these fragments are probably latite.

In places the rock of this unit looks like typical volcanic tuff composed of fragments of gray latite, basalt, and decomposed granite of all sizes and shapes. Other phases are made up of latite fragments less than an inch across with a few fragments of basalt. The aggregate, which has the tenacity of a homogenous rock, resembles the intrusive breccia of the mineralized area, but its matrix lacks the characteristic hydrothermal alteration.

Above the member just described the flows become more massive and homogenous. The accumulation was apparently gradational from dark purplish basalt upward into red vesicular basalt and then into flow breccias containing abundant fragments of the gray latite. Overlying the latite breccia is a thick series of basalt flow breccias consisting of a rubble of angular and subangular fragments of basalt up to 2 feet, but most commonly about 2 inches, in diameter.

The foregoing is but a brief description of the volcanic series. The lithology and structure are complicated and constitute a problem beyond the scope of this report.

RHYOLITE

Rhyolite intrusions are abundant throughout the mapped area and in a mile-wide strip that extends westward for about 2 miles. These intrusions occur as dikes and irregular bodies in the granite and as irregular dikes and sills in the lavas. The dikes are 10 to 100 feet thick and generally dip steeply. The sill-like body intruded between the granite and lavas in the central part of the area is 300 to 500 feet thick and has numerous apophyses.

The rhyolite is pink, light cream, or light gray and has a fine-grained, almost glassy texture. It is generally porphyritic, but only the larger bodies contain conspicuous phenocrysts. Flow banding is common. In places the rock is speckled with small, dark-red blebs formed by the oxidation of pyrite.

Under the microscope a thin section of the typical pink porphyritic rhyolite is seen to consist of laths of unaltered sanidine, averaging 0.03 inch in length, and corroded grains of quartz, averaging 0.01 inch in diameter, in a fine-grained groundmass that

but a little replaced sulphides to form bornite, covellite, and chalcocite.

Pyrite oxidized and went into solution leaving behind only clean, empty cavities. The earthy hematite and limonite that are so abundant in the oxidized ore bodies were derived mainly through oxidation of chlorite and alteration of specularite.

WALL-ROCK ALTERATION

During the process of mineralization the solutions did not penetrate into the country rock more than a few feet beyond the fracture walls. Silicification, accompanied by more or less chloritization, was the only type of alteration recognized. The finely disseminated mafic mineral of the rhyolite groundmass was changed to chlorite. The most apparent change in the rhyolite is the bleaching of the groundmass to a dull, chalky white.

Megascopically and microscopically, the granite adjacent to the veins does not appear altered.

The intrusive breccia is more widely silicified than either the granite or rhyolite, doubtless partly due to its greater permeability, but also because much of its alteration took place at the time of its intrusion. In thin section the included rhyolite fragments are seen to be completely recrystallized to coarse-grained quartz intergrown with adularia.

SOURCE OF MINERALIZING SOLUTIONS

There is a distinct zoning in the intensity of mineralization in depth and longitudinally from the northwestern part of the area to the southeast. The outcrop of a small vein cut by Cloudburst Canyon about a mile northwest of the Collins Mine contains abundant specularite and chlorite with some oxidized copper and lead minerals. Specularite and chlorite are abundant in the lower levels of the Collins vein but decrease in amount toward the surface. There are less of these minerals in the Mammoth ore bodies than in the Collins and still less in the Mohawk and New Year ore bodies.

Lead, zinc, and copper appear to increase with depth in the Collins and in the Mammoth-Mohawk veins. The zone highest in copper, however, seems to be just above the 300-foot level in the Collins vein.

Molybdenum and vanadium are highest at intermediate depth in the Collins vein and increase slightly with depth in the Mammoth-Mohawk vein. Also the southern end of this vein seems to be higher in these metals than the northern end.

The highest gold content is at intermediate depths in the Collins and Mammoth mines and decreases markedly toward the southeast. It is lowest in the New Year ore bodies.

The progressive increase in intensity of the high temperature mineralization from the southeast to the northwest points to a source for the mineralizing solutions somewhere in that direction.

have been deposited by emanations from magmatic sources, as in the Valley of Ten Thousand Smokes, Alaska,[23] and in the lavas poured out during the eruption of Vesuvius[24] in 1631.

SUPERGENE ENRICHMENT

The physical character of the Mammoth ore bodies was especially favorable for deep oxidation and for secondary transportation and enrichment of the ore minerals. The present climate is warm and arid, and the rainfall is comparable to other areas in the Southwest where oxidation is deep. The relief is relatively high and the water table deep. The veins are extremely permeable. Though oxidation is deep and the gangue only slightly reactive, the transportation and enrichment of the metals was largely prevented by the scarcity of pyrite which plays such a vital role in the production of sulphuric acid and ferric sulphate so necessary in enrichment processes.

Due, probably, to hypogene zoning rather than supergene enrichment, the lead and zinc content of the ore appears to increase slightly with depth.

Gold has undoubtedly migrated to some extent. The ores with highest gold content seem to lie at intermediate depths. In the Aguaya tunnel and in the Smith workings supergene gold occurs as thin films deposited on iron-rich minerals in the intruded breccia adjoining the veins. The chemical character of the deposits favors the solution and transportation of gold. Manganese dioxide is present throughout the veins, and the mine water is said to contain about 85 parts per million of sodium chloride.[25]

Except in the Collins Mine thorough oxidation extends well below the water level. On the 750-foot level of the Mammoth Mine, which is 17 feet below the water level, there is said to be no noticeable decrease in the degree of oxidation. The maximum depth to which oxidation penetrated is unknown.

Galena oxidized in place, largely to cerussite with only very minor amounts of the complex lead phosphates and arsenates.

Zinc probably migrated to some extent as the zinc sulphate before it was finally fixed as smithsonite and hemimorphite; the effect was a more complete dissemination of the zinc rather than a concentration. As zinc has never been a source of revenue in the Mammoth ores, few assays that show its general distribution are available.

Copper went into solution and suffered more or less transportation, mainly as the sulphate but also as the colloidal silicate. Most of the copper was precipitated as carbonates or as chrysocolla,

[23] E. G. Zeis, *The Valley of Ten Thousand Smokes* (Nat. Geog. Soc. Katmai Series), I (1929), No. 4.

[24] F. Zambonni and G. Garobbi, Abstract by H. S. Washington, *Am. Mineralogist,* XII (1927), 1-10.

[25] T. A. Rickard, "Formation of Bonanzas," *Am. Inst. Min. Eng. Trans.,* XXXI (1901), 198.

makes up about 80 per cent of the rock. This groundmass consists of overlapping grains of quartz and feldspar, 0.03 millimeter in average diameter. Forming a mat over the entire groundmass are tiny prisms of a light-green mineral that resembles epidote or zoisite. It is undoubtedly not an original constituent of the rock. It alters to fine grains of hematite which color the rock pink.

Along the borders or less commonly in the interiors of most of the larger intrusive bodies are irregular areas of breccia composed of angular rhyolite fragments in a matrix of banded rhyolite. These areas are outcrops of conduits through which flow of extremely viscous material continued after the remainder of the intrusive mass had solidified. The included fragments are generally of the same texture as that of the normal phase of the intruded mass. There were doubtless periods when the propelling force in these conduits took the form of explosions caused by sudden release of gases that originated in the parent magma. Evidence of hydrothermal action is clearly brought out in microscopic study of these breccias. The feldspar phenocrysts tend to be bent or crushed; the quartz grains are corroded or embayed and generally shattered. Secondary quartz has formed between the fragments of shattered minerals and in fractures in the rock. Some sanidine crystals are partly replaced by quartz which spreads through the interior of the crystal. A few of the feldspar phenocrysts are of albite of the composition $Ab_{90}An_{10}$. If these are the result of hydrothermal action, the albitization occurred early, since much of it is crushed, and the fractures are filled with secondary quartz. A little epidote occurs in the feldspar grains.

In places the breccia contains small fragments of basalt with indistinct borders that blend into the rhyolite matrix as if they had been partly assimilated. In many occurrences these fragments must have been transported a considerable distance by the magma. The breccia in these pipes is similar in many respects to the typical intrusive breccia, which is believed to have originated in a like manner but on a much larger scale.

INTRUSIVE BRECCIA

The intruded breccia is closely associated with the thick, sill-like body of rhyolite that was intruded between the granite and the lava flows in the center of the mineralized area. The largest outcrop, which is 900 feet north of the Mammoth shaft, forms the northern extension of the ridge on which the shaft buildings and camp of the Mammoth-St. Anthony are located. It outcrops intermittantly on top of the ridge northward from the Mammoth shaft and on the hillside east of the Collins glory holes. Numerous smaller bodies outcrop south and west of the Mammoth shaft.

The breccia occurs on the tunnel level of the Collins, on the 300-foot and higher levels of the Mammoth, and on all levels in the Mohawk-New Year mines. It is unknown below the 300-foot level in the Mammoth Mine except at one place at the north limit of 701 stope on the 700-foot level.

The breccia differs considerably from place to place. The fragments generally do not exceed 1.2 inches in diameter. In some exposures fragments of rhyolite, basalt, granite, quartz, and several varieties of feldspar are present in an area of a few square inches. In other places the fragments are almost entirely of rhyolite, and in still others granitic material predominates. In some exposures the matrix is light tan or gray, and the rock has the appearance of typical Portland cement aggregate. In others the matrix is dark greenish gray or oxidized to red and brown. Generally the rock is porous and contains quartz-filled vugs and veinlets. Small deposits of fluorite are locally present.

The breccia commonly forms one wall of the veins in the Mohawk Mine, but the mineralization is confined to the adjacent rhyolite and separated from the breccia by a gouge seam. Where traversed by faults it forms a dark chloritic gouge unlike that produced by granite or rhyolite. The light colored breccia contains very little secondary quartz or adularia.

In the darker breccia the alteration is more conspicuous. Many of the rhyolite fragments show incipient alteration to coarse-grained quartz that completely destroys the original texture. Adularia appears as minute rhombic sections which apparently form from the orthoclase in the rhyolite. Some of the feldspar fragments are partly replaced by quartz. A little sericite is developed in the plagioclase. Secondary quartz associated with more or less adularia occurs in numerous veinlets and coarse-grained aggregates.

Small bodies of andesite breccia occur associated with the intruded breccia, generally near the granite contact. One of these bodies is cut in the southwest crosscut on the adit level of the Collins Mine, and another in the Smith Mine. Some of the rock is on the dump of the Mohawk Extension shaft. This andesitic material is similar to that intruded into the granite.

These basic bodies may be either independent injections into the intruded breccia or a phase of the intruded breccia composed largely of fragmental material derived from the earlier andesite porphyry.

BASALT INTRUSIONS

Dikes and small intrusive bodies of basalt are commonly intruded along some of the later faults and along the borders of rhyolite intrusions in the area east of the Mammoth fault. The basalt is a hard, dense, bluish black to brown or reddish rock that breaks with conchoidal fracture. One dike along the south wall of a small rhyolite intrusion at co-ordinate position 2000 N. and 400 W. contains lenses of brecciated rhyolite in a matrix of basalt.

Thin sections of the typical intruded basalt show the rock to be 35 to 50 per cent feldspar in laths up to 0.04 inch in length. In most specimens the feldspar is too altered for determination. The

followed or were partly contemporaneous with a period of intense leaching which took place along certain channels that are especially related to concentrations of these minerals. The leaching was more intense and left less evidence of oxidation than that normally associated with supergene alterations. Only vein quartz resisted the intense leaching action. After the honeycomb and boxwork of quartz was at least partly formed, deposition of wulfenite began in open cavities and on the walls of channels. The solutions that deposited wulfenite penetrated farther into the unbrecciated vein material than the later solutions that deposited vanadium and farther than supergene solutions. Wulfenite crystals occur attached to quartz crystals in small vugs well removed from any evidence of supergene alteration.

Descloizite and mottramite followed by vanadinite began to form after wulfenite crystals as large as any now present in the deposit had formed. The earliest vanadium minerals contained copper and zinc in addition to lead.

In places crusts of vanadinite entirely cover large wulfenite crystals. Later the wulfenite was partly or wholly leached out, and fine crystals of vanadinite were deposited on the walls of, and projecting into, the resulting cavities. On the other hand, wulfenite appears to have been entirely stable in contact with supergene solutions. Specimens show all the common supergene minerals deposited on wulfenite crystals with no evidence of corrosion or replacement.

Doubtless some vanadium was dissolved and reprecipitated by supergene solutions, probably as descloizite or mottramite. Experiments by Notestein[22] demonstrate that vanadium is soluble in ground water carrying sulphate ions, also that calcite precipitates vanadium from sulphate solutions.

The solutions that leached the early minerals and deposited molybdenum and vanadium were distinctly different from the solutions that deposited the early minerals, though they doubtless were from the same source. The lead in the wulfenite, as well as the lead, zinc, and copper in the vanadium minerals, was probably derived from galena, sphalerite, and chalcopyrite of the preceding stages.

Little can be surmised concerning the nature of the solutions that deposited molybdenum, but it may be postulated that they were first strongly acid and that they became neutral and finally alkaline by reaction with vein minerals and country rock. Similarly, litttle is known about the conditions favoring the precipitation of lead molybdate in ore deposits. MoO_3 is only slightly soluble in water but dissolves readily in alkalies forming molybdates. It is also soluble in dilute sulphuric and hydrochloric acids. Lead molybdate can be precipitated in alkaline solutions or solutions of weak acids.

Molybdenum and vanadium minerals other than the sulphides

[22] F. B. Notestein, "Some Experiments on Uranium-Vanadium," *Econ. Geology*, XIII (1918), 50.

posits such as those at Mammoth. Newhouse[18] found traces of molybdenum and vanadium in certain galenas, pyrites, and sphalerites and concludes that at least a partial source of these metals is the small amounts contained isomorphously in the primary sulphides. Claussen[19] made spectroscopic analysis on five samples each of pyrite, sphalerite, and galena from various localities. His results showed molybdenum to be present in amounts estimated at 0.000n per cent in four pyrites and one galena; vanadium estimated at 0.0n per cent in two pyrites and four galenas.

In general lead deposits containing wulfenite and vanadinite in their oxidized zones are relatively small, as pointed out by Newhouse.[20] Hillebrand[21] found appreciable amounts of vanadium in more basic igneous and metamorphic rocks, up to 0.08 per cent or more of V_2O_5, but found practically none in the highly siliceous rocks. He made a few determinations for molybdenum and concluded that this element is confined to the more siliceous rocks. Several other investigators have determined similar amounts of these metals in rocks.

ORIGIN OF THE MOLYBDENUM AND VANADIUM MINERALS

Were the molybdenum minerals and most, if not all, of the vanadium minerals deposited by hypogene solutions? There is no other known source of vanadium and molybdenum for these deposits. They were not deposited by the same solutions that brought the primary sulphides but belong to a period that was later than the sulphides yet distinctly earlier than the supergene minerals. Minerals of molybdenum and vanadium that are generally conceded to be hypogene could not be found in the unoxidized ores, nor could decisive chemical reactions for these elements be obtained from 5-gram samples of the hypogene sulphides. To account for the molybdenum content of the Mammoth ores above the water table by enrichment of a primary deposition assumed to contain 0.01 per cent MoO_3 would require the complete leaching and erosion of at least 10,000 feet of vein above the present outcrops. It is hardly conceivable that such loose, open brecciation could have existed very deep below the surface. For the same reason it appears improbable that the molybdenum and vanadium were leached from the overlying or surrounding rocks and deposited in the veins by supergene solutions.

The observed mineral relations show that wulfenite and the vanadates largely preceded the definitely supergene minerals and

[18] W. H. Newhouse, "The Source of Vanadium, Molybdenum, Tungsten, and Chromium in Oxidized Lead Deposits," *Am. Mineralogist*, XIX (1934), 209-20.

[19] G. E. Claussen, "Spectroscopic Analysis of Certain Galenas, Sphalerites, and Pyrites," *Am. Mineralogist*, XIX (1934), 221-24.

[20] Newhouse, *op. cit.*, p. 220.

[21] W. F. Hillebrand, "Vanadium and Molybdenum in Rocks," *Am. Jour. Sci.*, *VI* (1898), 209.

original mafic minerals are altered to iron oxides, carbonate, serpentine, a little sericite, and perhaps some chlorite. Olivine phenocrysts appear as sparse, poorly preserved pseudomorphs of serpentine and carbonate outlined by vague rims of iron oxides.

GILA CONGLOMERATE

The Gila conglomerate, originally described by Gilbert,[2] is a thick deposit of fairly well consolidated alluvial material, accumulated under arid conditions in the valleys of southern Arizona.

Deposits believed to be equivalent to this formation underlie a large part of the region around Mammoth. Bryan[3] considers beds in the San Pedro Valley, in the Winkelman quadrangle, from which he and Gidley collected numerous fossils, as equivalent to the Gila conglomerate of the Ray and Christmas quadrangles. Gidley[4] determined fossils from two localities as of probable late Pliocene age.

In the vicinity of the Mammoth Mine the formation is a semiconsolidated, roughly stratified conglomerate of poorly sorted, rounded to subangular pebbles. The pebbles consist of basalt, basic porphyry, and crystalline rocks, most of which are unknown in the vicinity. Their original source probably was southwest of the area.

The conglomerate is tilted and cut by many normal faults of small displacement. The Mammoth fault depressed blocks of the conglomerate so that in places it forms the hanging wall, in contact with granite, rhyolite, and intrusive breccia of the footwall.

According to Bryan:

> The mountains of the San Pedro Valley region of southern Arizona are the residual elevation resulting from an uplift that involved the Gila conglomerate. This well known formation, restricted according to Gilbert's original definition and the usage of Ransome, is a valley fill now deformed and dissected, but accumulated under arid conditions in enclosed or partly enclosed valleys.[5]

QUATERNARY ALLUVIUM

All the unconsolidated or slightly consolidated alluvial material in the area is termed Quaternary alluvium, or simply alluvium. It consists of unsorted or slightly sorted, angular fragments of local rocks, mainly rhyolite, and rounded pebbles derived from the Gila conglomerate.

[2] G. K. Gilbert, *U.S. Geog. and Geol. Surveys W. 100th Mer. Report*, III (1875), 540-41.

[3] Kirk Bryan and G. E. P. Smith, quoted by C. P. Ross, "Geology and Ore Deposits of the Aravaipa and Stanley Mining Districts, Graham County, Arizona," from a paper in preparation.

[4] J. W. Gidley, Preliminary Report on Fossil Vertebrates of the San Pedro Valley, Arizona (U.S. Geol. Survey Prof. Paper 31), 1922, pp. 120-21.

[5] Kirk Bryan, *San Pedro Valley, Arizona, and the Geographic Cycle* (abstract, Geol. Soc. America, Bull.) XLV (1926), 166.

Structure

GENERAL STATEMENT

The major structures of the region trend northwestward, roughly parallel to the Santa Catalina and Galiuro mountain ranges. This trend is exemplified in the strike of the fault that forms the west contact of the lava with the granite, in the strike of the Mammoth fault and the Mammoth vein, and in the strike of the tilted lava flows. An eastward trend of secondary importance is shown by the Turtle fault and the Collins vein.

STRUCTURE OF THE LAVA FLOWS

The lava flows have been tilted 45 to 65 degrees NE. The mechanics of this deformation is not clear, but two possible explanations will be offered.

The tilting may be due to folding in which compressive stresses in a southwest direction thrust the flat-lying lavas into a series of folds with axes striking northwesterly. The lava flows in the Mammoth area would, in this event, represent the east flank of an anticline. A parallel synclinal structure for the San Pedro Valley is suggested by the abnormally steep dips of some of the older Tertiary sediments on both sides of the valley. The eastward dip of the Paleozoic and older sediments forming the west flank of the Galiuro Mountains may not support this view; but on the other hand, these sediments could have had a much steeper dip to the east before the folding took place.

This explanation of the structure would involve extensive thrust faulting in the underlying granite, but no evidence of the existence of such faults has been found. Minor thrust faults are present in Tucson Wash, just north of the mouth of Cloudburst Canyon, but their extension cannot be traced beyond a small area.

The second hypothesis suggested is that the lavas constitute a faulted block or series of blocks tilted by rotational movement on curved fault surfaces accompanied by some shearing along the bedding planes. In this case it is assumed that the lavas flowed out over the land surface and solidified with a moderate initial dip toward the east. Subsequent normal and reverse faulting increased this dip and brought the flows into their present attitude. This type of faulting is suggested by Burbank[6] to account for the tilting of the lavas in the Bonanza district, Colorado. The prevalence of high-angle, northwesterly striking faults in the Mammoth area is in keeping with this idea. The tilted blocks would thus constitute an area bounded on the east (depressed side) by a major fault that coincides roughly with the bed of the San Pedro River, and on the west by a fault that forms the contact with the granite west of the district. The Turtle

[6]W. S. Burbank, *Geology and Ore Deposits of the Bonanza Mining District, Colorado* (U.S. Geol. Survey Prof. Paper 169), 1932, pp. 51-54.

solutions. There is, however, a gradation of minerals characteristic of decreasing temperatures of deposition. All three stages have a group of minerals generally recognized as forming from hypogene solutions.

Between the third and fourth stages there is a complete change of minerals, and some of the minerals of earlier stages were destroyed by the solutions that deposited the minerals of the fourth stage. Likewise between the fourth and fifth stages there was a complete change from molybdenum, vanadium, and manganese minerals to carbonates, sulphates, silicates, and secondary sulphides of lead, zinc, and copper.

The minerals of the fourth and fifth stages are all of a type generally recognized as supergene, formed by the oxidation of earlier hypogene sulphides. The minerals of the fifth stage seem clearly to have resulted from the oxidation of sulphides and are of the usual supergene type. The fourth stage, however, is clearly separated from the fifth stage in time of formation and in place of maximum development. The question naturally arises why this separation should exist, if both have resulted from the oxidation of the same sulphide body.

SOURCE OF MOLYBDENUM AND VANADIUM

Careful search by many students of this type of deposit has revealed no primary minerals to account for the molybdenum and vanadium present in the oxidized ores. Lindgren[14] remarks that wulfenite is common in the oxidized zone of deposits containing galena and molybdenite but does not name the deposits to which he refers. Emmons[15] states that the oxidation products of molybdenite include molybdite, molybdic ocher, ilsemannite, and powellite and adds that it is noteworthy that wulfenite[16] is not found in association with molybdenite. The writer knows of no descriptions in the literature that mention wulfenite in association with molybdenite. Wulfenite could probably be formed if galena and molybdenite were present in a deposit undergoing oxidation. Molybdenite is difficultly soluble. According to Emmons[17] molybdenite immersed in hydrochloric acid and in sulphuric acid after one month showed no loss, and neither ferric sulphate nor ferric chloride increased its solubility. However, as molybdenite does alter in oxidized zones, it must be somewhat soluble in ground water. Since the common alteration products are oxides, the decomposition of molybdenite is possibly accomplished by hydrolysis. No molybdenite, however, has been detected in de-

[14] Waldemar Lindgren, *Mineral Deposits* (3rd ed., 1928), p. 985.

[15] W. H. Emmons, *The Enrichment of Ore Deposits* (U.S. Geol. Survey Bull. 625), 1917, p. 424.

[16] *Op. cit.*, p. 425.

[17] *Op. cit.*, p. 424.

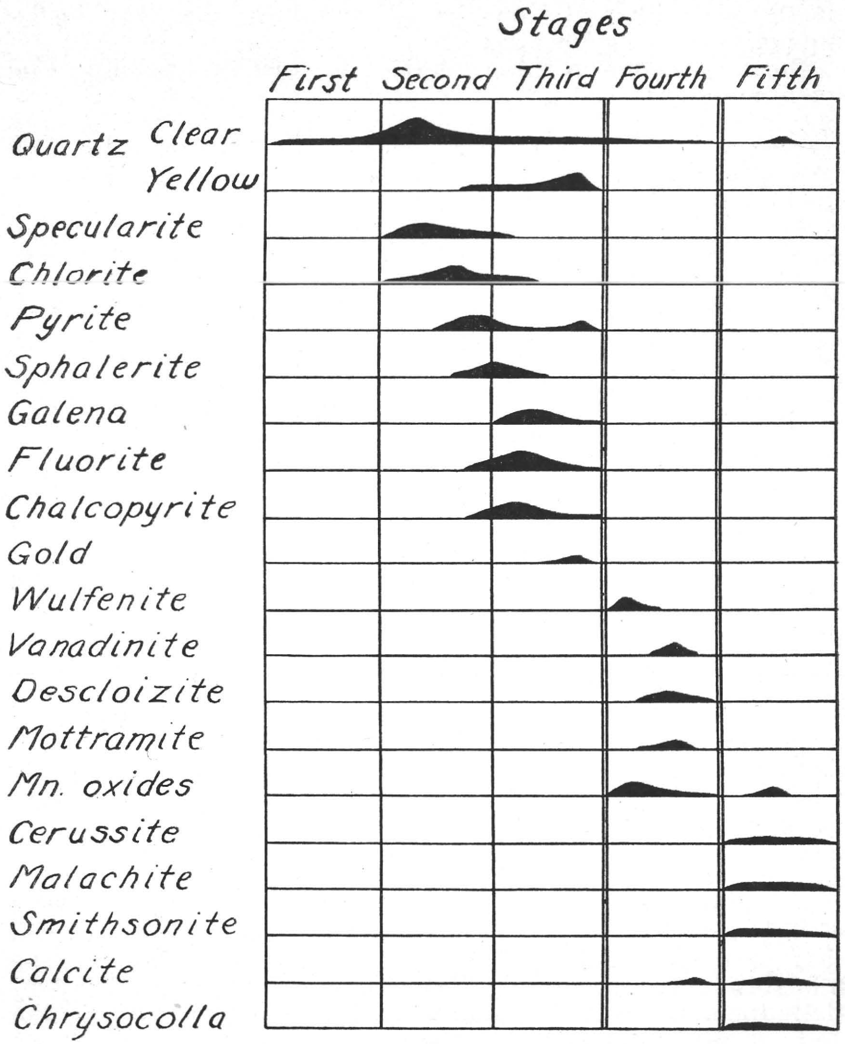

Figure 1.—General paragenetic relations of the vein minerals. The vertical lines indicate periods during which there was movement along the vein fault.

RELATION OF THE SEVERAL STAGES OF MINERALIZATION

There are two distinct breaks in the mineral sequence. During the first three stages there is a slight change in the vein minerals after each reopening, but in each case minerals of the earlier stage carry over into the following stage. The difference is due to a change in the physical conditions under which deposition took place rather than to an abrupt change in nature or source of the

fault cut off the lavas on the south, but the tilted structure coninues northward for at least 10 miles.

Two miles south of Feldman, Camp Grant Wash shows a section of the Apache group resting on granite and overlain by Devonian and Mississippian limestone, with the same structural attitude as the lavas to the south.

Much of the area occupied by the lavas is covered by late Tertiary sediments and recent debris. In many places the nature of the flows themselves hinders determination of strikes and dips. In many exposures the lavas are not banded, and contacts between units are partly or wholly concealed, but wherever reliable measurements can be made the general attitude of the flows is remarkably consistent. The strike ranges from N. 30 to 45 degrees W. and the dip from 45 to 65 degrees NE. The attitude of the lavas is also shown by the trend of rhyolite sills intruded into them.

Similar difficulties were experienced in mapping the faults in the lava-covered area; but the data obtained show a preponderance of strong, northwesterly striking faults.

The Turtle fault, which forms the south boundary of the lavas, brings the tilted flows in contact with the granite in such a manner that the strike of the flows is approximately at right angles to the strike of the fault. If the tilting is the result of block faulting it is obvious that the amount of displacement on the Turtle fault necessary to bring about the existing relation between the flows and the granite would be less than if folding were the agent.

It is also possible that a combination of folding and faulting may have produced the structure.

INTRUSIONS

All the rhyolite and some basalt occur as intrusions in older rock. The nature of the minor intrusive bodies is described on pages 9 and 14 and illustrated on Plate I.

The only intrusive body of important structural significance is a thick, sill-like mass of rhyolite intruded between the granite and lava flows in the central part of the area. As already mentioned, the lavas accumulated on an irregular erosion surface; and before their extrusion the southern part of the area was an eastward-trending valley with a parallel, low, rounded ridge to the north. Granitic sands and gravel accumulated in the valley to thicknesses of 150 feet or more so that the total relief was probably less than 100 feet. The central, thickest part of the sill coincides with this ancient valley, and northward the sill swings east along the south flank of the ridge. In the southern part of the area the footwall of the sill is marked by the Dream vein, which dips 45 to 65 degrees NE. The strike of the Mammoth-Mohawk vein is roughly parallel to the footwall. In the southern properties the vein is entirely within the sill, but, continuing northwestward with the same general strike, it passes out of the sill and into the footwall granite in the Mammoth ground.

The invading magma made room for itself partly by picking up and carrying forward the buried valley fill and partly by bowing up the overlying formations, as is evidenced by the abnormally steep dip of the lavas at the east. Intrusion was close to the surface where cooling and solidification were rapid. The ingress of molten material occurred slowly so that only the active channels contained liquid material. In many places the magma became extremely viscous before flow in a given channel ceased. Also the position of the feeding channels changed frequently, and the sill was built up of overlapping tongues.

During the early stages of intrusion, gases accompanied the molten rhyolite, which at intervals built up pressures that were relieved by explosions that shattered both the wall rocks and the solidified rhyolite. When fresh supplies of liquid material moved into the vent thus opened, the shattered rock was picked up and carried forward. The result was a heterogenous breccia containing as much as 60 or 70 per cent of clastic material derived from widely separated sources. The breccia near the footwall of the sill is composed almost entirely of granite detritus such as makes up the arkose. In some places the fragments are largely basalt, and in other places rhyolite fragments predominate. Noticeable changes in composition commonly occur within a range of 10 feet.

All the breccia shows evidence of alteration caused by action of accompanying gases. The nature of this alteration is described on pages 13-14.

The violence of the explosions opened new fractures that extended into the footwall granite and into the overlying lavas far beyond the zones of shattering. These fractures were also invaded by breccia and rhyolite magma, thus complicating the structure with apophyses and satellitic bodies. Toward the end of the intrusive period the violence waned and injection of magma continued quietly. Points of weakness developed in the breccia and in the earlier rhyolite into which tongues of magma forced their way. Sheets of rhyolite are commonly interfingered with breccia. This structure is beautifully illustrated in the breccia and rhyolite outcrops south and northeast of the Collins glory holes and also along the top of the ridge for 500 feet north of the Mammoth shaft. Large masses of breccia are suspended in rhyolite; the largest of these is a wedge-shaped mass between the Mohawk and Dream veins, shown in section E-E′, F-F′, G-G′ (Pl. III). Many smaller bodies are exposed by the mine workings, but little is known of their extent and shape except that the outlines of some of them must be extremely irregular.

The structural relations of the rhyolite and breccia as well as the broader structural features of the entire intrusion were further complicated during the period of faulting that produced the vein fissures and to some extent by later faults.

This rhyolite sill is the host rock of the ore in the Mohawk-New Year mines. The included masses of breccia exerted an important influence on the localization of the ore shoots.

dently quite different from the earlier solutions, at least in the minerals which they deposited.

The early action of these solutions was chiefly leaching. The metallic minerals along their paths were largely destroyed, leaving a honeycomb of porous quartz. In places even the rock fragments of the breccia were leached out, leaving a boxwork formed by the quartz veinlets that had been deposited between the fragments.

Following the period of leaching, wulfenite began to form, depositing in thin plates attached to the quartz skeleton. The deposition of vanadium minerals began later, probably not until after the deposition of wulfenite had largely ceased. Of these descloizite and mottramite were earliest, followed by vanadinite. Where vanadinite was deposited on wulfenite crystals, the latter are commonly corroded and in places completely leached out.

Abundant pyrolusite formed immediately preceding and accompanying descloizite and mottramite. It fills open spaces or coats the walls of cavities in the porous quartz and in places forms botryoidal crusts on fragments and on wulfenite crystals. Powdery black manganese dioxide is commonly intermixed with microscopic crystals of descloizite.

Some of the most perfectly formed crystals of molybdenum and vanadium minerals occur as crusts coating the walls and breccia fragments of fractures extending out of the veins into the wall rock. Minerals of earlier stages are entirely absent in these fractures, and those of the fifth stage are rare or lacking.

In the Mammoth-Mohawk vein the amount of molybdenum and vanadium, as well as lead and zinc, appears to increase with depth. In the Collins vein lead and zinc increase with depth, whereas molybdenum and vanadium are highest at intermediate depth and almost absent on the lowest level.

FIFTH STAGE OF MINERALIZATION

The fifth stage consists of carbonates, sulphates, and silicates of the metallic elements together with some secondary sulphides that have obviously resulted from the oxidation of hypogene minerals by supergene solutions. These minerals are all essentially the same age and are distinctly later than the molybdenum and vanadium minerals of the fourth stage.

Cerussite is the most abundant fifth-stage mineral. Some specimens show clearly that wulfenite is earlier than cerussite, whereas none show conclusive evidence that cerussite is earlier. Some wulfenite appears to have formed directly from galena. A little cerussite and ecdemite are generally present, but both are later than the wulfenite. Cerussite is rarly associated with vanadium minerals.

Some crystals of wulfenite are completely embedded in malachite and chrysocolla. Mimetite, ecdemite, beudantite, calcite, smithsonite, and hemimorphite are all later than mottramite and hence doubtless later than wulfenite. A little calcite was earlier than the vanadium minerals.

space in the mid-section of the veinlet. These veinlets of coarse, amethystine quartz are commonly an inch wide.

The fine-grained quartz is colorless in thin section and light amber to yellowish-green in hand specimens. It is the only vein material in which free gold was recognized, and its distribution in the veins corresponds rather consistently with that of the gold. It was not observed in the ore shoots on the 700-foot level of the Collins Mine where the ore carries 0.02 ounce or less of gold but is abundant where the gold content increases to 0.2 ounce or more. Amethyst quartz similar to that associated with the gold-bearing quartz is common in low-grade sections of the veins.

DISCUSSION OF EARLY MINERALIZATION

During the earliest stages of mineralization, while quartz was forming in narrow veinlets in the upper portions of the channels, deposition of metallic minerals was probably going on at some deeper zone. By the time the solutions reached the higher elevations they were fairly dilute and nearly in equilibrium with the wall rocks. They carried mainly potash, soda, silica, and alumina and were almost lacking in the metallic elements.

This simple, early mineralization was interrupted by further movement that produced considerable brecciation along the course of the vein fault. The resulting increased permeability of the channel caused a sudden shifting of the zones of deposition. Minerals that were previously of a deeper zone approached nearer to the surface. For a time deposition was rapid from the hot, concentrated solutions that penetrated the relatively cool rocks nearer the surface. But as these rocks were gradually heated, deposition became less rapid, and the grain size of the minerals increased.

Calcium and magnesium were deposited as chlorite. The saturation point in calcium was not reached until near the close of this stage. In the early part of this stage the temperature was still too high for the formation of sulphides, but toward the end the deposition of pyrite and sphalerite had almost completely superseded that of chlorite and specularite.

The movement along the vein fault that marks the end of the second stage had very little influence on the sequence of mineralization. The minerals that were forming at the close of the second stage carry over into the third, and throughout the third stage there is a gradual decrease in the intensity of mineralization following a normal sequence of minerals—namely, pyrite, sphalerite, galena, and chalcopyrite.

FOURTH STAGE, MOLYBDENUM AND VANADIUM MINERALIZATION

After the close of the third period of mineralization, which has just been described, further movement along the vein faults again shattered the earlier vein filling and opened new fractures, some of which extended out into the country rock. These new fractures and breccia zones formed channels for solutions that were evi-

FAULTING

The mantle of debris, as well as the nature of the rocks themselves, tends to conceal the faults in many places. The criteria most useful for their recognition are: presence of calcite veins, brecciation, change of formation, and basic dikes.

The presence of calcite along fault planes is probably the most useful criterion. Black calcite occurs in veins 6 inches to 2 feet wide in faulted or fractured zones which are otherwise unmineralized. Where the gouge and fault breccia of granite or lava are not distinguishable from the adjoining weathered rock, the presence of calcite filling presents sufficient contrast for the recognition of the break. In places bits of calcite float can be traced over a surface completely obscured by debris. Calcite-filled faults crossing narrow ridges are marked by distinct notches. The black calcite filling is, in most cases, accompanied by colorless calcite that occurs as thin plates attached to fragments of the breccia. Silicification along the faults is not common.

Brecciation is very useful in tracing faults through areas of rhyolite, but in other formations the breccia cannot always be distinguished from the weathered rock. Faults showing wide breccia zones in rhyolite commonly contract to narrow gouge seams in granite or lava. Rhyolite breccia slightly recemented by silica and calcite is so resistant to weathering that in places it forms welts several feet high along the outcrop of a fault. The Turtle fault on the hillside east of Tucson Wash is such an outcrop.

Change of formation is most useful as a criterion of faulting where the late Tertiary sediments are brought into contact with igneous rocks, a condition common in the case of certain late post-mineral faults. Changes from rhyolite to granite or lava rarely indicate the presence of faults even though the change is accompanied by brecciation along the contact. The rhyolite is intrusive into the other rocks, and some brecciation occurred along the intrusive contacts.

Basic dikes are confined to a few late postmineral faults as the Mammoth fault and the Turtle fault east of its intersection with the Mammoth fault.

The study of the fault problem is greatly hindered by a lack of marker beds that can be used in the measurement of displacements. Rarely can more than a rough estimate of the displacement be made.

The large number of faults and fractures cut by the underground workings indicates that only a small part of the faults have been recognized on the surface. The fault pattern is without doubt more complicated than indicated by Plate I.

Of 320 faults and fractures mapped in the underground workings of the area, 78 per cent have an average strike of N. 47 degrees W. Of these, 56 per cent have an average dip of 65 degrees SW, 38 per cent an average dip of 65 degrees NE, and 6 per cent are vertical. Forty-three of the recorded fractures strike N. 34 degrees E. Of this group 50 per cent have a mean dip of 68 degrees NW, 30 per cent a mean dip of 65 degrees SE, and the remainder are vertical.

The percentage of northwestward-striking faults and fractures is about the same in each of the three principal mines of the area. In the Mohawk-New Year Mine 72 per cent of them dip northeast and 28 per cent dip southwest, whereas in the Mammoth and Collins mines 76 per cent of the northwestward-striking fractures dip southwest and 24 per cent northeast.

Premineral Faulting

A positive distinction between premineral and postmineral faults is difficult. With a few exceptions, discussed later, displacement on the postmineral faults is small. In some places the vein appears to have been displaced a few feet at the intersection with cross fractures, but the relations, obscured by supergene alteration of the vein, are uncertain.

The mine workings cut numerous fractures and breccia zones, but only a few of them, most of which are mineralized, can be projected for even a hundred feet. The minor fractures seem to be closely related to the major faults occupied by the veins, and they are probably the result of the same regional stress.

Mammoth vein fault

The main fault, which contains the principal ore shoots, is continuous through the Mammoth and Mohawk-New Year workings. Its continuity is somewhat obscured in the barren gap between the two properties where the formation changes from predominantly rhyolite into one predominantly granite. The workings, however, overlap sufficiently to show a continuation.

The general strike of this fault is northwest, the dip 70 to 80 degrees SW. In the north end of the Mammoth Mine the vein swings to a strike that is nearly due west, and the dip steepens to nearly vertical. It is possible that the main fault does not actually change direction at this point but is joined by a branch or cross fault. The mineralization, however, followed the west fault. If the main fault does continue northwestward, it is not known to be mineralized.

The amount of displacement probably amounts to at least several hundred feet. The movement began with the early intrusion, recurred at intervals during the entire period of hypogene mineralization, and continued well into the supergene period.

In the Mohawk-New Year ground the vein fault swings nearly due east and dips southward (491 vein).

A second fault (391 vein) strikes northwesterly, nearly continuous with the strike of the main fault in the Mammoth ground but dips 62 to 70 degrees NE. It intersects the hanging wall of the main fault. If the outcrops of the two faults could be traced on the surface they would probably intersect at a point about 500 feet northwest of the Mohawk shaft. The lime of intersection plunges southeastward from the 200-foot level at the northwest

sufficiently abundant to impart a greenish cast to the black vein filling. Supergene alteration has destroyed most of the sulphides of this stage in the upper levels, but pyrite and sphalerite appear to have been less abundant than on the 700-foot level. Also in the upper levels a deposition of coarse-grained, clear quartz begins to replace the earlier dark quartz. In the Mammoth vein no zone has been opened corresponding to that exposed on the lower levels of the Collins, and the effects of supergene oxidation and leaching make the detection of zoning impossible. Dark quartz with about the same texture and proportion of specularite as that of the upper levels of the Collins is common throughout the exposed vertical extent of the Mammoth vein. Little can be determined of the original extent of pyrite and sphalerite.

While deposition of pyrite and sphalerite was still in progress, but before deposition of galena began, there occurred another period of movement along the vein fault. The amount of displacement must have been slight. A network of fractures was produced in the existing vein material, but there was no brecciation comparable to that of the previous period.

The character of the deposition immediately following the reopening of the vein was similar to that immediately preceding, except that it took place in open fractures. Quartz was deposited in large euhedral grains. Veinlets with coarse comb structure and open spaces are common. The quartz grains show numerous inclusions commonly arranged in divergent lines.

Deposition of fluorite and galena began early in this stage. These minerals are essentially contemporaneous. Much of the galena replaces sphalerite, some replaces quartz and pyrite. Fluorite is widely distributed in the quartz vein filling of this stage, and some of it appears to have replaced quartz, but this relationship is not clear. Chalcopyrite is both earlier and later than galena, and some chalcopyrite also replaces sphalerite. The amount of chalcopyrite in these ore bodies is small compared with that of the other sulphides.

The quartz of this stage commonly replaces that of earlier stages, especially the early dark quartz.

Above the heavy sulphide zone of the Collins Mine and in the Mammoth vein there is another type of quartz showing age relations with the dark quartz corresponding closely with those of the quartz just described. This is extremely fine-grained (grains average about 0.00032 inch) and shows saw-tooth or colloform banding in thin sections, passing into coarse, flamboyant quartz with the grains projecting into and replacing areas of dark quartz. This flamboyant quartz also grows on fragments of country rock and commonly forms coronas around minute fragments of rhyolite included in areas of dark quartz. It is apparent that open spaces were not necessary for the development of the flamboyant texture, but where fractures were available this quartz was deposited on the walls, first as narrow, greenish bands that grade into course, comb quartz with euhedral terminal faces projecting into open fied by the same impurity that affects the color of wulfenite, for the two minerals together show similar color modifications.

Vanadinite [$PbCl \cdot Pb_4(VO_4)_3$]

Vanadinite is fairly abundant and widely distributed. It forms stubby hexagonal prisms, normally orange or coral in color. Very small, yellow prisms occur on the lower levels of the Collins Mine.

The vanadinite is not commonly associated with wulfenite, but where the two are present together, vanadinite was deposited on wulfenite.

Descloizite [$(Pb \cdot Zn)_2 \cdot OH \cdot VO_4$]

Descloizite occurs as thin crusts of very small, pointed crystals which coat breccia fragments and quartz boxwork in leached vein matter. The mineral is widely distributed and with mottramite is the most important source of vanadium in the ores. The crystals are of uniform brownish red throughout the area. Microscopic crystals of descloizite are commonly intermixed with powdery manganese oxides.

Descloizite has a longer range of deposition than the other vanadium minerals.

Mottramite [$(Pb,Cu)_2 \cdot OH \cdot VO_4$]

Mottramite crystals are jet black but otherwise like those of descloizite. Both minerals occur in thin crusts that scintillate very conspicuously in the light. The difference between the two minerals is not apparent except on close examination.

The age relations of mottramite are similar to those of descloizite except that descloizite continues to form a little later than mottramite.

Ecdemite [$Pb_4 \cdot As_2O_7 \cdot 2PbCl_2$ (?)]

The rare mineral ecdemite was identified in a specimen from 301 stope on the 300-foot level of the Mammoth Mine. It occurs as a bright orange incrustation on wulfenite crystals associated with cerussite that coats a remnant of galena.

Beudantite [$3Fe_2O_3 \cdot 2PbO \cdot 2SO_3 \cdot As_2O_5 \cdot 6H_2O$ (?)]

Beudantite, as yellowish-green tufts of fibers associated with wulfenite and limonite, is present in very small amounts in the upper levels of the Collins Mine.

SULPHATES

Barite ($BaSO_4$)

Barite was recognized only in the Collins ore bodies where it occurs in groups of large, tabular crystals in the siliceous filling of vein breccia. In most places it appears to be of hypogene origin and formed early in the mineral sequence. In the middle shoot of the sulphide vein, barite and black calcite occur in a narrow cross fracture. As barite was not recognized in any thin sections of the ore, its genetic relations are not clear.

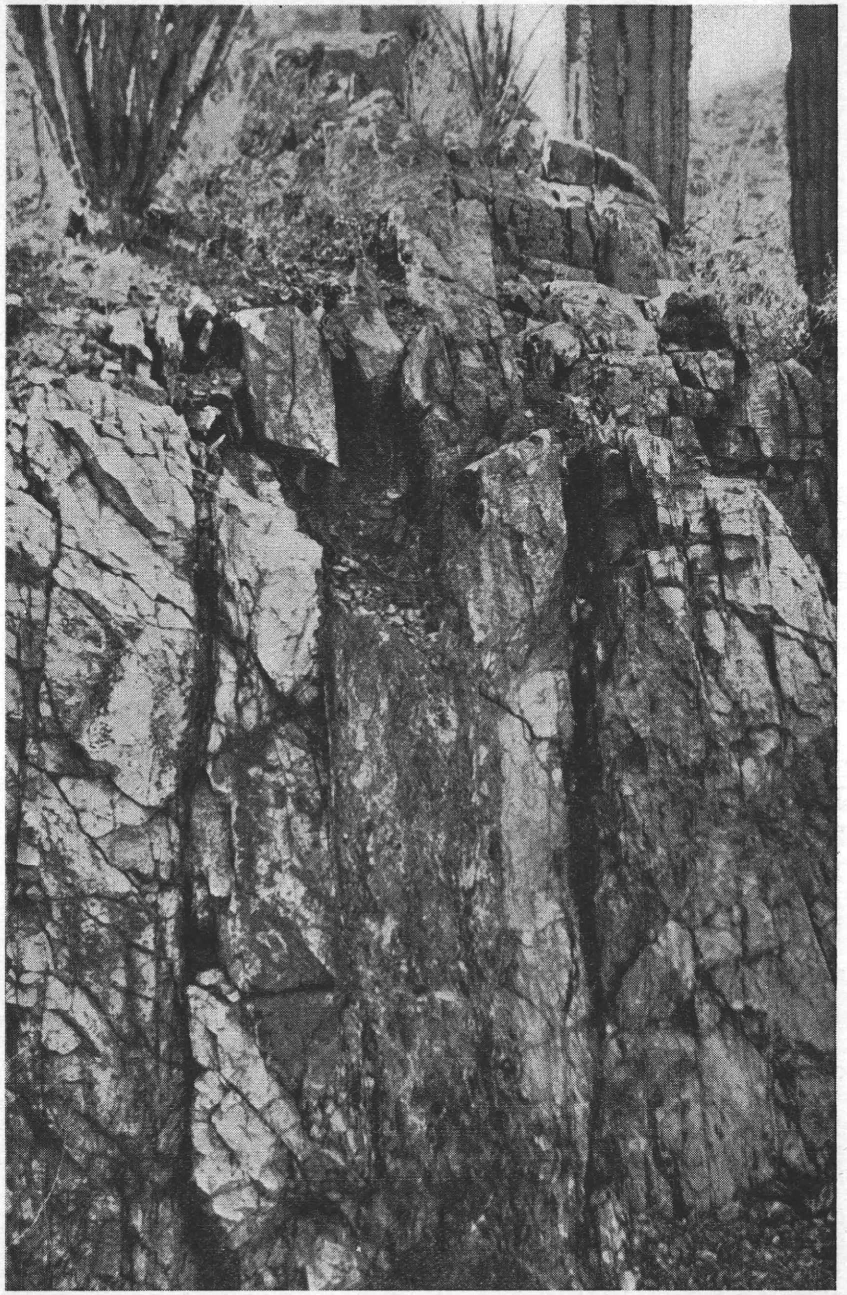

Plate XII.—Outcrop of the Collins east vein in south wall of Turtle shaft.

tween 100 and 200 feet. East of this offset the course of the fault can only be surmised. Small bodies of basalt are intruded into the fault fissure where it crosses the ridge north of the Collins Mine, and recurrences of these intrusions to the east are believed to mark the locus of the fault. Farther east the relatively sharp, straight contact of the intruded breccia with the recent alluvium probably marks the approximate trace of the original scarp.

West of the intersection with the Mammoth fault the character of the outcrop varies from place to place. On the hillside east of Tucson Wash it appears as a black calcite vein 1½ to 2 feet wide with a zone of rhyolite fault breccia on the footwall. The rhyolite fragments are recemented by silica and white calcite, forming a resistant aggregate that projects several feet above the adjacent surface. West of Tucson Wash, where granite forms the footwall of the fault and agglomeritic lavas the hanging wall, the fissure contains deposits of silica and calcite but no breccia.

The hanging wall moved down with respect to the footwall. As already described in the discussion of the structure of the lavas, this displacement must have been great in order to bring the granite and lava flows into their present relationship.

The outcrop of the Collins east vein ends abruptly at its intersection with the Turtle fault and appears to have been cut off by it, hence the Turtle fault is considered to be younger than the mineralization.

Mammoth fault

The Mammoth fault trends northwestward through the central part of the area, west of the Mohawk Mine and between Mammoth and Collins mines. It is exposed on the 300-, 500-, 600-, and 700-foot levels of the Mammoth Mine where it appears as a zone of coarse, loose breccia about 20 feet wide, interlayered with seams of clay gouge and in places by veins of black calcite. The fragments of the breccia are commonly coated with crusts of platy calcite, and the space between the fragments is partly filled with clay or coarse, arkose sand.

The strike of the fault, as determined from two exposures on the 700-foot level, is N. 22 degrees W.; the dip is northeast and ranges from 56 degrees on the lower levels to 70 degrees or more near the surface.

The fault is also exposed in the end of an adit now used for a powder magazine at an altitude of 3,250 feet and likewise in a short adit near the outcrop at an approximate altitude of 3,330 feet. Both of these exposures show intruded breccia in contact with the Gila conglomerate, which forms the hanging wall.

About 400 feet east of these points a drift has been driven northward from No. 2 shaft into the conglomerate for the purpose of mining waste for back filling the stopes. This drift is at the elevation of the 100-foot level and is partly above and partly below the contact of the intruded breccia with the conglomerate, which was deposited on an irregular erosion surface of the breccia. A cross section of this drift is shown on the east-west section A-A′

Chlorite [$5(Mg,Fe)O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 4H_2O$ (?)]

Chlorite is abundantly associated with specularite and quartz of the second stage of mineralization. On the lower levels of the Collins Mine it occurs as green felted masses of radiating silky fibers. In thin section it appears as irregular areas and shreds disseminated in the vein filling.

This chlorite was not stable under supergene conditions. In the earliest stage of alteration it changes from olive green to bright maroon, but its silky luster and original structure remain perfectly preserved. With further oxidation it goes to earthy hematite. Practically no chlorite remains in the oxidized ore bodies, though thin sections show evidence of its earlier abundance.

Serpentine ($3\,MgO \cdot 2SiO_2 \cdot 2H_2O$)

Serpentine occurs as an alteration mineral in the highly altered intruded breccia.

Kaolin ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$)

Clay minerals together with fine arkosic sand, iron oxides, and a little sericite constitute the gouge that prevails in the voids between fragments of crushed vein matter within the oxidized veins and on the foot and hanging walls of the veins. The clay forms most readily where the walls are of granite or intruded breccia.

Kaolin minerals were not observed in thin sections of the hypogene ores or altered wall rocks.

Chrysocolla ($CuSiO_3 \cdot 2H_2O$)

Chrysocolla fills cavities lined with quartz crystals and in places encloses wulfenite crystals. This chrysocolla contains abundant voids apparently formed by shrinkage during transformation from gel to solid.

Fragments of brecciated rhyolite in all stages of replacement by chrysocolla are fairly common in the lower levels of the Collins Mine. The copper for this replacement was probably concentrated in the kaolinized fragments by absorption from supergene solutions.

Where tenorite is present, it generally contains veinlets of chrysocolla and is surrounded by a layer of impure chrysocolla.

PHOSPHATES, ARSENATES, AND VANADATES

Pyromorphite [$PbCl \cdot Pb_4(PO_4)_3$]

Pyromorphite, associated with vanadinite, is present as short, olive-green, hexagonal prisms on thin crusts of mottramite.

Mimetite [$PbCl \cdot Pb_4(AsO_4)_3$]

Mimetite occurs as bright orange or canary-yellow botryoidal crusts on fragments or on walls of open fractures. The crusts are generally associated with wulfenite which is clearly earlier than the mimetite. The color of the mimetite is apparently modi-

Plate XV.—Quartz veinlet cutting intrusive breccia with crystals of adularia grouped along the margins of the veinlet. The outlines of adularia are shown by the Becke lines. Natural light; magnified 305 diameters.

in the wall rocks, especially in the intruded breccia. It can be recognized only in thin sections under the microscope, where it appears as small rhombs (Pl. XV).

Hemimorphite or calamine [$H_2(Zn_2O)SiO_4$]

Only small amounts of hemimorphite were observed. It occurs in granular masses, loosely adhering to porous quartz in the oxidized ore bodies and also as slender needles bristling from quartz crystals that formed on the walls of open cavities. One specimen shows tufts of the slender needles growing on wulfenite crystals.

Biotite [$H_2K(Mg,Fe)_3(Al,Fe)(SiO_4)_3$]

Biotite occurs in partly replaced granite within the veins. In the granite adjoining the veins it is largely replaced by chlorite. The biotite in the veins is similar in appearance to that in the normal granite.

(Pl. II). Assuming that the upper surface of the breccia dips approximately parallel to the dip of the conglomerate, the intersection of the surface with the Mammoth fault surface would then be roughly 150 feet below the outcrop of the fault. Subsequent erosion removed the conglomerate but probably only a few feet of the underlying intruded breccia, since small remnants of the same conglomerate may still be seen perched near the top of the ridge about 2,000 feet to the south; hence the displacement on the Mammoth fault is between 150 and 200 feet.

The fault and the Mammoth vein dip in opposite directions. On section C-C′ (Pl. II), which is approximately on the line of the crosscut west from the Mammoth shaft on the 700-foot level, the vein and the fault intersect about 200 feet below the 700-foot level. The footwall segment of the faulted vein must therefore meet the fault at less than 50 feet below the 700-foot level.

It has been suggested by some students of this area that the Mammoth vein is the faulted apex of the Collins vein. This relationship would involve a displacement of at least 1,200 feet on the Mammoth fault and would necessitate the erosional removal of at least 1,200 feet of material, largely intruded breccia, from the footwall side of the fault after the movement took place. The chief reason for the assumption that the two veins were originally continuous is that if the Mammoth vein is superimposed upon the Collins vein there is a gradual decrease in the degree of oxidation of the vein minerals from the upper part of the Mammoth vein to the lower levels of the Collins. No other vein that can be construed as a possible footwall segment of the Mammoth vein has been cut by the Mammoth workings west of the fault.

Ore Deposits

HISTORY OF MINING DEVELOPMENT

Hostility of the Apache Indians discouraged all permanent settlement of the upper San Pedro Valley until after the purchase of the territory by the United States in 1853. Prospecting in the Mammoth vicinity became feasible after the San Diego and San Antonio stage line built a road along the San Pedro River and established posts at sites of Benson and Winkelman.

Frank Shultz located the Hackney and Aaven claims on the Collins vein in 1879,[7] the Mohawk claim in 1881, and the Mammoth and Mars claims in 1882. He prospected the Mammoth claim in a small way but after three years sold it to George W. Fletcher who blocked out a large body of gold ore. In order to treat this ore Fletcher built a thirty-stamp amalgamation mill on the San Pedro River 3 miles northeast of the mine and established there the town of Mammoth.[8]

[7] Patent survey plats, U.S. Land Office.

[8] History obtained from unpublished notes of J. B. Tenney, from *Mineral Resources of the United States*, and oral communications from F. S. Naething, E. D. Morton, Carl Geib, and others.

In 1888 the Mammoth shaft was extended from the 300- to the 500-foot level, and in 1889 the property was purchased by an English company, which began operations under the name of Mammoth Gold Mines, Ltd. During the first year of its operations this company increased the size of the mill from thirty to fifty stamps and treated ore that averaged $14 a ton at a total cost of $4 a ton. The ore from the upper levels was free milling, but at greater depths the percentage of gold recovered by amalgamation decreased. The stopes were not adequately timbered, and in July, 1893, a large cave occurred between the 200- and 400-foot levels. Following this accident all work was suspended.

In 1894 Johnson, Barnhart, and Collins leased the Collins Mine and organized a company to exploit that deposit. Mining was begun on the 60-foot level by shrinkage stoping, and the ore was hauled to the Mammoth mill for treatment. By the end of 1895 over 40,000 tons of ore, which probably yielded about $6 a ton in gold had be mined.

In 1896 Mammoth Gold Mines, Ltd., was succeeded by the Mammoth Gold Mining Company. The new company built a Bleichert double-rope aerial tramway, nearly 3 miles long, from the mine to the mill. This tramway is said to have made a great saving in transportation costs.[9] A 200-ton cyanide plant was added to the old mill in order to treat the tailings, which contained about 40 per cent of the original gold content of the ore.

Later the Collins Mine was purchased by the Mammoth Gold Mines, Ltd., and connected to a crosscut from the 700-foot level of the Mammoth Mine. North of the Mammoth shaft a square-set stope, in places 60 feet wide, was extended upward from the 750-foot level. The broken and cavernous ground from the previous caving above the 500-foot level was a constant menace to the workings below. The open square-set stopes were not filled with waste rock, and, as mining progressed, the entire weight of the overlying ground was borne by the timbers. On the night of April 15, 1901, the ground caved from the 750-foot level to the surface. Over the stope the surface subsided 25 feet or more. Fortunately, no one was injured, the shaft and surface plant were not damaged, and, as most of the ore had been extracted from the caved section, the loss was not considered great.

Shortly afterwards, operations were stopped because of litigation. The mine was not reopened for twelve years.

The Great Western Copper Company leased the Mammoth Mine in 1913 and did considerable development work but made no production.

Prior to 1914, gold was the only metal recovered from the Mammoth ores, but the demand for molybdenum during the World War created a new interest in their wulfenite content.

The mill tailings, which already had been reworked by the cyanide process, were acquired by R. O. Boykin and Frank H.

[9] Wm. P. Blake, *Report of the Governor of Arizona: Annual Report of the Department of Interior, 1901*, pp. 188-90.

The black calcite is earlier than the colorless variety. In the late fault fissures it is clearly supergene, but in the lenses and transverse veins associated with the ore bodies it is of uncertain origin. The colorless calcite is sporadically distributed in oxidized veins. It is most abundant in the barren sections of the veins and is especially prominent in that section between the Mammoth and Mohawk mines. It is abundant as a cementing material in the breccia of the later faults, although it does not fill the spaces between the fragments.

The colorless calcite in the veins formed later than some of the supergene minerals and generally later than wulfenite and vanadinite.

Smithsonite ($ZnCO_3$)

Although not easily recognized in the ore bodies, smithsonite is doubtless widely distributed as crusts and porous masses in the oxidized vein filling, of which almost any fragment gives a decided chemical reaction for zinc. The mill heads carry from 2 to 3 per cent zinc of which most is probably in the form of smithsonite.

In places small colorless rhombohedrons of smithsonite form crusts on wulfenite and vanadinite.

Some of the calcite in the veins contains a little zinc.

Cerussite ($PbCO_3$)

In the oxidized ore bodies of the Mammoth and Mohawk mines cerussite is not easily recognized except by chemical tests. It is finely disseminated throughout the ore bodies, and the average ore mined contains 1.02 per cent lead.

In places cerussite occurs in small, almond-shaped masses included in the dark vein quartz. These kernels of carbonate may have formed in place from galena.

In the Collins Mine cerussite is relatively conspicuous as coatings on remnants of galena and rounded masses derived from galena.

The mineral is generally compact, earthy, or finely granular. It also occurs as long orthorhombic crystals projecting into open cavities.

Malachite [$CuCO_3 \cdot Cu(OH)_2$] and azurite [$2CuCO_3 \cdot Cu(OH)_2$]

Malachite, with much smaller amounts of azurite, forms emerald green, mosslike masses commonly associated with cerussite. As short prisms or tufts of fine, green needles, it occurs associated with crystalline cerussite in cavities. Nodules of galena with replacement shells of covellite and chalcocite are surrounded by cerussite mixed with malachite and azurite.

SILICATES

Adularia ($KAlSi_3O_8$)

Orthoclase produced by hydrothermal solutions occurs sparsely intergrown with quartz in the veins and as an alteration product

Limonite forms pseudomorphs after pyrite, but, since pyrite was not abundant, the amount of limonite formed in this manner is not large. A little limonite was produced by alteration of iron minerals in the granite.

Magnetite (Fe_3O_4)

Some magnetite is present in table concentrates of the ore, but it is probably a constituent of country rock included in the veins. So far as is known magnetite was not deposited by the mineralizing solutions.

Pyrolusite (MnO_2)

Powdery manganese dioxide is widely distributed in the leached, spongy vein matter. Less commonly it occurs as thin, botryoidal crusts. The fine, black powder is generally intimately mixed with finely crystalline descloizite and accompanies the vanadium minerals.

Tenorite (CuO)

Black, coallike nodules of copper oxide, less than an inch or two in diameter, are present, generally in the barren sections of the veins. The nodules are surrounded by thin shells of chrysocolla, and the enclosing rock within a radius of several inches shows more or less copper stain.

Psilomelane (Mn_2MnO_4)

Botryoidal masses of psilomelane ranging from the size of peas to pieces weighing several pounds were seen in the broken ore and lying on the surface. The mode of occurrence of this mineral is unknown.

CARBONATES

Calcite ($CaCO_3$)

Calcite is fairly common as small, black veins and as colorless crystals in breccia.

Many of the fissures, especially the later fault fissures, are occupied by veins of coarsely crystalline, brownish-black calcite. Some small fractures that cut across the main veins are filled with black calcite. Lenticular bodies of black calcite, up to a foot thick by more than 20 feet long, commonly occur in the ore bodies.

Microscopically, the dark color of the calcite is seen to be due to thin films of manganese dioxide deposited along cleavage planes. Later the calcite was completely recrystallized into a fine-grained aggregate. The manganese dioxide collected into irregular inclusions between the calcite grains. In places the dark inclusions form ragged, parallel lines marking the direction of the original cleavage, but more commonly they appear as brown feathery wisps or smudges.

Hereford, who organized the Arizona Rare Metals Company and erected a mill to recover the wulfenite by gravity concentration. As the tailings still contained a little wulfenite after this treatment, they were reworked later by sulphidization and flotation. The price of molybdenum declined at the end of the war, by which time the tailings had been reworked three times and, according to some accounts, four times.

In 1915 the Mammoth and Collins mines were taken over by Col. Epes Randolph and associates, under the name of Mammoth Development Company. During the next year this company began underground development, enlarged the mill, and added flotation machinery. Progress was interrupted in October, 1917, by a fire that destroyed the shaft timbers from the surface to water level.

The St. Anthony Mining and Development Company succeeded Mammoth Development Company in 1918, retimbered the shaft, and began stoping in the rich wulfenite ore above the 520-foot level in the Collins Mine. Operations continued until after the Armistice when the price of molybdenum fell far below the limit of profitable mining. During this period of operation, 1916 to 1919, about 50,000 tons of ore were produced.

The Mohawk claim joins the Mammoth claim on the south and partly covers the southern extension of the Mammoth vein. In 1892 the Mohawk Gold Mining Company acquired this claim from Frank Schultz and proceeded to prospect the vein above the 300-foot level. A large ore body was blocked out on the 100- and 200-foot levels, and a 10-ton stamp mill was erected at Mammoth to treat the ore. Production followed at the rate of 70 tons a day from May 1, 1896, until the end of 1897 when the mine was closed, probably because the material mined was too low grade to yield a profit. The capacity of the mill was doubled the next year, but mining was not resumed.

In 1906 the Mohawk Gold Mining Company was refinanced. A 30-ton mill was built at the mine and arrangements were made to pump water for the mill from the Mammoth Mine where a seemingly unlimited supply had been encountered in the shaft below the 750-foot level. A new vertical shaft was sunk 500 feet, and new ore bodies were discovered. Although the grade of the ore was low, production continued until the end of 1912.

The New Year claim, which adjoins the Mohawk on the east, was optioned from the heirs of Frank Schultz by Sam Houghton in 1926. Houghton sank a new vertical shaft 140 feet northeast of the Mohawk shaft and began development in the New Year ground. A small mill was begun in 1932, but it was never completed, and there was no production under Houghton's management.

The increase in the price of gold in 1933 created a fresh interest in the Mammoth mining camp, which had been unproductive for nearly fifteen years. The Molybdenum Gold Mining Company, subsidiary of the Molybdenum Corporation of America, took over the Mohawk-New Year properties and began underground development. The mill begun by Houghton was completed. Gold was recovered by the cyanide process and lead, molybdenum, and vanadium by gravity tables. In 1934 the mill treated 24,784 tons of ore.

In 1934 Mammoth-St. Anthony, Ltd., obtained the Mammoth group of claims and, under the direction of Foster S. Naething, prepared to reopen the Mammoth and Collins mines. This company began production in 1935 and sent its ore to the mill of Molybdenum Gold Mining Company. On January 1, 1937, Mammoth-St. Anthony, Ltd., purchased this mill from Molybdenum Gold Mining Company, increased its capacity from 90 to more than 200 tons a day in 1937, and to more than 400 tons by April, 1938.

Difficulty was experienced in finding a market where all the metals contained in the concentrates would be paid for. To improve this condition a small plant was erected in 1937 to treat the concentrates by fusion with sodium carbonate followed by lixiviation. The final products of the plant are metallic lead and a crude salt consisting mainly of sodium molybdate and vanadate.

PRODUCTION

From 1886 to the end of 1936, the Mammoth mining camp area produced metals valued at over $5,000,000, of which 83 per cent was gold. The total yield, segregated according to mines, metals, and years, is shown in Table 1. The production was made during three periods.

During the first period, 1886 to 1912, the ore was mined entirely for gold, of which approximately $3,510,835 was recovered. The Mammoth-Collins Mine produced 350,000 tons of ore that averaged 0.43 ounce of gold, which is double the grade maintained in the mill heads mined at present. The Mohawk-New Year ore probably averaged less than 0.2 ounce of gold per ton, which is little if any higher than that mined at the present time. The first period ended when the ore above water level could no longer be mined at a profit.

The increased demand for molybdenum during the World War inaugurated the second period of production. Ore that contained 3.5 to 4.5 pounds of MoO_3 and $4 in gold per ton could be mined at a profit. For a few years almost the entire molybdenum production of the United States came from this area. During 1916-19 the camp produced 447,876 pounds of MoO_3. The total value of the metals recovered during the four years of this period amounted to $614,620 of which only $216,010 was gold. The average price for the wulfenite concentrates was $1.337 per pound of metallic molybdenum contained.

With the signing of the Armistice the price of molybdenum declined sharply because of the large stocks of concentrates on hand. In the years following the war the uses of molybdenum increased rapidly, but the price continued to decrease because of the development of the large, low-grade molybdenite deposits at

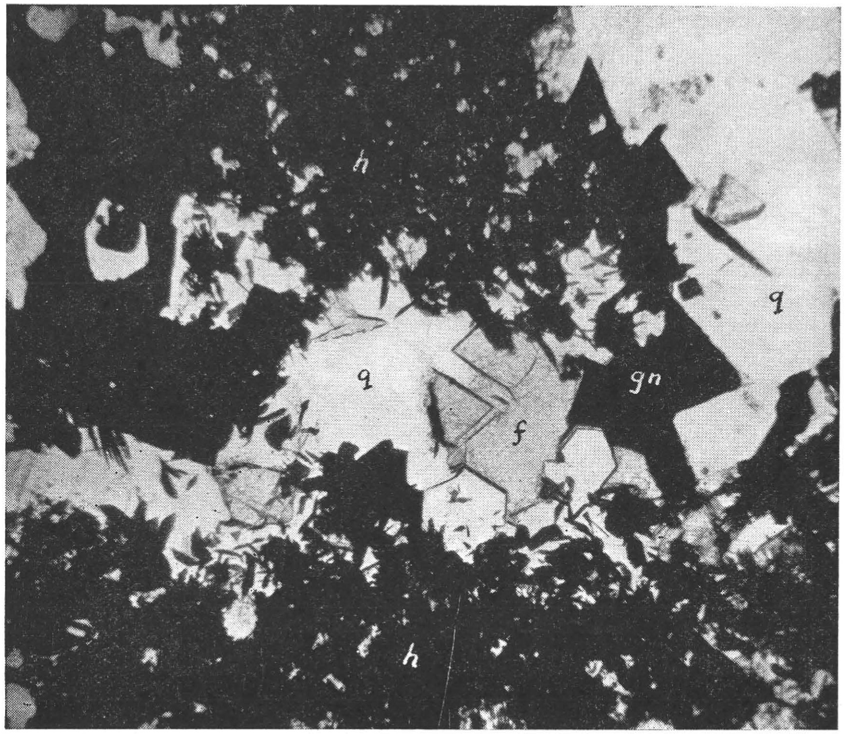

Plate XIV.—Thin section of the dark vein filling from the Collins 700-foot level, showing heavy mat of specularite flakes in quartz, with galena and fluorite intergrown with euhedral quartz in a veinlet of third-stage quartz. Specularite, *h*; quartz, *q*; fluorite, *f*; galena, *gn*. Natural light; magnified 54 diameters.

Hematite (Fe_2O_3) and other forms of ferric oxide

Specularite is abundant on the lower levels of the Collins Mine, especially at the ends of the massive sulphide shoots where it occurs in glistening black masses. Microscopically these masses consist of a dense mat of specularite flakes in quartz, accompanied by chlorite and a little fluorite (Pl. XIV). There is a gradual decrease in the amount of specularite from the Collins ore bodies at the northwest through the Mammoth and to the Mohawk veins at the southeast.

Amorphous, earthy hematite is abundant in all the oxidized ore bodies. Thin sections of the oxidized vein matter show specularite flakes in all stages of transformation to the amorphous variety. The larger masses of earthy hematite, however, formed by oxidation of chlorite.

pyrite and rarely shows mutual boundaries with pyrite. It is the mineral most subject to replacement by later sulphides.

In the oxidized zone sphalerite is altered to smithsonite and hemimorphite.

HALOIDS

Cerargyrite (AgCl)

The silver in the oxidized ore bodies is probably present as cerargyrite, although this mineral was not definitely recognized.

Fluorite (CaF_2)

Fluorite is rarely visible in the ores, though microscopically it is fairly abundant and widely distributed. Purple cubes of fluorite can be seen with the unaided eye in the intruded breccia.

Under the microscope all thin sections of the vein matter show some fluorite, and in most of them it is abundant. It occurs most commonly as small grains with angular boundaries which are parallel to three cleavage directions (Pl. XIV). A little fluorite was deposited early with fine-grained quartz containing chlorite and specularite, but the bulk of it formed late with the clear, coarse-grained quartz and is essentially contemporaneous with galena and chalcopyrite. Part of the fluorite of this stage is in large grains deposited in open cavities and closely associated with galena. In some vugs the two minerals show mutual boundaries.

Fluorite is fairly stable in the oxidized zones. In thin sections of the oxidized vein matter the fluorite grains are corroded around their borders and generally slightly discolored.

OXIDES AND HYDROUS OXIDES

Quartz (SiO_2)

Quartz is by far the most abundant of the vein minerals. It was the earliest mineral, and its deposition continued throughout the hypogene period and to some extent into the supergene period. The greatest volume of quartz was deposited in the second stage along with specularite and chlorite, most abundantly in the deeper zones but also in important amounts in the upper zones. The quartz of this stage is light gray to nearly black, with a dull, stony appearance caused by included flakes of specularite (Pl. XIV) and a fine-grained texture.

The later quartz is clear with a variety of textures from micro-crystalline and banded to coarse flamboyant and feathered. Much of the later quartz was deposited in open fractures and vugs where it exhibits beautiful comb structure. Some of the late quartz is light amber or yellowish green, and some of it contains minute specks of gold. This quartz is extremely fine-grained and is intricately banded. Amethyst which formed in veinlets with coarse comb structure is the latest of the hypogene quartz.

The supergene quartz occurs as thin crusts of very fine euhedral crystals deposited on leached, spongy remnants of hypogene quartz.

TABLE 1.—PRODUCTION OF MAMMOTH MINING CAMP, 1881-1936.

	Tons	Gold (ounces)	Gold value	Silver (ounces)	Lead (pounds)	MoO_3 (pounds)	V_2O_5 (pounds)	Total value
Mammoth-Collins 1881-1901	350,000	150,500	$3,110,835	....	....	....	....	$3,110,835
Mohawk-New Year 1896-1912	....	....	400,000	....	....	....	....	400,000
Mammoth-Collins 1916-1919	49,764	10,450	216,010	....	....	447,876	....	614,620
Mohawk-New Year 1934	24,784	2,691	94,050	....	....	70,546	103,937	155,225
Mammoth-Collins 1935	18,267	2,174	75,981	8,604	379,954	49,869	40,918	130,985
Mohawk-New Year 1935	17,468	1,892	66,125	3,305	334,657	93,649	63,849	141,198
Mammoth-Collins 1936	40,115	7,100	248,145	33,456	742,128	109,915	108,712	387,639
Mohawk-New Year 1936	34,036	3,522	123,094	7,675	786,375	137,899	132,570	263,631
Total	534,434	178,329	$4,334,240	53,040	2,243,114	909,754	449,786	$5,204,133

Climax, Colorado. Consequently the mines at Mammoth remained inactive for fourteen years.

The third period of production began with the increase in the price of gold in 1933. During 1934-36 the yield of gold and silver amounted to $647,859, divided about equally between the Mammoth-Collins and Mohawk-New Year mines. In addition $430,819 worth of lead, molybdenum, and vanadium was recovered. The total production for the 1934-36 period was worth $1,078,778. During the first half of 1937 production from the Mohawk-New Year Mine decreased markedly, whereas that of the Mammoth-Collins increased to more than 75 per cent of the total.

If the price of gold is maintained at $35, the value of future production will perhaps equal or exceed that of past production.

CHARACTER OF THE VEINS

General Description

The ore occurs in veins or lodes within fault fissures or brecciated zones. The ore does not occur uniformly throughout the veins but forms shoots separated by portions that are too narrow or of too low grade to be worked profitably.

The section of the fault between the Mammoth and Mohawk ore bodies is almost lacking in mineralization. The fault appears as a closely sheeted zone with little or no gouge. There has been some silicification with transparent, colorless quartz, in contrast with the dark gray, lemon-yellow, or amethyst quartz of the ore shoots. A little clear, white calcite in thin hexagonal plates only partly fills the open spaces in breccia. The rocks adjoining the barren fracture show only slight hydrothermal alteration.

The ore appears to have been deposited along sections of the faults where shattering and brecciation were relatively intense. In the Mohawk and New Year mines fracturing was more intense than in the parts of the Mammoth Mine now accessible. In places veins grade into lodes up to 40 feet in width, composed of a network of narrow, mineralized veins. The entire width was mined, although the rock between the veins was barren. These zones occur most commonly where one or both walls are of rhyolite, which is more brittle and more easily shattered than either the granite or the intruded breccia. In the caved section of the Mammoth Mine north of the main shaft the Mammoth vein was undoubtedly a wide fractured zone with interlacing mineralized veins. The stopes in this area are said to have been 60 feet in width, which is commensurate with the extent of the cave as seen on the surface.

The vein walls are generally marked by red or greenish-gray gouge and slickensides. Within the vein itself are clay gouge and slickensides roughly parallel to the walls or crossing from one wall to the other with a flatter dip than the vein. As may be seen in the 701 stope on the 700-foot level of the Mammoth Mine, mineralization spread out below these flat clay seams and contracted above them.

sulphides is chalcopyrite. In the oxidized ore bodies it has altered to copper carbonates and chrysocolla. Chalcopyrite was not abundant in these deposits, as the sulphide ore shoots contain an average of only 0.47 per cent copper. Apparently it was the only hypogene copper mineral.

Galena (PbS)

Galena is nearly as abundant as sphalerite in the unoxidized veins, and the wide distribution of cerussite, wulfenite, and anglesite in the oxidized veins indicates its abundance in the hypogene mineralization. Remnants from less than an ounce to several pounds in weight occur enclosed in shells of cerussite and copper carbonate in the oxidized veins. Galena remnants are common throughout the Collins ore bodies, are much less common in the Mammoth Mine, and are comparatively rare in the Mohawk and New Year mines.

Galena was late in the mineral sequence and followed all the sulphide minerals except chalcopyrite and the supergene copper sulphides. Nearly all the galena seen in polished sections is a replacement of sphalerite or was deposited in open spaces in quartz-lined vugs and in veinlets of comb quartz. Galena commonly shows mutual boundaries with fluorite that formed in a similar manner. It rarely replaces pyrite.

During oxidation lead was immediately fixed in more stable forms as anglesite, cerussite, and rarely as complex arsenates.

Pyrite (FeS_2)

Pyrite is not nearly so abundant as sphalerite and galena in the sulphide ore bodies of the Collins Mine. Cubical cavities in quartz indicate the earlier existence of pyrite in the oxidized parts of the veins. Many of the rhyolite bodies carried abundant pyrite as small, euhedral grains disseminated uniformly throughout the rock. In the outcrops it is oxidized to limonite or completely leached out, leaving cubical cavities surrounded by limonite stains. Magnetite of the granite within or close to the veins is generally replaced by pyrite. In the unoxidized ores pyrite occurs as irregular grains, generally in groups or chains and not intimately associated with the other sulphides.

The deposition of pyrite did not begin until specularite had nearly ceased to form. Much of it is older than sphalerite, but a little continued to form throughout the ore mineralization. Replacement of pyrite by later sulphides is insignificant.

Sphalerite (ZnS)

Sphalerite is the most abundant sulphide mineral. It occurs in irregular masses associated with galena or pyrite in the sulphide bodies of the Collins Mine. All the sphalerite is peppered with myriads of chalcopyrite inclusions, most of which are visible only under high magnification.

Sphalerite replaces chlorite and quartz but does not replace

Pyrite
Pyrolusite
Pyromorphite
Quartz
Serpentine
Silver (?)
Smithsonite
Sphalerite
Tenorite
Vanadinite
Wulfenite

NATIVE ELEMENTS

Gold (Au)

Gold is by far the most valuable constituent of the ore. The average New Year ore contains 0.09 ounce, and the Mammoth ore about 0.15 ounce of gold per ton. Gold occurs in veinlets of light amber or yellowish-green quartz which formed late in the mineral sequence, but whether or not all the hypogene gold is confined to this type of quartz could not be determined.

The distribution of gold indicates that the sulphides contain only a small part of it.

Native gold is also visible in the intruded breccia that borders the veins in the Aguaya tunnel, in the Smith workings, and in the Mohawk Extension Mine. It occurs as thin films coating breccia fragments that appear to be especially rich in iron. This gold was probably deposited from supergene solutions.

Silver (Ag)

Minor amounts of silver, generally less than 1.5 ounces per ton, are present in the mine-run ore. No native silver or other silver minerals were recognized. In the oxidized ore bodies the silver is probably present as the chloride.

SULPHIDES

Chalcocite (Cu_2S), covellite (CuS), and bornite (Cu_5FeS_4)

Chalcocite, covellite, and bornite occur as very thin films on other sulphides and as replacements of chalcopyrite and rarely sphalerite. In replacement areas all three generally show progressive replacement, with bornite earliest, followed by covellite and chalcocite. In places small masses of galena are replaced and surrounded by thin shells of intermixed covellite and chalcocite, enclosed in another shell consisting of a mixture of azurite, malachite, cerussite, and perhaps a little anglesite which grades outward into a thick shell of white cerussite.

The total amount of these copper sulphides is very small. In most polished sections of the ore they are not recognized except with the use of medium or high power objectives.

Chalcopyrite ($CuFeS_2$)

The chalcopyrite occurs largely as inclusions in sphalerite, where it is believed to have separated by unmixing from solid solution. Chalcopyrite also occurs as hypogene replacements of pyrite, sphalerite, and galena. It is contemporaneous with galena; in places chalcopyrite replaces galena and in other places galena replaces chalcopyrite. Generally the host of the supergene copper

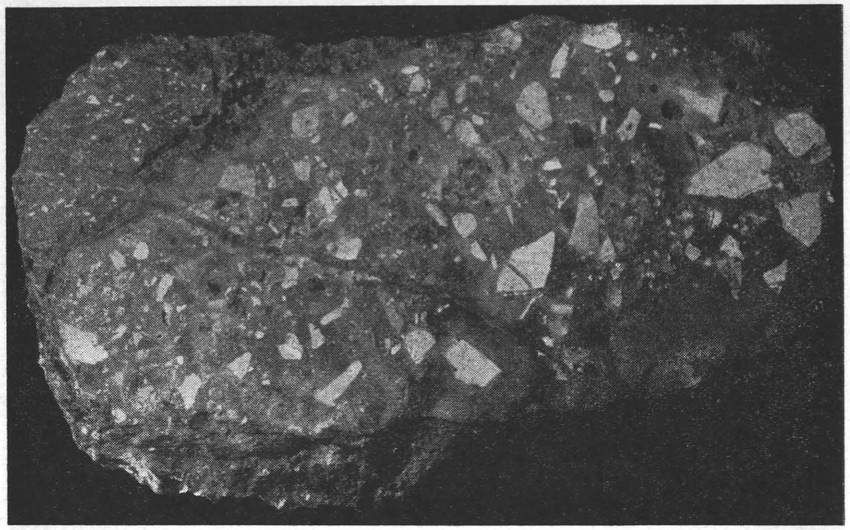

Plate XIII.—Typical breccia of angular rhyolite fragments in a matrix of quartz, chlorite, and specularite, Collins vein, 300-foot level. ⅔ natural size.

Postmineral movement along the faults crushed and shattered the vein matter. Because of consequent oxidation and leaching the original character of the mineralization cannot be accurately reconstructed. As now seen in underground workings the vein matter is a porous, earthy mass in which most of the constituent minerals are more or less masked by red or brown iron oxides and hydrates and black powdery manganese oxides. Quartz occurs in narrow, discontinuous stringers with lemon-yellow, crustified borders and coarse, amethystine comb structures in the center. Open spaces are generally present in the mid-portion of the veinlets. Dark-gray, stony quartz in the spaces between angular rhyolite fragments forms a cemented breccia (Pl. XIII), that is very conspicuous in parts of the vein where crushing has been relatively less intense. In more open parts of the vein yellow and orange crystals of wulfenite and vanadinite conspicuously line cavities or coat fragments of loose breccia. Scintillating crusts of descloizite and mottramite occur in a similar manner. Small lenses of sooty, black calcite, generally less than a foot thick by 20 feet long, are common in the veins. White calcite is present throughout but becomes more prominent where the vein is of low grade. Clay gouge is widely dispersed throughout the veins. Where the veins are narrow they contain a greater proportion of clayey material and are less porous. These places commonly show copper stains as well as fragments of galena surrounded by shells of cerussite and copper carbonates.

Replacement of rhyolite fragments by quartz was probably active in the most open part of the channel, where the remnants of rhyolite are generally less than ½ inch in greatest dimension. Farther from the central part of the vein the proportion of unreplaced rock and the size of the fragments gradually increase until only threadlike veinlets of quartz cut the rock. The vein proper commonly contains horses of unmineralized rhyolite that are not shattered in blasting and can easily be sorted from the broken ore in the stopes. The rhyolite fragments appear only slightly affected by the solutions that deposited the quartz.

The granite was less completely brecciated than the more brittle rhyolite and tended to form greater amounts of clay gouge. The original quartz was deposited as veinlets an inch or more wide between the granite blocks, or, in places where crushing was intense, completely replaced the granite. Where the vein is wide, blocks of unreplaced granite up to several feet in length remain. Due to subsequent crushing and leaching, these parts of the vein are soft and ashy in appearance and spotted with rounded, white, kaolinized remnants of the unreplaced granite. The crushed vein quartz between the rubble of unreplaced granite is loose and porous, stained dark brown or red by limonite, and intermixed with clay and crushed granite.

The intruded breccia appears to have been less amenable to replacement by the mineralizing solutions than either the rhyolite or the granite. Where both walls are breccia the vein is narrow, and the grade is below the limits of commercial ore. According to Vanderwilt,[10] the southeast end of the 391 stope between the 200- and 300-foot levels of the Mohawk Mine becomes too narrow to stope profitably where the vein passes into the breccia. As this vein was not followed far, however, it can not be concluded that the intruded breccia is not a favorable rock for ore.

Intruded breccia commonly forms one wall of the veins in the Mohawk Mine but is separated by a gouge seam from the mineralized portion, which always occurs in the adjoining rhyolite. In the Mammoth Mine the breccia is rarely in contact with the vein. On the 700-foot level it occurs at the north limit of 701 stope where the mineralization diminishes below the limit of commercial ore. Since, however, the same decrease in grade occurs on the level above where no intruded breccia is present in a similar relation to the ore, it cannot be concluded that the decrease in grade is due to the unfavorable rock.

The Sulphide Ore Body

The sulphide ore bodies developed on the 700-foot level of the Collins Mine do not share the general characteristics of the other veins in the area. Three ore shoots 160 feet to 240 feet long by 5 feet in average width have been opened by drifts along the vein. As the intervals between the shoots are unexplored, their continuity as a single vein is not established. A line connecting

[10] J. W. Vanderwilt, Private report on Mohawk-New Year Mine, 1934.

the three segments forms a broad arc, convex toward the northeast and roughly parallel to the Mammoth vein. The north end of the east shoot and the south end of the middle shoot are only 80 feet apart, and the relation of the strikes is such that the continuity of these two segments can safely be inferred (Pl. X).

The central core of the shoots consists of elongated masses of galena interspersed with quartz, silicified country rock, and a little sphalerite. The amount of galena diminishes sharply toward the borders, and sphalerite becomes more prominent in a gangue of wall-rock breccia recemented with dark quartz containing specularite and abundant chlorite. At the ends of the ore shoots the galena gives way to disseminated pyrite and sphalerite in a gangue of dark quartz, glistening with flakes of specularite. Chlorite becomes sufficiently abundant to give the vein a greenish cast. There is a progressive decrease in the amount of sulphides and an increase in the specularite toward the ends of the shoots. Transverse faults, definitely premineral, affect the continuity of the vein fracture slightly but exert a noticeable influence on the volume of the mineralization on opposite sides of the gouge filling.

The veins on the lower levels of the Collins Mine do not appear to have been affected by the later periods of movement along the vein faults, which so thoroughly shattered the veins elsewhere in the area. Probably for this reason they have been only slightly affected by supergene oxidation. Small areas of the vein are thoroughly oxidized, but the most noticeable change is a tarnish of copper sulphides on the cleavage faces of the galena. Meager deposits of wulfenite, vanadinite, and descloizite occur where there is open brecciation. The crystals are much smaller than is characteristic for these minerals in the other ore bodies of the area.

The Collins vein on the 700-foot level and portions of it as high as the 300-foot level are probably typical of the hypogene mineralization of the area.

MINERALS OF THE ORE DEPOSITS

The following minerals are associated with the ore deposits of the Mammoth area:

Adularia (orthoclase)	Covellite
Anglesite	Descloizite
Azurite	Ecdemite
Barite	Fluorite
Beudantite	Gold (native)
Biotite	Galena
Bornite	Hematite
Calcite	Hemimorphite (calamine)
Cerargyrite (?)	Kaolin
Cerussite	Limonite
Chalcocite	Magnetite
Chalcopyrite	Malachite
Chillagite (?)	Mimetite
Chlorite	Mottramite
Chrysocolla	Psilomelane

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A Geological and Geophysical Study of the Chelan Nickel Deposit, near Winesap, Washington

BY ERNEST N. PATTY* AND SHERWIN F. KELLY,† MEMBERS A.I.M.E.

(Chicago Meeting, February 1946)

THE present case history deals with the examination of an almost forgotten nickel prospect, near Winesap, Chelan County, Washington. Although the final results yielded no ore body of commercial importance, the integration of surface and underground exploration, geophysical survey and diamond drilling endow the story with interest. The program is significant because it is illustrative of how the most disappointing expenditures in mining exploration, the "not-finding" costs, could have been reduced had geophysical methods been applied at an appropriate stage in the prospecting work.

The Chelan nickel deposit was discovered about 1900, on a sage-brush-covered hillside with a southerly slope, adjacent to Winesap Canyon; the paved highway now extending from Wenatchee northward, up the Columbia River and into Okanogan Valley, is only a mile away. After the deposit was found, three short prospect tunnels were driven into it, and the prospect then remained dormant for 40 years. No. 1 tunnel was 80 ft. long, running north into the hillside. For the first 35 ft. this adit exposed a typical, iron-stained gossan with streaks and stains of malachite, and small seams of water-soluble nickel sulphate. Beyond this, it encountered a relatively fresh peridotite, well mineralized with blebs of pentlandite. Systematic sampling yielded an average assay of 1.5 per cent nickel and 0.3 per cent copper. Down the hillside to the south and 35 ft. lower in elevation, No. 2 tunnel was driven under No. 1 and in the same direction, traversing 50 ft. of gneiss before it reached the peridotite. At this point the latter formation showed only scattered blebs of sulphides, not of commercial grade. To the west, on the same contour line as No. 1 tunnel, and 800 ft. around the hillside from it, No. 3 tunnel was driven 50 ft. into the hill to explore a strong gossan outcrop that assayed 0.5 per cent nickel (Fig. 1).

From the geological exposures on the hillside and in the tunnels, it appears that the main mass of the hill is formed of an ancient and altered gneiss complex. Into this, a sill-like injection of amphibolite (altered peridotite) was intruded, which, at least in some places, contains commercial quantities of nickel sulphide. Its structure is obscure, but it appears to dip into the hill at an angle of about 15°. In the vicinity of No. 3 tunnel a large dike of quartz diorite cuts the peridotite or amphibolite; about 140 ft. north of the portal of the tunnel, a dike of andesite 90 ft. wide cuts boldly up the hillside to break the continuity of the peridotite in that direction.

The geological evidence available was not adequate to decide whether the peridotite forms a continuous sill, or occurs as isolated bodies in the gneiss. Not all of this peridotite carries commercial amounts of pentlandite, but if the mineral-

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Listed for New York Meeting, February 1945, which was canceled.

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† President, Sherwin F. Kelly Geophysical Services, Inc., Wilmington, Del. President, Geophysical Explorations Ltd. Toronto, Canada.

Printed in U. S. A., December 1945.

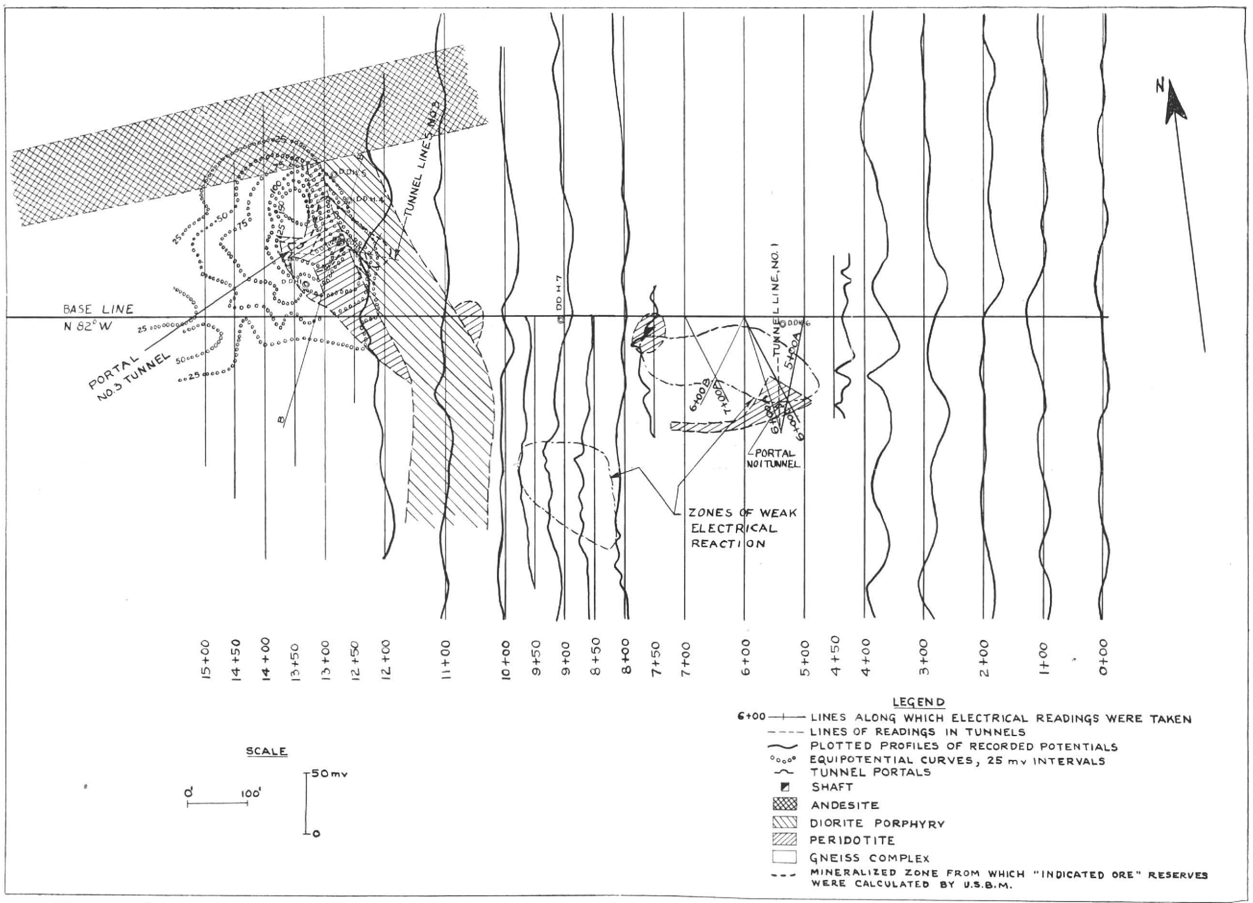

FIG. 1.—SURFACE PLAN: GEOLOGY AND GEOPHYSICAL SURVEY, CHELAN NICKEL PROSPECT NEAR WINESAP, WASHINGTON. Surface geology courtesy of U. S. Geological Survey.

liminary drilling results can point the way for further exploration to reveal the significance of the ore occurrence.

ACKNOWLEDGMENTS

Appreciation is hereby expressed to the U. S. Bureau of Mines, Dr. R. R. Sayres, Director, for supplying the drill-log data, and to the U. S. Geological Survey, Dr. W. P. Wrather, Director, for releasing maps of the surface geology and sections used in this article.

ized section of this formation extended all the way from No. 1 to No. 3 tunnel, a commercial orebody might be anticipated. To check this possibility a large number of open cuts and test pits were recently put down through the deep overburden of the hillside. Although many of these pits disclosed the altered periodotite or amphibolite, nickel mineralization was found at only a few points. The results of this test pitting were discouraging, but the strong gossan exposure at No. 3 tunnel could not be disregarded, so this tunnel was continued into the hill, and shortly broke into fresh sulphides averaging 1.5 per cent nickel and 0.3 per cent copper. Branches of the tunnel were driven, which outlined an elliptical body of ore 200 ft. long, and 30 ft. thick (measuring about 120 ft. wide on the horizontal). Then the various headings from No. 3 tunnel started running out of commercial ore in every direction.

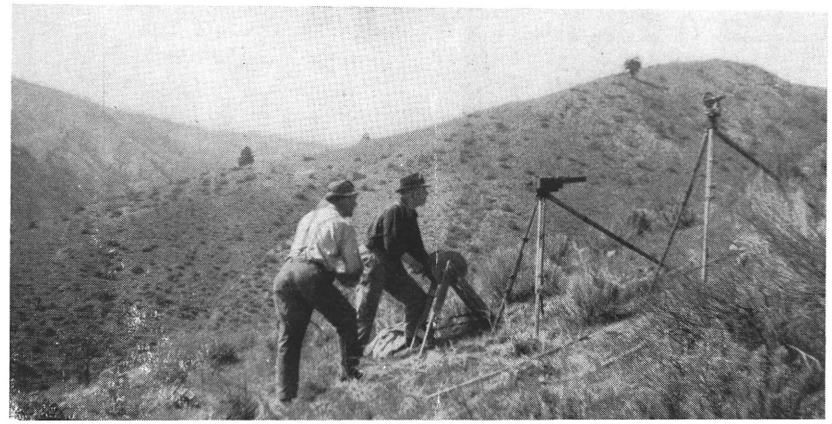

FIG. 2.—SPONTANEOUS POLARIZATION EQUIPMENT IN USE ON CHELAN NICKEL SURVEY.

CHOICE OF GEOPHYSICAL METHOD

At this point in the exploration program it was decided to make a geophysical survey for the purpose of determining, first, whether the showings in the vicinities of No. 1 tunnel and No. 3 tunnel were separate or constituted two exposures of a single, continuous band, which had been missed in the test pitting; and second, whether the ore exposed in No. 3 tunnel had any extensions, or neighboring sulphide lenses. The following factors influenced the choice of geophysical technique best adapted to answering these questions.

Although pyrrhotite accompanying the pentlandite would yield a magnetic reaction, similar anomalies due to the amphibolite would almost certainly becloud the results. Furthermore, sulphides containing little or no pyrrhotite would give no magnetic indication of their presence, rendering the magnetic results worse than useless under such circumstances. For these reasons the magnetic technique was ruled out.

Although electrical resistivity measurements would show zones of low resistance over sulphide mineralization, wet faults and shear zones would also produce similar anomalies, with consequent confusion in the interpretation of results; this method was therefore eliminated.

The spontaneous polarization method was decided upon as being the most direct and simple procedure for obtaining the desired information. This method, sometimes called the self-potential technique, is direct and rapid; it relies upon detecting, at the surface of the ground, those electrical currents that are spontaneously generated by sulphide mineralization, as a result of electrochemical reactions between the sulphides (metallic conductors of electricity) and the adjacent ground moisture (electrolytes). Readings were taken at 50-ft. intervals along profile lines spaced 100 ft. apart, and cutting across the strike of the mineral-bearing formation. For greater detail, some readings were taken closer, even at 5-ft. intervals; lines of observations were also run in No. 1 tunnel and No. 3 tunnel. The locations of the profiles thus read are shown on Fig. 1. An area about 1500 ft. east and west by 1000 ft. north and south was thus surveyed by the spontaneous polarization method in 1944.

The equipment is shown in Fig. 2.

Results of Geophysical Survey

The results of the geophysical survey are depicted in two ways on the accompanying maps (Figs. 1 and 3 to 5). First, the readings taken along a profile line are plotted against the corresponding observation stations. Since the point of primary interest is the magnitude of the electrical activity over the apex of the sulphide body, which is the negative pole of the battery, or point of inflow of the current from the surrounding rocks, the negative potentials are plotted *above* the line. The resultant profile of electrical activity therefore rises to a peak over the causative sulphide mass. Second, a series of related profiles, usually along parallel lines, can be used to construct a map of equipotential curves. Each equipotential curve joins the points that are at the same potential, or electrical level; they may thus be thought of as the contour lines of the mountain of electrical activity centered on the sulphide body. In the vicinity of tunnel No. 1, only the profiles were plotted, because the activity is too weak and irregular to justify drawing in the equipotential curves. In the vicinity of tunnel No. 3, both the observed profiles and the equipotential curves drawn from them are shown.

During the geophysical work three areas of electrical activity were recorded, only one of which was of important magnitude. They are all of interest, however, because the reactions observed are typical of different modes of sulphide occurrence. Examples are found of reactions indicative of low sulphide content in a broad zone, of very small pockets of stronger sulphide mineralization, and of a moderately large body of fairly good sulphide content.

The area in the immediate vicinity of tunnel No. 1 exhibits a very weak electrical activity, which in this instance, may be ascribed to the presence of sparsely disseminated sulphides. The maximum potentials observed at the surface, of the order of only 25 millivolts, were in a zone about 150 ft. wide, extending south from the base line between profiles 5 + 00 and 7 + 50. The appearance of the electrical profiles suggests that the strongest mineralization will be found between lines 5 + 00A and 6 + 00. The maximum width of the band is nearly 150 ft. on profiles 6 + 00, 6 + 00A and 6 + 00C, and then narrows east and west, to pinch out between profiles 4 + 50 and 5 + 00 on the east. and between 7 + 50 and 8 + 00 on the west. The detailed readings taken along the profile lines in this zone are shown in Fig. 3, where the profiles have been plotted as though they were all parallel, in order to avoid confusion of intersecting lines.

The weak electrical reactions just described are of the order of magnitude of those which can be produced by formational contacts, or by purely superficial effects. In the present instance, however, the resulting minor irregularities in the electrical profiles offer some contrast with the flatter appearance presented by those in the surrounding area. This, combined with the fact that the known occurrence of sulphides here provides a basis of cor-

the previous prospecting work, and also revealed no reason to anticipate additional, or better mineralization in the vicinity. The owners therefore decided to spend no more money on the venture, but made their information available to the U. S. Bureau of Mines, which conducted about 1000 ft. of diamond drilling on the property in the summer of 1944. This drilling was carried out principally in the vicinity of No. 3 tunnel, and outlines an ore body of limited horizontal extent, as indicated by the geophysical work. The general mass of the peridotite was shown to carry some sulphide mineralization, in two and three bands, but in only a small zone is the content of nickel and copper high enough to constitute ore, as shown on the plan map, Fig. 1. The Bureau of Mines estimated the ore zone to contain 30,000 tons with 0.6 to 1.7 per cent nickel and up to 0.7 per cent copper. No drilling was done to test beneath the zone of peak electrical activity, to see whether or not the sulphides are heavier there. The drilling also left open the question of how far down the dip the ore body may be expected to extend. Geophysical methods do not give quantitative indications of the depth to the root of a sulphide body, but only a rough measure of whether it lies at depth, or close to the surface. The appearance of the profiles of electrical activity over this body would normally be taken to indicate a somewhat greater extension downdip than that shown by the outlines of the ore body traced by the Bureau of Mines. The possibility is therefore presented that the sulphides may extend further down the dip, under the quartz diorite roof. Whether it does or not is probably an academic question, because the drilling has indicated an ore body of too small a horizontal extent to be of commercial importance. The lack of any electrical activity in the hanging-wall side of the quartz diorite dike indicates no sulphide mineralization northeast of this intrusive; the geological data and the drilling suggest that the faulting, which probably preceded or accompanied this intrusion, had lifted the deeper extension of the ore body upward, and that this faulted section in the hanging wall of the dike has since been removed by erosion. The immediate area therefore lacks commercial interest.

Logical Order of Exploration

The work on this prospect clearly indicates the logical order in which to conduct an exploration program for the maximum efficiency and economy. Geophysical exploration methods are but one step in the progressive narrowing of the search for ore, and normally should occupy a position intermediate between the geological reconnaisance and the underground exploration by drilling, shaft or tunnel. In such an instance as the present one (ignoring for purposes of illustration the fact that the tunnels were driven 40 years ago), the discovery of the deposit should be followed by a geological reconnaisance to determine the approximate zone favorable for ore deposition. Following this, a geophysical survey would reveal the locations and relative importance of the sulphide deposits. The uninteresting ones, such as between profiles 5 + 00 and 9 + 50, could be eliminated at once (all the expense of tunneling here would be eliminated, as well as of test pitting in the barren areas) and attention concentrated on the better reactions between profiles 12 + 00 and 15 + 00. The only question to be answered would be whether the sulphides responsible for the stronger electrical reactions occur in quantity and values sufficient to constitute an ore body. A moderate amount of diamond drilling, with possibly some tunneling, would usually answer that question, if it is to be a negative answer, thereby saving much costly, and wasted, underground development. If the answer, on the other hand, is encouraging, the geophysical and pre-of this geophysical deduction, the cost of test-pitting the hillside could have been obviated.

The only interesting area of electrical activity discovered in the course of this survey is in the vicinity of tunnel No. 3. It extends from profile 12 + 50 to profile 15 + 00, and for a maximum width of 300 ft. north from the base line. The profiles of the electrical potentials observed here contrast strongly with those recorded in the first zones described; see Fig. 4. The peak reactions are from 125 to 150 mv., and the plotted curves, with their broad bases, make a striking contrast to the type of reaction recorded near tunnel No. 1. The fact that the electrical activity in the vicinity of tunnel No. 3 is spread over a width of 200 to 300 ft. is indicative of a fair extension in depth of the causative sulphide mass, or masses. The alignment of the points of maximum reaction implies the presence of two bands of sulphide mineralization or one band with heavier streaks on the hanging wall and footwall.

The electrical readings taken in tunnel No. 3 provide an illuminating comparison with those taken in tunnel No. 1 (Figs. 3 and 5). It will be recalled that in tunnel No. 1 an acute peak of nearly 150 mv. was well-nigh masked by the overburden, so that only very minor activity was recorded at the surface above it. In tunnel No. 3, however, a peak of over 150 mv. occurs at station 4E, almost immediately below one of 130 mv. on profile 13 + 00. The electrical activity from the underlying sulphide body is so well spread through the country rock, by reason of the depth to the positive pole of the body, that the overburden reduces this peak hardly at all. The same observation applies to the peak of 175 mv. on the line north from station 4E, and the surface maximum of 125 to 150 mv. above it.

The individual potential maxima read in these tunnel lines are probably due to local concentrations of sulphide mineralization, and the saddle 40 ft. east of station 4E, between the first two maxima, coincides with a low-grade zone. The plotted curves show a good width and rounded outline entirely lacking from the profile read in tunnel No. 1, all of which points to a stronger and deeper sulphide mineralization in the vicinity of tunnel No. 3.

A striking feature of the profile read along the main tunnel is the pronounced development of positive potentials at the eastern end of the line. The last two readings were in the quartz diorite dike, much broken by faulting and the third from the last reading was close to a fault zone bordering the dike. It seems probable that the positive potentials recorded are the result of a current flow through the faulted dike and shear zone toward the surface, from the positive pole of the sulphide body lower down the dip.

In sum, the electrical activity recorded in the vicinity of tunnel No. 3 implies a small, moderately strong sulphide mineralization, with some extension in depth. A band of sulphides probably 200 ft. or so long and about 60 ft. wide is indicated, with the surface trace striking between N. 35° W. and N. 77° W. The results point to two bands of mineralization, or a single band with heavier mineralization along the footwall and hanging wall, but of limited horizontal extent. The appearance of the electrical profiles suggests a northeast dip for the sulphide mass. Preliminary drilling, based on geophysical results, could have yielded information indicating the best places at which to carry out further investigations. Some tunneling might have been required before finally condemning the deposit, but the cost of test pitting and much of the expense of tunneling could have been saved, as was demonstrated by subsequent events.

WORK BY BUREAU OF MINES

The geophysical work confirmed the deductions drawn from the results of

relation, is the only excuse for drawing conclusions from their general appearance. On this basis, they are taken to indicate a small region in which the average sulphide content is very low, probably less than 5 per cent. Irregular and pockety occurrences of slightly stronger mineralization are responsible for the individual peaks.

Tunnel No. 1 penetrates the hillside beneath this zone of weak electrical activity, and the observations made in it provide an interesting comparison with the readings at the surface. About 50 ft. in from the tunnel portal a peak of nearly 150 mv. was recorded (Fig. 3). The acute shape and narrow base of the plotted readings are striking, and are typical of the reaction set up by a sulphide pocket of extremely limited vertical extent. At the surface of the ground on profiles 5 + 00A and 6 + 00C, are two small electrical peaks approximately above this tunnel reaction, which demonstrate that even a shallow overburden (10 to 15 ft.) nearly masks the electrical activity of this small sulphide pocket, reinforcing the conclusion that its vertical extent is insignificant.

The deduction to be drawn from these phenomena is that this zone of low average sulphide content may yet contain small pockets of appreciably stronger sulphide mineralization. These bodies will be small and of irregular occurrence, and are too limited to produce distinctive reactions at the surface. It is therefore possible that such insignificant blebs may occur with sufficient frequency to "sweeten" slightly the average sulphide content.

It is probably just such a small sulphide

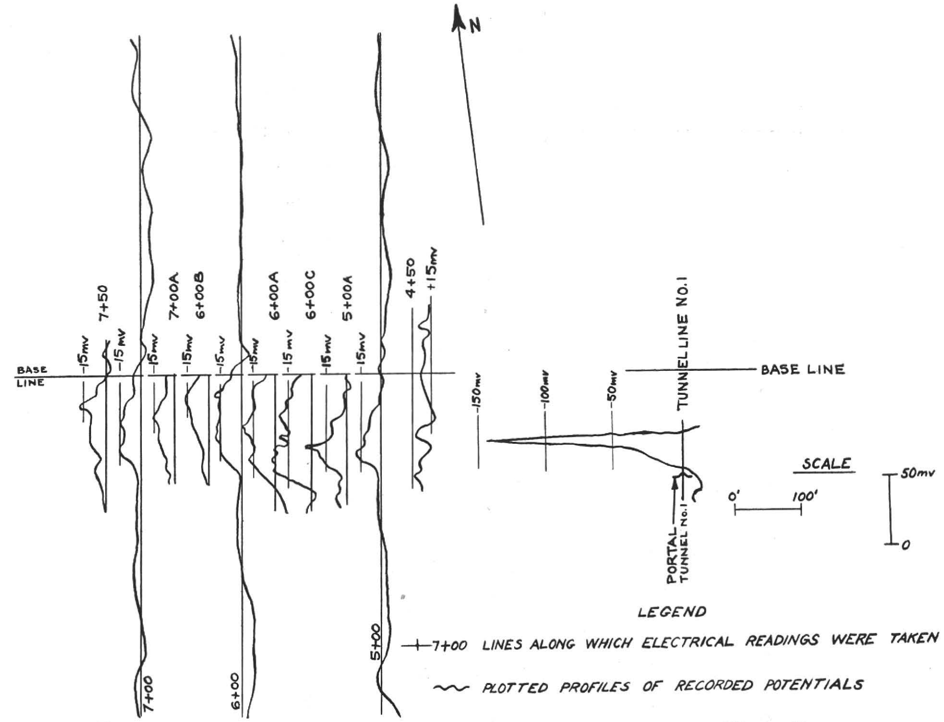

FIG. 3.—DETAILS OF SPONTANEOUS POLARIZATION PROFILES NEAR TUNNEL NO. 1, CHELAN NICKEL PROSPECT.

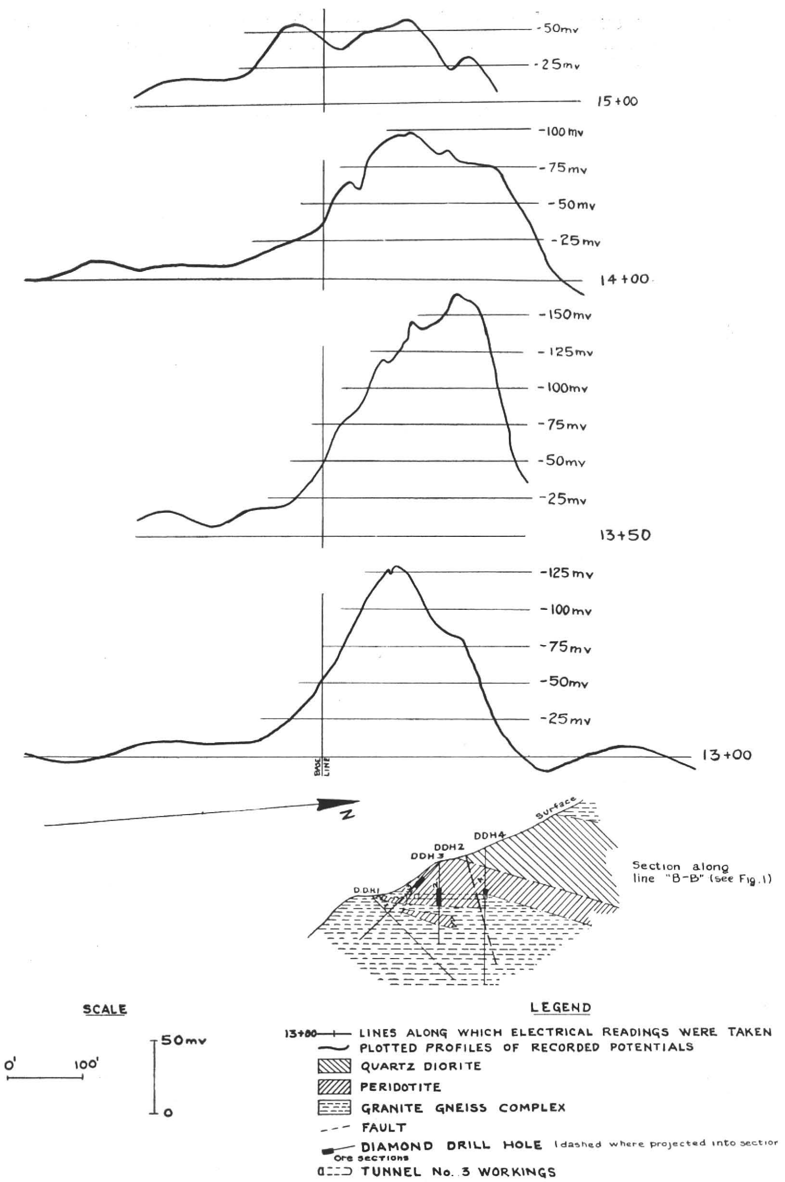

FIG. 4.—SPONTANEOUS POLARIZATION PROFILES AND DRILL DATA AT TUNNEL NO. 3, CHELAN NICKEL PROSPECT.
Drill data courtesy of U. S. Bureau of Mines.

pocket that yielded the favorable assays recorded in tunnel No. 1. In the samples taken between 35 ft. and 50 ft. in from the tunnel portal, the assay figures for copper and nickel are in general somewhat higher than elsewhere in the tunnel. This would imply that the sulphide content is somewhat higher here, which is also the zone in which the maximum potentials were recorded on the line of readings in the tunnel. Since the electrical reactions elsewhere in this general region indicate a lower average sulphide content, it is reasonable to assume that the copper-nickel content would also be lower.

Just east of this area of weak negative potentials there lies a zone of equally weak positive potentials, where a draw cuts back into the hillside. This could be due either to a fault which serves to conduct the outflowing current from the lower part of the sulphide body to the surface, to a formational contact, to purely superficial effects or to the sulphide mineralization extending to such a shallow depth that the draw approached close enough to its lower portion to encounter the weak positive potentials associated with the bottom of a sulphide formation. In any event, the ore exposed in No. 1 tunnel is an isolated, mineralized area of very limited extent, both horizontally and vertically, carrying only weakly disseminated sulphides.

The deductions drawn from the surface geophysical survey would most assuredly not have warranted the expense of driving any adits into the hillside at this point.

The only electrical activity ascribable to sulphide mineralization between No. 1 tunnel and No. 3 tunnel was found on profiles 8 + 50 to 9 + 50. The potentials are even weaker than in the vicinity of tunnel No. 1, so this small area could be ruled out from the point of view of commercial interest. The geophysical survey therefore indicated that there is no mineralization between No. 1 tunnel and No. 3 tunnel, and that the sulphides encountered in those two tunnels have no connection near the surface. On the basis

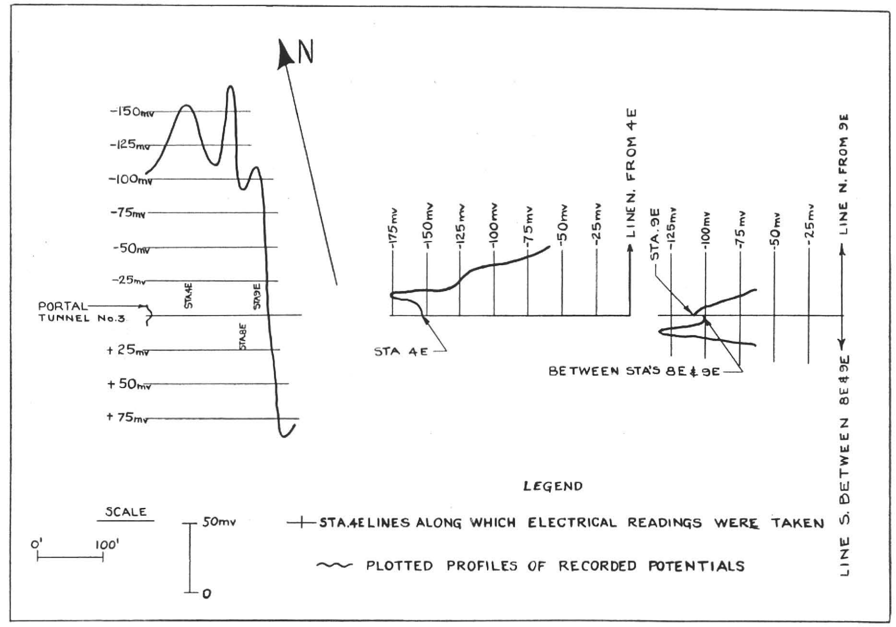

FIG. 5.—SPONTANEOUS POLARIZATION PROFILES IN TUNNEL NO. 3, CHELAN NICKEL PROSPECT.

Sept 19' 47

Mr G. M. Colvocoresses
1102 Luhrs Tower
Phoenix, Arizona

A 10/17/47

In regard to the report to the A. I. M. E. I shall do my best to locate same for you. I was sure that it had been returned at the Bank, However since they say no, I shall look carefully thru all of our papers.

I apologize for the oversight in not returning the report to your office. We appreciate your generosity in lending it to us. Thank you once again

Very Truly Yours
Walter H Singleton

CONGRESS HOTEL > > Tucson, Arizona

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W. W. PATRICK, OPERATOR

Sept 19' 47

Mr G. M. Colvocoresses
1102 Luhrs Tower
Phoenix, Arizona

a 10/1/47

In regard to the report to the C. C. M. C. I shall do my best to locate same for you. I was sure that it had been returned at the Bank, However since they say no, I shall look carefully thru all of our papers.

I apologize for the oversight in not returning the report to your office. We appreciate your generosity in lending it to us. Thank you once again

Very Truly Yours
Walter H. Leighton

See America First

November 12, 1946

Mr. F. M. Stevens
American Smelting & Refining Co.
Post Office Box 2229
Tucson, Arizona

Dear Mr. Stevens:

As requested by Mr. Wilson of your organization, I sent him information regarding the La Cholla Placer as this was obtained from Tom G. Young, and I hope that same will meet his requirements.

Some months ago I believe that you told me that your company held some property in the vicinity of San Manuel and expected to develop same at a later date. I have recently been informed that some friends and clients of mine are interested in the very large area in this section, and since they are not mining people, I presume that they might be glad to do business with your company if you should believe that their ground is likely to prove well mineralized.

I note that they are particularly interested in sections 24 and 25, township 8 south, range 16 east, also in portions of sections 19, 30 and 31, township 8 south, range 17 east, and you or some member of your staff are probably well acquainted with all this area and would be in a position to have some opinion concerning its possibilities.

The area in question seems to be close to the holdings of the Magma Company and those of the Anaconda Company, and it is very likely that my friends will have some exploration or development work carried out in the near future before they attempt to officially bring it to the attention of any of the large mining companies, If meantime you would care to give me any general data or have any duplicate maps covering this particular district, I should appreciate hearing from you, and we might start a preliminary discussion of the matter which, perhaps, might eventually prove to be mutually profitable.

Personal regards.

Yours very truly,

GMC:IM

October 16, 1947

Mrs. W. H. Singleton
2016 East Water Street
Tucson, Arizona

RE: San Manuel

Mine File

Dear Mrs. Singleton:

Thank you for your letter of September 19 in reference to the A. I. M. E. maps and data concerning the San Manuel District.

I am sorry that these appear to have been lost in some manner and should they turn up, I would be very glad to have you forward them to me; however I presume that much of the data is now obsolete since such a large amount of drilling and other exploration has been done during the last few months, and I hope that your property is developing in a very satisfactory manner.

Personal regards.

Yours very truly,

GMC

GMC:IM

a 1/24. 47

SHERWIN F. KELLY GEOPHYSICAL SERVICES, INC.

ROOM 318 900 MARKET STREET
WILMINGTON, DELAWARE

Lima, Peru
January 20th, 1947

Mr. George M. Colvocoresses
1102 Luhrs Tower
Phoenix, Arizona.

Re San Manuel

Dear Mr. Colvocoresses:

It was a disappointment to me to miss you when I passed through Phoenix, but I hope that next time my stay will be longer and that a better opportunity will be provided for us to get together. Your letter of Nov. 27th reached me after my return to New York City in December. I was there and at our Toronto office only briefly before leaving for Peru. We have been carrying out geophysical work in this country since last spring, and I have come down to look over the results and plan the continuation of the work.

The San Manuel area to which you refer is one wherein the use of geophysical methods has already been envisaged. Mr. Baragwanath had asked me to look at it with that in mind, which I did on my way from Tucson to Phoenix. One problem related to the determination of the depth of the Gila conglomerate where it overlies the ore-bearing monzonite. In other words, the idea would be to pick places of shallow cover for the first drilling sites. This could be done in cases of fairly shallow cover by applying the electrical resistivity technique of determining depths. The seismic method would also be applicable, even in case of great depth but would cost more. In view of the sulphide mineralization, I had envisaged the possibility of employing the spontaneous polarization technique, but my conversation with Mr. Rubley at San Manuel convinced me that the depth to the sulphide mineralization was probably too great.

It therefore seems as though geophysical methods would have only a limited application in that area, but that they might nevertheless be useful. I should be very glad indeed to look over any geological data with which you can furnish me, referring to your own interests in the area, and advise you whether or not application could be made along the lines outlined above, or along other lines.

The same invitation to let me look over the geology of your prospect will naturally apply to any other problem which you may have in hand at any time. My mail will be forwarded to me while I am in South America and I expect to be back in the States in March.

With cordial personal regards, I am

SFK/m

Sincerely yours

Sherwin F. Kelly

Sherwin F. Kelly

FRANK C. BROPHY
508 TITLE & TRUST BLDG.
PHOENIX, ARIZONA

Phone.
4-2609

Only red area is
claimed by Briggs

Finds

Surveyor will 2 then
2 or 3 [illegible] so [illegible]
[illegible] Can [illegible] [illegible] [illegible]
[illegible] Lease.

Prospecting

Mrs Vivian H

Singleton

c/o W. H. Singleton

Delta Chi House

1501. E 1st St

Tucson

January 24, 1947

Mr. Sherwin F. Kelly
Sherwin F. Kelly Geophysical Service, Inc.
Room 318---900 Market Street
Wilmington, Delaware

RE: San Manuel — File

Dear Mr. Kelly:

Thank you for your very interesting letter written from Lima, Peru, on January 20. The air mail service from Peru is certainly excellent since I received it yesterday.

I felt very confident that you or others had already considered the use of geophysical methods for the purpose of carrying on preliminary exploration at the San Manuel deposits, and I agree with you in believing that such a procedure might prove very useful; although as you say, there are doubtless limitations.

My own investigation of the area, which is owned by my clients in that particular section, has been delayed partly at my own request and partly in order to permit the surveyors who are now working on the property to complete the outlining of the claims and the location work which is now in progress, and I feel that I can make a much more comprehensive study of the entire situation after they have completed the survey and obtained further information regarding the geology of the area in question.

The present outlook is that my examination will be made sometime during the month of February and after same has been completed, I will certainly communicate with you further concerning the geological condition and the possible application of geophysical methods of exploration.

I gather that you will probably be back in the United States during the month of March and meantime I hope that you are enjoying your stay in Peru and will not meet with any unpleasant experiences by reason of the somewhat unsettled political conditions.

Personal regards.

Sincerely,
GMC

GMC:IM

Just received copy of your pamphlet on Chelan [illegible] many thanks

December 12, 1946

Director, U. S. Geological Survey
Washington 25, D. C.

San Manuel

Dear Sir:

Will you kindly advise me if you have available a copy of the report made by engineers of your bureau covering the drilling and other exploration work carried on in the San Manuel mining district of Arizona.

I understand that a copy of this report could at one time be obtained from your office for the sum of $1.00 per copy which I shall be prepared to remit if you advise me that the report can be sent.

Yours very truly,

GMC:IM

University of Arizona
TUCSON

COLLEGE OF MINES
ARIZONA BUREAU OF MINES

December 4, 1946

A 12/13/46

Mr. George M. Colvocoresses
1102 Luhrs Tower
Phoenix, Arizona

Dear Mr. Colvocoresses:

If the report on the San Manuel area is still available it will be from the Washington Office address: Director, U. S. Geological Survey, Washington 25, D.C., at a cost of $1.00.

There is a copy on file in the Arizona Bureau of Mines, but no extra copies for distribution.

Very sincerely,

B S Butler

B. S. Butler
Head, Dept. of Geology

BSB:bf

November 26, 1946

San Manuel

U. S. Geological Survey
University of Arizona
Tucson, Arizona

Gentlemen:

I would much like to secure a copy of USGS Strategic Minerals Investigations with preliminary maps 3-180 entitled "Geology of the San Manuel Area, Pinal County, Arizona", by G. M. Schwartz.

If this paper is available for free distribution, will you kindly send me a copy particularly the maps and otherwise advise me as to the cost of obtaining same.

Yours very truly,

GMC:IM

February 10, 1947

Mrs. Vivian H. Singleton
Delta Chi House
1501 East First Street
Tucson, Arizona

RE: San Manuel

Dear Mrs. Singleton:

This is merely written to request a little information as to the progress which is being made by your surveyors at your claims near San Manuel and to ask if you can give me a more definite idea as to the date when you are likely to have use for my services in making an examination of the property.

I have no wish to hurry this matter. In fact, I believe that it will be better to postpone it until sometime in March or perhaps even later, but I have to make plans for my own engagements somewhat in advance and want to be able to be at your service without too much delay anytime that you are likely to be ready for me.

Mr. Brophy has not returned the pamphlet on San Manuel which you took from my office and which I understood you turned over to him, but I am sure that I can get hold of that at almost anytime.

Meanwhile I have obtained from Washington some additional data regarding the geology and ore occurrence in the vicinity of your property which will, I think, be of considerable value in furthering my study of your ground.

Also I recently had an interesting conversation with an engineer representing the Freeport Sulphur Company who have taken over some claims in your vicinity and are drilling or preparing to drill on quite an extensive scale. Contact with these people may prove of value somewhat later.

Best personal regards.

Sincerely,

GMC:IM

November 18, 1946

Mrs. Vivian H. Singleton
Delta Chi House
1501 East First Street
Tucson, Arizona

RE: San Manuel

Dear Mrs. Singleton:

I am sending this letter in duplicate and addressing the envelope to your son in Tucson. No doubt he will forward one copy to you.

I am making considerable progress in obtaining maps and data concerning the San Manuel district and property which is being developed by the mining companies in that vicinity, and in this connection I am told that a man named John Daily together with his associates have recently located approximately 100 claims, some of which appear to be either in conflict or adjoining your property, and Mr. Daily has promised these to at least one large mining company.

Will you please advise me if the said Mr. Daily is associated with you?

As soon as I receive some data from your surveyor including the maps of your claims, I will make definite plans for examination of the property which I believe we agreed to defer until sometime in December when the surveying will be further advanced.

Merely to confirm our verbal arrangement, it is understood that my fee for examination and report on the property will be the sum of $500 plus expenses which expenses will not exceed $100 and probably will be a considerably smaller sum.

Yours very truly,

GMC:IM

MEMO

November 13, 1946

Call from Mrs. Vivian H. Singleton and her son, W. H. Singleton who may be addressed at the Delta Chi House, 1501 East First Street, Tucson, Arizona. These are the friends of Frank Brophy who hold a large area in the vicinity of San Manuel and adjoining the ground which is now being drilled by the Magma and Anaconda Companies. General location of same is shown on township map copy of which they left with me and on which their claims are marked in red.

At the present time they have a surveyor staking out their claims and it is my advise in which Brophy concurs that no examination should be made of the property until the surveyor has made sufficient progress to draw up a map showing the exact location of the Singleton property. They have 81 claims and are carrying on the location work along with the survey.

I explained that I was not in physical shape to do any large amount of walking, but would be able to obtain competent assistance so that I can undertake to supervise an examination of this property perhaps around the middle of December and after they have furnished me with the surveyor's maps and other data and I will subsequently advise them in regard to holding their property or dropping portions of same and in respect to the location of drill holes and/or other development work. Fee to be $500.00 plus expenses which would not exceed $100.00 and this was satisfactory.

They believe that the upper portion of their sulphide ore body will be found approximately 1300' below the surface and bottom of same approximately 2300' below the surface. They claim that the ore is rising toward the surface as it extends to the northeast and their claims lie northeast of the ground which has so far been developed by the Magma and the Anaconda.

Phoned Frank Brophy who approves of my recommendation.

July 31, 1947

Mr. Sherwin F. Kelly
Room 318
900 Market Street
Wilmington, Delaware

RE: San Manuel

File

Dear Mr. Kelly:

Replying to your letter of July 17, I never did make an examination of the San Manuel prospects concerning which I wrote you last winter.

My advice to the owners was to postpone any examination by an engineer until they had completed surveying their claims and noting the various outcrops if any, and I also suggested some geophysical work.

I have heard indirectly that they did arrange for a geophysical examination for at least a portion of the property which I believe was carried on by some local people, and I rather doubt if I shall be asked to do anything further in connection with this venture but should such be the case I may have occasion to communicate with you again.

I was glad to learn that you did not have any unpleasant personal experiences during your stay in South America and it seems as if Americans were becoming less and less welcome in many of those countries which is probably due to lack of gratitude for the help which was given them by the United States during the last war, and also perhaps to a certain amount of communistic influence.

Personal regards.

Yours very truly,

GMC:IM

SHERWIN F. KELLY GEOPHYSICAL SERVICES, INC.
ROOM 318 900 MARKET STREET
WILMINGTON, DELAWARE

July 17th,1947

a. 7/31/47

Mr George M. Colvocoresses
1102 Luhrs Tower
Phoenix, Arizona.

Dear Mr. Colvocoresses:

On picking up the loose ends of correspondence since returning from Peru (I returned only in June, far later than I had expected) I notice that we had exchanged some letters on the subject of of the San Manuel prospect, and that you were expecting to examine that area in February. I am wondering whether or not that produced interesting and useful information, and whether or not it is apropos to raise again the question of geophysics.

My stay in Peru was most interesting, and before returning to the States I had the opportunity of paying a visit to one of the Patiño tin mines in Bolivia. I had no unpleasant experiences myself, although I landed at the Patiño camp in the middle of a serious strike at a neighboring camp, where several of the American engineers were being held incommunicado. The camp I was visiting was serving as headquarters for negotiations, and therefore was in a somewhat excited state. Eventually the matter passed off peacefully and the engineers who were being held were released and returned to the camp where I was staying. By one of those interesting coincidences, which are frequent enough in mining not to be considered coincidences, one of these engineers turned out to be the engineer of a property at which we made a gophysical survey some 10 years ago in Mexico, and at whose house I had been a guest!

With best personal regards, I am

SFK/m

Sincerely yours

Sherwin F Kelly

Sherwin F'Kelly

August 29, 1947

Mr. Frank C. Brophy
46 West Monroe
Phoenix, Arizona

RE: San Manuel

-File

Dear Frank:

Sorry that we have not been able to make contact, but perhaps it is just as well that I should write to you concerning what I have in mind.

You will recall that Mrs. Vivan Singleton came to me at your suggestion last winter concerning her mining property in the San Manuel District which at that time she thought that she might wish to have me examine.

On the occasion of her last visit which was, I believe, in February, I showed her a geological map and description of the entire district which had been made up by the A.I.M.E. and of which only a few copies were available.

Mrs. Singleton was extremely anxious to have you look over this document and therefore borrowed it with the understanding that she would return it to this office in the near future or ask to have it returned to me from your office, but so far it has not come to hand.

It happens that I shall have to be in Tucson around the middle of September in connection with some other work and may find it advantageous to look over some portions of the San Manuel District in which case I would very much like to have the map and descriptinn mentioned above.

If by chance this document was left with you, will you please advise so that I can send up for it or otherwise please inform me as to Mrs. Singleton's present address so that I can write to her direct and ask for its return.

Personal regards.

Sincerely,

Colin

GMC:IM

September 4, 1947

Mrs. Vivian Singleton
2016 East Water Street
Tucson, Arizona

RE: San Manuel

Dear Mrs. Singleton:

You will probably recall that last February you borrowed from my office a map and a short geological description of the district at San Manuel.

At that time you said that you were anxious to show it to Mr. Frank Brophy and that you would either bring it back here later or that it would be returned to me from his office.

Mr. Brophy's office advises that there is no such document in their possession and therefore I presume that you may have it and if so will you kindly return it by mail at your early convenience. The map and document to which I refer was issued at a meeting of the local section of the A.I.M.E., and I do not think it would be possible for me to secure another copy at present.

I hope that everything is going well with you and with your mining development in the vicinity of San Manuel.

Yours very truly,

GMC:IM

GMC

February 3, 1947

San Manuel

Mr. R. C. Shelse', Chief Clerk
United States Department of the Interior
Geological Survey
Washington 25, D. C.

Dear Sir:

I wish to express my thanks for the copy of the pamphlets and maps entitled "Geology of the San Manuel area, Pinal County, Arizona" which has been duly received in accordance with your letter of January 27.

Yours very truly,

GMC:IM

FOR VICTORY BUY UNITED STATES WAR BONDS AND STAMPS

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

San Manuel

JAN 27 1947

A 3/3-47

Mr. George M. Colvocoresses,
1102 Luhrs Tower,
Phoenix, Ariz.

My dear Mr. Colvocoresses:

Because of the delay in replying to your letter of December 12, the Geological Survey has sent you a copy of Map 3-180, "Geology of the San Manuel area, Pinal County, Ariz." without charge from a few placed at the disposal of the Director.

Very truly yours,

R C Shelse'

R. C. Shelse'
Chief Clerk.

Larsen - Int. 3735

DEPARTMENT OF THE INTERIOR

INFORMATION SERVICE

GEOLOGICAL SURVEY

For Release DECEMBER 10, 1945

GEOLOGY OF THE SAN MANUEL AREA, PINAL COUNTY, ARIZONA

Recent exploration in the San Manuel area, about a mile south of the well-known Mammoth-St. Anthony mine at Tiger, Ariz., has revealed a large low-grade copper deposit, it was announced today by the Geological Survey of the Department of the Interior.

The San Manuel copper deposit has some features in common with the large disseminated copper deposits known as the "porphyry coppers," whose exploitation on a large scale has become in recent years a dominant factor in the domestic copper-mining industry, the report stated. If present indications of its size and grade are substantiated, and if suitable mining and metallurgical methods are developed, this may prove to be the most important Arizona copper discovery in the last decade.

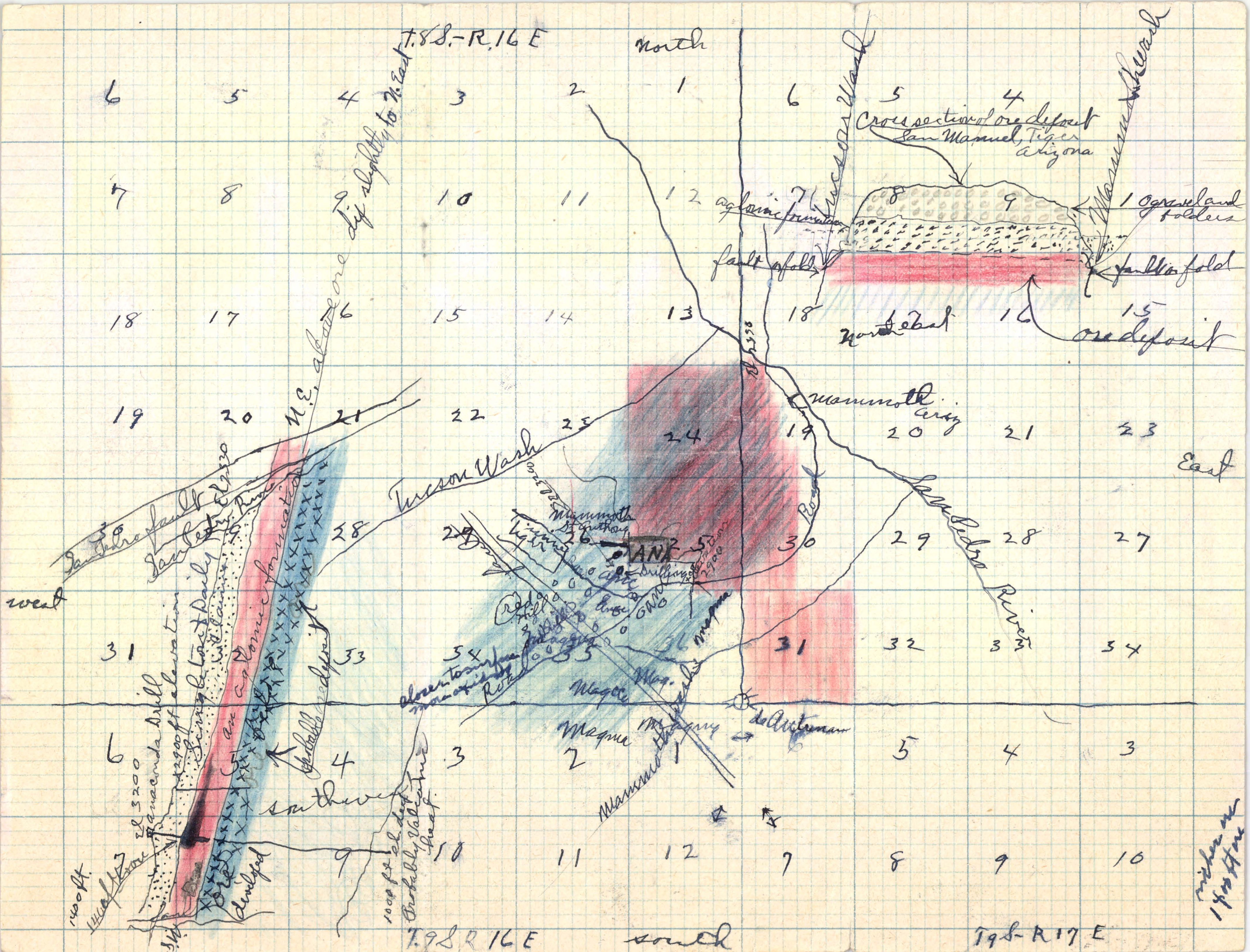
A detailed geological study of the area and correlation of surface geology with subsurface information, obtained from drill cuttings furnished by the Bureau of Mines and by private companies, has been carried out by the Geological Survey since January 1944. The Survey has prepared a preliminary report to the public on the geologic aspects of the new discovery. Preliminary maps and sections, together with a brief description of the geology of the San Manuel area, depict the general characteristics of the ore body and its geologic setting.

Small outcrops of low-grade copper ore in the area led to shallow prospecting, probably at an early date, but the low grade of the mineralized rock discouraged deep exploration. Recent interest in the area was stimulated by the possibility of obtaining quick production of copper for the war. At the request of the War Production Board, a brief examination of the area was made by Survey geologists in March 1943, and recommendations for further exploration were submitted. Drilling by the Bureau of Mines was begun in November 1943 and terminated in February 1945. Further drilling is being carried on by private companies.

The San Manuel ore body appears to be a tabular mass about 400 feet wide, dipping steeply southeast and coinciding with a zone of sericitic alteration in quartz monzonite and monzonite porphyry. Except for small outcrops near the center of the area, the deposit is concealed by a thick cover of Gila conglomerate, but by February 1945 exploratory drill holes had found copper mineralization extending under the conglomerate over a strike-length of 2,000 feet and to depths of more than 1,000 feet. The ore body has been oxidized to an average depth of about 700 feet. Below this oxidized zone is a zone of enriched chalcocite ore, which has an average thickness in the central part of about 250 feet. This zone is underlain by primary ore of lower grade. The size of the ore body will not be known until its limits can be determined by further exploration, but by late 1944 drilling had indicated 30,000,000 tons of low-grade ore containing an average of 0.8 to 0.9 percent copper and small amounts of molybdenum and gold.

Copies of this material consisting of the maps and sections and a brief description of the area and issued as Strategic Minerals Investigations, Preliminary Maps 3-180, may be purchased at a cost of $1.00 per copy from the Director, Geological Survey, Washington 25, D. C.

XXX


T.8S-R.16E
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Cross section of ore deposit San Manuel, Tiger Arizona
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San Pedro River
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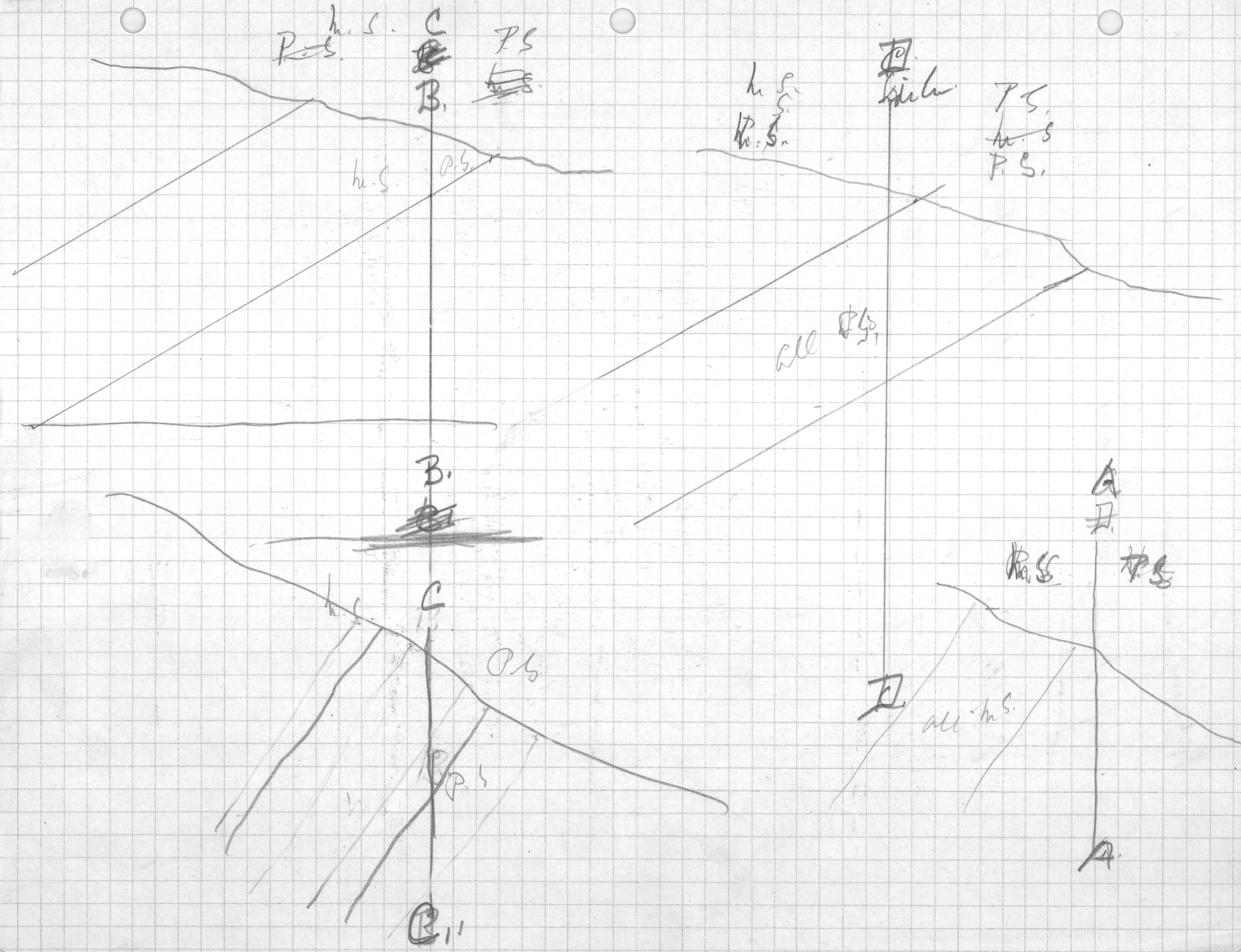
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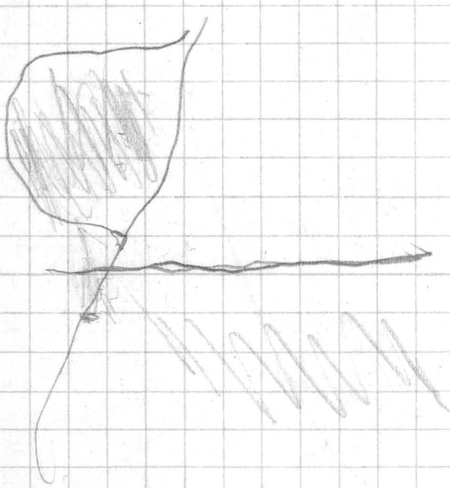
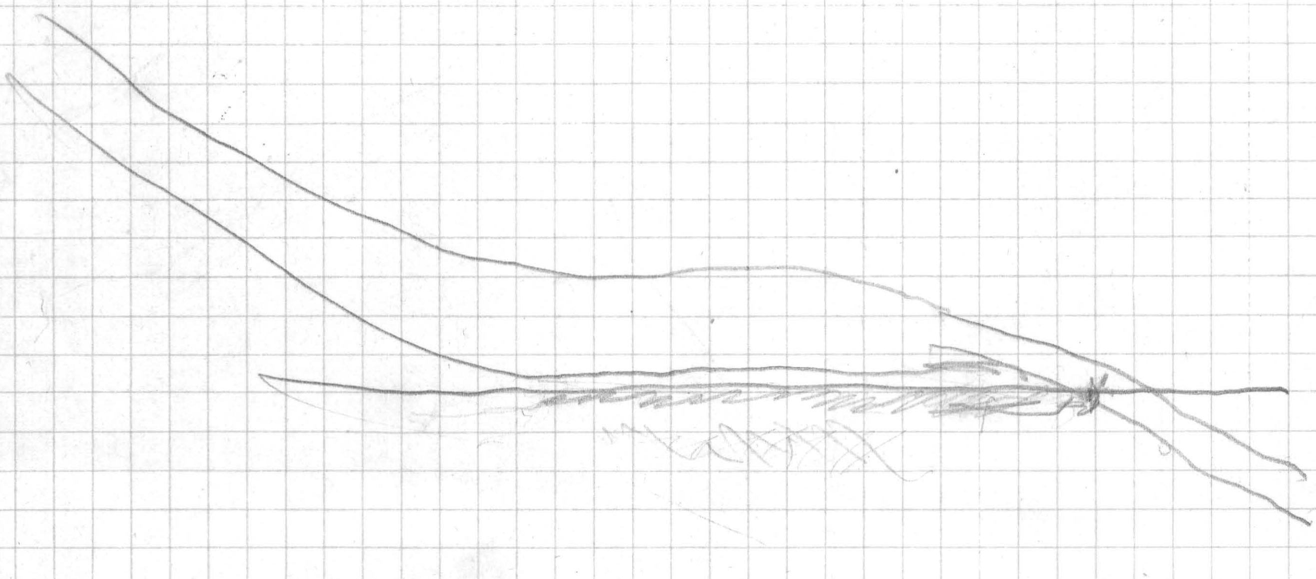
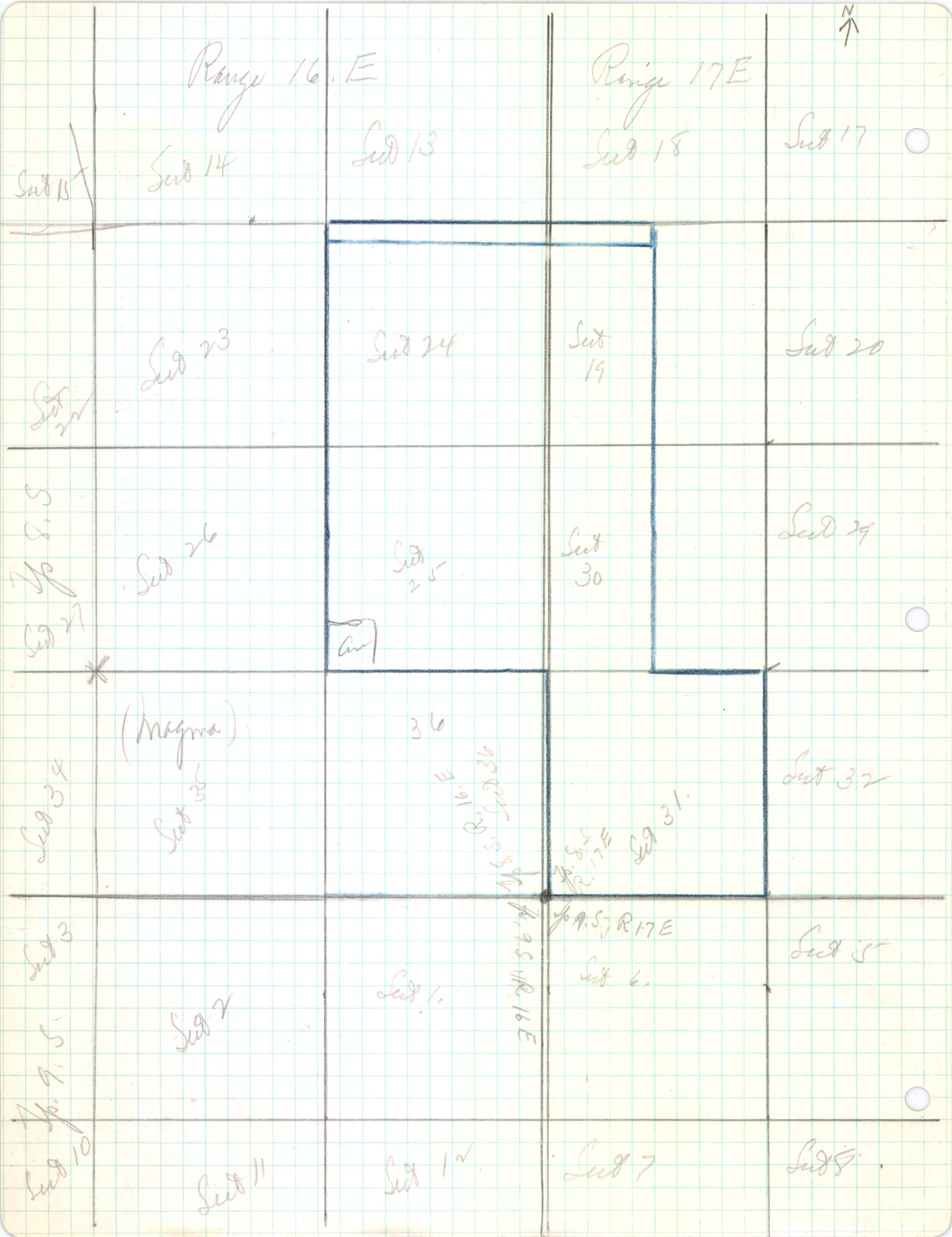
Morning Star Mine – Sect 17, 18, 19 & 20

Tp 10 S. R. 16 E

Mittleman Typus – R. 16 E Tp 6 & 7. S



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36
Tp 8 S R 16 E Sect 36
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Sect 31
Sect 32
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Sect 7
Sect 8

We have had no recent news from Alden and do not know whether or not he is in Sicily, but strongly suspect that such is the case. It does look as if the war is moving along pretty well and the preponderance of air power is certainly turning the scale rapidly in our favor and may bring a collapse of "Hitlerite Germany" before many months have gone by.

Marian is enjoying her stay in Iowa and I am very glad to have her away from the heat in Phoenix which has been pretty severe of late.

I have been kept much busier than usual during the past few weeks and it looks as if August would be quite active, although I can never look ahead for more than a very brief period. Incidentally I was much interested to note the many improvements which have been made in your office building and shops. You certainly have a fine lay-out and I was glad to know that your business is so active, but sincerely hope that you yourself will not try to do too much and run down your physical condition.

With best regards, and let me hear from you when you have an opportunity.

Sincerely,

GMC:b

Commentary of property [illegible] carrying [illegible]
Mammoth Mine.

Amounts 400 of [illegible] @
[illegible] @ 1300' [illegible] + 500

Locate [illegible] 64. claims

Copy of Mining Act to Mr
Singleton @ Box 670
Tucson, Ariz

Trip [illegible] Jan 1st + [illegible]
[illegible]

Con [illegible] of Mammoth Company [illegible]

December 3, 1946

Mr. W. H. Singleton
Delta Chi House
1501 East First Street
Tucson, Arizona

RE: San Manuel

Dear Singleton:

I have not as yet had any reply to my letter of November 18 addressed to your mother in your care, and I am anxious to know when I am likely to receive the maps and data from the surveyor who is working over your claims and marking the corners since I think that it is essential to have this information before I attempt to make an examination of the property.

I do not know your mother's address but please let me hear from you or from her in regard to the above as I have to take a trip to southern California in the very near future and may have to postpone the trip to San Manuel until after I return from California unless I can secure the data from the surveyor in the very near future.

Personal regards.

Yours very truly,

GMC: IM

November 12, 1946

San Manuel

Mr. Brent Rickard
A. I. M. E.
810 Valley Bank Building
Tucson, Arizona

Dear Rickard:

Many thanks for your kind letter of October 24 and I can assure you that I most deeply regretted my inability to attend the meeting of the Arizona Section of the A. I. M. E.

From my son, Alden, and others who were at the meeting, I understand that you had a most interesting and instructive session as well as very pleasant social gathering. I certainly hope to be with you on future similar occasions.

I was very glad to receive the technical papers on the ore occurrence, etc. at the Iron King Mine also on the mineral resourses of Germany. If you happen to have an extra copy of the paper which was presented on the San Manuel prospect, your No. 9, I should be greatly obliged to have a copy of this as I am interested in some areas in that section of the state concerning which I am writing today to your Mr. Stevens.

Personal regards.

Sincerely,

GMC:IM

November 15, 1946

Mr. F. M. Stephens
American Smelting & Refining Co.
Post Office Box 2229
Tucson, Arizona

RE; San Manuel
Claims

Dear Mr. Stephens:

Thank you very much for your letter of November 13 in reference to the above. I have not heard of John Daily in connection with the activity of my friends in that vicinity, but I will find out if he is by chance associated with them or perhaps developing some claims in their immediate vicinity.

I thank you very much for the reference to the Winkelman Quadrangle which I shall obtain, also I have already secured some other data including the paper on the San Manuel developments presented at the Tucson meeting of the A.I.M.E. concerning which I wrote to Mr. Rickard on the 12th.

In all probabilities I shall be in Tucson sometime in the near future, and will then have an opportunity to discuss this matter with you in person. Meantime I think that I can arrange to obtain the preliminary data and I thank you very much for the information given in your letter.

Personal regards.

Yours very truly,

GMC:IM

Aa-16A.13.19B

AMERICAN SMELTING AND REFINING COMPANY
SOUTHWESTERN MINING DEPARTMENT
P. O. BOX 2229
TUCSON, ARIZONA

D. J. POPE
MANAGER

VALLEY NATIONAL BLDG.
TELEPHONE 503

November 13, 1946

Mr. George M. Colvocoresses
1102 Luhrs Tower
Phoenix, Arizona

a 11/15/46

Dear Mr. Colvocoresses:

COPPER CLAIMS
in the
San Manuel area

I have yours of the twelfth advising that some friends of yours are interested in certain sections of land near Mammoth - as having prospective value in the way of potential copper mineralization. I also note that these people expect to carry out some exploration or development before officially presenting their holdings to any of the large companies, for consideration.

For your information I might say that Mr. John Daily was in the office a couple of weeks ago and stated that he and associates had located some 100 claims in the very sections you mention.

Although we have no property in this San Manuel area (you probably refer, in the second paragraph of your letter, to my mention of our Silver Bell property northwest of Tucson) we, of course, are somewhat familiar with the ground in the vicinity northeast of San Manuel. This ground is entirely covered by wash and therefore is a prospect for either a grophysical survey or a few random drill holes.

We have advised Mr. Daily that should his work develop something of special interest we would be glad of the opportunity to look further into the matter.

Regarding maps of this area, we have nothing that is at all reliable. Our chief source of information is the U. S. G. S. topographical sheet on the Winkelman Quadrangle. The San Manuel orebody is, I believe, in about the center of section 35 of T 8 5, R 16 E. You no doubt have this Quadrangle sheet and can get the general relationship of the various holdings from it.

If we had anything of help to you, we would be glad to let you have it. With best regards,

Yours very truly,

F. M. Stephens

F. M. STEPHENS

FMS:ar

AMERICAN SMELTING AND REFINING COMPANY
SOUTHWESTERN ORE PURCHASING DEPARTMENT
810 VALLEY BANK BUILDING
P. O. BOX 2229
TUCSON, ARIZONA

BRENT N. RICKARD
MANAGER

November 13, 1946

Ca 11/15/46

Mr. George M. Colvocoresses
1102 Luhrs Tower
Phoenix, Arizona

Dear Mr. Colvocoresses:

I thank you for your letter of November 12th. We had a fine meeting here in Tucson for the Arizona Section and were sorry you were unable to attend.

I regret to say that I do not have copy of the San Manuel paper presented at the meeting. You might possibly obtain one by writing to Mr. W. P. Goss, General Manager, Magma Copper Company, Superior, Arizona.

Yours very truly,

Brent N. Rickard

BRENT N. RICKARD

I have sent this San Manuel paper and the others to Mr. Parsons – and presume they will be printed some day!

I. K. C.
Counted Cop.

December 2nd, 1943

REPORT ON FORD MINE, PROPERTY OF THE MAMMOTH TIGER EXTENSION MINING COMPANY

Mr. William Miller
Higley, Arizona

Dear Sir:

As per our arrangement and following our joint visit to Mammoth on November 21st, I went to Tucson on November 26th for conference with Ed. Holderness on this matter and subsequently to Mammoth where the officials of the Mammoth-St. Anthony Company kindly showed me all of their maps and mine models. On the following morning I had a conference with William Ward who had just returned from the East and who gave me much information concerning the Ford Mine but was unable to accompany me to the property which I subsequently examined alone as far as I was able to do so with safety.

I beg to submit the following report on same:

LOCATION:

The five unpatented lode mining claims held by the Mammoth-Tiger Extension Mining Company are named Old Glory #1, 2, 3, 4 and 5 and are located to the south and west of the patented mining claims of the Mammoth-St. Anthony Mining Company in Township 8, South Range 16 East Gila and Salt River Base and Meridian as shown on the attached map (Exhibit A).

By comparison with the U. S. Patent Survey of the Claims of the Mammoth-St. Anthony Company I determined that a portion of Old Glory #4 as shown on the map which you furnished is in conflict with the Erfletch patented claim and to that extent it is invalid and hence not drawn in on my map which I believe to be approximately correct and which shows a portion of the St. Anthony holdings, the location of their shafts on the Mammoth and Collins Veins and of the workings on the deepest level (900') from the Collins Shaft.

The shaft and general location of the workings at the Ford Mine are also shown.

HISTORY:

The Tiger Extension is locally known as the Ford Mine having been first developed by a man of that name some forty years ago. It is reported that Ford sorted out and shipped a small quantity of high grade lead-silver ore, but I could find no stopes at or near to the surface from which this ore had been taken.

Later some work was done by Sam Houghton and a few years ago the property was taken over by Dietrich and Roy L. Baird of Los Angeles who organized and promoted the Mammoth-Tiger Extension Mining Company and subsequently secured an R.F.C. loan for $8,500 which was expended largely in developing the 4th level without finding any shoot of pay ore.

The one small shipment of lead ore made by Baird was too low grade to pay the freight and treatment charges and after the mine had been examined by Maitland, an R.F.C. Engineer, the Government refused to advance any further sums of money and how hold a lien on any shipments that may be made and claim to have a chattel mortgage on the equipment although according to Wm. Ward only one drill was purchased with Government funds and the balance of the equipment had previously been purchased and paid for by the Company.

GEOLOGY:

The country is pre Cambrian granite, badly faulted and intruded by dikes of later volcanic rocks mainly andesite and rhyolite which often form a breechia in the fault zone.

Since it is believed that the Mammoth vein is in reality a faulted segment of the Collins it may be said that only one productive vein has yet been found in this district. Repeated efforts to develop commercial ore in other veins such as the East Collins and Dream have proved quite futile, and the same is true of the numerous cross faults and outlying faults to which class the Ford vein or fault seems to belong.

Excepting only the Mammoth-St. Anthony, no mines are now being worked in this district nor have any been profitably worked in the past except on claims now owned by that company.

The workings on the Collins vein have now reached a depth of 900' but at this point they are nearly 1000' from the true side line of the Old Glory #4,--which is correctly shown on the attached sketch (Exhibit A). There are no cross veins from these workings which strike in the direction of the Tiger Company property and if the Ford fault on which the Tiger workings are located should extend to the southeast it would pass a long distance to the west of any of the known ore bodies in the St. Anthony Mine.

After a careful search I could find no trace of this fault on the east side of Tucson Wash nor could I learn that it had ever been located by others.

EQUIPMENT:

The principal items of equipment at the Ford Shaft comprise sheds over the hoist and compressor and two wooden shacks one of which was used as a change room and the other as a store-room in which there are now some empty oil-drums.

The shaft has a 30' head frame with sheave wheel and 5/8" hoisting cable, a single drum Fairbanks Morse gasoline hoist, a Chicago Pneumatic gas ~~drum~~ driven compressor with auxiliary receiver, a hand driven forge blower and anvil.

All of the above appear to be in workable condition and Ward told me that the company also had some drills and small tools which he had removed and locked up elsewhere for safe-keeping. The shaft is equipped with pipe lines for air and water. The total sale value of such equipment as I saw would probably be less than $1000.

FORD MINE WORKINGS:

These are located along a fault fissure in the granite in which there is a narrow dike of andesite. The general strike of this fault is north 20 to 40 degrees west and dips about 70° to the south west. The vertical shaft is sunk in the foot wall.

Access to the mine workings is gained thru an adit tunnel which runs northwest from near the collar of the shaft 12' above the level of Tucson Wash and the winzes which connect it with the lower levels which are shown on the maps that accompanied the application for the Government Loan.

The dangerous condition of the last ladder above the 1st level made it unsafe for me to personally inspect the lower workings but from Ward and Maitland, Engineer for the R.F.C., I obtained information in their regard which I believe to be accurate.

The adit level follows northwest and turns almost due north along the strike of the fault and andesite dike. This dike which follows the fault in the granite has a gouge which contains iron stained clay and breschiated rock. Along the fault seam and in the foot wall granite, as shown by short crosscuts, there are small pockets and narrow streaks of decomposed wall rock which show stains of lead and copper carbonate but there is no indication of any true vein or continuous shoot of ore although the surface showing indicated that such a shoot might have been found at greater depth.

The first level at a depth of 45' showed no improvement while the 2nd level 57' below presented a somewhat more encouraging picture, as the mineralization looked stronger to the eye but sampling failed to confirm this impression except near to the shaft where some carbonate ore had been mined during previous operations.

On the 3rd level, 61 feet further down, there was a little streak of oxidized ore near the northwest end of the drift and picked samples showed as much as 2.5% lead and 14% copper but they represented no substantial tonnage.

The 4th level, 41' below the 3rd or 206' below the collar of the shaft, was the location of practically all of the most recent operations. Here the drift was advanced northwest from 70 to 200' and at a distance of about 150' from the shaft a stope was carried up over a length of 25' and to a height of 20' and later a winze was sunk about 15' below the level.

In this area there were some nice looking stringers and pockets of galena and several picked samples were taken some of which assayed as much as 20% lead and 10% copper but the one car load of ore which was produced and shipped assayed

Gold	0.02 oz. per ton
Silver	7.60 " " "
Copper	1.22%
Lead	5.8 %
Zinc	0.10%.

The net loss resulting from shipping this ore to the El Paso Smelter was $87.81.

The R. F. C. subsequently refused to advance any further funds to permit the continuance of operations since their engineers after careful investigation had definitely concluded that there was no pay ore shoot in the mine and no reasonable hope that ore could be developed in commercial quantity either at greater depth or along the strike of the vein.

The collar of the Ford Shaft is at an elevation of 2900' or about 500' lower than the Collins Shaft and therefore it was to be expected that water would be encountered a short distance below the present workings and the flow would certainly be extremely heavy.

Practically all of the development work was done to the northwest from the shaft and Ward is of the opinion that better results might have been obtained by drifting along the fault to the southeast, but I could see no indications that such would have been the case and certainly there is no justification for continuing the development work in either direction.

During the course of operations a number of samples were taken and assayed by the St. Anthony Company. A few of these which apparently represented merely picked specimens showed a high content in lead and one carried 6.72 oz. silver. None of the other samples showed any appreciable quantity of gold or silver and they contained only traces or molybdenum and vanadium so that there does not appear to be any great similarity with the typical ore from the Mammoth-St. Anthony Mine.

RELATION OF FORD AND ST. ANTHONY MINE:

The attached sketch (Exhibit A) gives the location of the Mammoth and Collins Shafts, and veins and a rough outline of the workings on the 900' (deepest) level in the Collins Vein. From this Sketch it will be noted that this 900' level, where the ore lies furthest to the west, is just about 1000' north of the true east side line of the Old Glory #4 Claim. Since this vein dips to the southwest it might eventually cross the west line of the Erfletch Claim but this could only happen (unless it flattens out) at a depth of some 5000' to which it never will and never can be worked because the present inflow of water is 2000 gallons per minute involving a pumping cost of $250.00 per day and no attempt to go deeper will be made by the St. Anthony Company.

Moreover, and this is vitally important, the St. Anthony Company have staked claims along the outcrop on apex of the Collins Vein for a lineal distance of over 4 miles and even should the vein dip across their side lines at any point along its strike the Apex Law would give them the legal right to follow it down below the claims of other parties and to mine any ore that they might thus develop.

Messrs. Fozard (Manager), Richards (Mine Supt.) and Daggett (Engineer and Geologist) for the St. Anthony Company very kindly showed me all of the survey maps of their workings and the glass model of the mine all of which fully confirmed the above statements and there was not the slightest indication of any work at or near to the Tiger Extension Line. All of their mining has been done on the Collins Vein and on the Mammoth (including the Mohawk and New Year) which represents the upper segment of the Collins thrown to to the east over 1000' by the Mammoth fault. They have tried to find ore in the Dream Vein and Collins East Vein, but so far with no success. They have never found any sign of cross veins which might strike over into the Tiger Extension ground and they have never recognized on their ground any extension of the Ford vein. The St. Anthony Company cannot consider working below the 900' level because of the heavy and increasing flow of water at depth, and the lead-zinc sulphide ore which they are now mining there only barely pays its cost due to the bonus prices which the Government allows for those metals. According to reliable reports the St. Anthony Company may close down at any moment and is quite certain to do so as soon as the bonus payments are discontinued.

The officials of the St. Anthony Company have not the slightest reason to believe that the Tiger Extension Mine has any value and therefore would not consider any lease or purchase of this property although they would be only too glad to take over any mine in this vicinity which held a promise of being worked with profit.

Ed Holderness (whom I saw before visiting the mine) told me that the most favorable opinion on the Tiger Extension that he had ever expressed was to the effect that the Collins Vein might dip over into their ground at depth. He did not know how far the present workings were from the line, but thought that they might be about 500' away. However, he said that since he had learned of the very heavy flow of water in the St. Anthony 900' level he realized that any work at greater depth was out of the question and could not feel that the Tiger Extension had any value.

Similar opinions were expressed by William Ward except that after looking over the maps he realized that the workings on the Collins Vein were more nearly 1000' than 500' away from the Tiger Extension Ground.

CONCLUSION:

Abundant evidence, which I believe to be absolutely reliable, has convinced me that there is absolutely no truth in the suspicion that the St. Anthony Company are mining or ever have mined any ore in the Tiger Extension Company ground or anywhere near their line. The St. Anthony Company plan no further development either in depth or further to the north on the Collins Vein, where the pay ore shoot has a length of only 350'. At present they are extremely short of men to operate the better portions of their own mine and their margin of profit is so narrow as to make it very likely that they will shut down or greatly curtail their operations at any time. For all these reasons there is not the remotest chance that the St. Anthony Company would be interested in purchasing or leasing the Ford Mine at present, nor at any future time unless good ore should be found or strongly indicated on that property, which,--in my carefully considered opinion,--does not justify any further exploration or development work by its owners or anyone else.

The possibility of turning the Ford Mine over to some local leasers was discussed with Ward since it seemed to me that this offered the one and only procedure by which the present stockholders of the Tiger Extension Company might hope to get even a small return on their investment; but competent leasers are hard to obtain at present, even where the showings of ore are attractive, and,--in view of the lack of such showings on the Ford property,--the chance of being able to carry thru such a program seems to be extremely slight.

None the less and as a last resort I should advise you to:--

(1) Try to make a deal with the Reconstruction Finance Company to revise their claims so that the equipment would be released from any lien which they may hold and to agree that the royalty on any future shipments of ore should be equally divided between your Company and the Reconstruction Finance Company.

(2) To make every effort thru Ward, who is well acquainted with the Mine and with the local miners, to find some leasers who would take over and attempt to develop and operate the mine on the usual basis of a 10% royalty. There is always a possibility,--although in this instance it seems very remote,--that leasers, following up such showings of ore as they may be able to find, will improve the present showing and eventually be able to produce more ore than can logically be anticipated.

In any event, I regretfully, but strongly recommend that no further money should be spent for development or mining by you or your associates and should it prove impossible to obtain a satisfactory arrangement with the R. F. C. or to obtain any leasers to take over the workings, I can only suggest that the Company be liquidated or allowed to die in a manner which will not involve any further risk of throwing good money after bad.

Yours very truly,

S.h.C.

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