RARE METALS.

SOME MOLYBDENUM DEPOSITS OF MAINE, UTAH, AND CALIFORNIA.

By Frank L. Hess.

MOLYBDENUM DEPOSITS OF MAINE.

INTRODUCTION.

As Maine contains considerable areas of granitic rocks, it is not surprising to find that molybdenum, which is largely associated with granites, is here rather widely distributed. So far as known, it is found in Maine only in the form of the sulphide, molybdenite, accompanied by small amounts of its alteration product, molybdic ocher. The principal deposits now known are in Washington and Hancock counties, and these have been brought into more or less prominence through several companies which have been formed to exploit them.

WASHINGTON COUNTY.

AMERICAN MOLYBDENUM COMPANY'S PROPERTY.

Location and general features.—The American Molybdenum Company, of Boston, for several years worked upon a deposit in the town of Cooper,[a] 22 miles southwest of Calais, and spent a considerable amount of money upon buildings, machinery, and excavation. Granite, carrying molybdenite, was quarried from an open cut, and an excavation about 100 feet square and up to 10 or 12 feet deep was made.

The deposit is situated on the south slope of a gentle hill 500 or 600 feet high, overlooking the stretch of country between Lakes Cathance and Meddybemps. The rocks of the vicinity have been much scored by glaciers in an approximately northwest-southeast direction, and

[a] The Cooper deposits were described by George Otis Smith in "A molybdenite deposit in eastern Maine," Bull. U. S. Geol. Survey No. 260, 1905, pp. 197–199.

outcrop at many places through the thin soil. The prevailing rock is a comparatively fine-grained light-gray biotite granite, which weathers to a pinkish color. It is much broken by three prominent sets of joints. Two of these strike about northeast, one dipping 45° or less to the northwest, the other from 45° southeastward to vertical. The third set is older than the other two and runs nearly north and south with an almost vertical dip. Many of the joints of this third set have been filled with thin dikes of rather quartzose pegmatite from one-half inch to 3 inches thick. Ordinarily the most quartzose phases occur where the dike has narrowed to its smallest proportions, and at many such places molybdenite forms crusts in which the flakes lie in radial groups of considerable beauty. Between the molybdenite and the walls of the dike there is a thin layer of quartz and feldspar, the latter on the wall itself, but at some places in crystals so small as to escape casual examination. In width the molybdenite flakes commonly range between one-sixteenth inch and an inch, but may fall short of or exceed these limits. It is said that segregations occur weighing 10 or 12 pounds. In wider parts of the dikes feldspar is a conspicuous constituent, but molybdenite is more sparsely distributed and seems inclined to segregate in the middle of the dike.

Some of the thinner dikes lose their identity in that of the surrounding granite by structurally merging into it, but may reappear a few inches or a foot farther along. Others apparently stop abruptly, ending in vugs filled with crystals of quartz, feldspar, and here and there purple fluorspar, reaching one-fourth inch in thickness. Similar vugs occur in the body of some of the dikes, but they rarely carry much molybdenite in either place. A "pocket" containing a mass of molybdenite ranging from a few flakes to several pounds may occur in places at what seems to be a point just beyond the end of a dike.

The influence of the dikes extends into the granite to varying distances, in some places for 4 or 5 feet from a dike less than 1 inch thick. In such places the granite is miarolitic, that is, full of small vugs, which show well-crystallized feldspar, quartz, and occasionally purple fluorspar, giving the rock a peculiar spotted appearance. Apparently the original constituents have been dissolved by some agency and recrystallization has taken place. A little pyrite and chalcopyrite are apt to occur in both the vugs and the dikes. Here flakes of molybdenite, mostly small, few reaching one-fourth inch in diameter, and very thin, are to be found distributed through the granite. Although in such places the molybdenite flakes seem sporadic, close examination often shows minute seams running from one flake to another or to the dikes.

The joints that carry the pegmatite and the molybdenite are much less plentiful than the others. No molybdenite was seen in the northeast-southwest joints. The molybdenite has been altered to molybdic ocher in a few places, but in very small quantity. This ocher has usually been supposed to be molybdic oxide, but Waldemar T. Schaller has recently shown that it is iron molybdate in all specimens that he has examined. Besides the minerals already described, a single piece of native bismuth the size of a hazelnut was found by the writer. In Australia the occurrence of bismuth with molybdenite is frequently noted, but it is uncommon in this country.

Extent of the deposits.—A shaft said to be 50 feet deep with a drift at the bottom 200 feet long, now filled with water, is reported to have shown molybdenite throughout in as large proportion as in the quarry. A ditch 225 feet long and 4 feet deep, running southward from the quarry, showed molybdenite through its whole length, making a stretch of over 300 feet north and south in which the granite has been proved to carry the mineral. Less is known about the width at this point, but in the quarry it is at least 100 feet.

Method of treatment.—The American Molybdenum Company endeavored to extract the molybdenite by screening. The plant consisted of a 35-horsepower boiler and engine, a Sturtevant jaw crusher and roll, and four sets of special rolls, each 3 feet in diameter and 10 inches wide. The crusher was but a couple of feet above the floor, from which the material, crushed to about one-fourth inch square, was elevated to the Sturtevant roll, 18 inches in diameter by 4 inches wide, which reduced the ore to about one-eighth inch. It was then elevated to a bin at the top of the building, from which it fell to a series of two special rolls, thence was elevated to a third special roll, and run through a 34-mesh screen. The molybdenite caught on the screen was delivered to a box at the end. The material going through the screen was carried by an elevator and screw conveyor to a fourth roll, from which it fell onto a 40-mesh screen and from that to a 60-mesh screen. What went through the 60-mesh screen was elevated and sent to the tailings pile. It is readily seen that the repeated elevations of the material meant a considerable waste of power. The mill ran only six weeks, and is said to have made about a ton of concentrates, a portion of which seen by the writer was very clean. In the tailings some fine flakes of molybdenite were found, but the amount seemed small. Such a process, if mechanically perfected, might work profitably on deposits where, as in this one, the molybdenite flakes are comparatively broad, but would be wholly unsuited to deposits like many of those in Colorado and elsewhere, in which the individual flakes are of almost microscopic size.

CALAIS MOLYBDENUM MINING COMPANY'S PROPERTY.

The property of the American Molybdenum Company is adjoined on the north by that of the Calais Molybdenum Mining Company.

Less work has been done here, but the conditions of jointing and deposition appear to be similar to those on the property just described, of which this is an extension. Several test pits show the same form of molybdenum-bearing dikes and apparently the rock is of about the same richness. The molybdenite evidently still follows the north-south joints.

The width of the molybdenite-bearing granite at this place has not been determined any more definitely than on the property to the south. No molybdenite was seen in the material thrown from a prospect hole about 1,000 feet northeast of the test pits, although it was said that some had been found. None is known to exist on the north side of the road at this point, nor does any appear on the surface between the pits and the road. It would seem, therefore, that the impregnated zone is probably less than 1,000 feet wide, which is about the distance from the road to the prospect hole farthest east. Further prospecting, however, may show this estimate to be in error. The impregnated area on this property is known to extend 300 or 400 feet northward from the American Molybdenum Company's property, and may extend much farther, as molybdenite is reported from points half a mile or more to the northwest.

NEIGHBORING AREAS.

Less is known of areas lying west of those described, but a few prospect holes have shown some molybdenite. Southwest of the property of the American Molybdenum Company and south of Cooper Church, some molybdenite in small flakes and segregations has been found in a number of prospect holes. The granite here also is dotted with small vugs similar to those on the property of the American Molybdenum Company.

HANCOCK COUNTY.

CATHERINES HILL.

The known deposits of molybdenum in Hancock County lie along the north and west sides of Tunk Pond, a sheet of water about 7 or 8 miles long and a mile or more broad. Its northeast end is 8 miles west of Cherryfield, and its southwest end about 2 miles north of Tunk Pond station. At the north side of the lake a partially bare, glaciated knob, 500 or 600 feet high, known as Catherines Hill, has been prospected to some extent. The hill shows several benches with vertical faces, running northeast and southwest, from 12 to 18 feet high, due to the sheeting and jointing of the granite. The granite is light gray in color, of a prominently granular appearance, showing little or no muscovite, small amounts of biotite, and considerable variation in texture. In places the quartz grains, although only one-eighth to one-fourth inch in diameter, are the most noticeable of the minerals, while in other places the feldspars are more prominent and here and there become prophyritic, reaching three-fourths of an inch in length. The dip of the principal joints varies considerably each way from the perpendicular. The sheeting, which is practically horizontal, is also conspicuous. Several crushed zones, 2 to 4 feet wide, were noted running about north and south.

Several companies have sunk prospect holes and done some blasting along the face of a small cliff, so that the deposits have been exposed at a number of places extending over about 300 feet east and west, two-thirds of the way to the top of the hill. Molybdenite is said to be found also at the foot of the hill. It occurs in flakes, said to reach several inches in width but ordinarily much smaller, and in small bunches, generally less than three-fourths of an inch in diameter. It apparently accompanies a series of pegmatite dikes which dip in various directions but for the most part steeply. The larger number of the dikes seen are over 1 or 2 inches thick, though in places they widen to form vugs up to 4 or 5 inches across, which contain druses of quartz crystals up to 3 inches long and 2 inches thick. Some of the vugs are almost filled with quartz and feldspar crystals, with smaller amounts of biotite and molybdenite, but in general, as in the Washington County deposits, the amount of molybdenite in these enlarged portions of the dikes is small. It is, however, apt to be deposited at their ends and in the inner parts of the dikes, from which places it disseminates into the granite, here and there probably to a distance of 3 or 4 feet. As at the Cooper deposits, near the dikes the granite shows at many places a different texture, small crystals of feldspar forming rosettes, one-half inch across, around a crystal of quartz, or around pyrite, as indicated by the rust-lined cavities. It seems hardly possible that these rosettes can be due to the original structure of the granite, and they are probably the result of a readjustment which may have been caused by solutions accompanying the pegmatite. The molybdenite does not seem to occur in this recrystallized granite so much as in the less affected portion near it, which contains molybdenite flakes, thin but up to one-half inch or more wide. A peculiarity of the small pegmatite dikes is that bunches of quartz, feldspar, and mica crystals occur where the dikes apparently end. The dikes' influence, shown by a coarseness of structure, can apparently be traced in the surrounding granite for several inches. If molybdenite is present in the vugs and enlargements of the dikes, it is generally in small quantity. The dissemination in the granite would seem to indicate that the minerals were deposited from a solution, possibly a gaseous solution, as it does not seem possible that a liquid solution could have penetrated the dense granite to the distances observed.

OTHER LOCALITIES.

Halfway toward the southwest end of the lake, one-fourth mile west of Sand Cove, molybdenite has been found at several places on a flat formed of granite of the same type as that in Catherines Hill. But little work has been done on the deposits and they can not be seen to advantage. A couple of blasts were put in during the visit of the writer, but they showed nothing new, although some molybdenite was obtained at each blast. There are two principal occurrences, one of which is on the south side of a ravine cut in the granite to a depth of 20 or 30 feet. The granite is jointed vertically along a north-northwest course, which has probably determined the position of the ravine. Another series of joints cuts this set at right angles. The granite contains more biotite than that of Catherines Hill, and the porphyritic crystals of feldspar show a zonal growth, generally with the outer zone lighter in color than the inner ones. The granite is here cut by aplite dikes up to a foot or more in width. Quartzose pegmatite dikes cut both the granite and the aplite and are accompanied by molybdenite very much as in the deposits already described. One noticeable feature is that in places the dikes become very thin, some of them less than one-sixteenth inch thick, and have little influence upon the surrounding granite or aplite. Along these dikes bunches of molybdenite several inches in diameter are found. No dissemination of the molybdenite could be seen in the granite. A quarter of a mile southwest of this deposit several shots have been put in showing similar occurrences of molybdenite. Between these two places molybdenite has been found on the surface at a number of points. It is also reported to occur on the south side and elsewhere around the lake, but these localities were not visited.

CUMBERLAND COUNTY.[a]

Molybdenite has been found in the granite at a number of places in the town of Brunswick, but the deposits are of mineralogical interest only. A thin vein was exposed for some distance in digging a sewer for the town.

OXFORD COUNTY.

Molybdenite has been reported from several places in Oxford County. Three places were visited—one in the town of Greenwood, 6 miles north of Norway village; another on the Horatio N. Flagg farm in the town of Buckfield, 10 miles east of Paris; and a third at Crocker Mountain, half a mile east of Mount Mica and about 4 miles east of Paris.

At each of these places the rock is a quartz-biotite gneiss, which much resembles a crushed granite, intruded by pegmatite, also some-

[a] Communicated by Prof. L. A. Lee, State geologist, Brunswick, Me.

what squeezed. On the Flagg farm both gneiss and pegmatite have been crushed until the pegmatite shows merely as mashed lenses in the gneiss. The gneiss carries more or less graphite at each of these places, reaching a maximum at Crocker Mountain. The graphite is flaky and much resembles molybdenite, but specimens collected at each place and submitted to Waldemar T. Schaller, of the Geological Survey laboratory, showed no trace of molybdenum. Others report having specimens tested which showed its presence, and it would seem entirely possible that molybdenite should occur in these gneisses, considering their possible origin from a granite and later intrusion by pegmatites. Molybdenite is occasionally found in the pegmatite at Mount Mica.

ORIGIN OF THE MOLYBDENITE.

There can be but little doubt that the origin of the molybdenite is connected with the pegmatite dikes, for in the deposits described it has been seen nowhere except in connection with them. The distribution of the molybdenite through the granite adjacent to the dikes and the recrystallization of the granite seem to indicate very hot, possibly gaseous, solutions or some other form more capable of penetrating the rocks than the watery solutions as now understood. The granite is as dense and compact as most granites except where it has been altered in the vicinity of the pegmatite dikes. The molybdenite, quartz, and feldspar seem to have been nearly contemporaneous, the feldspar probably being first deposited and the quartz and molybdenite afterwards, although at times this order may have been reversed.

RICHNESS OF DEPOSITS.

The quantity of molybdenum in the deposits is very difficult of determination. Hand specimens which show a very high percentage of molybdenite may be obtained from the dikes, and specimens which also show molybdenite may be taken from certain portions of the granite. At the same time, with an equal amount of effort, a much larger number of specimens which will probably show no molybdenite may be obtained from the same area. The average assay of a hand-picked specimen is worse than useless, as it gives an apparent value very much above any possible mining values. Owing to the unequal distribution of the molybdenite in the rock it is very hard to pick a fair sample in any manner. After a sample is obtained, it is then very difficult to determine the percentage of molybdenite it contains, as the processes for separating the molybdenite are often questionable in their results. In nearly all mechanical processes loss of molybdenite is inevitable owing to the form of the mineral. It usually breaks into thin flakes, even if occurring in a mass. If a water flotation or an air-blast separation is attempted part of the flakes are usually carried away with the gangue. Sieves lose a part of the finest material and magnetic separation appears to be somewhat uncertain unless it is adapted to the individual ore in each case. In a purely chemical separation the samples analyzed are almost always very small—but a few grams at most—and thus the determination is again incompetent, for the specimen can not be quartered down with even moderate exactness owing to the segregation of the mineral in the rock and the difficulty of pulverizing the flakes of molybdenite. It seems possible that a better method might be worked out along the line of oxidizing the molybdenite by roasting, dissolving in ammonia, and determining the molybdenum from the resulting solution. In such a process large amounts of material could be used, but it would be an expensive operation.

Should such a method as that just outlined be practicable, it would give accurately the amount of molybdenite contained in a given parcel of rock, and might be applicable as a means of extraction to certain deposits where the molybdenite flakes are finer than those in the Maine deposits.

Owing to the mechanical difficulties experienced, there is likely to be a great difference between possibility and practicability of extraction of molybdenite, so that the most desirable test of a deposit is one that will show just what extraction may be expected in practice. For such results an actual mill run, by the method of work contemplated, is probably the only satisfactory mode of testing molybdenite deposits, unless they are rich enough to be worked by hand picking, in which case pockets must be close together and the masses of considerable size.

AN OCCURRENCE OF MOLYBDENITE AT CORONA, CAL.

During 1906 molybdenite was discovered in a granite quarry operated by John Fletcher, about 4½ miles northeast of Corona, Riverside County, Cal. This quarry, which was visited by the writer in the latter part of January, 1907, is located in an embayment in a group of granite hills reaching a height of about 1,500 feet above sea level, and rising about 1,000 feet above the surrounding plain. The molybdenite occurs on the west face of one of the hills, about 50 feet above its base.

The granite is cut by thin pegmatite dikes one-half inch to 2 inches wide. Molybdenite in flakes up to one-half inch across accompanies the dikes in small quantity. In one or two places small flakes may be found in the granite for a distance of 2 or 3 inches from the dikes. The only other metallic mineral found in the dike is iron pyrites in which an assay is said to have shown some copper, gold, and silver.

Molybdenite is also found on both surfaces of joints in the granite, but in such places it does not appear to penetrate the granite more than one-eighth of an inch. Along these joints no alteration of the granite beyond simple weathering is to be seen, nor have any other minerals been deposited in the cracks, unless stains of iron oxide may indicate the former presence of iron pyrite.

Molybdenite has been shown over a narrow strip for a distance of 50 feet, but the total amount is small and the deposit gives no promise of having economic value.

WULFENITE AT ALTA, UTAH.

Alta is one of the older mining camps of Utah, and for many years wulfenite (lead molybdate) has been known to occur there, but it has always been sold for its lead content, as aside from the lead it contained it has had a merely mineralogical interest until recent years. Since the rarer metals have come into more prominent use, however, the minerals of these metals have been sought for more closely and wulfenite has acquired a new importance as a source of molybdenum.

Alta is situated at the head of Little Cottonwood Creek, 16 miles east of Sandy, from which place it may be reached by stage. Its elevation is about 9,000 feet.

The Continental-Alta mine is about a mile east of Alta and 300 or 400 feet higher. It has been worked for a number of years as a silver-lead mine, but has not been a heavy producer. The country rock is a siliceous limestone, dipping 15° to 30° northeastward from a granite mass which forms the walls of the lower portion of Little Cottonwood Canyon. There is considerable faulting, and the main fault along which most of the ore bodies are said to have been found shows in some places 30 feet of crushed limestone. Here and there the crushed fragments are rounded, apparently from solution rather than from movement, as in such places the limestone of which they are composed has taken a sugary appearance from recrystallization, and is much more friable than that in the less altered fragments. These zones probably lie in the channels of greatest circulation, either present or past.

A dike of fine-grained, almost white rhyolite 2½ feet thick is cut by the main tunnel 300 feet from the mouth. A smaller dike, 2 to 4 inches thick, has been intruded into a fault fissure close by. The effect of the dike on the limestone is apparently confined to very local metamorphism. Most of the ores mined have been oxidized—argentiferous lead carbonates and oxides, carrying small amounts of copper and gold—and with these has been mixed a small proportion of wulfenite.

The wulfenite occurs in the crushed zones, especially where the fragments are most waterworn and decayed, in delicate light-yellow translucent scales standing on edge on the fragments of limestone. In no place were they seen to penetrate the rock. Some of the crystals are covered with clay, showing that the waters are no longer depositing wulfenite in those places. The wulfenite has probably been formed by the oxidation of galena carrying molybdenite. Some powdery black oxide of manganese occurs with the wulfenite.

The ores are transported 4½ miles down the valley by an aerial tram to a concentrating plant, where the company reports having had little trouble in concentrating the wulfenite into a comparatively clean product. However, from the quantity of ore in sight at the time of the writer's visit it would seem impossible to make a profitable production of wulfenite.

The Continental-Alta property is adjoined on the south by the City Rocks, an old mine to which is credited a larger production of silver-lead ore. The ore carries more copper than that in the Continental-Alta, and much more wulfenite. The ore is all oxidized and follows a fault running N. 45° E. magnetic, dipping steeply to the northwest.

About 200 feet from the mouth of the main tunnel is an ore shoot 3 to 4 feet thick and 25 feet long, which has been followed by an upraise for 500 feet. Here also the wulfenite occurs in the crushed limestone upon much decayed fragments. Some powdery black oxide of manganese occurs in the shoot, but copper minerals are apparently absent where wulfenite occurs. Some massicot and plattnerite (yellow and black lead oxides) are found in the vein. The wulfenite occurs in the same fragile, delicate yellow scales as in the Continental-Alta, but in larger quantity. It is peculiarly beautiful in the candlelight, the hundreds of flat faces reflecting the light so that each looks like a tiny flame. It is almost impossible to transport specimens without great injury owing to the ease with which the crystals are detached.

These ore bodies are sufficiently rich to make it seem feasible to concentrate the wulfenite from the other lead minerals. However, one of the largest companies dealing in molybdenum minerals has refused to buy from this camp on account of the impurities the wulfenite contains. Though it was said that vanadium was the principal objectionable ingredient, none was found by the writer in a qualitative test of one sample. No complete analysis is at hand.

Wulfenite is said to occur in small quantity in practically all the oxidized ores of the camp, but the City Rocks mine seems to contain the greatest amount. Molybdenite is known to occur in a canyon on the south side of Little Cottonwood Canyon, but as the ground was covered with snow the locality was not visited. It is reported in small quantity from other points in the vicinity.

THE ARKANSAS ANTIMONY DEPOSITS.

By Frank L. Hess.

INTRODUCTION.

Owing to the high price reached by metallic antimony during 1906, interest was somewhat revived in the comparatively little known and recently neglected Arkansas deposits of the metal, all of which lie in the northern part of Sevier County, near Gilham, a village on the

Fig. 12.—Map showing distribution of igneous rocks in Arkansas. (After J. Francis Williams, Arkansas Geological Survey.)

Kansas City Southern Railway. (See fig. 12.) Aside from their economic features, these deposits are of much geologic interest, as they lie in unaltered sediments and show no close connection with igneous rocks.

The following papers treating of the antimony deposits and ores of Sevier County have been published:

WILLIAMS, CHARLES P. Note on the occurrence of antimony in Arkansas: Trans. Am. Inst. Min. Eng., vol. 3, 1875, pp. 150–151.

Paper read in 1874; gives analyses of several specimens of stibnite from Sevier County, Ark.

SANTOS, J. R. Analysis of native antimony ocher from Sevier County, Ark.: Chem. News, London, vol. 36, No. 933, 1877, p. 167.

An analysis of a specimen of oxide of antimony giving a formula of $2Sb_2O_4H_2O$. Possibly a mixture of cervantite and stibiconite.

DUNNINGTON, F. P. The minerals of a deposit of antimony ores in Sevier County, Ark.: Proc. Am. Assoc. Adv. Sci., vol. 26, 1878, pp. 181–185.

Read at the Nashville meeting, August, 1877. Describes the Antimony Bluff and Stewart mines, and gives several analyses of ores. Had not visited the mines.

WAIT, CHARLES E. The antimony deposits of Arkansas: Trans. Am. Inst. Min. Eng., vol. 8, 1880, pp. 42–52.

Gives description of Bob Wolf, Antimony Bluff, and Stewart mines, with results of a large number of assays and analyses. The best paper on the deposits.

COMSTOCK, THEO. B. A preliminary examination of the geology of western-central Arkansas: Ann. Rept. Arkansas Geol. Survey, 1888, vol. 1, pp. 136–137.

Gives general description of the geology of the Stewart, Conboy, Antimony Bluff, Valley, and Otto mines.

JENNEY, WALTER P. The lead and zinc deposits of the Missisippi Valley: Trans. Am. Inst. Min. Eng., vol. 22, 1894, pp. 206–208.

Gives a general description of the veins and ascribes an igneous origin for their derivation. His article is general, but good.

ASHLEY, GEORGE H. Geology of the Paleozoic area of Arkansas south of the novaculite region: Proc. Am. Phil. Soc., vol. 36, No. 155, 1897, pp. 306–308. Reprinted in Contributions to Biology from the Hopkins Seaside Laboratory, No. 12, Stanford Univ., 1897, pp. 306–308.

Briefly describes the antimony deposits, and gives a better idea of the distribution of the veins than the others.

BAIN, H. F. Preliminary report on the lead and zinc deposits of the Ozark region: Twenty-second Ann. Rept. U. S. Geol. Survey, p. 2, 1901, p. 133.

Describes the Bellah mine from the standpoint of zinc production.

In but one of these articles is there attempted an explanation of the origin of the veins or ores, there is but little description of the ores as such, and there is some disagreement as to the facts observed in regard to the structure of the veins and their relation to the country rock. In an endeavor to clear up some of these items and to get some idea of the amount of ore available, the writer visited the locality in November, 1907, but owing to the abandonment of the mines they were mostly filled with water and opportunities for examination were limited.

The history of the mines is not entirely clear. According to local belief, antimony was discovered in the vicinity shortly after the civil war by several hunters who set a number of rocks together to inclose a fire on which to roast venison. Some of these rocks were noticed to be peculiarly heavy, and when the fire became hot, they partially melted and gave off fumes which imparted a disagreeable taste to the meat. Portions of the rock were taken to Little Rock, where they were identified as antimony ore. Charles E. Wait[a] states that the discovery of antimony took place in the winter of 1873-74. However, work was commenced about 1873 and was carried on, whenever high prices for antimony permitted, for thirty years.

GEOLOGY.

STRATIGRAPHY AND STRUCTURE.

The rocks of the region are alternating thinly bedded sandstones and sandy or muddy shales, of Pennsylvanian and Mississippian age.[b] They are of a light-yellowish or drab color where exposed, and dark gray to black where unweathered. The rocks have been thrown into very regular parallel folds running a trifle north of east. The folds are so close that in many places the dip of the rocks approaches perpendicularity, and so regular that the strike of the rocks is sometimes used to tell direction.

The topography of the country is governed largely by the rock structure, and each fold makes its individual hill or valley, modified by the erosion of the streams. The country is rough but the relief is not great, and the hills probably nowhere reach a height of over 200 feet above the valleys. The main streams flow southward across the structural features, but the tributaries in general flow along the synclines until a weak point in the rocks allows them to cut through.

In the process of folding the shales have been compelled to slip upon the stiffer sandstone beds, and this has produced some slickensiding and crushing. The folding is supposed to be of the same age as that of the Appalachians,[c] probably post-Carboniferous.

In many places the sandstones and shales contain veins of quartz ranging in thickness from a small fraction of an inch to several feet. The main veins, wherever seen, apparently follow the trend of the structure, though locally the thinner ones form a stockwork in the fractures of the rocks. No continuous joints or faults were seen cutting the rocks across the strike, and none have been reported by others, so that veins are to be expected only along structure lines and such cracks or joints as would naturally be formed by the folding of the rocks in one direction.

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[a] Op. cit., p. 42.
[b] Ashley, George H., op. cit., pp. 245-246.
[c] Griswold, L. S., Whetstones and novaculites of Arkansas: Ann. Rept. Arkansas Geol. Survey for 1890, 1891, p. 213.

IGNEOUS ROCKS.

The nearest known exposed igneous rock is the peridotite of Pike County, which has recently attracted much attention as furnishing a possible source of diamonds. This rock is located in secs. 21 and 28, T. 8 S., R. 25 W., between 35 and 40 miles somewhat south of east from Gilham, which is in sec. 10, T. 7 S., R. 31 W., and 25 miles from the Busby mine, the nearest point at which stibnite has been known to be found. It is probably an early Tertiary or late Cretaceous intrusion, as it cuts sandstones of Cretaceous age.[a] The next nearest igneous rock is an augitic dike in Montgomery County, somewhat farther away, and still farther east are the Magnet Cove and Fourche Mountain areas of syenitic and other rocks. These rocks are supposed to be of about the same age as the peridotite of Pike County. In other directions no igneous rocks are known for very much longer distances.

THE ANTIMONY VEINS.

BOB WOLF MINE.

The Bob Wolf property lies 3 miles east and somewhat north of Gilham. It is locally known as Wolfton, but it was first known by the former name and is so designated in the literature. It was first worked for silver under the supposition that the stibnite was galena.[b] The shaft, which is now much caved, is said by Charles E. Wait [c] to have been 60 feet deep.

The dip of the country rock, which is considerably disturbed for about 2 feet on each side, could not be measured along the vein, nor could the exact relationship between the two be determined, but in the road about 200 feet north of the vein, the rocks have a strike of N. 70° E., with a steep southerly dip. In a valley 200 or 300 feet north of the main shaft a smaller quartz vein also strikes N. 70° E.

The rock in which the main vein is located is a soft, sandy, yellow to olive "shelly"[d] shale with thin drab intercalated sandstones. Where less weathered the sandstone is a very dark gray. One-fourth mile west of the main shaft almost black shale of muddy origin is exposed. As seen in the top of the shaft and in a prospect hole a short distance east of it, the vein runs about east and west with an almost vertical dip. It varies in width up to 10 or 12 inches, and may be traced by old excavations along its course for half a mile or

[a] Branner, J. C., and Brackett, R. N., The peridotite of Pike County, Ark.: Am. Jour. Sci., 3d ser., vol. 38, 1899, p. 55.

[b] Personal communication from William Conboy, of Gilham, Ark.

[c] Op. cit., p. 44.

[d] "Shelly" is a term much used in the oil regions to distinguish a shale which breaks in curved plates somewhat resembling shells.

more, swelling and thinning along both strike and dip. The vein is comby; that is, the quartz has formed crystals which extend from the sides toward the center and show terminal faces. It could not be seen that the solutions from which the vein was deposited had exercised any influence whatever, such as hardening or silicification, on the inclosing rock. Many pieces of shale forming nuclei from which quartz crystals radiate, yet so soft that they crumble and fall out like clay, are included in the vein. The vein is largely barren, and where stibnite occurs, it is found mostly between the combs of quartz. The blades of stibnite lie nearly parallel with the walls and so approximately at right angles to the quartz crystals. Some very small crystals of stibnite, less than one-fourth inch long, show the peculiar erratically bent forms characteristic of the mineral. Fragments of ore lying on the dump show an antimony oxide, probably cervantite (Sb_2O_4). Here and there a small amount of calcite forms thin bands in the veins. The calcite is mixed with siderite, which in places is of a uniform reddish-brown color, from oxidation.

No sphalerite, iron sulphides, or other accessory minerals were found in the pieces of ore picked up around the mine. In an analysis of a specimen from the upper part of the vein, Wait[a] found about 0.5 per cent each of arsenic and bismuth. In ore obtained near the bottom of the shaft neither of these minerals was present, but he found 0.002 per cent of cobalt. Unless the sample taken for analysis was large, so minute a quantity would be indeterminable. Under certain circumstances, in dealing with such small amounts, copper might readily be mistaken for cobalt, and as copper is noted in many veins, whereas this is the only occurrence of cobalt observed, this determination should probably be accepted with caution.

ANTIMONY BLUFF SHAFT.

The old Antimony Bluff shaft was not visited by the present writer, as he was assured that it was so badly caved that nothing could be seen of the vein. This shaft was described by Wait,[a] who states that the vein had a strike of N. 13° E. and a dip of 70° N., cutting across the stratification. What he evidently intended to say was that the main vein had a strike of 13° N. of E., for he makes the strike the same as that of the veins at the Ben Wolf and Stewart mines, and they are near the latter direction.[b] The vein contained stibnite in masses reaching 30 inches in thickness and pieces were taken out weighing 100 to 500 pounds. The ore was remarkably

[a] Op. cit., pp. 45–49.
[b] T. B. Comstock (loc. cit.) says that the vein dipped 79° N. 27° W.

pure. Analysis of a specimen obtained at a depth of 50 feet gave the following result:

Analysis of stibnite ore from Antimony Bluff shaft.

Stibnite	99.711
Chalcopyrite	.055
Bismuthinite	.005
Gangue	.229
Silver	None.
	100.000

A minute trace of arsenic was found in a specimen examined later, and some arsenopyrite was found in needle-like crystals in "a siliceous slate" accompanying the vein at one place. There was a small vein a few inches in thickness on the north side of the shaft which contained some lead, zinc, and iron. Wait found silver up to 8 ounces per ton in the ore, but only in those specimens which contained lead.

At 60 feet in depth the ore pinched out, water came in, and the shaft was abandoned.[a]

NEW DISCOVERY SHAFT.

Half a mile or more east of the Antimony Bluff mine, a shaft said to be between 100 and 125 feet deep was sunk in 1902, and a plant consisting of a shaft house, boiler, engines, ore crusher, and blacksmith shop was put up on a vein carrying some sphalerite and galena. This property is known as the New Discovery. When visited the vein was not visible at the surface and the shaft could not be entered, but to judge from a small amount of ore in the bin the deposit is evidently somewhat different from the others seen. The ore is a brecciated sandstone cemented with small veins containing sphalerite, galena, quartz, and siderite. There are also small amounts of pyrites, which may be copper bearing. Only one piece showing stibnite was found, and it was not certainly from this shaft. David Ziedler, who worked in the shaft until it reached a depth of 40 or 50 feet, stated to the writer that he saw no stibnite in the vein down to that depth. The ore bears little resemblance to the ores from the antimony-bearing veins, and the amount of quartz present is very much less.

CONBOY SHAFT AND TUNNEL.

The old Conboy diggings are in the northeast corner of sec. 5, T. 7 S., R. 30 W., about one-half mile east of the New Discovery shaft. An inclined shaft 90 feet deep was sunk along a quartz vein out-

[a] Comstock, T. B., op. cit., p. 142.

cropping on the north side of a hill, about 100 feet above the base. The shaft follows the dip of the vein and is inclined about 45°.

The stibnite in the shaft is said to have averaged 6 inches in thickness for 50 feet from the surface, below which it became thinner until it pinched out altogether. If there was any such amount of stibnite as this in the shaft the ore shoot must have been very narrow, for the sides were not mined. Mr. Conboy stated to the writer that some of the ore was so rich in silver that it was sold for 22 cents per pound. The fragments of ore found near the shaft show a distinct banded structure, with comby quartz one-half inch thick on each side of a central band of stibnite 1 to 2 inches thick, whose crystals lay roughly parallel to the walls. Scattered through the stibnite are small crystals of quartz and some particles of siderite. Outside of the comby vein there are several thin bands of siderite with some impurities, probably stibnite. No galena was seen. A tunnel 310 feet long cut the vein about 12 feet below the bottom of the shaft. At this depth the vein had pinched to almost nothing and no ore was in sight. A drift was run 75 feet eastward along the vein and although there was no ore in the roof of the drift, it is said that in the floor 6 or 7 inches of stibnite was found at the thickest part. The drift is now caved and could not be examined.

The tunnel affords the best place to study the relations of the rocks and veins, as the walls are clean and there is no caving. The rocks strike N. 77° E., with a dip of 45° N. 13° W. The vein follows the bedding and lies between dark sandy shales and a stiffer thin bed of sandstone. Slipping between the beds, due to folding, is noticeable.

OTHER SHAFTS NEAR THE CONBOY.

About one-half mile farther east, in a general way along the strike of the vein, a couple of shafts have been sunk on a vein which may or may not be the same as that at the Conboy slope. Very little stibnite was to be seen in the fragments from the vein. There were small amounts of pyrite, sphalerite, and galena, with the usual quartz and considerable siderite. The vein seems to be not over a few inches wide.

Various other excavations have been made along this vein which show it to be parallel to the vein on which the Stewart diggings are located, the last of them being located 50 or 60 feet north of the Stewart vein.

STEWART MINE.

About the old Stewart mine there is now but little to be seen except a caved trench showing the direction the diggings followed. C. E. Wait [a] states that this antimony deposit was discovered considerably

[a] Op. cit., p. 49.

later than the Antimony Bluff and Bob Wolf outcrops, but according to local tradition the Stewart was probably the first discovered.[a]

It is said that at some time between 1870 and 1872 stibnite was hauled from this mine to Little Rock, over 100 miles distant, and to Fulton, on Red River, about 65 miles distant. Thence it was taken to New Orleans by boat, and from that city shipped to England.

The diggings follow a direction about N. 82° E. The dip could not be seen, but is said by Comstock[b] to be 60°–80° N. Wait[c] states that in 1877, at a depth of 32 feet, the vein was about 1 foot thick and carried a streak of stibnite 4 inches thick. He shows the remarkable purity of the stibnite by the following analysis:

Analysis of stibnite from Stewart mine.

Antimony	69.87
Sulphur	27.91
Iron	.02
Zinc	.01
Silica	2.69
Silver	None.
	100.50

He found specimens of zinkenite ($PbS.Sb_2S_3$), jamesonite ($2PbS.Sb_2S_3$), and an oxidation product of the latter, bindheimite ($PbO.Sb_2O_5.H_2O$). One specimen of jamesonite gave 0.2229 per cent of silver; 0.01 per cent or less each of copper, bismuth, and cadmium; and a trace of gold. Some galena occurred in the vein, but sphalerite is not reported, though its presence would be expected. A piece of ore picked up on the dump showed massive stibnite in which the ordinary bladed structure was wholly absent.

The total output of the mine is unknown; 25 long tons were produced in 1877,[d] and between 1886 and 1889 the yield was 50 tons of high-grade ore. Some other small amounts have also been taken out.

MAY MINE.

The May claim lies about half a mile east of the Stewart, on a vein along which a considerable number of excavations have been made and which may or may not be a continuation of the Stewart vein. It is in the NE. $\frac{1}{4}$ sec. 4, T. 30 W., R. 7 S., about 1 mile south of Antimony post-office, and about 8 miles north of east from Gilham. The excavations show that the vein strikes N. 80° E., with a southerly dip that is almost vertical. The vein follows the bedding of the country rock, which is sandy and muddy shale, a good deal shattered. There has been some horizontal movement along the vein, but no vertical movement could be noted, though the exposures are poor and it

[a] Personal communication from William Conboy, of Gilham, Ark.
[b] Op. cit., p. 138.
[c] Op. cit., p. 52.
[d] Wait, C. E., op. cit., p. 52.

can not be stated that there has been none. The shale is thinly bedded and is so dark a short distance below the surface that the dumps from the shafts look much like " slack " piles in the bituminous coal fields.

This claim was worked for antimony as late as 1903, and there is on it a shaft house with hoisting and air-compressing machinery in fair shape. The shaft is located almost at the foot of the south slope of a hill, about 30 feet south of the outcrop of the vein. At the time it was visited the shaft was full of water.

Mr. Paul Knod, of Gilham, one of the owners of the property, gave the following information concerning the mine:

The shaft is vertical, 8 by 9 feet, 125 feet deep, and solidly cribbed for 113 feet below the surface. At a depth of 45 feet a crosscut reached the vein at 27 feet, where only a little disseminated stibnite was carried in the quartz.

At 80 feet in depth a crosscut reached the vein in 22 feet, at which point it carried a sheet of solid stibnite 6 inches thick. A drift was run 33 feet to the east, and a stope 10 feet wide was driven 18 feet high. From 16 to 18 tons of ore was taken out of this drift and stope. At 100 feet in depth the vein was reached by a crosscut 17 feet long. A drift was run 18 feet to the east, where the ore was about 10 inches thick in the face.

The last work was done in 1903. In that year 27 tons of ore, which ran 61.5 per cent antimony and brought $57 per ton, was shipped to New York.

A small amount of bismuth and traces only of arsenic and copper are said to have been found in the ores.

There is now lying upon the dump probably between 20 and 30 tons of ore that needs some concentrating to make it marketable. The ore contains quartz, siderite, calcite, and some pyrite as impurities.

Some years before the present shaft was dug two other shafts, 300 and 600 feet west of it, were sunk simultaneously. The shaft 600 feet west reached a depth of 110 feet, and at one place had 22 inches of stibnite. The third shaft, sunk to 90 feet in depth, had a " feather-edge " of stibnite at the surface and but 5 inches at the thickest.

In 1906 plans were made by the company owning the claims to work the mines again, but before the work could be commenced the price of antimony fell too low to make it profitable.

BUSBY MINE.

The Busby mine is in the northeast corner of Sevier County and is said by Ashley [a] to have shown some stibnite, but there is no record of any production.

OTTO AND VALLEY MINES.

The Otto mine is located near the middle of sec. 20, T. 31. W., R. 7 S., about 3½ miles southwest of Gilham, in the valley of a tributary of Roaring Fork. The country rocks are similar to those described at the other mines. The mine is now caved in and nearly filled with water, so that but little can be seen. However, the vein is fairly well

[a] Op. cit., p. 307.

exposed at the top of the shaft, where it is split into two branches, each 10 or 12 inches thick and about 3 feet apart. They evidently join at a depth of 20 or 25 feet. The strike is about N. 72° E., and the dip approximately vertical. The rocks are somewhat disturbed at the surface, probably from weathering, so that the relation of the vein to the rocks is not certain. Half a mile farther west the rocks strike N. 80° E.

Comstock[a] visited the mine in 1887 and states that the ores contained a considerable amount of lead, and one assay gave 1.2 ounces of silver per ton. Pieces of ore picked up on the dump showed much zinc blende in small crystals. In some specimens quartz shows peculiar reentrant angles and is somewhat etched.

Ashley[b] states that at the time he visited the mine (1892) the shaft was sunk to a depth of 230 feet and was still in good ore. According to local tradition, over a thousand tons of antimony ore was produced by this mine.

The Valley shaft was situated a few hundred feet east of the Otto. It did not produce much antimony, and but little is known of its ores.

BELLAH MINE.

The Bellah mine, 6½ miles southwest of Gilham, was not visited by the writer, as it was said to be full of water. It has recently been operated as a zinc mine, and, according to Bain,[c] was worked during the war by the Confederate Government for lead. He states that a well-defined vein 3 to 8 feet wide cuts across the shales with a strike of N. 82° E., and is perpendicular at the surface, dipping 80° N. at 145 feet in depth. It was at that time (1900) developed to a depth of 160 feet. The vein shows both vertically and horizontally striated slickensides, and is made up of comby quartz containing angular fragments of the country rock. Below 115 feet zinc blende is the more important ore, with lesser amounts of galena and chalcopyrite. No mention is made of antimonial ores. Ore seen by the present writer showed a quartz comb with zinc blende spread over the ends of the quartz crystal.

OTHER VEINS.

Besides the veins on which the deposits here described are located, others which have similar trend and apparently similar relations to the country rock and belong to the same age as those in the vicinity of Gilham are reported by Ashley[b] to occur north of Gilham in Tps. 5 and 6. Some of these carry considerable chalcopyrite. Jenney[d] says that this system of veins may be followed northeastward past

[a] Op. cit., pp. 143–144.
[b] Op. cit., p. 308.
[c] Op. cit., p. 133.
[d] Op. cit., pp. 206–208.

Little Rock, but this may be too great a generalization. Joseph A. Taff, of the United States Geological Survey, in a personal communication, states that west of this area, in Oklahoma, there are many apparently similar but smaller quartz veins.

SUMMARY AND DEDUCTIONS.

In general the veins described are comby quartz structures following the bedding planes of the shales and sandstone in which they are found. They are slickensided, showing both horizontal and vertical striations. The country rock has not been affected by the solutions from which the quartz has been deposited, even the included fragments in the veins remaining unaltered, but forming nuclei from which the quartz crystallized.

The original minerals found in the veins are quartz, stibnite, jamesonite, zinkenite, galena, sphalerite, pyrite, chalcopyrite, siderite, and calcite. Traces are found of arsenic, bismuth, cadmium, cobalt(?), silver, and, minutely and rarely, gold. Cervantite and bindheimite occur as oxidation products of stibnite and jamesonite, respectively.

The ores have been mostly rather pure oxide and sulphide of antimony, or lead ores, in many places silver bearing, for 40 to 115 feet from the surface, below which sphalerite and other impurities begin to come in. The ores which are easily oxidizable, or those whose oxidation products are readily soluble, have been more or less completely leached from the upper portions of the veins to the depth mentioned, which probably corresponds to the lower limit of variation of the ground-water surface.

The minerals occurring in the veins are deposited upon the faces of the quartz crystals forming the combs, and are therefore younger than most of the quartz, although a certain amount of quartz has been deposited later with the metallic minerals.

There is a central area through which the veins predominantly carry stibnite; elsewhere either the other minerals preponderate or no stibnite is present. This area runs northeastward from the Otto mine to the May—a distance of about 8 miles in a direct line, and is perhaps 2 miles wide.

The ore bodies occur in thin lenticular masses whose longest dimension approaches verticality and may reach more than 100 feet. The width may be from 3 or 4 feet to 20 or even 40 feet; the thickness ranges from a "feather-edge" to 2½ feet.

The list of minerals given above as being found in the veins at once suggests igneous origin—that is, that the solutions from which the veins were deposited had their origin in igneous magmas, or at least picked up their load of minerals from them. The rather wide distribution in Arkansas of small igneous intrusions whose general trend is about the same as that of the veins, and which, as in the vicinity of Hot Springs, even now are either directly or indirectly responsible for flowing hot waters, such as the springs for which the town is named, gives such a theory much plausibility. In the folding of the strata the upper parts of the anticlines are cracked by the tensional strains put upon them. Exactly the same thing must happen to the lowest strata turning under the synclines. Into these cracks the waters forced from below would naturally flow, but the beds in the middle and upper portions of the synclines are compressed and less fractured, so that the solutions would be turned aside to continue upward by way of bedding planes where unevenness and slipping had been caused by dissimilarity of the beds, as of shale and sandstone, and along such cracks they would travel to the surface. If the explanation that the veins were formed by waters connected with the intrusive rocks is accepted for their origin, then their age would be but little less than that of the intrusions, probably early Tertiary or late Cretaceous.

With such a deep-seated origin it is probable that the lenses of ore will alternately make and pinch out to a considerable depth, and in times of high prices for ore, such as prevailed during 1906, some of the mines might be worked at a profit. It can not be stated, however, what the vertical extent of any ore shoot may be, and below the ground-water level varying amounts of impurities consisting of zinc blende, chalcopyrite, and iron pyrite are to be expected.

ANTIMONY IN SOUTHERN UTAH.

By G. B. Richardson.

INTRODUCTION.

The occurrence of antimony in southern Utah has long been known. The deposits have been worked at irregular intervals since 1880 and it is reported that more than $100,000 worth of ore has been shipped from the property on Coyote Creek, in Garfield County. This property was described by Blake [a] and a report on the general geology of the region was made by Dutton.[b]

The rise in the price of antimony in 1905 and 1906 led to renewed activity in developing the neglected deposits in the United States, and after a period of no production covering several years, 295 tons, part of which came from Utah,[c] were mined in this country in 1906. A large concentrating mill has recently been erected in the valley of Coyote Creek, and preparations have been made for active mining. The writer spent a few days at this property in September, 1907, and is indebted to Mr. Thompson Campbell, of the Utah Antimony Company, for many courtesies.

LOCATION.

Coyote Creek is a branch of the East Fork of Sevier River. The stream occupies a short, narrow valley in the northwestern part of Garfield County, in the midst of the high plateaus of Utah. The camp is about 40 miles by road southeast of Marysvale, the terminus of the San Pete and Sevier branch of the Rio Grande Western Railway. The elevation of the mines is about 7,000 feet; the Awapa Plateau to the north and the Aquarius Plateau to the south and east rise 2,000 to 3,000 feet higher.

[a] Blake, W. P., Mineral Resources U. S. for 1883 and 1884, U. S. Geol. Survey, 1885, pp. 643–644.

[b] Dutton, C. E., Geology of the High Plateaus of Utah, 1880.

[c] The Mineral Industry during 1906, p. 4.

OUTLINE OF GEOLOGY.

The rocks of this general region form a part of the igneous complex of south-central Utah. They consist of lava sheets, beds of tuff and volcanic conglomerate, and intrusive masses of various types. These igneous rocks cap the highest plateaus and overlie an eroded surface of Eocene strata which outcrop at lower elevations around the igneous uplands. Beneath the Tertiary rocks lie several thousand feet of Mesozoic and Paleozoic sediments, which are exposed in a series of descending benches southward from the High Plateaus to the platform in which Colorado River has cut the Grand Canyon. The plateaus are traversed by a number of normal faults of large displacement which trend in general north and south. One of these faults, together with the action of erosion, has exposed a small area of Eocene sediments in Coyote Creek valley and it is in these beds that the antimony occurs.

The valley of Coyote Creek is occupied by a variable succession of strata. At the base of the section there is 150 feet of gray conglomerate composed of rounded pebbles of quartz and quartzite up to 6 inches in diameter, in a sandy matrix. The conglomerate is overlain by a great mass of fine-textured buff and reddish sandstone, with subordinate drab and red sandy and clayey shale and thin-bedded limestone, amounting in all to several hundred feet in thickness. No fossils have been found in these rocks, but because of their lithologic resemblance to Eocene strata elsewhere in the plateau region they are provisionally referred to that period. These sediments are succeeded by about 1,000 feet of andesitic tuff and lava which cap the surrounding plateaus. The rocks lie approximately flat, though there is a general low northeastward dip. At the mouth of Coyote Canyon a fault causes the strata to dip steeply westward.

OCCURRENCE OF THE ORE.

The ore consists of stibnite and its oxidation products, which occur generally in flat-lying deposits in the sandstone and conglomerate. The chief zone of mineralization is adjacent to the contact of the conglomerate and overlying sandstone, the ore occurring most commonly in fine-textured argillaceous sandstone a few feet above the conglomerate. In many places a bed of clay shale about 5 feet thick immediately underlies the ore-bearing sandstone, and locally the upper part of the conglomerate is mineralized. The ore does not occur persistently and uniformly, though it is present most commonly at this general horizon on both sides of Coyote Creek.

In the early days of development attention was given chiefly to the lenses of ore, the " kidney " deposits. The known lenses have now all been worked out, but it is said that they ranged from several inches to 20 feet in thickness. It is reported that 55 tons of ore were removed from one of these lenses. At present no large bodies of stibnite are in sight but there is a great amount of low-grade ore.

The occurrence and character of the deposits vary in the different prospects. A common occurrence is in layer-like bodies of irregular thickness but averaging only a few inches. The "layers" are not continuous beds and they are only approximately parallel to the bedding. Many of them are undulatory and thicken and thin out irregularly. In a number of places thin bodies of ore were observed cutting across the bedding of the sandstone and connecting the more nearly horizontal deposits. The ore also commonly occurs disseminated in the sandstone, in irregular segregations.

A characteristic feature of the antimony deposits of Coyote Creek is that the ore consists only of stibnite and its oxidation products, gangue minerals being almost completely absent. Only one exception was observed, at the Emily claim, on the south side of the creek, where in a small gash vein but a few inches wide stibnite and pyrite are associated with calcite. A thin section cut along the contact of the stibnite with the country rock shows an uneven junction, the stibnite extending very irregularly into the sandstone. Locally stibnite, with well-defined crystal faces, penetrates and is partly embedded in adjacent quartz grains of the sandstone.

The stibnite occurs in a variety of forms. In the larger ore bodies it is commonly present in aggregates of prismatic crystals arranged radially or in columnar masses. In one group crystals 6 inches long were observed. It is also present in indiscriminately mixed groups of acicular crystals. Adjacent to the outcrop the stibnite is almost invariably oxidized and the steel-gray sulphide gives place to the lighter brown, yellow, and white oxidation products. A number of oxidized specimens were examined by Dr. W. T. Schaller, of the United States Geological Survey, to determine the variety of these products. He reports that they are anhydrous and easily fusible and that they are either valentinite or senarmontite—probably the former, as reported by Blake.[a] In many places the valentinite occurs in acicular crystals as a pseudomorph after stibnite. Associated with the ore and forming efflorescences on the walls of the country rock, the following minerals are locally present: Epsomite; a hydrous magnesium sulphate; a hydrous aluminum sulphate, probably alunogen; a hydrous ferrous sulphate; and gypsum.

Small quantities of arsenic minerals have been found in the valley of Coyote Creek contiguous to the antimony deposits, but, so far as the writer is aware, not immediately associated with them. On the north side of the creek, about 100 feet southeast of the stibnite pros-

[a] Loc. cit.

pect known as " Black Jack No. 2," there is a small deposit of the sulphides of arsenic in shales of Eocene age. Realgar and orpiment in irregular seams ranging in thickness from a fraction of an inch to about 6 inches and only a few inches in length occur in a blue-drab clay shale. No other vein minerals are present and the realgar and orpiment, in small crystals, are intimately associated. Other similar occurrences of small amounts of arsenic are reported in the valley of Coyote Creek.

The occurrence of the ore indicates that it is of epigenitic origin—that is, it was formed subsequently to the deposition of the rocks in which it is found, and its origin is probably connected with the adjacent igneous rocks, as suggested by Blake. The antimony may have been derived from these rocks either during their intrusion through the sediments or less probably after their eruption on the surface, the stibnite being deposited from percolating solutions in part filling existing spaces and in part by metasomatic replacement. The bed of shale which in many places immediately underlies the ore apparently arrested the solutions and determined the local concentration of the stibnite. In such places evidently the solutions were not directly ascending but moved either laterally or from above.

DEVELOPMENT.

The deposits of antimony adjacent to Coyote Creek have been worked sporadically for the last twenty-seven years. For the most part this work has been limited to the exploitation of the large lenses and little or no systematic mining has been done. There has been considerable prospecting, however, and a score or more of tunnels have been driven into the deposits at various places on both sides of the creek.

In the past work has been chiefly directed toward getting high-grade ore running between 50 and 60 per cent of antimony. The " kidney " deposits were exploited, and hand-sorted ore was shipped. One attempt was made to smelt the ore on the property, but all efforts proved that with such methods competition could not be met.

It is difficult to estimate the amount of available antimony, but in the dumps of the old prospects and in the tunnels there is a great amount of low-grade ore in sight. The problem is how to handle the material economically. Toward this end a modern concentrating mill has been erected and it is proposed to make star metal on the property.

CARNOTITE AND ASSOCIATED MINERALS IN WESTERN ROUTT COUNTY, COLO.

By Hoyt S. Gale.

INTRODUCTION.

In a short paper, published about a year ago, the author described an occurrence of carnotite at a locality on Coal Creek, in eastern Rio Blanco County, Colo.[a] During the summer of 1907, while engaged in a further reconnaissance in the northwestern part of the same State, he found opportunity to examine another occurrence of the same mineral in Routt County, in a locality about 60 miles in a direction a little north of due west from the prospects previously described. The Routt County deposits are said to have been known some time previous to the discovery of those at the Coal Creek locality. They are situated at the southern foot of Blue Mountain (known as Yampa Plateau on the early maps of the region), about 18 miles due east from the Colorado-Utah boundary. The prospects visited lie along the summit and flanks of the highest hogback, about 2 miles west of Skull Creek, which is the main east fork of Red Wash. A number of claims have been staked there and some prospecting has been done along a narrow strip of land adjacent to the sandstone hogback in which the ores occur. This strip extends from east to west through the northern tier of 40-acre tracts in sec. 35, T. 4 N., R. 101 W., of the resurvey of that part of Colorado, and the prospects are said to extend beyond these limits along the outcrop of the same group of strata. These prospects are mentioned in a recent report of the Colorado State Bureau of Mines, and analyses of some of the ores are given there.[b]

This group of claims is of interest as furnishing another instance of the occurrence of these rare minerals, and especially as Dr. Hillebrand has discovered the presence of a selenite, presumably of copper, in some of the ores collected. The deposits are also interesting

[a] Carnotite in Rio Blanco County, Colo.: Bull. U. S. Geol. Survey No. 315, 1907, pp. 110–117.

[b] Report for 1905–6, Denver, Colo., 1908.

on account of the remarkable simplicity of the structural and stratigraphic relations of the beds containing the ores. The Blue Mountain deposits are essentially similar to those on Coal Creek, and the description of the geology of the former in the present paper will serve by comparison as a convenient means of correcting a misapprehension derived from the tentative conclusions of the former observations. As explained in another paragraph it is now recognized that the deposits at both places occur in rocks of Jurassic age, which are therefore older than the Dakota formation.

STRUCTURE.

The ores occur in the steeply tilted ledges at the southern foot of Blue Mountain. This locality is on the southern flank of a domal flexure or uplift which has been described in the early surveys as the Midland uplift. This name is derived from that of Midland Ridge, the northern border of the same structural feature, now represented by a high and very conspicuous escarpment, partly surrounding and inclosing an interior basin eroded along a portion of the main axis of the uplift.

The principal axis of the Midland uplift lies in an east-west direction. It pitches sharply and terminates near the State line on the west and continues eastward for 30 miles or more. At the upper valley of Wolf Creek the axis bends southward, and pitching also in that direction crosses White River at the mouth of Wolf Creek, where it is lost in the flat-lying strata of the plateau ridges to the south.

STRATIGRAPHY.

The rocks in which the carnotite and associated minerals are found are of Jurassic age. The discovery of determinative fossils, notably in one of the prospect pits from which the ore itself has been obtained, is considered to have definitely established this point.[a] The rock in which the ore occurs is a coarse white sandstone, exceedingly massive and of great thickness. The deposits occur in the upper massive beds of the sandstone group. The chief distinguishing feature of this sandstone is its amazing development of cross-bedding or false-bedding structure. This character continues to the same remarkable extent as far as the formation has been traced. Measurements give the thickness of this formation near the carnotite prospects as approximately 800 feet. It is divided about midway, below the horizon of the carnotite-bearing strata, by a small group of clay beds of a brilliant red color resembling that of the much thicker series of red clay and

[a] The fossils were found in the principal development here described. The following species were identified by Dr. T. W. Stanton: *Trigonia quadrangularis* H. and W., *Tancredia* sp. The specimens are deposited in the National Museum.

shales below. The massive sandstone ledges are relatively more resistant to erosion than any of the adjacent formations either above or below, and they thus commonly form the highest summits or hogbacks, the adjoining beds, where not protected by them, being eroded to lower valley lands.

This formation was mapped and described as Triassic in age in the work of the early Hayden Survey, probably through lack of paleontologic evidence. It is clearly the same as that described by Powell under the name White Cliff sandstone in his "Geology of the Uinta Mountains." From Powell's descriptions of the continuity of outcrop of these particular beds even as far as southwestern Colorado and adjacent parts of Utah, it seems very clear that this formation is the same as that named La Plata by Cross in his work in that region. It is thus of the same geologic age as the beds in which the carnotite and associated vanadiferous minerals are described from various localities farther south in both Utah and Colorado, and it is also similar to these beds in lithologic character.

It is now recognized that the Coal Creek deposits are in this same formation, the stratigraphic relation of the beds being less evident at that place. The Jurassic sandstones were not differentiated from the overlying Dakota in the former description.

The beds immediately underlying the white cross-bedded Jurassic sandstone consist of a considerable thickness of red and brilliantly colored strata, probably in large part shale, containing limestone and sandstone layers. This thickness was found by rough measurement to be approximately 900 feet in the vicinity of the carnotite deposits. It is this group that forms the major part of the escarpment of the Midland Ridge, which rises on the northern side of the Midland Basin and is a most conspicuous and extraordinary feature of the landscape. This great wall with its banding in vivid red and gray may be seen from an extensive territory on the south, to and beyond the White River valley. Below these "Red Beds" is a second group of massive white sandstones. The "Red Beds" and underlying sandstone probably range in age from Triassic above to Carboniferous below.

The series of beds immediately overlying the white Jurassic sandstone, which contains the carnotite deposits, is composed of a group of variegated clays and marls with some limestone layers. A few layers of a compact, thoroughly silicified conglomerate also occur. The colored shales are characteristically of shades of clear pink and green. They occupy many bare wash banks or slopes, especially where protected by some harder beds above, but they give way so readily to erosion that in greater part they lie in low valley areas or badland washes. Marine Jurassic fossils occur in these beds at several horizons near their base. The strata are very clearly the group described by Powell as the Flaming Gorge, and probably correspond in age in their upper or fresh-water part to the formation known as Morrison east of the Rocky Mountains.

Above these varicolored shales there is another group of harder beds, consisting of conglomerate, firmly indurated sandstone, and interbedded shales. This group is commonly conceded to represent the Dakota formation, as recognized over an extensive territory in this part of the United States. The Dakota also commonly forms hogbacks. It underlies a great thickness of Upper Cretaceous and Tertiary strata.

NATURE OF THE DEPOSITS.

The best showing of the minerals was found at the summit of the highest hogback in the NW. ¼ NW. ¼ sec. 35, T. 4 N., R. 101 W. The bare rock ledge of which this ridge is composed is somewhat difficult of access and the prospects are not easily found. The ores observed were fragments and blocks thrown out upon the dump, and also the minerals themselves in place at the protected face of the deepest excavated pit.

The ores present a beautiful display of colors. The carnotite appears to constitute a relatively small percentage of the minerals found. It is in the form of a film or thin crust of powdery or amorphous material of bright canary-yellow color. The carnotite is distinguished by the chemical tests for uranium and vanadium. The ore contains also some arsenic in the quinquivalent state. The deposit as a whole occupies a brecciated zone in the rock, the minerals being concentrated in or evidently distributed from the coarser joints or more porous layers. To a less extent some of the minerals are found impregnating the more massive sandstone.

A yellow mineral closely resembling the carnotite in color and appearance was found in greater amount. This proved on testing[a] to be a vanadate of copper, containing no uranium and therefore not carnotite. These two minerals are often difficult to distinguish without chemical tests. The vanadate of copper is found as minute clusters or aggregates of folia or plates of clear crystalline appearence, scattered over the surface or jointing planes of the country rock. These folia or plates are somewhat distinct from the more amorphous carnotite substance, and are also of a darker-greenish hue. The mineral also occurs, however, as a powdery crust or impregnation, when its only distinction from the uranium-bearing mineral is its slightly darker, more greenish cast. Doctor Hillebrand considers this mineral

[a] All tests on the specimens described were made by Dr. W. F. Hillebrand in the chemical laboratory of the United States Geological Survey.

the same as some light-olive and yellowish-green varieties collected and described by Boutwell from deposits near Richardson, in southeastern Utah.[a]

The most conspicuous minerals present in the prospects are exhibited as bright-green stains, which penetrate the country rock to a much greater extent than either of the yellow minerals. These stains have the characteristic color of malachite, the common copper carbonate, and some of the green substance was proved on testing to be that mineral. The veins and rock containing malachite also show the blue copper carbonate, azurite, in lesser amount, usually in small rounded knots or balls. These two minerals present the beautiful contrast of green and blue so commonly known. A considerable portion of the green stain, however, especially that part found most intimately associated with the yellow copper vanadate, proved to be practically free from all carbonate material, and as it gave the reaction for sulphates and to a small extent for silicates, it is thought to be composed of those compounds of copper. It is suggested by Doctor Hillebrand that this substance is very probably the basic copper sulphate, brochantite. Without the acid test for carbonates or in a mixture of the two minerals malachite and brochantite, it seems that it would be extremely difficult to detect even under the microscope the difference between them.

A most interesting discovery of the chemical tests has shown the presence of a copper selenite associated with the green copper minerals, both sulphates and carbonates. This is, Doctor Hillebrand observes, the first occurrence noted of a selenite in the United States. It is possible that the supposed selenite may be a selenate, but as selenates have not yet been discovered in nature it seems likely that the former class is represented.

Much of the rock containing the basic copper sulphate and copper vanadate is speckled with small black blotches. These were found to contain manganese in peroxide form and also copper, perhaps as a manganite of copper, though it is not at all improbable that the other elements are present also.

In another prospect pit, about 100 feet southwest of the prospect described above, at the head of a small draw or gash eroded in the face of the bare rock ledges leading up from the south side of the ridge, the same massive sandstone rock was found stained with a green mineral, but without the yellow or blue ores. Tests of specimens of this substance showed that it was wholly unlike either of the other two green minerals described above, containing much chromium but no copper, vanadium, nor uranium. A similar sandstone

[a] Boutwell, J. M., Vanadium and uranium in southeastern Utah: Bull. U. S. Geol. Survey No. 260, 1905, p. 205.

is described from the Montrose and San Miguel county localities,[a] where it was thought to be possibly analogous to the vanadium mica roscoelite, as under the microscope it was found to present a chloritic appearance. The color is a bright green, very similar to the green minerals described above, with perhaps a very slightly deeper tinge of blue.

At places near both prospects the rock is stained with the more common iron deposits (oxides and hydrates), which color it rusty brown or ocher-yellow.

The deposits as a group resemble in general character the previously described occurrences of this mineral, both the Coal Creek deposits and those still farther south in Colorado and Utah. The association of silicified wood noted at the Coal Creek locality has not been found, the latter possibly being rather of an accidental nature than bearing any genetic relation to the deposition of the minerals.[b] As stated, the minerals are very evidently mere crusts or coatings, or surficial impregnations in sheared, brecciated, and jointed zones in the rock mass. These zones of brecciation evidently mark the path of the mineralized solutions from which the deposits have been derived.

The extent and practical value of the Blue Mountain deposits is not yet shown to be of much importance. Nowhere had development work been carried more than 10 or 15 feet in from the surface. At none of the prospects seen did there appear to be any great quantity of the minerals exposed by present developments. The occurrence of the minerals is of itself an interesting feature, and there is a possibility of further discoveries.

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[a] Hillebrand, W. F., and Ransome, F. L., On carnotite and associated vanadiferous minerals in western Colorado: Am. Jour. Sci., 4th ser., vol. 10, 1900, p. 134.

[b] Cf. Boutwell, J. M., op. cit., p. 209.

TUNGSTEN DEPOSITS IN THE SNAKE RANGE, WHITE PINE COUNTY, EASTERN NEVADA.

By F. B. Weeks.

INTRODUCTION.

A brief description of the tungsten deposits in the Snake Range, eastern Nevada, was published by the writer (2)[a] in 1901, and in 1902 F. D. Smith (6) published an account of the occurrence and development of the prospects. In October, 1907, the writer made a more detailed study of the development at this locality and the character and occurrence of the ore deposition.

SITUATION.

In 1900 a mining district was formed under the name Tungsten mining district, embracing several square miles along the western slope of the Snake Range south of Wheeler Peak (locally known as Jeff Davis Peak). This range as an orographic feature begins about 25 miles south of this locality and extends northward from its southern limit about 135 miles between latitude 38° and 40°. It includes the Deep Creek or Ibanpah Range and the group of connecting hills known as "Kern Mountains." This is one of the most extensive and prominent ranges between the Wasatch and the Sierra Nevada. Its highest point, Wheeler Peak, reaches an elevation of 12,000 feet. (See fig. 5, p. 118.) In the area of the tungsten prospects the surface of the mountain slope is dissected by several wide, shallow gulches which are dry except when occupied by melting snow or storm waters. There are several small springs, but at present the water sinks in the gulch gravels.

The region is about 45 miles southeast of the nearest railroad at Ely, Nev. This road—the Nevada Northern—is 140 miles long and connects with the Southern Pacific Railroad at Cobre, Nev. The wagon road to Ely is an excellent mountain road which crosses the

[a] Numbers in parenthesis refer to corresponding numbers in "List of recent publications" at end of this paper.

Schell Creek Range (see map, fig. 5) over a comparatively low pass with no very steep grades. Prior to September, 1906, the outlet to the railroad was via Osceola over the Snake Range to Newhouse, Utah, a distance of 100 miles.

GEOLOGY.

The rocks of the region are granites, which may be in part the oldest rocks; Cambrian argillites, quartzites, shales, and limestones, and an intrusive granite porphyry which is younger than any of the sedimentaries. Within the Tungsten mining district the only rocks exposed are the granite porphyry and the quartzites and argillites.

The granite porphyry ranges from fine to coarse in texture and from light to dark gray and red in color. It occupies the lower part of the mountain slope and forms a portion of a considerable mass which extends to the northeast for several miles and is exposed on the eastern side of the range. There seem to be slight indications of deformation within the eruptive mass, and contact metamorphism is developed only to a limited extent. Apparently the intrusion took place since the formation of the mountain range. In general character and mode of occurrence this intrusion of granite porphyry resembles many intrusive masses in other parts of Utah and Nevada. Some of these are known to be post-Carboniferous and they may be of much more recent occurrence.

The base of the sedimentary rocks is not exposed in the Tungsten mining district. Only a small area of purplish argillite is exposed in the northwest corner of the district, overlain by 100 to 200 feet of quartzite. The quartzites are gray, blue, and purple, the gray quartzite forming the larger part of the series. The strata are cut by many quartz veinlets which are probably of secondary origin, formed during the silicification of the original sandstone. The rocks are fine grained and the alteration by silicification is very complete. In thickness the beds range from a few inches to 2 feet. The argillite is a compact purple rock in rather thick layers. In this area it is little altered, but in other parts of this region the process of metamorphism has progressed much farther and the rock has been called "silvery slate."

GEOLOGIC STRUCTURE.

The Snake Range in this region is a quaquaversal dome, having its center near Wheeler Peak. Subsequent to the uplift there was an intrusion of a considerable mass of igneous rocks that tilted the beds to a high angle in some parts of the region and displaced them in others. The steep southerly dips in Wheeler Peak and the high ridges to the south flatten to 25° in the Tungsten district. North of Wheeler Peak the fold has been broken by several northeast-southwest faults of considerable displacement, the beds having a northeast-southwest strike and dipping 45° NW.

In the area shown on the map the metamorphism and deformation which accompanied the intrusion are not so extensive as in other parts of the region.

VEINS.

GENERAL DESCRIPTION.

The veins carrying the tungsten ore are not vertical, but pitch to the northwest or southeast at varying angles, ranging from 55° to 75°, the general direction being northeast and southwest. The actual outcrop is usually limited to a few feet. From the close proximity of some of the veins it might be considered that they are branches from a main vein, but neither outcrops nor underground workings have shown this to be the case. In some places the vein splits into several narrow veins separated by the country rock. Their occurrence is irregular and from the débris it appears probable that there are veins now covered by "slide rock." In width they range from a few inches to 3 feet. The composition of the vein material is essentially quartz and hübnerite, with here and there a little fluorite, pyrite, and scheelite. The quartz is compact and contains no pores, vugs, or honeycombed areas. A few assays have been made which show the presence of gold and silver, but the amount is small and no attempt has been made to recover it. Well-defined walls are of common occurrence, but they are not persistent.

OCCURRENCE OF THE TUNGSTEN ORES.

The hübnerite occurs irregularly through the vein material. In some places there has been a concentration of the ore near the walls. Hübnerite crystals, varying in size and completely surrounding the quartz crystals, and also quartz crystals inclosing the hübnerite, are abundant. The greater part of the ore is disseminated in fine grains through the quartz or in irregular massive bodies. Where the veins pinch to a few inches in width the hübnerite occurs in thin stringers or is interlaminated with the quartz. No wolframite has yet been determined from this region. In 1901 Dr. W. F. Hillebrand made a qualitative test of two or three specimens from the principal vein which showed the ore to be hübnerite. Scheelite has been found very sparsely disseminated in zones which appear to indicate shearing. It occurs in small flakes instead of the usual granular or massive forms.

EXTENT OF MINERALIZATION.

There appears to be a general consensus of opinion among prospectors and others interested in tungsten deposits that these ore-bearing veins do not extend in depth. No workings have thus far been put down which determine this point. It may be true that some, possibly most, of the individual veins do not extend to great depths. In considering the question of depth, however, it should be remembered that in this region the intrusive mass is a part of a magma of unknown depth, which has been forced through a considerable thickness of sedimentary strata. In the area under discussion erosion has removed at least 300 feet from the upper part of the principal vein. In the light of present knowledge of veins of this kind it seems probable that there may be ore-bearing veins within the igneous mass which have not yet been exposed by erosion.

ORIGIN OF THE VEINS.

The magma which intruded the sedimentary strata probably cooled entirely beneath the surface and is now exposed by erosion as a body of granite porphyry. Before complete consolidation the magma was subjected to strains which produced cracks and fissures. These fissures, varying in width and vertical extent, were distributed irregularly through a portion of the rock, but in the main strike in a nearly uniform direction. The latest phase of consolidation consisted in the deposition of the fissure filling by magmatic waters carrying in solution silica and a small amount of certain rare metals.

MINING DEVELOPMENTS.

About 30 claims have been located within the Tungsten mining district, and at present all of them are controlled by the Tungsten Mining and Milling Company.

The principal underground workings are on the Hub claim (No. 1 on map, fig. 13). Tunnel No. 1 (fig. 13) is 225 feet in length, and the face is 125 feet below the surface, which forms the deepest working on any of the veins. At 150 feet from the mouth of the tunnel an upraise has been made to join an incline from the surface. In this tunnel nearly all the various features described under the headings "Veins" and "Occurrence of the tungsten ore" are exhibited. The vein ranges from a few inches to 3 feet in width, strikes N. 68° E., and dips 65° NW. Present developments show that this is the largest and most prominently mineralized vein in the region. Tunnel No. 2 is about 125 feet vertically above No. 1 and is 59 feet in length. This portion of the vein is split into four parts, separated by the granite porphyry. There is about 18 inches of streaky ore in the face of this tunnel. Shaft No. 1 is 37 feet in depth. Near the surface the vein is pinched, but about midway of the shaft it is about 3 feet wide. Shaft No. 2 shows the vein about 30 inches in width, with a small amount of ore. In the face of the tunnel near shaft No. 2 the vein is 24 inches wide, with ore in streaks.

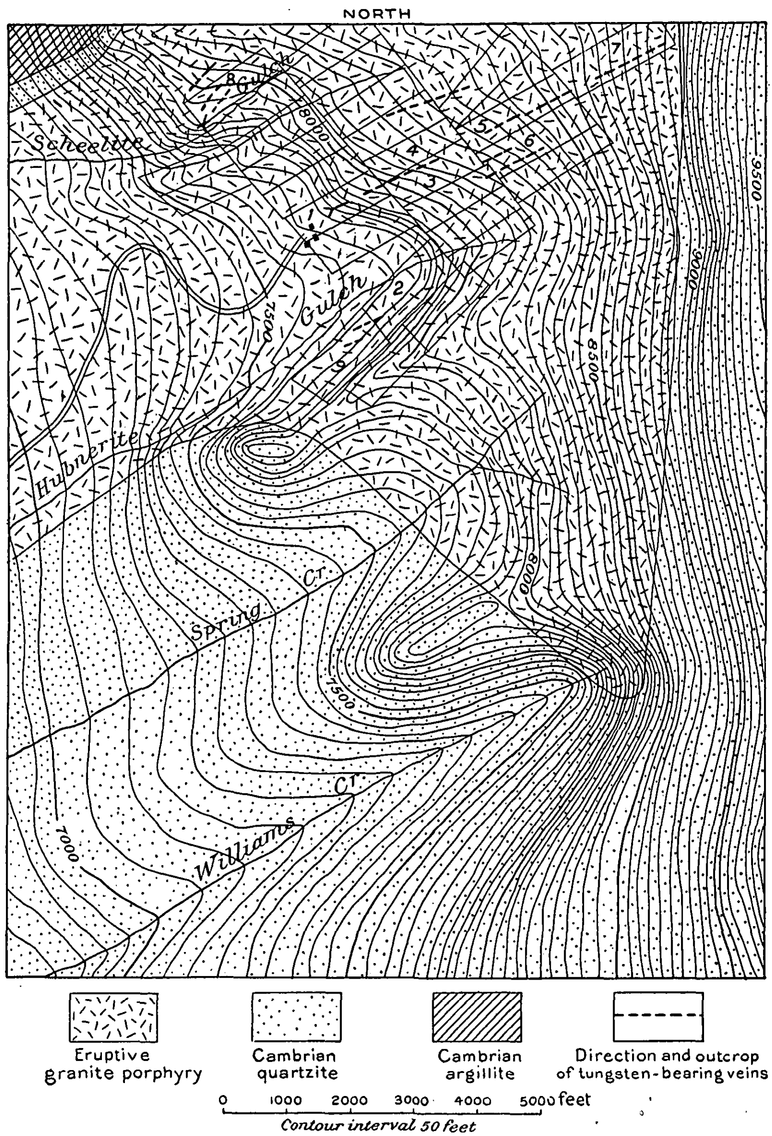

Fig. 13.—Geologic and topographic sketch map of Tungsten mining district, White Pine County, Nev.

On the slope below the outcrop of this vein several tons of ore, which was reported to average about 68 per cent of tungstic acid, were picked up among the "slide rock" and shipped before underground work was begun. Grains of hübnerite are disseminated through the finer material of the slope and the bottoms of the gulches. Considerable ore has also been gathered from time to time and added to the dumps.

The development work on the Tungsten claim (No. 3 on map) consists of two tunnels and a shaft. On the Wolframite and Great Eastern claims (Nos. 4 and 5 on map) are several small trenches exposing narrow veins with ore. On the Eagle claim (No. 7 on map), just below the contact of the granite porphyry and quartzite, the vein is exposed in a trench, standing nearly vertical and striking N. 40° E. Hübnerite with a small amount of scheelite is found here. In the quartzite débris it was found that small veinlets of quartz penetrate the quartzite, a few of them carrying a little hübnerite. It is probable that this ore occurs near the contact zone. The region is said to have been thoroughly prospected and very little material of this kind has been found in the quartzite, which therefore seems unlikely to yield a deposit of commercial importance.

In the Side Issue claim (No. 2 on map), on the south side of Hübnerite Gulch, a mineralized vein is exposed in a 10-foot cut pitching 80° S. and striking N. 45° E. On the lower side of the cut the vein is 2 feet wide and it is said that from this place a piece of solid hübnerite was taken weighing 114 pounds. On the upper side of the cut the vein is split into two 6-inch veins separated by 4 feet of granite porphyry. In the bottom of the gulch these veins have pinched to a thickness of 3 inches each. The country rock is a coarse-grained, light-colored porphyry which, it is said, can be worked more easily than the rock in other parts of the district.

On the Tungstic claim (No. 9 on map) is a 4-foot vein striking N. 65° E. which shows very little ore. About 50 feet above is a 3-foot quartz vein in which no ore was seen.

In the ridge west and a little north of the Hub claim a hübnerite-bearing vein is exposed in several places. Several small veins appear to extend in a direction about N. 60° E.

The Star claim (No. 8 on map) is developed by a tunnel 32 feet long in which the vein ranges from 6 inches to 2 feet in thickness, pitching 55° SE. and striking N. 30° E. In this tunnel scheelite associated with hübnerite occurs in larger quantity than in any other known locality in the district. About 55 feet and 70 feet south of this vein are two hübnerite-bearing veins striking N. 42° E. The country rock is granite porphyry of a more pronounced reddish color than in other parts of the area. A short distance north of the tunnel a 1-foot vein striking N. 42° E. and showing considerable hübnerite is exposed in a shallow trench.

METHODS OF MINING.

The vein material is exceedingly hard and difficult to mine. Drills quickly become dulled and the rock does not shoot well. The work is all done by hand labor and tunneling is said to cost nearly $30 per running foot. At present it would appear advisable to develop the vein by open cuts at different levels with a steel-lined shoot on the surface on each side—one to care for the waste and the other for the ore. A much larger amount of material would be dislodged by each shot than when confined in a tunnel or shaft. There would be no expense for hoisting and there would always be good light for sorting. In handling the material care should be taken to save the fines, as a considerable part of the hübnerite occurs in grains disseminated through the quartz. The scheelite also is likely to be thrown away in the waste on account of its general resemblance to quartz.

On account of the large percentage of waste a considerable amount of hand sorting is necessary. After crushing, the hübnerite is easily separated from the quartz. A hand-made jig, operated by horse-power, was used and afterwards replaced by a 5-horsepower gasoline engine.

SUMMARY.

The occurrence and character of the vein material vary so much within a few feet that the depth and width of the veins and the amount of hübnerite can not be estimated. Nature has, however, done much to assist in determining the other factors which affect the commercial value of these deposits. Several springs of small flow occur at a considerable elevation above the natural location for a concentrating plant and their combined flow would be sufficient for milling purposes. Williams Creek has an estimated flow of 700 cubic feet per minute and would furnish power to generate electricity for a mill and drilling purposes. There is still sufficient timber on the higher mountain slopes to furnish mine timbers. The lower slopes are covered in spots with mountain mahogany, which makes a good domestic fuel. There are ranches in the valley which could furnish general supplies. Railroad facilities are now at a considerable distance, but surveys have been made for a railroad to connect Ely with southwestern Nevada and Salt Lake to the northeast. One of these surveyed lines crosses the Schell Creek Range into Spring Valley opposite Osceola, about 20 miles north of the Tungsten mining district.

RECENT PUBLICATIONS RELATING TO THE OCCURRENCE OF TUNGSTEN ORES IN THE UNITED STATES.

1. Trans. Am. Inst. Min. Eng., vol. 28, 1899, pp. 543–546.
2. Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 6, 1901, pp. 319–320.
3. Mineral Resources U. S. for 1900, U. S. Geol. Survey, 1901, pp. 257–259.
4. Bull. South Dakota Geol. Survey No. 3, 1902.
5. Bull. South Dakota Geol. Survey No. 6, 1902.
6. Eng. and Min. Jour., vol. 73, 1902, pp. 304–305.
7. Mineral Resources U. S. for 1903, U. S. Geol. Survey, 1904, pp. 304–307.
8. Eng. and Min. Jour., vol. 78, 1904, p. 263.
9. Min. Reporter, vol. 50, 1904, p. 217.
10. Econ. Geology, vol. 2, 1907, pp. 453–463.
11. Eng. and Min. Jour., vol. 83, 1907, pp. 951–952.

NOTE ON A TUNGSTEN-BEARING VEIN NEAR RAYMOND, CAL.

By Frank L. Hess.

On the I. X. L. claim, located in the foothills of the Sierra Nevada about 12 miles north of Raymond, Madera County, Cal., a small amount of wolframite has been found in a vein which had been located for a copper property. The claim was visited by the writer in December, 1906.

The country rock is an andalusite mica schist, in which the andalusite is considerably crushed and altered. Numerous large, parallel, nearly vertical quartz veins cut the inclined schists and stand out prominently from the weathered surfaces, forming the summits of some of the hills. There are many copper stains in the rocks, and some ore is being mined from neighboring claims. Alongside the road are the ruins of an old smelter which, to judge from the remnants lying around, evidently ran on the oxidized copper ores many years ago.

No copper staining was seen upon this particular vein, which is from 4 to 16 inches wide where exposed. The vein is composed of a glassy quartz in which bunches of wolframite up to 2 or 3 pounds in weight were found. At a depth of 40 feet the vein pinched out entirely, though it could probably be picked up again by following down along the evident fault coincident with its dip. Only a small amount of wolframite, probably 200 or 300 pounds, is said to have been taken out. Pyrite is an accessory mineral.

MONAZITE DEPOSITS OF THE CAROLINAS.

By Douglas B. Sterrett.

INTRODUCTION.

Monazite has earned a prominent place in the commercial world through the rare-earth metal, thorium, which it carries as an accessory constituent. As a source of cerium and other rare-earth metals also, monazite is of great interest to chemists. In composition it is essentially an anhydrous phosphate of cerium, praseodymium, neodymium, and lanthanum in which thoria and silica are present in variable amounts. The amount of thoria in monazite ranges from less than 1 to 20 per cent or more, but its average amount in monazite obtained for commercial purposes varies between 3 and 9 per cent. Though sometimes found in large crystals and masses of many pounds' weight, monazite for economic purposes is obtained in the form of sand, occurring in opaque to translucent and in some cases transparent grains and crystals. Monazite ranges in color mainly from light yellow to reddish yellow and brown; some of it is greenish. The freshly broken and unaltered mineral has a resinous to adamantine luster, which is especially marked on the cleavage faces. The mineral is brittle and has a hardness of 5 to 5.5. It can readily be crushed between the teeth and yields a soft grit, quite distinct from the harder minerals sometimes mistaken for it. The specific gravity ranges from 4.9 to 5.3, and is generally over 5.

The principal use made of the thoria extracted from monazite is in the manufacture of incandescent mantles for gas lighting. These mantles are made by immersing sections of a cotton gauze or netting, woven in tubular form, in a saturated solution of the salts of certain rare earths. The composition of this mixture of salts used by different manufacturers is kept secret, but it is said to contain thorium largely in excess of the other constituents. The sections of the tubes are then dried after one end has been drawn in to the form of a mantle by a platinum wire. When dry, the organic matter of the cotton is burned off and the mantle is saturated with some form of wax, which holds it in shape during shipment and is readily burned off when it is set up for use.

The production of monazite in the United States for commercial purposes has, up to the present time, come entirely from North and South Carolina. The occurrence of the mineral and the development of the industry in these States have been described in reports by Henry B. C. Nitze,[a] Joseph Hyde Pratt,[b] L. C. Graton,[c] and the writer.[d]

The value of the production of monazite from the Carolinas is small compared with that of the more important minerals produced in the United States. The benefit to the region in which the monazite is mined, however, has been considerable. During the five years 1902 to 1906 there was produced in the Carolinas about 3,612,692 pounds of crude monazite, valued at $530,866. This includes a small quantity of zircon and tantalum minerals.[e] In 1906 the production was about 846,175 pounds of sand carrying 80 per cent of monazite. The value of this sand was $152,312, corresponding to a price of 18 cents per pound. During 1907 the activity in mining was not so great as in the two previous years, and the price paid for 80 or 90 per cent monazite sand was as low as 10 to 12 cents per pound.

The present paper is intended to furnish general information on monazite, including a description of the deposits in the Carolinas and of the occurrence of the mineral in them, with a discussion of their bearing on its origin. The data used were obtained during brief visits to different parts of the region during the last five years and a more detailed study of the formations in the southeastern part of the Morganton quadrangle, North Carolina, during the field seasons of 1906 and 1907.

Acknowledgment is here made for the courtesy and general information received from the various operators in the monazite field. Among these are Mr. George L. English, of the National Light and Thorium Company; Mr. W. F. Smith and Mr. M. E. Gettys, of the Carolinas Monazite Company; Mr. Hugh Stewart, formerly of the British Monazite Company; and Mr. Herman Wanke, of the German Monazite Company. Further acknowledgment is made to Mr. A. Keith for valuable criticism.

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[a] Monazite and monazite deposits in North Carolina: Bull. North Carolina Geol. Survey No. 9, 1895.

[b] Monazite: Mineral Resources U. S. for 1901 to 1905, U. S. Geol. Survey, 1902 to 1906. Also Mining industry in North Carolina, an annual publication of North Carolina Geol. Survey, 1901, 1903, 1904, and 1905.

[c] Gold and tin deposits of the southern Appalachians: Bull U. S. Geol. Survey No. 293, 1906, pp. 116–118.

[d] Monazite: Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907.

[e] Sterrett, D. B., op. cit., p. 1208.

GEOGRAPHY.

Geographically, the area in which deposits of monazite of commercial value have been found lies in the central portion of western North Carolina and in the extreme northwestern part of South Carolina. Fig. 14 shows the area containing monazite deposits of known commercial value. This area covers about 3,500 square miles and includes part or all of Alexander, Iredell, Caldwell, Catawba, Burke, McDowell, Gaston, Lincoln, Cleveland, Rutherford, and Polk counties in North Carolina, and Cherokee, Laurens, Spartanburg, Greenville, Pickens, Anderson, and Oconee counties in South Carolina. The larger towns within or near the monazite region are Statesville, Hickory, and Shelby in North Carolina, and Gaffney, Spartanburg, and Greenville in South Carolina. The appearance

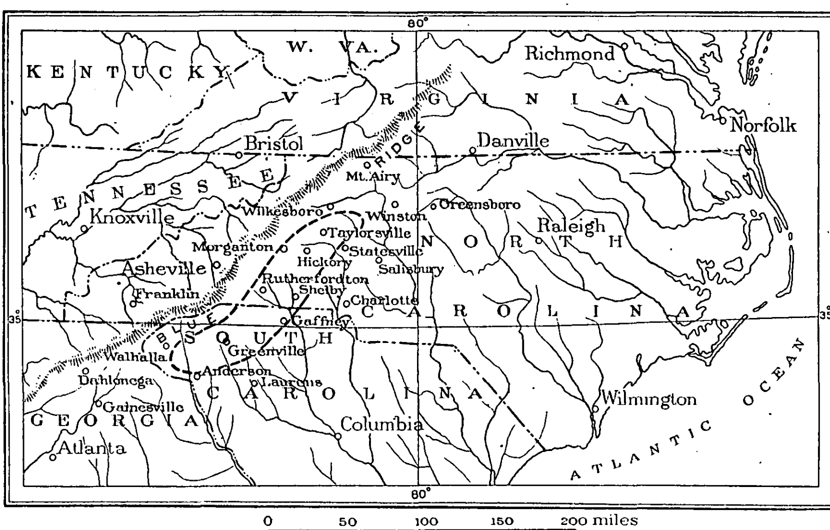

FIG. 14.—Map showing area of monazite deposits of known commercial value in southern Appalachian region.

of Alexander County, N. C., in the list of counties with valuable monazite deposits is the result of prospecting by mining companies during 1907.

PHYSIOGRAPHY.

Physiographically, North and South Carolina are divided into three parts. These are the Coastal Plain, extending from the Atlantic Ocean northwestward for 100 to 150 miles; the Piedmont Plateau, extending from the limits of the Coastal Plain northwestward for 100 to 130 miles to the foot of the Blue Ridge; and the mountain region, extending northwestward from the Piedmont Plateau to the State lines. The Coastal Plain and the Piedmont Plateau are prominent in both States, but only North Carolina contains a large portion of the mountain area.

The Coastal Plain is a broad, nearly flat stretch of country rising from sea level on the southeast to an elevation of a few hundred feet on the northwest, in which direction it is practically limited by the boundaries of the rock formations of which it is composed. The Piedmont Plateau is an elevated district rising from a few hundred feet above sea level on the southeast to 1,200 or 1,500 feet on the northwest. It forms a plateau much dissected by valleys from 50 to 200 or 300 feet deep, and its regularity is further disturbed by scattered mountain peaks and smaller hills rising above its general level. The features of the plateau are best observed from a prominent ridge or one of the smaller hills of the region. In the mountain region are included the Blue Ridge and its foothills, and the higher mountains to the northwest. The country in the mountain region is exceedingly rough, and the elevations range from 1,500 to over 6,500 feet.

The region in which valuable deposits of monazite have been found may be defined as a belt from 20 to 30 miles wide and over 150 miles long. (See fig. 14.) This belt lies wholly within the Piedmont Plateau and borders closely on the Blue Ridge, to whose general course it is roughly parallel.

GEOLOGY.

FORMATIONS.

The most important rocks of the monazite belt are gneisses and schists. These include the Carolina gneiss, the Roan gneiss, and gneissoid, porphyritic, and massive granites. Other rocks are pegmatite, peridotite and allied rocks, quartz diorite, and diabase.[a]

The oldest formation in the monazite region is of Archean age and is called the Carolina gneiss. It is the most extensive formation and appears in nearly every section. The composition and structure of the Carolina gneiss are varied. The most common types are mica, garnet, cyanite, and graphite gneisses and schists, or combinations of two or more of these types. These rocks range in color from light gray to dark gray, and in many places where graphite is abundant in them have a light bluish-gray to bluish-black cast. Some of the gneisses and schists are fine grained and are composed of several distinguishing minerals, as biotite, muscovite, cyanite in fine needles, and graphite, besides fine grains of quartz and other minerals; other rocks are composed of the same minerals in coarser grains or flakes. Garnet appears in both fine and coarse grained gneisses and schists and may be fairly large, even in the rocks of finer grain. The presence of much pegmatitic material is a characteristic feature of the Carolina gneiss.

[a] The formation names used in the description of these rocks are taken from Keith, A., Geologic Atlas U. S., folios 116 (Asheville), 124 (Mount Mitchell), and 147 (Pisgah), and others.

The Roan gneiss is the next oldest formation in the region and is also of Archean age. It consists of hornblende gneiss and schist, with here and there the less metamorphosed phase, diorite. The hornblende gneiss and schist are nearly black to dark green in color, and are composed chiefly of small interwoven and matted hornblende crystals. These hornblendic rocks grade into diorite, which is also dark colored but contains a noticeable amount of feldspar and has a granitoid texture. Bands of mica gneiss or schist are included in many both large and small masses of Roan gneiss. This formation is prominent along the northwest side of the monazite belt, throughout its length. In the central and more eastern portions, however, it is of less importance and in many places does not appear at all.

The age of many of the granites and granite gneisses has not been determined, though a part are probably Archean. In importance, granite and its different phases are second and are particularly prominent in many localities where extensive monazite deposits have been found. In composition the granite may be biotitic, muscovitic, or hornblendic; its texture may be porphyritic, massive, gneissic, or schistose. Where both porphyritic and schistose the feldspar phenocrysts generally assume an augen form, caused by crushing and elongation in the direction of shearing. Some large masses of granite gneiss have an abundant development of small red garnets. The occurrence of much quartz in veins and veinlets throughout the mass is a characteristic feature of most of the granites of this region. Some of this quartz is simply massive; at other places it has a more or less well-defined crystal form. Drusy surfaces are not uncommon on such crystals. The abundance of quartz veins is not invariably confined to the granite masses, but in numerous places extends some distance from the contact of the granite into adjacent formations.

Pegmatite is a common rock throughout the monazite region, especially in those areas where commercial deposits of monazite are found. Two principal occurrences of pegmatite are here recognized. In one it forms distinct masses or bodies with the typical composition and texture—that is, it is composed of quartz and feldspar, with or without mica and other accessory minerals, crystallized out on a large scale. The other type is a pegmatized gneiss, representing the addition of the pegmatite minerals to the gneiss, with perhaps some recrystallization of portions of the inclosing rocks. In some places secondary quartz is the principal mineral added, while feldspar appears in smaller quantities. In others the feldspar is more prominent, and is prone to assume a porphyritic form in the gneiss, producing a typical augen gneiss. Very commonly the gneisses and schists are banded with or cut at all angles by streaks of pegmatitic or granitic material. The recrystallization of the gneisses and schists, with the development of pegmatitic material or the injection of such material into the rocks, may be called pegmatization. In many places the process has gone so far that it is very difficult to distinguish pegmatized rock from granite gneiss, and especially from flow-banded and porphyritic granite gneiss. This difficulty is due partly to the fact that granite and pegmatite are composed of the same minerals and have no sharp division line between the size of their grains.

The peridotites are dark-green to greenish-black basic rocks, containing one or more of the ferromagnesian minerals olivine, pyroxene, and in places hornblende as chief constituents. So far as known the peridotites of this region are of Archean age and are apparently genetically connected with the Roan gneiss. Though composing but a very small part of the rocks of the monazite belt, the peridotites generally outcrop prominently wherever they occur, and many outcrops are marked by large rounded "nigger-head" bowlders scattered over the surface. For the most part the peridotites have altered to talcose or chloritic soapstone or to serpentine. This alteration is, in some places, only superficial, but in others whole masses have been so metamorphosed. The usual form of occurrence of the peridotites is in lens-shaped bodies parallel, or nearly so, to the schistosity of the inclosing rocks.

Quartz diorite of undetermined age is one of the less important intrusive rocks in the monazite region. It is a fine-textured rock, composed of granular quartz and feldspar with more or less hornblende, locally with garnet distributed promiscuously through it. The occurrence of quartz diorite is generally in small dikes ranging from a few inches up to several feet in thickness. The diminutive size of these dikes, however, is offset by their abundance and resistance to erosion, owing to which they leave much débris over many of their outcrops in the form of hard rounded bowlders.

Diabase is the latest intrusive rock known in the region and is probably of Triassic age. It is a dense, hard rock of dark-green to black color, composed chiefly of olivine and a feldspar rich in lime. It is rather abundant in places and the outcrop is generally marked by characteristic spheroidal "nigger-head" bowlders scattered over the surface. The diabase dikes range from a few inches up to 100 feet or so in thickness.

STRUCTURE.

The regional metamorphism, with accompanying folding and faulting, of the rocks in this area has been extreme. In many places, especially in the Carolina gneiss, it is very difficult to determine the original nature of the formations, for much of the sedimentary structure or igneous texture of the rocks has been destroyed by mashing and recrystallization. The Carolina gneiss has been intruded by rocks of later age and cut by them into irregular-shaped masses, many of which fork out into long tongues or occur as narrow streaks in the intrusives, or vice versa. There have been successive intrusions of igneous rocks of later age into the earlier formations. Thus the Carolina gneiss is cut by the Roan gneiss, and both are cut by granites of later age. Many of the granites have included blocks of the formation in which they have been intruded. In places the inclusion has been more or less absorbed by the surrounding granite, the composition of which has thereby been affected. Thus, where masses of hornblende gneiss are included in granite, the latter is generally highly hornblendic in their vicinity.

The structure of the pegmatite in the rocks of this region is extremely irregular. In some places the pegmatite occurs in the form of sheets or lenses interbedded and folded with the inclosing gneisses and schists. In other places it occurs in dikes, veins, or lenses either conformable with the inclosing rocks through part of its extent and cutting across them in other parts, or in irregular masses having no definite orientation with respect to the accompanying formations. In pegmatized rock masses the pegmatization has generally affected certain beds, which may grade into regular pegmatite in either the direction of their greatest or that of their least extension. In such rocks it is often impossible to determine the line of demarcation between the two. There is also a gradation between the pegmatized beds and ordinary gneiss.

Quartz diorite almost invariably occurs in small dikes, in places conformable with the schistosity of the country rock, though elsewhere cutting across it at all angles. The diabase dikes commonly cut across the strike and dip of all the older formations, filling a series of fissures which have a general northwest to north strike.

WEATHERING AND SOILS.

The rocks of the Piedmont Plateau have undergone such extensive weathering that good outcrops are the exception, and a thick mantle of residual soil covers much of the country. The variety of rock underlying certain soils can in many places be determined, unless decomposition has been too thorough, by studying the outcrops and graduations from such exposures into the residual soil.

The Carolina gneiss, on partial disintegration and decomposition, commonly forms a gravelly soil with a red clayey matrix. This is especially characteristic of the garnetiferous and graphite-cyanite types, which are abundant in parts of the monazite region. The pebbles are composed of small fragments of the original rock, such as tufts of cyanite impregnated with hematite or limonite, iron-stained garnets, or pieces of hematite. On more complete decomposition a fine reddish clayey soil results, with no decided characteristics. Other types of the Carolina gneiss, in which mica is an important constituent, leave a micaceous soil, much of which assumes a purplish color. Granite and its various phases, on partial disintegration and decomposition, yield light sandy soils. On more complete decomposition the granites yield soils of a light to dark reddish color, depending on the quantity of ferromagnesian minerals, as biotite or hornblende, in the original rock. The quartz grains of the granite remain as sand mixed through a clayey matrix. This quartz sand is almost everywhere to be seen at the immediate surface, from which the clays have been washed by rains. Where Carolina gneiss and granite are intimately associated, or where pegmatization has been extensive in a body of Carolina gneiss, there results a sandy soil, characteristic of granite, through which are scattered pebbles of hematite and ferruginous cyanite, characteristic of the Carolina gneiss. The relative importance of pebbles in such soils decreases as the quantity of pegmatite or of granite in the rock formations increases. These features of the soils are especially marked on the broad, flat ridges characterizing much of the Piedmont Plateau region. The roan gneiss leaves a greenish sandy soil on disintegration, and an ocher-yellow to dark reddish-brown or chocolate-colored clayey soil on decomposition. Black stains of manganese are associated with many of the soils derived from hornblendic rocks.

A clew to the nature of the rock formations in a given region is often furnished by the character of the gravels in the bottom lands and streams draining that region. Thus in this area a very light-colored gravel with much quartz débris indicates a granite or its contact or a very highly pegmatized country rock. Garnets and hematite iron ore, with which blocks of mica or cyanite gneiss are associated, indicate Carolina gneiss. Quantities of black sands in the stream gravels, containing magnetite, ilmenite, hornblende, etc., are characteristic of the Roan gneiss.

OCCURRENCE OF MONAZITE.

Up to the present time the only deposits of monazite successfully worked have been the gravel beds in streams and bottom lands, and in certain places surface soils adjoining rich gravel deposits. Prospecting and careful mill tests on monazite-bearing gneiss and schist have failed to discover deposits of a nature that could be worked extensively. The saprolite or rotted rock underlying some gravel deposits has been washed in small areas, with results reported to be favorable.

PLACERS.

Commercial deposits of monazite in gravel occur in the beds of creeks and streams and the bottom lands along them. The thickness of the gravels ranges from a foot or two, including overburden, to 6 or 8 or more feet. The distribution of the monazite in them is, as with all heavy minerals, richer near the bed rock and poorer above, grading into the overburden. In some deposits the whole bed, with the finer alluvium at the surface, is rich enough to be washed directly or sluiced down and washed. The extent and value of these deposits vary with the topography of the country and the nature of the gravels. The best deposits are more commonly associated with light-colored gravels and sands, containing considerable quartz débris and fragments of other light-colored rocks, such as pegmatite, granite, mica, and cyanite gneiss. On the other hand, the absence of much quartz and pegmatitic or granitic débris from the gravels is generally characteristic of low-grade deposits of monazite. The presence of black sands—magnetite, ilmenite, hornblende, etc.—in the gravels does not necessarily indicate a low-grade deposit, unless quartz and pegmatitic minerals are lacking also.

RESIDUAL DEPOSITS.

The surface soils on land adjoining some of the rich monazite deposits have been found to contain sufficient monazite to make sluicing down and concentrating profitable. This is the case to a depth of 3 or 4 inches or more in many residual soils that have suffered but little displacement on the surface, and to depths of several feet where the drift soil has collected on the gentle slopes below a steeper hillside. The partial concentration of monazite in the top layer of soil is caused by the washing away of the clay and other light decomposition products of the rock. The supply of monazite in the stream gravels in favorable areas is often replenished by the wash from the hillside soils during rains. This is especially true where the hills have any considerable slope and the land is cultivated. Under such conditions it is frequently profitable to work the stream gravels two or more times in a year.

The saprolite or rotted rock underlying the richer deposits of monazite is at some places sluiced down to depths of a few inches to a foot or so, along with the overlying gravels. At other places small amounts are removed and washed separately for the monazite they contain. The formations that have been found especially favorable for such work are highly pegmatized gneiss or schist. Such deposits have generally soon been lost or grown poor, probably on account of the fact that the miners have cut through the richer bed or failed to follow it in the direction of its extension. The occurrence of monazite in saprolite will be considered along with the occurrence of monazite in hard rock formations, as the former is merely an altered phase of the latter.

MONAZITE IN ROCK FORMATIONS.

Two separate companies have, at different times, undertaken to work a deposit of monazite-bearing rock about 3 miles northeast of Shelby, N. C. In each case the undertaking failed, because it was impossible to obtain sufficient ore of the high grade necessary to make the operations a success. At a number of the placer deposits ledges of rock have been found, either in the bed of the streams or near by, which contained monazite in noticeable quantity. So far the rock in which the monazite has been found in noticeable amounts is pegmatized gneiss.

It is possible at many of the mines to pan the saprolitic pegmatized gneiss under the monazite-bearing gravels almost at random and obtain monazite. The amount of the mineral obtained when the panning is done with a long-handled shovel ranges from a few grains to a teaspoonful per shovelful, according to the richness of the beds. Mr. George L. English has kindly furnished the results of a test made by him on the monazite content of the saprolite underlying the gravels at the F. K. McClurd mine, near Carpenter Knob, Cleveland County, N. C. From 30 cubic feet of saprolite 424 grams of concentrates, carrying about 40 per cent of monazite, were obtained by washing in a sluice box. This approximates closely one-third of a pound of pure monazite to a cubic yard of saprolite.

The monazite content of the rock at the deposit 3 miles northeast of Shelby, N. C., has been given a thorough test with a well-equipped mill by the British Monazite Company. The following data are given through the courtesy of Mr. Hugh Stewart, by whom the tests were made. Practically all of the rock at the mine, through a vertical height of 15 to 18 feet across the bedding, carried monazite. The quantity in different beds ranged from 0.03 per cent and less up to 1.10 per cent and more. While the mill was in operation all beds carrying 0.4 to 0.5 per cent or more were treated as ore, while lower-grade material was discarded. According to Mr. Stewart, one ore bed with a thickness of about 3½ feet was found to average 1.10 per cent of monazite.

Most of the pegmatized gneiss bodies which are rich in monazite represent phases of the Carolina gneiss in which the original nature of the rock has been largely obliterated as a result of the addition of new minerals and the recrystallization of the original ores into pegmatitic material. The texture developed during this pegmatization is generally porphyritic, in which the feldspar phenocrysts assume somewhat of an augen form. The feldspar phenocrysts range in size from those smaller than a grain of wheat to those the size of a walnut. The porphyritic gneiss may grade into less or more highly pegmatized gneiss, and from the latter into regular pegmatite. This gradation may be between two separate beds or from one part to another of the same bed. In those beds or portions of beds where there has been little pegmatization monazite occurs sparingly. The same is true where pegmatization has been complete and but little of the original gneiss remains. It is, then, the beds of gneissic rock which are rich in secondary quartz and contain numerous small masses of feldspar throughout that carry the most monazite. In such rocks there is generally much biotite, with graphite and perhaps some muscovite and other accessory minerals, as well as abundant quartz and feldspar. The quartz occurs in layers or scattered grains throughout the rock, inclosing and replacing the other constituents. The feldspar crystals chiefly replace, though they partly displace, the other minerals of the rock. Monazite in a rock matrix almost invariably possesses crystal form, in places having brilliant faces and sharp angles.

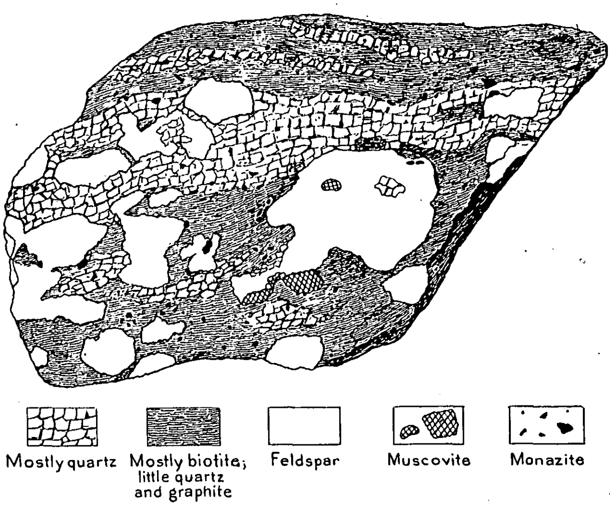

FIG. 15.—Hand specimen of monazite-bearing rock from British Monazite Company's mine, 3 miles northeast of Shelby, N. C. Three-fourths natural size.

As a typical example of rich monazite-bearing rock, that from the British Monazite Company's mine, 3 miles northeast of Shelby, is chosen for description. Fig. 15 represents a section across a hand specimen of this rock and shows the main features to which attention will be called below. The chief constituents of this rock are quartz, feldspar (mostly the potash variety), biotite, graphite, muscovite, monazite, and a little zircon. It has a banded structure caused by the more or less separate occurrences of certain minerals arranged in parallel streaks, with a roughly parallel orientation of the crystals or grains of each mineral. The principal features of the banding as seen in the section consist of one large quartz streak with several smaller streaks and individual grains in a regular biotite schist. The other minerals of the section occupy various positions and show diverse relations to the minerals of these bands and to each other. The feldspar is porphyritic and occurs chiefly in individual crystals, some of which are of considerable size. A number of the feldspar phenocrysts are small bodies of pegmatite in themselves. As an example, the largest feldspar crystal shown in the section includes both quartz and muscovite. The feldspar at the lower left-hand side of this crystal also has much quartz and muscovite associated with it. As shown in the section, the feldspar phenocrysts replace the other minerals. This replacement is especially well shown by the interruption, with but little displacement, of the lower biotite band by the large crystal described above. Graphite occurs in large amounts with biotite, though it is associated with nearly every other mineral of the rock. Where present, muscovite is chiefly associated with the feldspar. Monazite seems to be indiscriminately scattered through the rock, included in or associated with all the foregoing minerals. Though generally free from inclusions it is not invariably so, and in one case a plate of graphite was observed within a monazite crystal. All the minerals observed in the rock, with the exception of zircon, have been noted as inclusions in the feldspar phenocrysts.

In microscopic sections cut from specimens from one of the ore streaks, the minerals described above were observed, together with some iron staining. The feldspar is principally orthoclase and microcline, partially kaolinized. The quartz is plainly secondary, and occurs in bands or streaks of grains parallel with the schistosity of the rock. In some places the quartz has been deposited in the fractures or between the grains of other minerals; in others it replaces or includes fragments of such minerals as biotite and graphite.

Gas cavities and inclusions of very fine acicular needles, probably rutile, are abundant in the quartz. Biotite occurs in interwoven laths and crystals roughly parallel to the banding of the rock. The pleochroism of the biotite is light yellow-brown to greenish brown or dark purplish red. Graphite occurs as plates and laths, in general lying parallel to the banding of the rock. Some of it is interbanded and even interleaved with biotite; elsewhere the plates are turned across the foliation. In one section a lath of graphite was observed inclosed in quartz which filled a fracture across the foliation of a biotite crystal. Monazite occurs in contact with the various minerals of the sections, though it is more commonly surrounded by or included in grains of biotite and quartz. The position of the monazite in the biotite indicates replacement, and the biotite foliæ are not displaced around the crystals. In the microscopic sections sufficient feldspar was not observed to determine its relation to the other minerals.

The rock has been so thoroughly recrystallized that it is difficult to give the relative order of formation of the minerals. Biotite, if not still in its original condition, was probably the first mineral to form during recrystallization. Part of the graphite was probably contemporaneous with the biotite. Some, however, was introduced later and formed at the same time with the quartz. The small amount of muscovite in the rock was probably next to form, followed closely by quartz. From the small amount of feldspar in the microscopic sections, it was not possible to state its relative period of formation. From the hand specimen, however, shown in fig. 15, it is evident that the feldspar was introduced later than the quartz, or possibly contemporaneously with part of it.

ORIGIN OF MONAZITE.

Monazite has been observed in pegmatite, pegmatized gneisses and schists, and granite gneiss. The occurrence of monazite in pegmatite is that of an accessory original constituent, with the crystal form more or less well developed. But few occurrences in granites have been observed by the writer, and those were in highly gneissic porphyritic granite. The occurrence in pegmatized gneisses and schists indicates either a gathering together of the proper elements from the original rock and their formation into monazite during recrystallization, or the introduction of the proper elements from external sources, along with the materials causing pegmatization. It is probable that pegmatization in which much quartz with but little feldspar has formed represents a phase of recrystallization, in which the quartz may either, in part or wholly, have come from the original rock itself or may have been added by solutions passing through the formations. In either case the materials do not represent the work of active magmatic solutions or magmas such as might give rise to regular pegmatite bodies. In those recrystallized or pegmatized rocks where the feldspathic component of pegmatite is not plentiful, monazite occurs but sparingly. On the other hand, monazite is found more abundantly in rock formations in which feldspar plays a prominent part. The common proximity of this form of pegmatization to granite masses gives evidence of its formation through magmatic agencies. Such pegmatized gneisses are probably the result of active magmatic solutions passing through the rock, both aiding in recrystallization of the original constituents, and depositing the materials held in solution when conditions of temperature or agents of precipitation were favorable. As evidence in favor of the association of monazite with the agencies that produce pegmatite may be cited the occurrence of large crystals of that mineral in the pegmatite worked for mica in Mitchell County, N. C.

The monazite of rock formations has, then, probably been derived from aqueo-igneous solutions such as give rise to certain forms of pegmatite and have in these cases affected large masses of rock.

SUMMARY.

The commercial value of monazite is due to the presence in the mineral of a small percentage of thorium. This element forms the basis for the manufacture of various forms of incandescent gas lights. The value of the production of monazite in the United States is small compared to that of other important minerals. Monazite deposits of commercial value have been found within an area of about 3,500 square miles, lying wholly in the Piedmont Plateau region of North and South Carolina. The principal rocks of this region are mica, garnet, cyanite, graphite, hornblende and granite gneisses and schists, massive granite, pegmatite, peridotite, quartz diorite, and diabase. The structure of the rock formations is complex and in many localities metamorphism has been so extensive that the original nature of the rocks can not be determined. The rocks are in many places concealed by a heavy mantle of residual soil, but their character can often be learned by a study of these soils.

The only deposits of monazite that have been extensively and successfully worked are placers. These deposits are richest in regions where granitic rocks and pegmatized gneisses and schists abound. Residual surface soils and monazite-bearing saprolite are in some places sluiced down from small areas and concentrated. The best-known occurrence of monazite in a rock matrix is in porphyritic pegmatized gneiss. In ordinary gneiss and in highly pegmatized gneiss, in which the pegmatite is so abundant that but little of the original rock remains, monazite occurs sparingly. In beds where pegmatization is prominent but not extreme monazite occurs more plentifully. Monazite in pegmatized gneiss is thought to be derived from aqueo-igneous solutions passing through the rock and depositing and recrystallizing portions of it into the minerals of pegmatite.

MINERALS OF THE RARE-EARTH METALS AT BARINGER HILL, LLANO COUNTY, TEX.

By Frank L. Hess.

GENERAL DESCRIPTION OF THE DEPOSIT.

Baringer Hill is located about 100 miles northwest of Austin, Tex., on the west bank of Colorado River, near the western edge of the Burnet quadrangle as mapped by the United States Geological Survey. It is 12 miles north of Kingsland, the nearest railroad point, 16 miles west of Burnet, and 22 miles northeast of the town of Llano. It is a low mound rising above the flood plain of the Colorado, and formed by the resistance to erosion of a pegmatite dike intruded in a porphyritic granite.

Few if any other deposits in the world, and certainly no other in America, outside of the monazite localities, have yielded such amounts of the rare-earth metal minerals as Baringer Hill.

The writer visited this region in the latter part of February, 1907, fortunately at a time when Mr. William E. Hidden, who has been largely instrumental in making this locality famous through his contributions to mineralogical literature on the rare minerals found here, was conducting mining operations.

The hill is named for John Baringer, who discovered in it large amounts of gadolinite about 1887. No one in the neighborhood knew what the mineral was and specimens were sent to a number of places before it was identified. A piece fell into the hands of Mr. Hidden, who at once looked up the deposit and afterwards obtained possession of the property. Meanwhile Mr. Baringer had taken out a quantity of gadolinite estimated at 800 to 1,200 pounds, which was largely picked up and carried off by persons in the neighborhood as curiosities. Some of the choicer pieces, showing crystal form, found their way into various museums. The property is now controlled by the Nernst Lamp Company, of Pittsburg, Pa., and is worked by that concern for yttria minerals. Since its acquirement by this company a considerable amount of work has been done on the deposit, consisting mostly of open cuts around the edge of the pegmatite, reaching a depth of 30 or 40 feet. A large block, 30 feet in height and more in diameter, consisting mostly of quartz, is left standing in the middle.

In general the "Llano region," in the heart of which Baringer Hill is located, is an island of pre-Cambrian rocks intruded by plutonics and surrounded by an irregular zone of Cambrian and other Paleozoics, including some that are possibly Devonian and some Carboniferous rocks. The inner portion includes parts of Burnet, Llano, and Mason counties, and is situated at almost the geographic center of Texas. The history of this island has been considerably discussed, and views differ as to whether it was an island during the deposition of the Cretaceous, by which the area is almost entirely surrounded, or whether it has been exposed by denudation of the later rocks. The coal measures extend to the north from the region, giving some evidence of an area of high land previous to the deposition of the Cretaceous. Personally, the writer is inclined to agree with the view that the region has been denuded, although his investigations have been but superficial. The plutonics are granitoid rocks of many textures, and differ considerably in composition. Large areas are composed of the rather coarse red granite, the principal outcrops of which occur near Marble Falls and from which the State capitol of Texas was built. Peculiar dikes of a chocolate-brown granite near Llano contain blue quartz.[a]

Other dikes containing this blue quartz are of a reddish color. In many localities the granite is very porphyritic, containing feldspars from 1 inch to 2 inches in longer diameter. There are also gray and fine-grained red granites, and in some places they have taken a gneissoid form. The granites are, at least in part, intrusive in crystalline schists and gneisses of uncertain origin, which are here and there graphitic and contain interbedded strata of crystalline limestone. There are some later dikes of diabasic character, which are comparatively fresh. Southwest of Llano are areas of serpentine and other basic rocks.

In many places the granites are cut by pegmatite dikes, ranging in width from a few inches to 60 feet, which show a much greater percentage of quartz than of feldspar and other constituents, and afford beautiful illustrations of the most acidic phase of pegmatites. In a 6-inch dike there may be but a few feldspar crystals from 1 inch to 3 inches long fringing the edges of the dike; in other dikes, or in other portions of the same dike, gradations from pure quartz to almost pure feldspar may be observed.

Baringer Hill is formed by such a dike on a huge scale. It is a small mound which, before mining was begun, rose perhaps 40 feet

[a] Described by Joseph P. Iddings, Quartz-feldspar porphyry (graniphyro-liparose-alaskose) from Llano, Tex.: Jour. Geol., vol. 12, 1904, pp. 225–331.

above a surrounding flat, was about 100 feet wide, and from 200 to 250 feet long. The longer axis runs east and west and is nearly at right angles to the course of the Colorado River at this point. The country rock is a coarse porphyritic granite with feldspar phenocrysts about 1 inch long. This granite seems to weather and erode rather easily, and the river has cut a flood plain perhaps one-fourth of a mile wide at this point, while the dike, owing to its greater hardness and freshness, has better withstood the erosion. The pegmatite, an unsymmetrical body with irregular walls, is intruded into the granite in what seems to be a pipe or short dike.

At the edges of the intrusion is a graphic granite of peculiar beauty and definite structure, being more like the text-book illustrations than the usual graphic granite found in the field. The altered band is from 1 foot to 5 or 6 feet thick, and apparently surrounds the pegmatite. No segregation of the feldspar or quartz in particular parts of the dike can be noted, except that the feldspar may possibly be more inclined to occupy the sides of the intrusion. As far as shown it occupies most of the western and southern sides, and the quartz occupies the center and much of the eastern side.

One quartz mass is more than 40 feet across. The quartz has distinct white bands, from one-eighth to one-half inch wide, which seem to be due to a movement akin to flowage and are similar to those found in many pegmatitic masses in other portions of the country. The white banding is due to small liquid inclusions, many of them containing bubbles which either do not move from change of inclination of the fragment containing them, or do so but slowly. The cavities are minute, largely of irregular, angular shapes, suggesting at first glance particles of broken minerals, and occur in straight or broken lines that probably follow fine cracks which were later cemented. Groups of these cracks, with their inclusions, form the bands, which seem to lie approximately parallel to the walls of the dike or at such angles with them as might easily be formed by the flowage of the material into the space it occupied in the granite. The condition of the quartz seems to show that the pegmatite, after being forced into the granite, partly cooled and solidified and then made another small movement, or a series of slight movements, at which time the minute fractures were formed in the quartz and the magmatic fluids were forced into them, but as the mass was not yet totally solidified the cracks were effectually healed and the fluid was inclosed. Such movements may be supposed to have been consequent on the readjustment of the mass on cooling. Between the fracture bands the quartz is glassy and clear. At one place a vug was found large enough for a man to enter, lined with "smoky" quartz crystals reaching 1,000 pounds or more in weight. This would seem to indicate that the pegmatite had been intruded in a pasty or semifluid condition and that the vugs represent the spaces occupied by segregated water that was squeezed from the magma as the minerals took their final solidified form.

The feldspar is an intergrowth of microcline and albite, of a brownish flesh color, beautifully fresh, and occurs (1) in large masses reaching over 30 feet in diameter, and (2) as huge crystals, many of which, though they rarely show terminal planes, have one or more sharply defined edges, especially where partially surrounded by quartz. An edge 34 inches long was measured on one crystal thus embedded. A smaller crystal was seen which was about a foot long, weighed perhaps 20 pounds, and showed fine terminations and twinning planes.

A large amount of feldspar has been mined and thrown on the dump, and it is possible that in time the dump material may be utilized, either for its potassium content, as a fertilizer, or for pottery making.

Large crystals of fluorspar, measuring a foot along the edge, occur in the quartz, but this mineral does not form any considerable percentage of the mass. The fluorspar ranges from almost colorless to violet so dark that it is practically opaque. Where found alone in the quartz it was, so far as observed, of lighter color than where found with dark-colored minerals. Mr. Hidden informed the writer that it sometimes becomes luminous at the temperature of a living room.

Ilmenite occurs in radiating bunches of sheets or blades ranging from 1 inch to 10 or 11 inches in width and from one-sixteenth to one-fourth of an inch in thickness. In cross section the ilmenite looks like the ribs of a fan, with the outer ends from one-fourth to three-fourths of an inch apart. Similar aggregations take different angles, and numbers of such groups are found lying close together. With them occurs biotite mica in like bunches, the sheets of which are said to reach 3 feet in width by an inch in thickness. The mica is reported by Mr. Hidden to contain cæsium and rubidium, and to be close to lepidomelane in constitution. Small flakes of lithia mica reaching half an inch in diameter are found, generally along cracks in the quartz. No muscovite was seen, but it is said to be found occasionally. Compared with the mass the total amount of mica is very small.

THE RARE-EARTH MINERALS.

The greatest interest in the dike centers in the accessory minerals, particularly in the occurrence of the rare-earth metal minerals, which, as stated, probably have never been found at any other place in such large masses and in such quantities as in this locality. So far the excavations are comparatively shallow, and such minerals as are found are more or less weathered. Many show their crystalline form, but owing to alteration the crystals are now imperfect.

Allanite, a variable silicate of calcium, iron, aluminum, and the cerium metals (cerium, praseodymium, neodymium, and lanthanum), and in smaller amount those of the yttrium group, occurs in large masses, one of which weighed 300 pounds and was embedded in purple fluorspar. It is a dense black mineral with a fine luster, and a hardness of about 6. Around the edges and along cracks it shows alteration to a brown substance having a hardness of about 5.5. The percentage of yttria ordinarily occurring in allanite is small and rarely exceeds 2½ per cent.

Cyrtolite is rather common in the dike in peculiarly fine, polysynthetic groupings with curved faces. It is brown on the surface, with a darker or nearly black interior, and is evidently a mixture of substances. It carries a considerable amount of zirconia and some yttria, and is supposed by Mr. Hidden to be an alteration product of zircon. If it is such a derivative, the original mineral was probably much more complicated than ordinary zircon. It makes a fair radiograph, which also gives evidence of its nonhomogeneity.

Fergusonite, a variable columbate of the yttrium group and other of the rare-earth metals, occurs in four varieties, so different as to be almost distinct minerals. The difference between them is due to oxidation and hydration. No anhydrous varieties are found. It is found in crystalline form surrounded by decomposition zones. Bunches of irregular crystals have been broken out, weighing over 65 pounds. It is generally a mixture of minerals, as may be easily seen on a smooth surface, from the different colors. The difference in composition is strikingly shown in a radiograph, the variations being marked by difference in radiation. According to the two analyses by Hidden and Mackintosh,[a] the fergusonite obtained here carries from 31.36 to 42.33 per cent of yttria and accompanying rare-earth metals, and 42.79 to 46.27 per cent of columbium dioxide. The two analyses give 1.54 per cent and 7.05 per cent of uranium oxides. These are probably very irregularly distributed through the material, as shown both by the mineral itself and especially by its radiographs, which are of striking beauty.

Gadolinite, a silicate of beryllium, iron, and yttrium, is the most important of the minerals found here. It contains about 42 per cent of the yttrium oxides, with a molecular weight of 260, and occurs in crystals and masses of irregular shape up to 200 pounds in weight. The outer portion of the mineral and that adjacent to the cracks is altered to dense brick-red material, but the mineral

[a] Hidden, W. E., and Mackintosh, J. B., Yttria and thoria minerals from Llano County, Tex.: Am. Jour. Sci., 3d ser., vol. 38, 1889, pp. 483–484. The minerals of this locality have been well described by these writers in a number of papers.

itself is of a fine, glassy black, with a smooth conchoidal fracture. Thin splinters are bottle-green in color. It has a specific gravity of a little over 4.2, and a hardness of 6.5 to 7. A specimen collected makes no impression on a photographic plate with fifty hours' exposure.

Polycrase, a columbate and titanate of yttrium, erbium, cerium, and uranium, occurs in grains, small masses, and plates, the last associated with ilmenite in such a manner as to suggest the probability of replacement. It normally contains between 20 and 30 per cent of yttrium oxide, but is in too small amount to be commercially important. It is very radioactive, and quickly affects a photographic plate.

Other rare-earth metal minerals found in the dike are yttrialite, rowlandite, nivenite, gummite of several varieties, thorogummite, mackintoshite, and tengerite. These minerals are apt to occur in any part of the dike, either in the quartz or the feldspar, but have so far been found mostly along the outer portions. A peculiarity of their occurrence is that they are found in bunches from which, if in quartz, radial cracks extend in every direction, and by following such cracks the minerals are found. An illustration of such an occurrence was published by William E. Hidden in 1905.[a] The cause of these "stars," as they have been called by Mr. Hidden, is not clear, but the thought suggests itself that the rare-earth metal minerals may have crystallized first from the magma, and the solidifying quartz, being unable otherwise to accommodate itself to the incompressible nucleus, cracked in this manner.

Mr. Hidden stated that in mining ore of the largest pockets the faces and hands of himself and his assistant were affected as if by sunburn, and, as in sunburn, the covered flesh was not irritated. He suggested radioactivity as the cause, and inasmuch as the minerals under consideration are radioactive, the explanation seems plausible.[b]

The following was given by Mr. Hidden in a personal communication as a complete list of the minerals found in Baringer Hill:

Minerals found in Baringer Hill, Llano County, Tex.

SILICATES.

Albite; Microcline; } occur as intergrowths making up the mass of the feldspar.

Allanite; a variable silicate of calcium, iron, the cerium metals, and less amounts of the yttrium group, in masses weighing up to 300 pounds, embedded in purple fluor spar.

Biotite; close to lepidomelane.

Cyrtolite; hydrated silicate of zirconium, yttrium, and cerium. Radioactive, abundant.

[a] Some results of late mineral research in Llano County, Tex.: Am. Jour. Sci., 4th ser., vol. 19, 1905, p. 432.

[b] Mr. Hidden has described this incident in the article referred to above.

Gadolinite; a silicate of beryllium, iron, and yttrium in masses weighing up to 200 pounds.

Lithia mica; apparently a later deposition in cracks in quartz. Small flakes one-half inch or less across.

Orthoclase; not abundant.

Yttrialite; an anhydrous silicate of thoria, yttrium, and cerium earths. Contains about 30 per cent silica, 46 per cent yttria, 10 to 12 per cent thoria, and 5 to 6 per cent ceria. Does not occur in large quantity.

Rowlandite; practically a hydrated yttrium silicate. Contains 5 per cent fluorine.

COLUMBATES.

Fergusonite; four varieties, due to oxidation and hydration. Neither is anhydrous. Purest, 5.65 specific gravity. So different as to be almost distinct minerals. Crystals surrounded by decomposition zones.

Polycrase; columbate and titanate of yttrium, erbium, cerium, and uranium. Contains about 25 per cent of yttria.

OXIDES.

Hematite; specular, small quantity.

Magnetite; without metallic acids or rare earths.

Ilmenite; iron-titanium oxide in beautiful crystals, as well as plates up to 8 or 9 inches broad.

Rutile; titanium oxide, in prismatic and reticulated forms one-fourth inch thick.

Quartz; large masses and crystals of white quartz and "smoky" crystals up to 1,000 pounds in weight. Amethysts of gem quality reach 1 inch by one-half inch.

URANATES.

Mackintoshite; 3 parts thorite to 1 part uraninite; contains 13 per cent silica and a small amount of yttria. Radioactive; several times more so than its alteration product.

Thorogummite; formed from mackintoshite by addition of H_2O and alteration of UO_2 to UO_3.

Nivenite; a uranate of uranium, thorium, yttrium, and lead. Contains 10 per cent of lead. The most soluble uranate yet discovered; soluble in 5 per cent solution of SO_3. Prints well and gives great detail. Occurs in cubes and masses. (See Dana's System of Mineralogy, p. 889, for two analyses.) Alters to gummite.

Gummite; several varieties.

PHOSPHATE.

Autunite; hydrous phosphate of uranium and calcium; secondary, not analyzed.

CARBONATES.

Tengerite; carbonate of yttrium and beryllium. Generally globular, but occurs also as crystals up to one-sixteenth inch in length singly and as little nests. May be a mixture of beryllium and yttrium carbonates.

Lanthanite; carbonate of lanthanum, containing also cerium, praseodymium, and calcium. In incrustations on allanite.

SULPHIDES.

Chalcopyrite; iron-copper sulphide, massive, in small amount.
Pyrite; iron sulphide, cubic and octahedral.
Sphalerite; zinc sulphide; the purest fergusonite contains some zinc.
Molybdenite; molybdenum sulphide in scales 5 inches wide, which form masses weighing up to 10½ pounds. Alters to powellite.

MOLYBDATE.

Powellite; calcium molybdate, in white crusts lining cavities where MbS has been. Sugary white radiating or plumose crystals, one-fourth to three-fourths inch long. Locally greenish.

It is interesting to note that among the numerous minerals in this dike no tourmaline, zircon, beryl, monazite, cassiterite, garnet, or tungsten minerals have been found. Cassiterite has been reported from the neighborhood, but its occurrence is extremely doubtful.

With the exception of the alteration products and probably of the lithia mica, which, as noted, occurs along cracks in the quartz, all the minerals are believed to be original constituents of the dike.

The possibility of finding dikes having a like variety of minerals at once suggests itself, and much prospecting has been done for them. A few specimens of the rare-earth metal minerals have been found at other places in the neighborhood, but only a few, and in small quantity. However, similar dikes occur, as already stated, and these have not all been thoroughly investigated. It is to be remembered that these minerals form but a small fraction of 1 per cent of the mass, and it might easily happen that comparatively large amounts could exist in a dike and not be exposed at the outcrop. They are minerals which are altered to softer products by exposure, and would thus be easily removed by erosion and weathering. The cracks surrounding nuclei of the minerals should be useful in prospecting.

ECONOMIC VALUE.

The economic interest in the rare-earth metal minerals centers in their incandescence on being heated, and owing to this property they have been much sought. Thoria, beryllia, yttria, and zirconia show it in the greatest degree. It was found, however, that thoria and beryllia, which form the bulk of the incandescent oxides used in gas mantles are too easily volatilized to be used in an electric glower, such as that of the Nernst lamp. Yttria and zirconia, however, will stand the necessary high temperature. Up to the discovery of this deposit it was practically impossible to get sufficient yttria-bearing minerals to manufacture the lamps, but fergusonite and gadolinite, with lesser amounts of cyrtolite, are found here in large enough quantity to meet the requirements. The zirconia is obtained from zircon brought from other localities.

In the manufacture of the glowers for the Nernst lamp, a paste consisting of 25 per cent of yttria and 75 per cent of zirconia is squirted into strips of the proper thickness, baked, and cut into the required lengths. When cold the mixture is nonconducting, but after being heated it becomes a conductor and gives a brilliant light.

The needs of the Nernst Lamp Company, which owns the deposit, require only the occasional working of the mine. After enough yttria minerals are obtained to supply its wants for a few months ahead the mine is closed. But a few hundred pounds per year are extracted.

TIN ORE AT SPOKANE, WASH.

By Arthur J. Collier.

INTRODUCTION.

One of the mineral discoveries reported during the year 1907 which has attracted considerable attention is that of tin ore at Silver Hill, southeast of Spokane, Wash. Prospects of silver-bearing galena had been known at this place, and a search for metalliferous minerals and also for coal had been carried on here for several years. The tin-bearing mineral, cassiterite, was identified as such by Richard Marsh, of Spokane, in the summer of 1906, but prospecting for tin was not commenced before March, 1907. By the 1st of June several carloads of selected ore had been mined and piled on the dump. The first authentic report of this discovery published outside of the local newspapers was by A. R. Whitman,[a] of Spokane, June 1, 1907.

As the locality is a new one for tin ore, none having been previously reported from the State of Washington, the writer spent several days early in the season examining the prospects, and again visited the region in October to note the developments made during the summer. The owners, Messrs. Charles Robbins and Richard Marsh, of Spokane, provided every facility for this examination and cheerfully supplied all of the information resulting from their explorations. Mr. A. R. Whitman also offered the results of his observations and accompanied the writer on one of his visits to the field. The present report is based on these limited investigations, and is necessarily incomplete, although many of the facts relating to the occurrence of the ore have been ascertained.

GEOGRAPHY.

Spokane, the most important city of eastern Washington, is situated about 18 miles from the Idaho State line and 90 miles south of the Canadian boundary, on the lines of the Northern Pacific,

[a] A tin deposit near Spokane: Min. and Sci. Press, vol. 94, June 1, 1907, p. 697; vol. 95, July 13, 1907, p. 49.

Great Northern, and Union Pacific railroad systems. It is a center for extensive agricultural, lumbering, and mining interests. Vast expanses of rich wheat lands in the Palouse and Big Bend countries lie to the south and west. Great forests of valuable timber lie within 100 miles to the east, and the mines of the Cœur d'Alene district, the chief producers of lead-silver ores in the United States, are within 100 miles to the southeast. Spokane River has a fall of several hundred feet and furnishes the surrounding country with

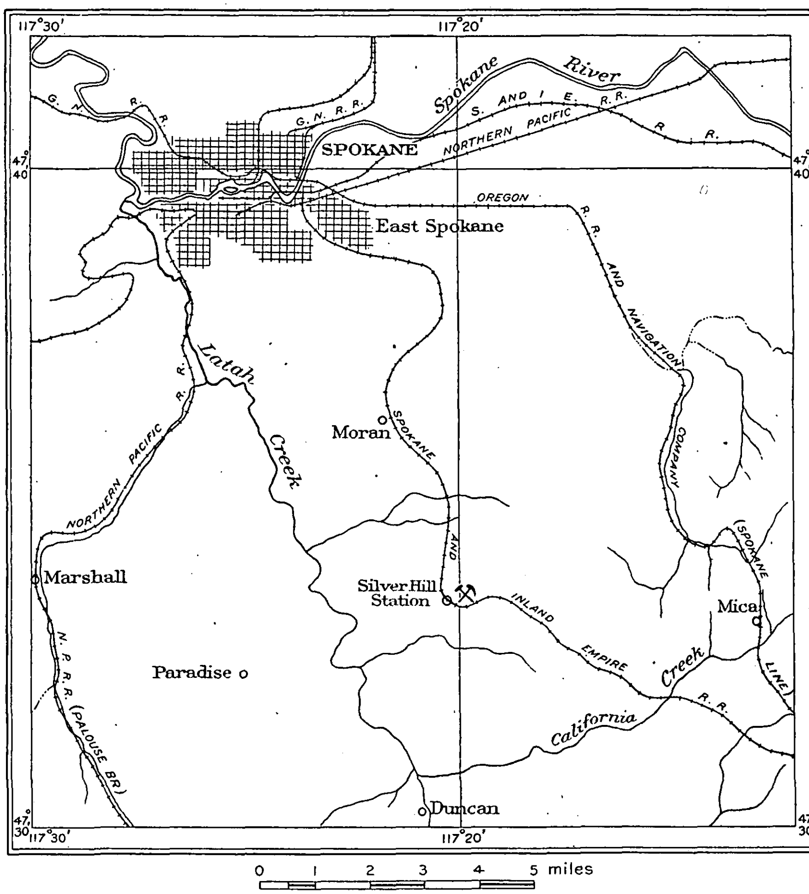

FIG. 16.—Index map showing location of tin deposit at Silver Hill, near Spokane, Wash.

water power. Several electric interurban railroads radiating from Spokane are operated with power from the falls.

The tin deposits (see fig. 16) are situated on one of these roads within half an hour's ride from the center of the city. The location is an ideal one for mining, milling, and shipping ore, provided it is found in sufficient quantities, the only element lacking being coal. No deposits of coal suitable for smelting tin ores are known within 150 miles.

TOPOGRAPHY.

The area covered by the index map (fig. 16) has a total relief of 1,900 feet, the lowest point along Spokane River being less than 1,800 feet above sea level, and the elevation of the highest point in a mountain between the two railroads southeast of the city being 3,700 feet. It presents three notable topographic features—a broad, flat valley 1,900 to 2,000 feet above the sea, a level plateau 2,300 to 2,400 feet above the sea, and the mountainous area already noted. The plateau is a constructional feature and approximately represents the surface of the Yakima basalt,[a] which extends westward and southward for several hundred miles underlying the wheat lands of the Big Bend and Palouse countries. It is well represented at Moran Prairie, west of the Inland Empire Railroad between Spokane and Silver Hill. Latah Creek occupies a narrow canyon cut out of the plateau west of the prairie, and the slopes of the mountainous area rise more or less abruptly from its eastern margin, which for several miles is marked by the line of the Inland Empire road. The topography of the mountainous area is not remarkably rugged, and although the slopes are steep in many places they are usually covered with soil. Spokane Valley, several miles wide and 300 feet lower than the plateau, extends east and west across the north end of the area mapped. At the falls in the center of the city the river plunges into a gorge cut below the valley floor.

The history of this topography is about as follows:[b] Previous to the outpouring of the basalts, the region south and west of Spokane was one of well-developed drainage, with mountains, hills, and valleys produced by erosion. Then occurred one of the most remarkable volcanic outbursts that the earth has known. The old topography for hundreds of miles was submerged in seas of lava and basalt, which welled up from fissures in the earth's crust. Only the higher mountains, like that southeast of Spokane, projected above the basalt in islands and promontories. The basalt surface was later elevated to its present position, and the rivers and creeks flowing across it have eroded valleys and canyons like those of Spokane River and Latah Creek. This subsequent drainage was more or less modified in some places by the ice invasion during the glacial period, but there is no evidence of ice action in the vicinity of Silver Hill.

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[a] Smith, G. O., Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey 1901, pp. 15–17, Calkins, F. C., Water-Sup. and Irr. Paper No. 118, U. S. Geol. Survey, 1905, pp. 30–45.

[b] Willis, Bailey, Changes in river courses in Washington Territory due to glaciation; Bull. U. S. Geol. Survey No. 40, 1887, pp. 7–8.

GEOLOGY.

GENERAL CONDITIONS.

The geology of the Spokane region has not been examined in detail, but the rocks of the vicinity fall into three groups whose relations are known in a general way. The rocks which seem to be the oldest in the region comprise a complex mass of gneisses and schists with many igneous intrusions of various kinds. These rocks form the mountains southeast of Spokane and contain the tin deposits. They probably extend westward under the basalts for an indefinite distance. South of Spokane such rocks crop out through the basalts at intervals for 40 or 50 miles, and they are almost continuously exposed around the northern edge of the basalt area to the north-central part of the State. Deposits of tungsten ore have been reported from them near Deertrail, Stevens County, 40 miles northwest of Spokane, and also near Loomis, Okanogan County, 130 miles distant in the same direction. East of the crystalline schists and gneisses there is an extensive area of only slightly metamorphosed slates, quartzites, and limestones which have been studied in great detail in the Cœur d'Alene mining district of Idaho [a] and are known to be of Algonkian age. The contact relations of the metamorphic rocks near Spokane with the Algonkian rocks have not been definitely determined, although the former apparently underlie the latter. This fact, together with their highly metamorphosed condition, suggests strongly that the gneisses and schists at Spokane are older than the Cœur d'Alene rocks and are, therefore, Archean in age, and this opinion is held by the writer, although he is aware that Carboniferous fossils have been obtained from what appear to be rocks of the same complex in the north-central part of the State.

The basalts are of Miocene age and overlap the crystalline schists in the vicinity of Spokane, their eastern limit coinciding approximately with that of Moran Prairie. For several miles between Spokane and Silver Hill the Inland Empire Railroad follows this contact.

LOCAL GEOLOGY.

The tin deposits occur in the metamorphic rocks regarded as Archean. These rocks are very much shattered and here include biotite gneisses, dark-colored quartzites, and mica schists, in many places graphitic and spotted with large crystals of andalusite, as well as numerous intrusive bodies of granite, pegmatite, aplite, quartz, and a more basic rock somewhat resembling basalt. Exposures in the

[a] Ransome, F. L., Ore deposits of the Cœur d'Alene district: Bull. U. S. Geol. Survey No. 260, 1904, pp. 274–303. Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62 (in press).

railroad cuts indicate that the structure is very complex, and on the map (fig. 17) the schists and quartzites are not differentiated from the gneisses, owing to the meager evidence afforded by the outcrops.

Dikes or veins of pegmatite, aplite, and quartz believed to be aqueo-igneous intrusions in the metamorphic rocks make the most conspicuous outcrops. They will be described in connection with the ore deposits. The larger masses of such rock usually have their longer dimensions parallel with the bedding or schistosity, but some of the smaller veins cut across it. Near their contacts with the surrounding rocks these veins and dikes usually consist of the ordinary pegmatite and aplite minerals—quartz, orthoclase, and muscovite, with tourmaline and in some places apatite as accessory constituents The larger

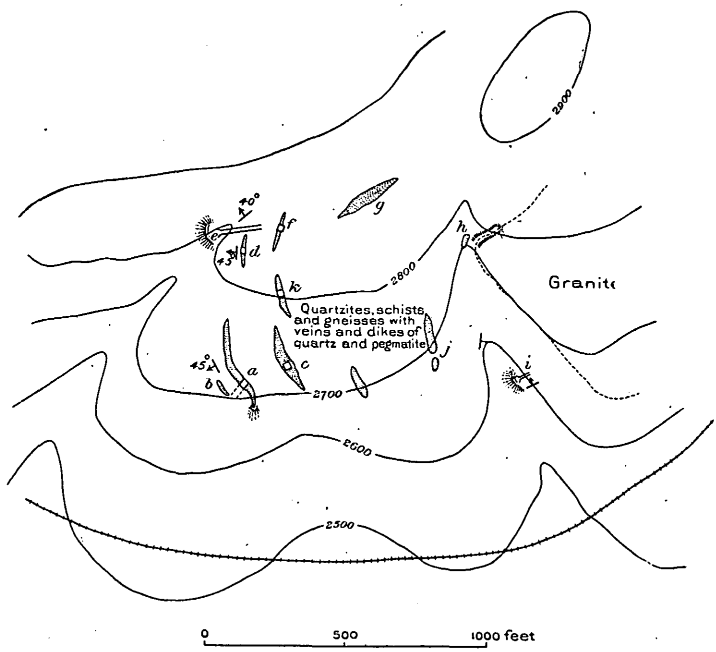

FIG. 17.—Sketch map showing distribution of outcrops of granite, pegmatite, and quartz at Silver Hill, near Spokane, Wash. See text for explanation of reference letters.

masses away from the contacts vary greatly in composition. Some of them contain cassiterite associated with more or less sillimanite and andalusite; others consist of nearly pure quartz.

Granite occurs in stocks or bosses, one of which is shown on the map (fig. 17). It is a moderately coarse-grained rock which shows no evidence of shearing, and consists essentially of quartz, biotite, and both orthoclase and plagioclase feldspar, having approximately the composition of monzonite. Tungsten ores, wolframite and scheelite, have been found at the contact of this granite with the sedimentary rocks, and the granite is regarded as a possible magma from which the tin ores emanated.

The metamorphic rocks exposed in the railroad cuts include some irregular masses, too small to show on the map, of a reddish-brown igneous rock resembling basalt, and what is thought to be a sill of the same rock cuts one of the bodies of tin ore. In some places the rock contains small veins of pegmatite and is evidently older than the latest granitic intrusions. Although the specimens obtained of this rock are more or less weathered, its mineral constituents have been partly determined. It consists essentially of plagioclase feldspar, augite, and biotite, and is tentatively regarded as kersantite.

The distribution of the rocks, as indicated by their outcrops, is shown on the sketch map (fig. 17), the area covered being about 20 acres. Pegmatites and aplites of varying composition are in many places intimately associated with masses of nearly pure granular quartz and are not differentiated on the map from the quartz veins. Tin ores have been found in these intrusives at the four points marked *a*, *f*, *h*, and *j*. The principal developments for tin ore consist of an open cut called the "west cut" and a shaft and drift at the point marked *a*. A deep shaft at the point *f* and a tunnel at *e* are old excavations made on an outcrop of quartz in a search for lead-silver ores. The tunnel at *e* crosscuts the strike of the metamorphic rocks and exposes a thickness of about 100 feet of sedimentary rocks, mostly quartzite, cut by many small veins of pegmatite and aplite. A tunnel at the point marked *i* was excavated several years ago in a search for coal, the rock discovered being a very black, smutty graphitic schist, spotted with large phenocrysts of andalusite. An open cut, called the "east cut," near the point *h* exposes a contact of granite with quartzite along which tungsten ores have been found.

Veins of granular quartz containing some silver-bearing galena are exposed at the points marked *b* and *d*, and several outcrops of similar quartz in which no metallic minerals have been found are located near the point marked *g*.

THE TIN ORE.

CHARACTER.

The cassiterite found at Silver Hill is nearly black and without definite crystal outlines. It is distributed through a nearly white fine-grained rock characterized by slight tinges of pink, in grains from the size of a pin head to several inches in diameter. An analysis of the crushed rock from which the cassiterite had been removed by panning gave the following result:

Analysis of tin-bearing rock at Silver Hill, Washington.

[Richard Marsh, analyst.]

SiO_2	74.02
Fe	2.24
Mg	1.22
CaO	2.28
Al_2O_3	17.05
	96.81

When examined with a lens, the peculiar appearance of the gangue is found to be due largely to a fine fibrous mineral in radiating aggregates. All masses of this rock that have been examined shade off into bodies of nearly pure sugary granular quartz, much of it yellowish from iron stain. Where the tin-bearing rock joins the quartz the two interlock along the contact, producing a texture resembling that of pegmatite. This texture is much more evident in a large outcrop marked *c* on the sketch map (fig. 17), in which no cassiterite has been found. Characteristic pegmatite consisting of coarse-grained quartz, orthoclase, muscovite, and black tourmaline occurs at the contact of the tin ore with the hanging wall at the west cut (*a*, fig. 17).

The mineral characteristics of the tin-bearing rock were determined microscopically in thin sections. It consists essentially of quartz, orthoclase feldspar, sillimanite in slender radiating crystals; and a highly refractive, faintly pleochroic mineral without definite outlines, which has been determined as andalusite. There are also patches of sericite and kaolin. The quartz contains minute fluid and gaseous inclusions arranged in parallel lines along many of which fractures have been developed. The feldspars are slightly clouded in the thin sections examined, but present no evidence of decomposition other than weathering. Where feldspar is in contact with andalusite or sillimanite its boundaries are distinct, and here and there sillimanite fibers are included in the quartz. Neither fluorite nor lithia mica has been identified in the tin ores or the inclosing rocks. The cassiterite as seen in the thin section presents no evidence of being due to secondary deposition. Except for the andalusite the mineral characteristics of the ore-bearing rock are similar to those of a rather fine-grained pegmatite.

Sillimanite has often been found as a constituent of granite and pegmatite, but andalusite has seldom, if ever, been reported as a constituent of pegmatite, and in no instance known to the writer has it been found in association with tin ore, though it has been reported as a constituent of granite masses near their contacts. The inclusion of andalusite in this pegmatite mass is, therefore, apparently a unique occurrence. Many of the inclosing schists contain andalusite as an essential constituent, and it is probable that the andalusite of the ore bodies has in some way been derived from them, for there is no evidence of its having been produced by the decomposition of the feldspars. Examination of a number of thin sections of the granular quartz associated with these ore bodies shows that the rock consists of rather large interlocking grains of quartz with only scattered foils of muscovite mica. The quartz grains are marked by parallel lines of inclusions and fracture planes, like the quartz of the tin ore, and the texture also seems to be similar. These masses of quartz are regarded by the writer as more siliceous portions of the pegmatite bodies, due to a different phase of the same aqueo-igneous action. Pegmatites and aplites are regarded as products of granite intrusions in which the more siliceous minerals are concentrated. When granite masses gradually cool and solidify the dark-colored minerals crystallize more readily than the siliceous minerals such as quartz and orthoclase, and in the last stages of consolidation the portions remaining liquid contain an excess of silica, together with a large percentage of the water contained in the whole of the original magma. The material is practically a solution of siliceous minerals in superheated water, and if it escapes into fissures in the surrounding rocks it forms pegmatite dikes near the sources of emanation and may deposit quartz veins farther away.

The cassiterite at Silver Hill is apparently an original constituent of the pegmatite. In this respect the Spokane tin ore resembles that of North Carolina[a] and the Black Hills. Silver-bearing galena, wherever it has been found, is confined to the more siliceous veins. Wolframite and scheelite also seem to be associated with the masses of quartz near their contacts with the granite or pegmatites. In the open cut along the contact of granite and quartzite at the point marked *h* (fig. 17), and also in the main shaft at the point marked *a*, these ores form nodules up to 2 inches in diameter in masses of nearly pure quartz. Scheelite is more common than wolframite, and was probably deposited first. Some of the nodules of scheelite are surrounded by a thin crust or rim of wolframite. Mr. A. R. Whitman has inferred from this that the scheelite was first deposited and afterwards partly altered to wolframite by solutions containing iron and manganese. The alternative hypothesis, that the wolframite was originally deposited as such around the scheelite nodules, is equally possible, however, and equally well supported by the evidence at hand.

DEVELOPMENTS AND FORM OF ORE BODIES.

Tin ore of the type described has been found at four localities in this area. At the point *f* (fig. 17) a large bowlder of such ore was found on the surface near the old shaft. At the point *h* a bowlder

[a] Graton, L. C., Gold and tin deposits of the southern Appalachians: Bull. U. S. Geol. Survey No. 293, 1906, p. 82.

weighing about 500 pounds and containing approximately 10 per cent of cassiterite was found, but it was not traced to its bed-rock source, although considerable excavating has been done. At the point *j* there is an extensive outcrop of andalusite-bearing pegmatite like that containing the ore, but only a small amount of cassiterite has been found in a few small fragments on the surface.

The principal workings and the largest amount of tin ore found are at what is known as the "west cut" (*a*, fig. 17). This ore body was first developed by an open cut 150 feet long, in which a mass of pegmatite and quartz was uncovered. The tin-bearing rock dips to the southwest at an angle of about 45°, and lies between well-defined walls. The hanging wall is a biotite gneiss or gneissoid granite with the foliation parallel to the ore body. The foot wall consists of quartzite and black andalusite schist, but owing to the fact that there is a casing of more or less altered rock along the contact of the ore with the foot wall, the attitude of the bedding or schistosity has not been definitely determined. A sill of the basaltic rock, provisionally determined as kersantite, divides the vein into an upper and a lower portion. This sill ends abruptly against the hanging wall, but probably extends for some distance into the foot wall. It dips toward the northwest at an angle of about 5°, and reaches the floor at the end of the cut. The relations of the different rocks exposed are shown in the section (fig. 18). A small amount of cassiterite was found very much disseminated through the pegmatite above the kersantite sill. Below this sill the pegmatite for 20 or 30 feet contained sufficient cassiterite to make it a commercial ore. The mineral was most abundant in the central part of the pegmatite mass. The maximum thickness of ore found at any point was probably not less than 10 feet. From the point where the richest ore was found a shaft has been sunk to a depth of 125 feet on an incline of approximately 45°. In depth the pegmatite is displaced by barren quartz on the hanging wall, as is shown in the section (fig. 18). Some cassiterite was found to a depth of 50 feet, although it gradually decreases in

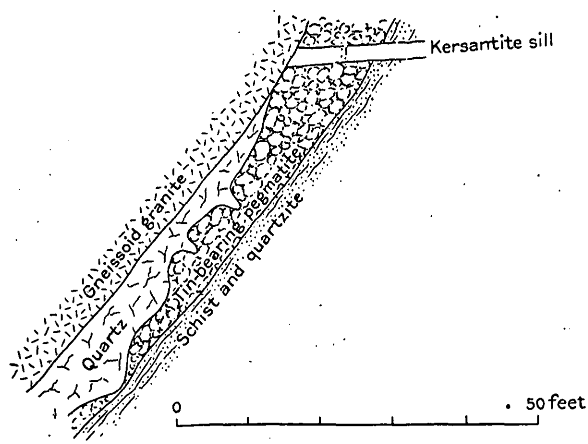

FIG. 18.—Section of ore body at Silver Hill, near Spokane, Wash.

amount below the bottom of the cut. Below the 100-foot level the walls of the ore body come together, and for some distance the vein or dike is not well defined, although large nodules of tungsten ore have been found. On the 100-foot level a drift has been run to the north for a distance of 100 feet. This drift is partly in barren quartz and partly in the pink pegmatite regarded as tin-bearing rock. About 35 feet from the shaft this rock contained a notable amount of cassiterite, and part of it was rich enough to be regarded as tin ore. At the end of the drift a second sill, probably of kersantite, was encountered dipping to the southeast. These excavations have gone far enough to show that the tin-bearing intrusion is of irregular form, that the tin is not uniformly distributed through it, and that it may be confined to an ore shoot pitching to the northwest.

VALUE OF THE ORE.

In the course of these excavations the tin ore has been carefully selected from the barren rock and piled on the dump, where, at the present time, there is probably from 100 to 200 tons. The quantity was roughly estimated at 125 tons by the writer. It is exceedingly difficult to make a close estimate of the value of this ore, as it consists of pieces varying in size up to 100 pounds or more, in which the cassiterite is unevenly distributed in grains from the size of a pin head to several pounds in weight. Mr. Richard Marsh has estimated the cassiterite or black tin contained at 6 per cent. Mr. A. R. Whitman estimates the metallic tin at 3 per cent. From an inspection of the dump, the writer is of the opinion that the former estimate may be more nearly correct. The cassiterite is reported by both Mr. Marsh and Mr. Whitman to be remarkably free from impurities, and it is believed that a concentrate containing 70 per cent metallic tin can be obtained. Scheelite and wolframite in small quantities have been found at a number of places in this vicinity, but they are not closely associated with the cassiterite in the lodes, and are not found in the concentrates. At present prices (February, 1908), metallic tin is worth about 28 cents per pound, and tungsten ores are worth twice as much per unit[a] as the tin ore. The tailings resulting from milling this ore make white sand of good quality, for which builders in Spokane are reported to be willing to pay as much as 75 cents a ton.

[a] The unit referred to is 1 per cent of metal contained in 2,000 pounds of ore. For the fluctuations in the price of tin and the tungsten minerals, see Mineral Resources for 1906, U. S. Geol. Survey, 1907. This report can be obtained on application to the Director of the Survey.

PROSPECTING FOR PLACER TIN.

The mountain mass from which Silver Hill is a spur owes its present contour to erosion, and the tin ores from the portions thus removed should be concentrated in stream gravels at no very great distance; the quantity of such placer tin, if it could be determined, would be an index to the quantity of tin in the lodes. No tin-bearing gravels have yet been discovered, but very little prospecting for such deposits has been done. As has been noted, most of the erosion of the mountain mass was accomplished before the outpouring of the basalts which filled all the valleys and submerged the lower hills. It is to be expected, therefore, that the greater part of the tin-bearing gravels, if such exist, are buried below the basalts and may never be discovered.

CONCLUSIONS.

Inasmuch as cassiterite is a mineral not affected by processes of secondary or surface enrichment, and in the present instance it is an original constituent of the igneous rocks in which it occurs, it is reasonable to expect that the quantity of ore exposed in outcrop will approximate that to be found at lower levels. The ore is contained in rather irregular aqueo-igneous veins or dikes, several of which outcrop in the area under examination. It has been found in four such outcrops, one of which yielded approximately 125 tons of ore. The others produced smaller amounts, but may not have been thoroughly prospected. No bodies of tungsten ore large enough to be of economic value have been discovered up to the present time.

Veins and dikes of pegmatite are not uncommon elsewhere in the metamorphic rocks of this region, which are continuously exposed for several miles to the east and outcrop at intervals for at least 40 miles to the south. No cassiterite has yet been found in these rocks except at Silver Hill, but such discoveries are to be expected.

The developments at Silver Hill indicate that the tin ore is to be found in detached masses whose relations to each other can not yet be forecast, and the economic value of the deposit will depend to a considerable extent on the amount of excavation necessary to locate other ore bodies. This can be determined only by experience involving a further outlay of capital and possibly requiring several years' time, but the discoveries already made are of sufficient value to warrant such investigations.

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SURVEY PUBLICATIONS ON ANTIMONY, CHROMIUM, NICKEL, PLATINUM, QUICKSILVER, TIN, TUNGSTEN, URANIUM, VANADIUM, ETC.

The principal publications by the United States Geological Survey on the rarer metals are the following:

BECKER, G. F. Geology of the quicksilver deposits of the Pacific slope, with atlas. Monograph XIII. 486 pp. 1888.

——— Quicksilver ore deposits. In Mineral Resources U. S. for 1892, pp. 139–168. 1893.

BLAKE, W. P. Nickel; its ores, distribution, and metallurgy. In Mineral Resources U. S. for 1882, pp. 399–420. 1883.

——— Tin ores and deposits. In Mineral Resources U. S. for 1883–84, pp. 592–640. 1885.

BOUTWELL, J. M. Quicksilver. In Mineral Resources U. S. for 1906, pp. 491–499. 1907.

CHRISTY, S. B. Quicksilver reduction at New Almaden [Cal.]. In Mineral Resources U. S. for 1883–84, pp. 503–536. 1885.

COLLIER, A. J. Chromite or chromic iron ore. In Mineral Resources U. S. for 1906, pp. 541–542. 1907.

DAY, D. T. Platinum. In Mineral Resources U. S. for 1906, pp. 551–562. 1907.

——— and RICHARDS, R. H. Investigations of black sands from placer mines. In Bulletin No. 285, pp. 150–164. 1906.

EMMONS, S. F. Platinum in copper ores in Wyoming. In Bulletin No. 213, pp. 94–97. 1903.

GALE, H. S. Carnotite in Rio Blanco County, Colorado. In Bulletin No. 315, pp. 110–117. 1907.

GLENN, W. Chromic iron. In Seventeenth Ann. Rept., pt. 3, pp. 261–273. 1896.

GRATON, L. C. The Carolina tin belt. In Bulletin No. 260, pp. 188–195. 1905.

——— Reconnaissance of some gold and tin deposits in the southern Appalachians. Bulletin No. 293. 134 pp. 1906.

——— (See also Hess, F. L., and Graton, L. C.)

HESS, F. L. Antimony. In Mineral Resources U. S. for 1906, pp. 511–516. 1907.

——— Bismuth. In Mineral Resources U. S. for 1906, p. 517. 1907.

——— Nickel, cobalt, tungsten, vanadium, molybdenum, titanium, uranium, and tantalum. In Mineral Resources U. S. for 1906, pp. 519–540. 1907.

——— Tin. In Mineral Resources U. S. for 1906, pp. 543–549. 1907.

——— Arsenic. In Mineral Resources U. S. for 1906, pp. 1055–1058. 1907.

——— Selenium. In Mineral Resources U. S. for 1906, p. 1271. 1907.

——— and GRATON, L. C. The occurrence and distribution of tin. In Bulletin No. 260, pp. 161–187. 1905.

HILLEBRAND, W. F., and RANSOME, F. L. On carnotite and associated vanadiferous minerals in western Colorado. In Bulletin No. 262, pp. 9–31. 1905.

HOBBS, W. H. The old tungsten mine at Trumbull, Conn. In Twenty-second Ann. Rept., pt. 2, pp. 7–22. 1902.

——— Tungsten mining at Trumbull, Conn. In Bulletin No. 213, p. 98. 1903.

KAY, G. F. Nickel deposits of Nickel Mountain, Oregon. In Bulletin No. 315, pp. 120–127. 1907.

KEMP, J. F. Geological relations and distribution of platinum and associated metals. Bulletin No. 193. 95 pp. 1902.

PACKARD, R. L. Genesis of nickel ores. In Mineral Resources U. S. for 1892, pp. 170–177. 1893.

RANSOME, F. L. (See Hillebrand, W. F., and Ransome, F. L.)

RICHARDS, R. H. (See Day, D. T., and Richards, R. H.)

RICHARDSON, G. B. Tin in the Franklin Mountains, Texas. In Bulletin No. 285, pp. 146–149. 1906.

ROLKER, C. M. The production of tin in various parts of the world. In Sixteenth Ann. Rept., pt. 3, pp. 458–538. 1895.

ULKE, T. Occurrence of tin ore in North Carolina and Virginia. In Mineral Resources U. S. for 1893, pp. 178–182. 1894.

WEED, W. H. The El Paso tin deposits [Texas]. Bulletin No. 178. 6 pp. 1901.

——— Tin deposits at El Paso, Tex. In Bulletin No. 213, pp. 99–102. 1903.

WEEKS, F. B. An occurrence of tungsten ore in eastern Nevada. In Twenty-first Ann. Rept., pt. 6, pp. 319–320. 1901.

——— Tungsten ore in eastern Nevada. In Bulletin No. 213, p. 103. 1903.