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TUNGSTEN DEPOSITS IN THE BORIANA DISTRICT AND THE AQUARIUS RANGE MOHAVE COUNTY, ARIZONA

BY

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By S. W. Hobbs

ABSTRACT

Tungsten-bearing quartz veins associated with granitic rocks occur in the Boriana district and the Aquarius Range of Arizona.

The Boriana mine has long been the chief producer of tungsten in Arizona and was at one time one of the largest producers in the United States. The mine is in an elongate belt of phyllite, striking northeastward and nearly vertical, about half a mile wide, and bordered on both sides by intrusive granite. The ore minerals scheelite, wolframite, and chalcopyrite occur in narrow quartz veins, which form composite lodes that follow the foliation of the phyllite. Two such lodes, separated by about 125 feet of phyllite, were being mined in 1943. The vein zones are continuous and the structure is simple. Minor faulting has offset the veins, and the latest movement occurred since the formation of the ore. The veins apparently originate in a small granite stock in the center of the belt of phyllite. A broad ore shoot, which contains the best ore in the mine, plunges gently toward the granite contact. Measured ore in the mine in December 1943 amounted to about 2,400 tons containing 1 to 1½ percent WO_3 and indicated ore amounted to 9,700 tons of a similar grade. It is estimated that about 44,000 tons of ore with an average content of about 1 percent WO_3 lies below the lowest level and between the present workings and the granite contact.

The chief deposit in the Aquarius Range is at the Williams mine. It consists of a quartz vein a foot in average width, associated with an aplite dike which cuts a homogeneous mass of granite. The vein, striking nearly east-west and dipping 20° to 30° N., has a quartz gangue enclosing pyrite, chalcopyrite, and a manganese-rich wolframite or huebnerite. The vein has been explored for 640 feet along its strike and for 320 feet down the dip. What may be the same vein is exposed 500 feet west of the workings. Minor east-west faulting has chopped the flat vein into several segments, each one downthrown on the north relatively to its neighbor. The ore is very pockety, and no structural control has been recognized that would serve as a guide in looking for pockets of ore. About 10,700 tons of vein material is developed, and it is inferred from geologic evidence that the mine contains, in all, about 98,000 tons of vein material; the average grade of this material cannot, however, be estimated at present.

Other small prospects have been developed within a few miles of the Williams mine, on veins that are similar to the Williams vein in composition, though their dips range from low to vertical. All of these prospects are small and are in ore of relatively low grade.

INTRODUCTION

The Boriana and Aquarius Range tungsten deposits, in Mohave County, Ariz., represent but two of several occurrences of tungsten minerals in the State. The Boriana mine in the Hualpai Mountains has long been the principal tungsten producer in the State and was at one time one of the largest producers in the country. The Aquarius Range deposits, on the other hand, have produced but a relatively small amount of tungsten. In both localities the tungsten occurs in quartz veins, the wall rock of which is phyllite at the Boriana mine and granite and aplite in the Aquarius Range.

The tungsten minerals in the Boriana mine are scheelite and wolframite; the tungsten of the Aquarius Range occurs in huebnerite or a wolframite near the huebnerite end of the series. As the two localities are in different districts and exemplify different modes of occurrence, they will be discussed separately.

BORIANA MINE

Location and history

The Boriana mine is in the central part of the Hualpai Mountains, near the crest, about 20 miles airline southeast of the town of Kingman, Ariz. (fig. 27 and pl. 42). Kingman is connected with the mine by 43 miles of road, which follows the main line of the Atchison, Topeka, & Santa Fe Railroad to the town of Yucca, from which it continues eastward for a distance of 18 miles to the property. Yucca is the nearest railway shipping point, and the road between Yucca and the mine, though rough, can be traveled in all weathers.

At what time tungsten was discovered in the Boriana district is not accurately known. The discovery was made before 1915, for in that year the property was acquired by the Yucca Tungsten Co., a subsidiary of the York Metal & Alloys Co. of York, Pa. The veins were worked from 1915 until the decline of prices in 1919 made production unprofitable, and in 1918 the mine was the largest producer in Arizona.

In 1929, after ten years of nonproductivity, the mine was taken over by the Boriana Mining Co., a subsidiary of the Stoody Co. of Whittier, Calif. In 1929-30 a 1,500-foot haulage tunnel was driven and other development work done, including the construction of a mill. Production was maintained by the Boriana Mining Co. until 1937, when the property was leased by the Molybdenum Corporation of America. In November 1937 the mill burned down, and the mine was nonproductive through 1938 and the first nine months of 1939. After the building, in 1938, of a new gravity flotation mill of 150 tons daily capacity, the mine again became active, and it produced until October 1943 when it was temporarily closed down.1, 2/

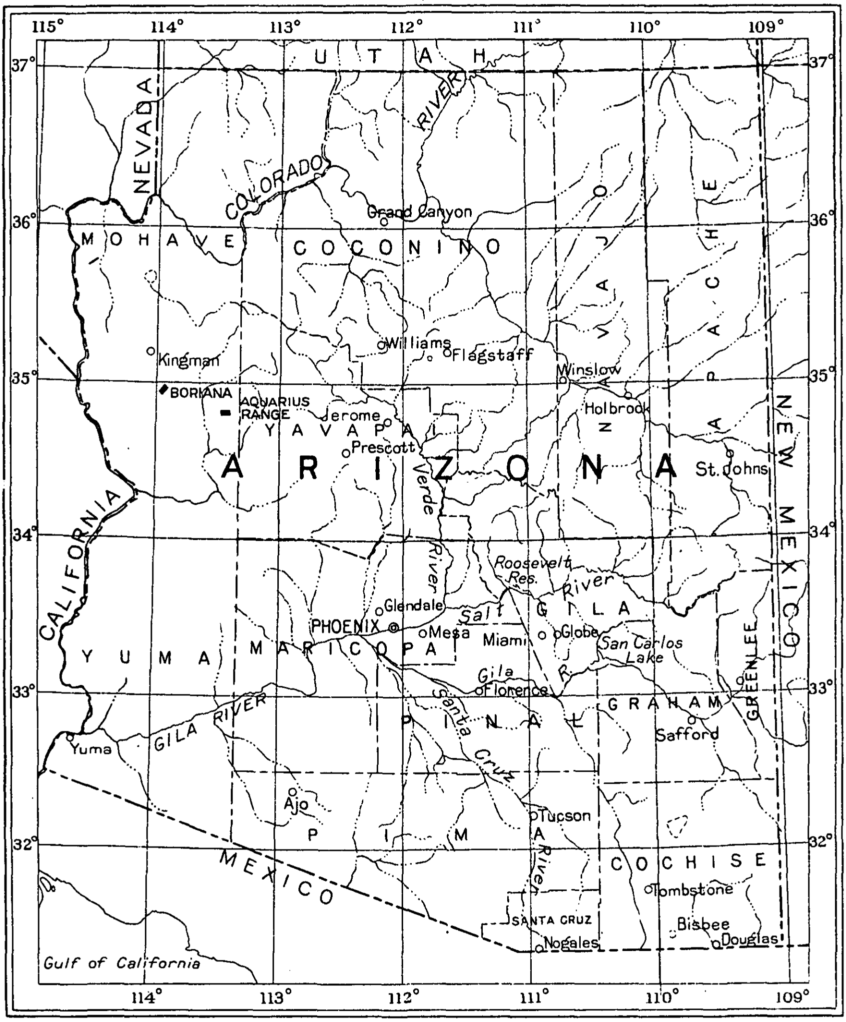


Figure 27.--Index map of Arizona showing location of the Boriana and Aquarius Range tungsten deposits.

Since the beginning of active production, about 1915, up to 1943, the district has produced approximately 108,000 units of WO_3,3/ most of it within the last ten years.

1/ Mining World, vol. 3, No. 4, 1941. Gives the flow sheet of the mill and discusses the mining conditions.

2/ All information on production and development is from Mineral Resources and Minerals Yearbook.

3/ Oral communications from Mr. H. L. Veatch and Mr. Al Greslin.

Previous work

Little detailed information regarding the geology of the district has hitherto been available, but several publications on general reconnaissance in the region touch upon features of the local geology. Lee,4/ Schrader,5/ Darton,6/ Bastin,7/ and Hess 8/ all mention mineral deposits in closely adjacent areas or discuss the general geology of the Hualpai Mountains. Hewett and others 9/ briefly discuss the Boriana mine in a bulletin on the mineral resources of the region around Boulder Dam, and Wilson 10/ has a section on the mine in his report on the tungsten deposits of Arizona.

The principal field work on which the present report is based was done between June 16 and August 9, 1941. The writer, assisted by Mr. M. R. Klepper, mapped the topography and geology of the district on a scale of 400 feet to the inch, and mapped the geology in the mine workings in greater detail on a scale of 40 feet to the inch. Transit surveys of the mine were made available by the company. The writer is greatly indebted to Mr. H. L. Veatch, manager of the Boriana mine, and to Mr. Merle Otto, engineer at the mine, for their cooperation and help in the work. Mr. Otto spent much time as guide in the mine workings. Mr. D. G. Wyant of the Geological Survey spent nine days in July 1943 mapping the new work on the 700 and 800 levels of the mine, and the writer revisited the property for four days in December 1943.

Topography and general setting

The Hualpai Mountains are a north-trending range about 35 miles long, having a general altitude of about 7,000 feet, and a maximum elevation of 8,200 on Hualpai Peak near the north end. The plain joins the western foot of the range at an elevation of about 4,000 feet, giving an average relief of about 3,000 feet. The mountains are thoroughly dissected, and several of the canyons cut deeply into the core of the range. One of these canyons drains southwestward, obliquely to the trend of the range, and emerges onto the alluvial plain due east of the town of Yucca.

4/ Lee, W. T., Geologic reconnaissance of a part of Western Arizona: U. S. Geol. Survey Bull. 352, pp. 24-25, 1908.

5/ Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains and Grand Wash Cliffs, Mohave County, Ariz.: U. S. Geol. Survey Bull. 397, pp. 20-21, 1909.

6/ Darton, N. H., and others, Guidebook of the Western United States, Part C. The Santa Fe route: U. S. Geol. Survey Bull. 613, pp. 137-142, 1916. Mentions general features of the region. No specific work on rocks.

7/ Bastin, E. S., Origin of certain rich silver ores near Chloride and Kingman, Ariz.: U. S. Geol. Survey Bull. 750, pp. 17-39, 1924. Discusses rocks related to those in the Hualpai Mountains near Boriana.

8/ Hess, F. L., Molybdenum deposits, a short review: U. S. Geol. Survey Bull. 761, pp. 13-14, 1924.

9/ Hewett, D. F., Callaghan, Eugene, Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T., Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 89, 1936.

10/ Wilson, E. D., Tungsten deposits of Arizona: Arizona Bur. Mines Bull. 148, Geol. ser. 14 (Arizona Univ. Bull. vol. 12, no. 2), pp. 11-14 (Boriana mine), pp. 16-18 (Aquarius region), 1941.

The Boriana mine (pl. 43) is near the head of this canyon, within a quarter of a mile of the divide. The property and workings of the mine cross the divide and extend into the headwaters of Cane Springs Creek, a tributary of the Big Sandy River, on the east side of the Hualpai Mountains. The relief in the immediate vicinity of the mine is over 1,000 feet, and the slopes are steep. Outcrops are good on the whole, but the most abundant country rock, which is phyllite with a well-developed cleavage and vertical dip, is highly subject to creep; much of the phyllite near the surface is loosened and shows the effect of drag, and large parts of the slopes are littered with slabs and flakes of the rock.

Typical desert vegetation prevails in this region on the lower slopes and foothills, but scrub pines and scattered groves of large yellow pines grow near the top of the range. Although the northeastern slopes of some of the hills are covered with dense brush, the country is for the most part open and easily accessible.

Geology

The principal rocks of the Boriana district are two—phyllitic schist and intrusive granite. The phyllite is part of a narrow elongate mass of rock, averaging half a mile wide and extending for several miles northeastward parallel to its foliation, which is enclosed in the granite as a large roof pendant. Numerous quartz veins, mostly parallel to the foliation, cut the phyllite, but only those near the center of the belt contain tungsten in commercial quantity. Many faults of small displacement are visible underground, but few of these can be detected on the surface.

Phyllite.--The phyllite belt of the Boriana district extends for many miles northeastward, parallel to its foliation, going clear across the range. It varies in width from a fraction of a mile to a mile and a half, and is bordered by the granite on both sides for most of its length. The position and extent of the canyon in which Boriana is located is determined principally by differential erosion of the phyllite, which is less resistant than the granite. In the vicinity of the Boriana mine the phyllite belt strikes N. 30° to 40° E. and has an average width of about half a mile.

The predominant rock of the belt is a fine-grained well-foliated to blocky phyllite, composed essentially of sericite, chlorite, and quartz. The foliation is most conspicuous near the center of the belt, where the parting planes are marked by especially abundant chlorite and sericite, so that the rock splits easily into thin smooth plates. Near the intrusive granite contacts on the sides of the phyllite belt the rock is coarser-grained, for there muscovite and biotite largely supersede the sericite and chlorite to form a true schist. Certain layers in the phyllite are more sandy than others and mark the original bedding of the rock, which is essentially parallel to the foliation. Most of the phyllite is gray or dark gray-green, but the sandy layers may be light yellow and the chlorite-rich layers dark green.

Granite.--The largest igneous rock body in the Hualpai Mountains is a medium- to coarse-grained biotite granite, locally porphyritic and composed essentially of feldspar, quartz, and biotite. This granite intrudes the phyllite, which apparently forms a very large roof pendant. The contacts are mostly parallel to the strike of the phyllite, but locally the granite cuts across the strike of the foliation, in some places abruptly but more commonly in a series of alternating tongues of schist and granite. Much of the granite has a gneissic foliation parallel to the schistosity of the phyllite. North of the ridge crest and only a stone's throw north of the end line of the Boriana claims, a tongue or embayment of granitic rock extends from the main body of granite on the west into the middle of the phyllite belt. This body, which may be called the northern body, consists of a medium-grained rock that is composed essentially of microcline, plagioclase, gray glassy quartz, and biotite. It appears to be a little more sodic than the main granite mass, but the difference is not great enough to show that it is a distinct intrusion. This northern granite body is also exposed at the northeast end of the 700-foot level where it intrudes the phyllite as a series of tongues parallel to the foliation. Faulting has complicated the relationships as exposed underground.

The main body of granite is fairly uniform in composition and texture through large areas, but near the contact of the main body with the phyllite the rock shows considerable variation, probably caused by assimilation of phyllite, which generally increases the proportion of dark minerals and thus darkens the rock. The granite encloses numerous zenoliths of phyllite, many of which have been much recrystallized and drawn out into dark streaks. The granite embayment north of the divide, on the other hand, has lost part of its dark minerals, together with some feldspar, having been partly converted to a greisen, doubtless by fumarolic action. This granite, therefore, may represent a cupola in which the volatile constituents of the cooling magma were concentrated, a condition that would have a direct bearing on the origin of the Boriana veins, which appear to stem from this mass.

Aplite.--Aplite dikes cut both phyllite and granite near the contact, and they are especially prominent in the northern embayment of granite. One large dike which extends from this body into the phyllite is typical of most of the aplite. It is fine grained, with an aplitic texture, and consisted originally of quartz and feldspar, but it now is mostly altered to a greisen composed of quartz and muscovite.

Structure

The structure of the Boriana district is relatively simple. The elongation of the phyllite belt is parallel to the foliation, whose general strike ranges from about N. 30° E. in the southwestern part of the area to about N. 40° E. in the northeastern part, and whose general dip is 75° to 90° SE. There are minor deviations outside these limits, but on the whole the attitude of the phyllite is remarkably uniform. The apparent dip, however, of the phyllite near the surface is in many places much lower than the true dip and even locally in an opposite direction from the true dip, for it is the result of drag, whose effect is particularly noticeable in the steep-sided canyon immediately west of and parallel to the main adit.

Besides the conspicuous primary foliation, the phyllite has a less well developed secondary foliation diverging from it at an angle of about 35°. This secondary foliation has resulted from an actual bending of the primary foliation into a new plane by a shearing force. The primary foliation may be seen in places to bend sharply 35° northwestward from its original direction and then bend sharply back to the original direction. Little if any folding is involved. The segments bent out of their original trend vary widely in size, some being merely small wrinkles, others several inches or even many feet in extent. The largest offset was observed on the first prominent knoll north of the divide (pl. 43), where a vein follows the secondary trend for nearly 100 feet along its course.

Faults are numerous in the district, but many of them are small. A few may have displacements of over 100 feet. Most of the faults fall into three major groups. Those of the first group follow the foliation of the phyllite and are consequently parallel to the veins. They are represented only by gouge zones of varying thickness, which afford no measure of their displacement. The especially marked foliation along the quartz vein of the Boriana deposit may be due in part to intense shearing along these strike faults. The faults of the second group have the same strike as the foliation but dip 30° to 55° SE. Several of these faults show reverse movement, and at one place, on the 700 mine level, the east Boriana vein has been offset 25 to 30 feet by one of these faults (pl. 44, sec. C-C'). The faults of the third group strike across the veins at various angles but rarely offset them more than a foot or two, although a transverse fault zone in the northeast extension of the west vein on the 700 level has broken the vein into a number of small segments, the aggregate offset of which is considerably more than that along other faults of this group. One of the strongest faults intersects the veins at the short crosscut 300 feet from the northeast end of the 700 level. The evidence suggests a movement of the northeast side about 130 feet to the north so as to bring the east vein system opposite the west vein system.

The relative ages of the faults cannot be fully determined. However, since the veins are offset and vein material is dragged along the fault planes, the latest movement on them is obviously later than the mineralization.

Ore deposits

Most of the minable tungsten ore in the Boriana district is in the Boriana mine, the one main exception being a deposit worked in some small-scale leasing operations at the north end of the Boriana veins, on property owned in part by the Molybdenum Corporation of America.

The tungsten minerals of the Boriana mine are wolframite and scheelite, contained in quartz veins that follow the foliation of the phyllite. These veins also contain chalcopyrite, a few other sulfides, and fluorite. Quartz veins are numerous throughout the phyllite belt, but only those within a zone about 125 feet wide in the west-central part of the belt contain significant quantities of tungsten. The tungsten mineralization is limited, moreover, to that portion of the zone northeast of the main portal of the Boriana mine, all the veins in the southwestern part of the area mapped being essentially barren. Plate 43 shows the actual outcrops of the larger veins. Many veins too small to map were seen, and many others are undoubtedly concealed by surface debris. The relatively continuous exposure of the ore-bearing veins north of the mine portal is due to their being uncovered in open cuts and surface workings.

The mine workings follow two groups of small veins, known respectively as the west veins and the east veins, which are separated by 90 to 135 feet of phyllite. This intervening phyllite contains small subsidiary veins, in which there is a little tungsten.

The Boriana mine is developed by means of nine levels, numbered 0, 100, 200, 300, 400, 500, 650, 700, and 800, and three sublevels numbered 400A, 400B, and 400C; it comprises in all more than 15,500 feet of level workings (pl. 44). Levels 0, 100, 200, 300, and 500 open directly on to the hillside, but the levels above 300 are not interconnected. Level No. 500 is the main haulage level, its portal being near the mill. It is connected with the 650, 700, and 800 levels by an underground shaft. In 1943, most of the ore above the 700 level had been mined, and preparations have been made to stope the ore between the 700 and 800 levels.

Large parts of the older workings are caved and inaccessible. The same characteristics of the phyllite that cause it to creep on the hillsides make the mine openings difficult to maintain; because of rising floors and the crushing in of the sides, the haulageways must be enlarged and retimbered at regular intervals. Plate 44 is a map of the mine workings with cross sections showing the veins, and plate 45 is a longitudinal projection of the workings and stopes.

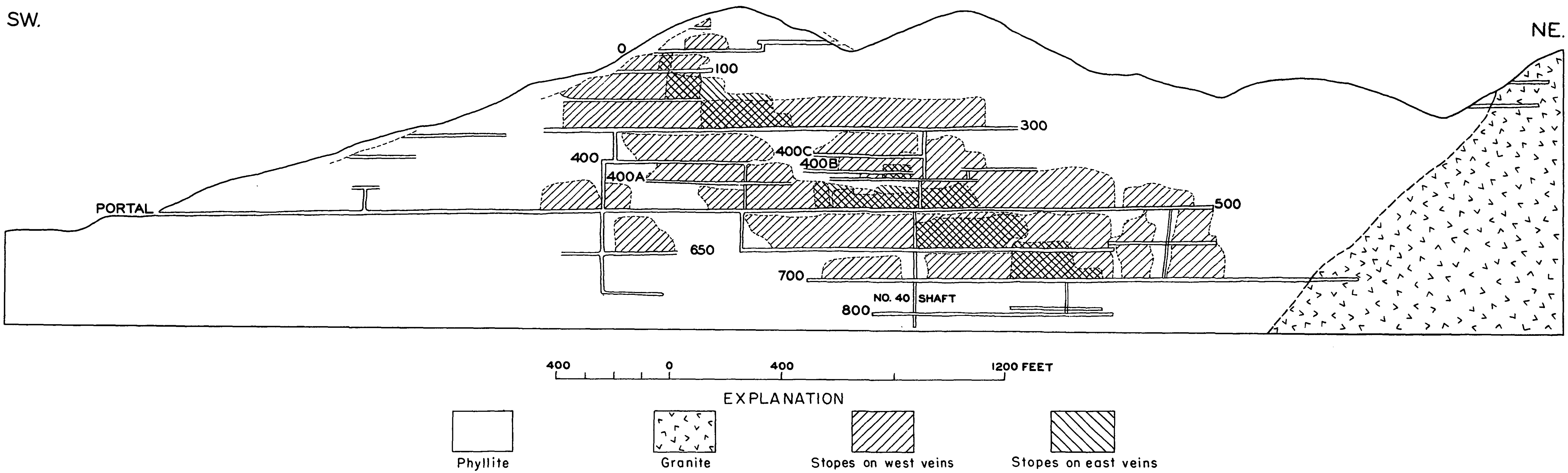
Mineralogy

The principal gangue mineral of the veins is a coarse-grained glassy gray quartz, which is accompanied by some fluorite, a very little calcite, and small stringers of late microcline. Wolframite, scheelite, and chalcopyrite are the main ore minerals, but some pyrite, arsenopyrite, and molybdenite occur locally. Some beryl was found in the veins on the 700 level and also in the veins which cut the granite at the surface. A small amount of gold and silver is present, but in what form is not known. The ore minerals are scattered through the veins in small pockets or bunches, so closely spaced in the better part of the mine as to make all the vein rock ore. The ore minerals are not associated according to any constant rule: some wolframite is accompanied by masses of sulfide, and some by scheelite without any sulfide whatever. Frequently the scheelite forms pockets of crystals in quartz completely barren of other minerals.

Fluorite of a rich purple color is the second most abundant gangue mineral, but even where it is most abundant it makes up scarcely 5 percent of the vein. It occurs in small lenses and pods in the quartz veins. Some short veins of pure fluorite, about 1 inch thick, have been noted at the borders of larger quartz veins, or even in the phyllite wall rock.

Chalcopyrite, the most abundant of the metallic minerals, forms irregular masses and bunches in the quartz veins. Some sections of the narrow 1- to 2-inch veins consist entirely of this sulfide.

The tungsten minerals—wolframite and scheelite—occur in different proportions in different parts of the mine, but the average ratio is about 1:1. The wolframite forms black, shiny, elongate prisms and irregular masses from $\frac{1}{4}$ inch to 2 inches or more in length. These may occur singly in the quartz, or in clusters with other ore minerals. Frequently the wolframite is coated and seamed with scheelite, by which it is evidently being replaced.



LONGITUDINAL PROJECTION OF BORIANA MINE WORKINGS

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The scheelite, when alone in the quartz, occurs as well-formed crystals up to 2 inches long, commonly fractured and cemented with later quartz or microcline. Much of the scheelite associated with other minerals has partly replaced wolframite. The scheelite has an intense blue-white fluorescence and is virtually free from molybdenum.

The other sulfides are very scarce and are found mostly in or near the veins and greisenized granite at the north end of the principal vein zone. Small masses of molybdenite occur in the greisenized granite, but little if any of the mineral appears to be associated with scheelite.

The sequence of mineralization in the ore is roughly: (1) wolframite, (2) scheelite and most of the sulfide, and (3) some late sulfide. Some chalcopyrite occurs in small veinlets of quartz and microcline which cut both scheelite and wolframite. There has been a reopening of the veins and introduction of new quartz, which apparently continued to form for a long time. The proportion of scheelite to wolframite tends to increase northward as the granite stock is approached, and the small veins in the granite contain little wolframite. This relation suggests a zoning outward from the granite.

Veins

The veins of the Boriana mine form composite lodes from 4 to 15 feet wide, each made up of two or more parallel quartz veins and stringers, separated by phyllite. Of the three or four such lodes that occur in the zone of mineralization, which is 150 to 200 feet wide, two are especially prominent. These, which are known respectively as the west veins and the east veins, have proved to be the richest and most persistent. The west vein zone consists, for most of its length, of two veins, from 4 to 10 inches thick, one on each side of the drift, with several minor stringers between. The east vein zone contains one major vein, 10 or 12 inches in average thickness, together with several stringers. Plate 46 shows the distribution of veins on the 700 and 800 levels.

The veins are continuous for hundreds of feet, but they characteristically pinch and swell. Some pinch out completely, to be replaced by others en echelon—one vein beginning nearly opposite the end of another and in a slightly different but parallel plane. The vein zone is very continuous underground, and it can be traced for long distances on the surface where the veins and the silicified phyllite adjacent to them locally stand out as little ridges.

Many of the veins have sharp contacts with the wall rock and are bordered by thin films of sericite, so that the vein material is readily broken from the phyllite. Some of the veins, however, merge laterally with the country rock through a zone of silicification, and such transition occurs also along the strike of some veins, which die out in this manner.

At several places in the northern end of the 700 level within 400 feet of the main granite contact silicification of the phyllite has been accompanied by recrystallization of the sericite to form coarse flakes of muscovite, and the resulting rock is similar to greisen. The alteration may indicate that granite is close below.

The veins at the northeast end of the 700 level pass from the phyllite into granite and are reported to thin down and feather out within a few hundred feet. A cement bulkhead, installed to control an excessive water flow from this part of the mine, prevented an examination by the writer of the veins in the granite. The reported behavior of the veins in the granite underground corresponds to that observed on the surface at the north granite body.

Quartz veins structurally and mineralogically similar to those in the Boriana mine occur near the granite contact at the northeast end of the vein zone. At this place the foliation of the phyllite meets the granite contact at an angle of 60°, and quartz veins 2 to 8 inches wide in the phyllite have been followed, in drifts, directly into the granite across a sharp contact. At the contact the strike of the veins changes abruptly from N. 50° or 60° E. in the phyllite to N. 30° to 40° E. in the granite. Here as in the Boriana workings there are two principal veins, 160 feet apart, together with several minor veins. The veins are solid and fresh in the phyllite, but in the granite they are much oxidized and broken, with a conspicuous gouge on one or the other of the walls. The proportion of scheelite to wolframite is much higher than at the Boriana mine. All the sulfides have been oxidized and destroyed. Some of the veins have been followed into the granite for 200 feet, but they are very narrow, irregular, and discontinuous. The granite adjacent to them has been highly greisenized.

Numerous minor cross-faults offset the veins, and considerable movement parallel to the walls has taken place both within and without the veins. Crushing and recementation indicate a reopening of some veins before the end of mineralization, and zones of soft, crushed, uncemented material consisting of sulfides and wolframite give evidence of movement after the latest mineralization. The east vein, on the 700 level, is displaced about 25 feet by a conspicuous reverse fault dipping 45° E. Near the north end of the 700 level west the veins are cut by numerous faults, at various angles to the veins, which make the mining of the ore more difficult.

A crosscut at the north end of the 700 level did not intersect the east vein system although it was presumably driven far enough to do so if the veins were in their proper position. This may indicate that the vein has pinched out or that all of the veins at the north end of the mine have been shifted to the west so that the east vein zone becomes approximately continuous with the west vein zone. Actual relations are obscured.

Origin

The scheelite- and wolframite-bearing quartz veins of the Boriana mine are believed to have been formed by deposition from mineralizing solutions that followed fractures along certain joint planes in the granite and certain foliation planes in the phyllite. The fractures were presumably formed by shearing movements which may have produced some open spaces. The phyllite, however, is so weak that any such openings, unless they were extremely minute or held open by hydrostatic pressure, would probably have been closed immediately by the weight of the rock.

The source of the mineralizing solutions cannot be identified with certainty, but all the evidence points to the granite embayment at the north end of the vein zone—or more strictly to a deep-lying mass of magma that crystallized later than the granite now exposed—as the immediate source. The veins trend directly toward this mass, both on the surface and underground. Although none can be traced continuously on the surface from the Boriana mine to the granite, some quartz veins in phyllite adjacent to the granite mass can be traced into the granite across a sharp contact, and veins on the 700 level of the mine can be followed into a granite which is undoubtedly a part of the same body. These scheelite-bearing veins in the granite are nearly on strike with the Boriana veins and show similar features, but once they enter the granite they narrow and disappear within a few hundred feet. Further evidence of a genetic relation between the scheelite-bearing veins and the granite is given by minute grains of scheelite in the granite itself, by zones of scheelite-bearing greisen in the granite, and by the suggestion of zoning outward from the granite in the Boriana veins.

These and other facts already stated indicate that the tongue of granite at the north end of the vein zone forms a small cupola in which the volatile components of a cooling magma were concentrated and from which the tungsten-bearing veins stemmed.

Localization of tungsten ore

It has already been noted that all of the important tungsten mineralization took place north of the main portal of the Boriana mine. As mining has progressed it has also become apparent that the tungsten was not evenly distributed throughout the vein zone but concentrated in a broad rather ill-defined inner part of that zone. Ore in the economic sense is further restricted to a few ore shoots. Plate 45 shows a longitudinal projection of the east and west workings of the Boriana mine, and the pattern of the stoped area outlines an ore shoot or zone of mineralization, which plunges to the northeast at a rather low angle and seems to flatten slightly in that direction. A more definite ore shoot was outlined by the old stopes, from which the ore was mined when the cut-off for millheads was placed at 2 percent WO_3, and, although lower-grade material was being mined in 1943, operations were still confined to the vicinity of the shoot.

The cause of the localization is not clear, for strong quartz veins continue both north and south of the shoot. The phyllite adjacent to the richer parts of the veins is softer than elsewhere, sericite being there especially abundant in the wall rocks; where the phyllite is hard and blocky, the veins are relatively narrow and generally lean. The localization of the ore shoots is possibly related to the strains developed in the phyllite at the time when the secondary foliation was formed; rock weakened by these strains might have opened up enough along certain favored zones to allow the introduction of the tungsten-bearing solutions. The shoots in the east veins are parallel to those in the west veins, but seem to be narrower.

Production and grade of ore

Detailed statistics on the grade and tonnage of the ore that has been removed from the mine are not available. It is known, however, that between 1915 and the summer of 1943 the mine produced about 108,000 units of WO_3. Prior to 1937, when the Molybdenum Corporation took over the property, no part of a vein was mined unless it contained at least 2 percent WO_3 and was at least 10 inches wide, this limitation being necessary in order to avoid excessive dilution of the ore with barren phyllite. In later years, lower-grade ore was used; the cut-off was placed at about 1 to 1½ percent WO_3, although the mill heads were considerably lower because of contamination with barren phyllite. The ore also contained about 1 to 1½ percent of copper.

The veins that cross the phyllite-granite contact at the northeast end of the zone were being worked by a number of lessees from small adits and shallow trenches. The ore was hand-sorted and concentrated in a small gravity mill, and a small but rather steady production was maintained. In the fall of 1943 this work was being directed by Dalton Robinette. When this portion of the deposit was first worked, several rich pockets of scheelite were taken from surface exposures at the greisenized border of the aplite dike that cuts the granite and schist on the west side of the granite embayment.

Reserves

To estimate reserves for the Boriana mine is difficult, principally because the ore being mined in 1943 was close to the cut-off value at the then current prices and because the amount of ore actually developed was small. The estimates that follow are based on the assumption that the veins originated in the granite embayment at the northeast end of the deposit and that, for this reason, the effects of mineralization do not extend far northeast of the granite contact. The form of this contact underground greatly affects the volume of ore available. Although the contact where visible at the surface is dipping 75° to 80° SW., the exposures of granite on the 700 level establish a general dip of 45°. All estimates of ore reserves are based on this dip of the contact.

Measurable ore in the mine in October 1943 was contained in a block 335 feet long between the 700 and 800 levels. This block contained 2,400 tons of vein material that averaged 10 inches in width and contained between 1½ and 2 percent WO_3. There was approximately 4,300 tons of indicated ore between the 700 and 800 levels. Another body of ore, partly blocked out, lies in the east veins between the 300 and 400 levels in the same zone as the ore shoot. This block contained about 5,400 tons of ore that is properly classed as indicated since it was opened on two sides only and was of unknown grade.

Estimates as to the amount of inferred ore—meaning ore whose existence appears probable from indirect geologic evidence—were determined mainly by projecting the ore shoot below the 800 level to its intersection with the assumed downward projection of the granite contact. Assuming an average thickness of 10 inches of quartz in the vein, the inferred ore comprises about 32,800 tons in the west veins and 11,200 tons in the east veins. The grade of this ore is unknown, but on the basis of the values in the known part of the shoot it may be estimated at about 1 percent.

The amount of vein material between the ore shoot and the surface is estimated as more than 150,000 tons, but its grade is apparently low. Some tungsten ore has been taken from surface trenches along the vein, but it was too pockety to be mined on a large scale.

TUNGSTEN DEPOSITS IN THE AQUARIUS RANGE

The principal tungsten deposit in the Aquarius Range, Mohave County, Ariz., is at the Williams mine (fig. 28), which is on the east slope of the range near its crest. The mine is reached by a road, 27 miles long, which turns eastward from the Big Sandy River road at Cane Springs, 14 miles north of the town of Wikieup. The nearest store is at Cane Springs. Other deposits, adjoining the Williams mine on the west, are reached by a road extending eastward from Wikieup.

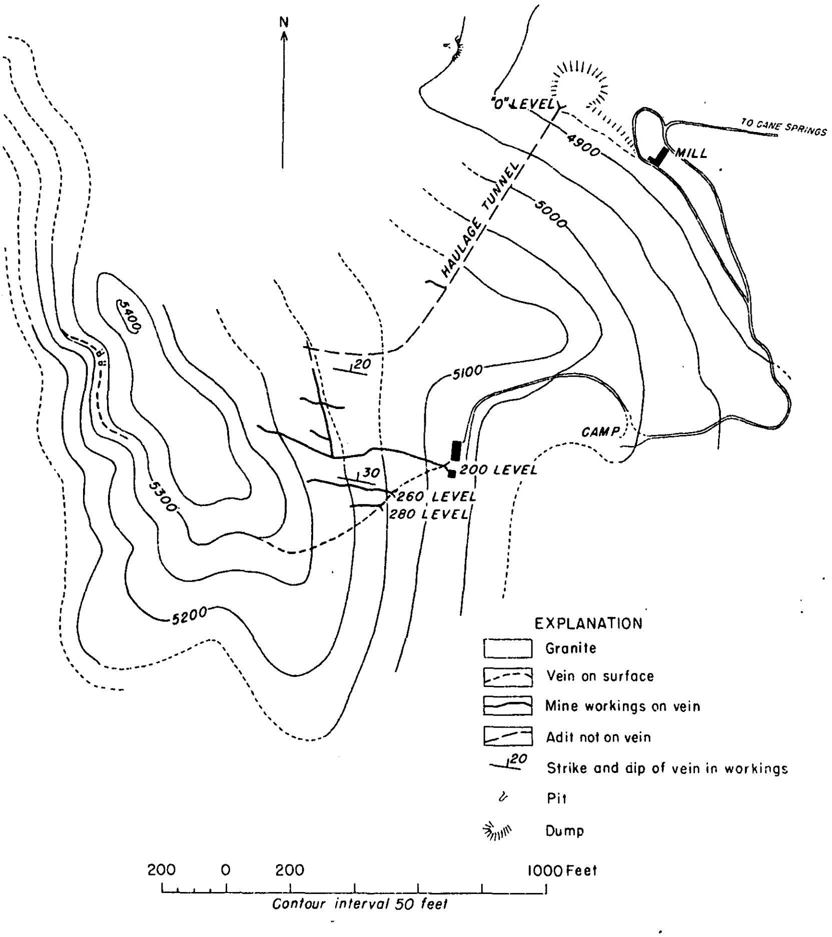


Figure 28.--Map of the Williams tungsten mine, Mohave County, Arizona.

The claims worked in the Williams mine were located by Ed Williams in 1909, and development work has been done on them intermittently since that time. Some ore was taken from the tunnels on the east side of the deposit and from pits and small shafts on the west in 1917-18. The Continental Mining Co. acquired the property in 1940 but has since released its interests. In December 1943 the mine was under lease to Mr. W. S. Bradbury.

Geology

The Aquarius Range is asymmetric in cross-profile, having a precipitous western face and a gentle back slope to the east. It is partly capped with flat-lying lavas. The Williams mine is near a shallow saddle in the crest, from which the lavas have been completely removed, so that the underlying granite is exposed, but higher peaks to the north and the south are still capped with lava. Some complexities in the relations of the lavas to the granite are probably caused by faulting.

The granite, which is the country rock of the ore deposits, is coarse-grained and fairly uniform in character, being composed predominantly of orthoclase and quartz with smaller amounts of plagioclase, biotite, and hornblende. It is cut by irregular dikes of pegmatite and aplite and by quartz veins that are usually associated with these dikes. There are apparently two main systems of dikes and veins in the district. One system strikes east-west and dips gently to the north; the other strikes parallel to the first but dips very steeply to the north. The Williams mine is located on a vein, dipping 18° to 30° N., which consists mainly of quartz and which contains the tungsten mineral huebnerite. This vein is partly within and partly adjacent to an aplite dike of easterly trend, with which pegmatite is associated in several places.

Mineralogy

The vein minerals consist of the quartz gangue, huebnerite (manganese tungstate)—or wolframite (iron-manganese tungstate) near the huebnerite end of the series—and several sulfides, including pyrite and chalcopyrite. No scheelite was found in the veins. Although the quartz vein extends throughout the Williams mine and huebnerite may be found scattered through the whole vein, the tungsten minerals, together with the sulfides, tend to be localized in pockets or zones in a way that is not explained by any obvious structural control. The results, shown in plate 47, of some sampling of the vein done by the Continental Mining Co. indicate the rather erratic distribution of the tungsten.

The huebnerite or wolframite occurs chiefly as bladed crystals enclosed in the quartz, some of them nearly 3 inches long, but in the Williams mine a part of it occurs in a 1- to 2-inch mica seam on the border of the vein. Where sulfides also are present, they tend to occupy the center of the vein and the tungsten mineral is localized along the borders.

Williams mine

Extent and structure of the vein

The mine property, consisting of 10 claims, lies on the southward-sloping nose of a granite hill, across which the ore-bearing vein appears to extend. The hill crest rises about 500 feet above the lowest workings, but the position of the vein gives a maximum vertical head of about 400 feet on the vein proper above the lowest level (fig. 28).

The workings consist of about 3,150 feet of tunnels, drifts, and winzes, and some old stopes. The old workings comprise three levels, which drift on the vein from its outcrop on the eastern slope, together with stopes and a winze from the lowest or main level. The Continental Mining Co. drove a development and haulage tunnel from the north to intersect the vein and connect with the winze that follows the vein down from the main drift. The haulage tunnel has been named the "O" and the three upper levels the 200-, 260-, and 280-foot levels. The company also did a little drifting on levels branching from the winze, and it did some stoping from these new levels as well as from the 200.

The position of the vein and of the underground workings is shown in figure 28. Open cuts and pits expose the vein on the eastern hillslope between the entrances to the 200 and 280 levels, and for about 100 feet uphill above the upper level. This part of the vein strikes east and dips 25° to 30° N. The upper slopes of the hill are largely covered with waste, but some outcrops of quartz stringers in granite and aplite may represent the ore zone crossing the hill.

The west side of the hill consists of steep cliffs and bluffs, and at the base of the main bluff, 5,275 feet above sea level, there are some old cuts and workings on a vein very similar to the one exposed in the workings to the east. The vein on the west slope strikes N. 55° W. and dips 36° NE., and is thus considerably out of alinement with the east vein, but its surface trend, its gentle dips, and its general character suggest that it may nevertheless be the same vein or belong to the same vein zone.

Apparently there is only one vein in the mine, for, although faults separate several disconnected vein segments, it seems likely that all of them are parts of the same vein. The underground workings afford a clearer picture than the surface exposures of the structural details. Plate 47 shows the position of the vein in the tunnels and winzes. The general strike of the vein in the tunnels is about N. 80° W., but there are many irregularities in its trend. The dip of the vein decreases from 30° in the 260 and 200 levels to 18° or 20° in the lower parts of the winze, where the vein is cut off by a fault. Many small faults are indicated by offsets on the vein and by conspicuous layers of gouge. Most of the faults fall into two main sets, both of which have about the same easterly strike as the veins; the faults of one set, however, stand nearly vertical or dip steeply to the north, whereas those of the other set dip gently to the north.

The steep faults, with a few possible exceptions to be discussed later, are normal and of small displacement, and their principal effect is to break the vein into a series of steps descending to the north. This effect is best shown in the cross section of the winze (pl. 47), but in several instances what is there shown as a single fault is in fact a narrow fault zone composed of several closely spaced breaks. At the west end of the 200 level the complex of vertical faults has badly disrupted the vein. It is noteworthy that the dip of the steeper faults decreases to the north, where, in the lower end of the winze and on the "O" level, dips of 55° to 64° are common. As the dip of the vein and its attendant low-angle faults also decrease northward, they and the steeper faults may have been tilted together following their formation. Crosscutting relations indicate that the latest movement was a slight overthrusting on the low-angle fractures.

The low-angle faults are marked by gouge zones very nearly parallel to the vein; these are mostly in the aplite adjacent to the vein quartz, but in some places they cut the granite or the vein itself. The thickness of the gouge varies widely from place to place but averages about 4 inches. The main low-angle fault was observed in two places to offset steep faults, its hanging wall having moved upward about 4 or 5 feet. The latest movement, on this fault at least, was therefore one of thrusting.

In a few places, the best example being in the crosscut turning off from the "O" level, thrust faults that are steeper than the vein have slightly offset the vein. These faults are probably related to those parallel to the vein, and they may be the result of adjustment to the offsets produced in the vein and aplite by the steep normal faults. After these normal faults had offset the aplite-vein zone—a zone of weakness—later thrusting along this weak zone would tend to displace it on steep overthrusts at the places where it was intersected by the earlier faults.

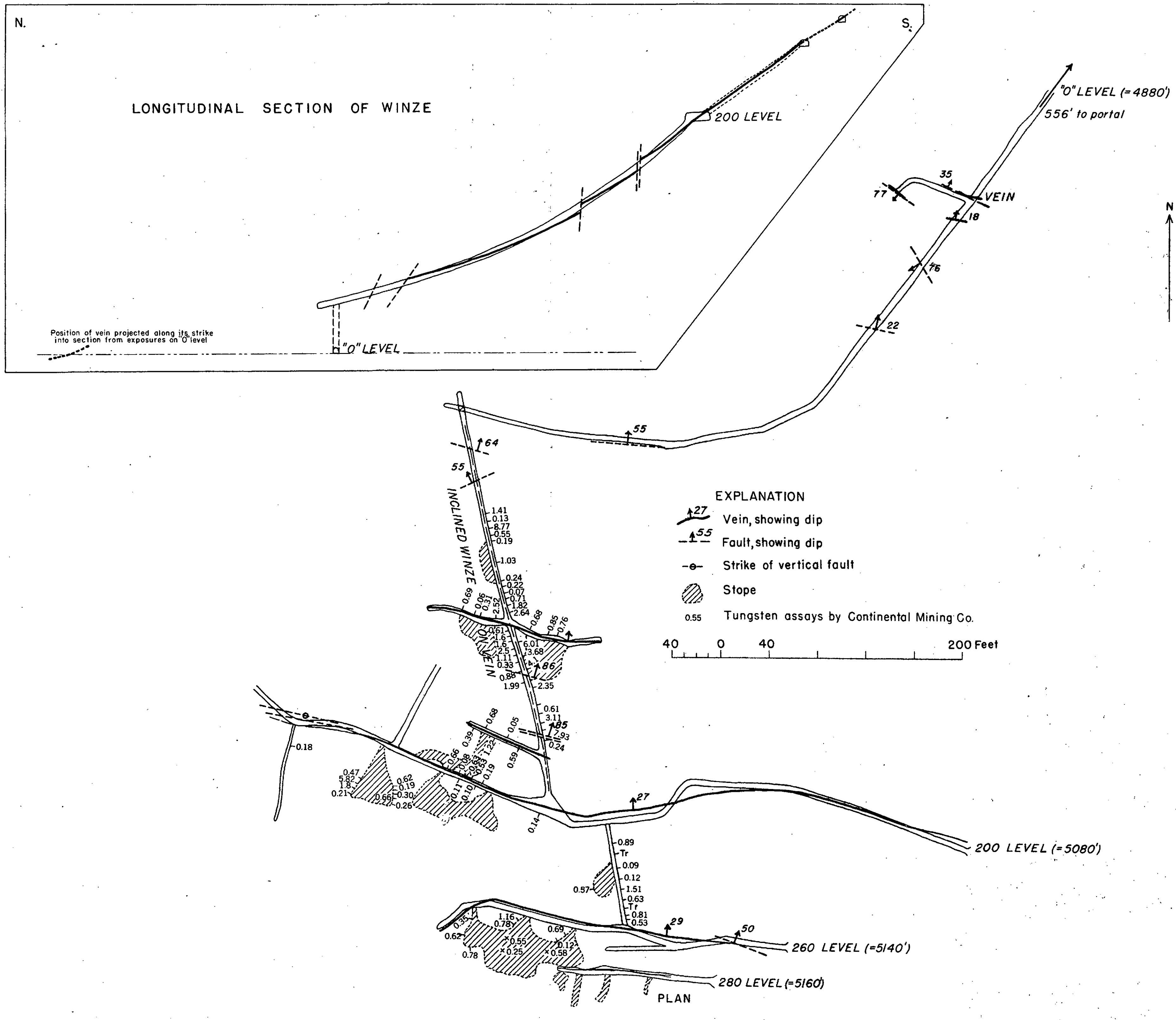
The vein ranges in thickness from a few inches to several feet. Nowhere, however, does it pinch and swell very abruptly, and it was nowhere seen to pinch out. In places it may split into two or more parallel stringers. At the breast of the 200 level the vein appears to be thinning out, but this appearance may be due to complex faulting; in a raise, however, it seemed to be unusually thin, and also poor in tungsten. But apart from the recognized effects of faulting, the vein is essentially continuous throughout the extent of the upper workings, at least, of the Williams mine.

The winze follows the vein down the dip for a distance of 280 feet from the collar, to a point where the vein is in the roof of the winze and apparently abuts against a steep fault. The winze continues in granite for about 60 feet farther to the head of a vertical shaft which connects it with the "O" level. No evidence was found in the lower part of the winze or in the shaft to show whether the vein is displaced upward or downward by the fault, but two facts suggest that it is displaced upward. The first is that none of the normal faults in the mine is known to have a throw of over 6 or 7 feet, and the second is the existence of a vein, similar in all respects to the main vein, on the "O" level about where the main vein would intersect if it were projected with similar dip from the point where it disappears in the inclined winze.

Outlook

The main vein has been proved to extend throughout the upper workings, from them up to the surface, and at least as far down as the place in the winze where the vein disappears. It seems likely, moreover, that the vein continues at least as far down as the "O" level, and if this were proved its known extent would be greatly increased; more development work will be necessary, however, to prove this extension. It is probable, too, that the vein extends at least 500 feet westward from the mine workings and emerges on the west slope of the range, being represented by the outcrop of what is known as the west-side vein.

All this discussion of extent applies to the vein as a whole. It has not dealt, however, with the extent and volume of the tungsten ore in the vein. In the section now opened by



GEOLOGIC MAP OF MINE WORKINGS OF WILLIAMS TUNGSTEN MINE the workings, very little new ore is actually developed. The old stopes on the 200 and 260 levels were opened on pockets of ore, but they were abandoned when the grade became too low to make mining profitable at that time. A new raise near the end of the 200 level shows only a very thin vein of quartz, with low tungsten content. Some medium-grade ore was found in a raise that was driven from the first sublevel west of the winze. The results of certain assays, also, indicated a pocket of good ore east of the upper part of the winze, part of which was mined in 1942. In the eastern part of the tunnels the quartz veins are generally lean and show little promise.

The mine thus reveals wolframite at many places, and scattered pockets of ore of commercial grade, but very little of this ore has been blocked out. On the assumption that the average thickness of the vein is 1 foot, the amount of vein material actually developed in the workings and surface exposures is estimated to be about 10,700 tons. If the vein extends through the hill and to the depth of the "0" level, there may be some 98,000 tons, but how much of this, either in the mine or beyond it, is ore cannot be estimated with any assurance because of the pockety nature of the deposit. More development work would be necessary to determine the extent of the vein and the amount and grade of the ore. From the distribution of the wolframite as shown in the mine in 1943, it seems entirely probable that new bodies of commercial ore remain to be discovered, but no very pronounced structural control has been demonstrated that would help in looking for them.

Past production statistics are very incomplete and give little help in judging the value of the mine. It is reported that 750 units of WO_3 (a unit being 20 lbs.) was shipped from the property in 1916. In 1938 Roy Williams, owner of the mine, shipped 53 units of tungsten that probably came from the district, and the Continental Mining Co. shipped 399 units from the property in 1940. Since then the Continental Mining Co. has released the property. Production may be started again in 1944 by Mr. W. S. Bradbury.

Properties west of Williams mine

The veins that crop out on the west slope of the ridge, along the north side of Boner Canyon, include at least one gently dipping vein, similar to the Williams vein and on its projected strike, and two vertical veins that strike east. About a thousand feet west of the Williams property a few small openings, including a short tunnel, have been made on a vertical vein, striking east, that contains huebnerite. What may be the same vein is opened by a pit and some trenches about 1,200 feet farther west and on the same line of strike. Although these vertical veins have been explored only to a limited extent, they appear to be much like the gently dipping Williams vein in general character and in distribution of huebnerite.

A thousand feet to the north, in the head of a very steep-sided canyon, on what is known as the Short claim, there is another nearly vertical vein, from which a small amount of ore has been mined by surface trenching for several hundred feet along the strike. A tunnel has been started on the vein near the level of the creek, but it had been extended only 50 feet at the time of visit. From these workings eight units of WO_3 was shipped.

Adjoining the Short claim on the west are several claims, held by W. T. Hubbard, on which two small vertical veins and one gently dipping vein are exposed. A 260-foot crosscut has intersected one of the vertical veins at 202 feet. In the adit this vein is badly disrupted by later dikes, and its extent underground has not been definitely determined. The veins on this property are poorly exposed at the surface, but they appear to be similar in character to the others in the district. No estimate is possible as to the grade of the ore they contain.

Conclusion

The tungsten veins in the Aquarius Range have been known for many years, and that in the Williams mine has been rather thoroughly prospected. Only relatively small portions of the veins contain shoots of minable ore, and so far as known these shoots are small. Relatively little developed ore is in sight on any of the properties in the district, and further development work seems unlikely to show large tonnages. A continued small production can probably be made by lessees.