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

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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.

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G. M. Butler
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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:


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.

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.—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.

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.
The mapped area which forms a part of the Old Hat mining district is almost entirely in the W. 1/2 Sec. 26 and in the E. 1/2 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 "blow-outs" 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, palo-verde, 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 intermittent water-courses 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 1 1/4 or 1 1/2 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, $\text{Ab}_{70}\text{An}_{30}$, which constitutes about 28 per cent of the rock. Quartz forms about 28 per
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 33 1/3 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 \( \text{Ab}_{57}\text{An}_{43} \). 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

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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.