RARE METALS.

NOTES ON THE OCCURRENCE OF CINNABAR IN CENTRAL WESTERN ARIZONA.

By HOWLAND BANCROFT.

During the spring of 1909 the writer made a reconnaissance of the economic geology of central western Arizona, examining, among other deposits, the well-known[a] cinnabar prospects near Quartzite. Because of the scarcity of this mineral in Arizona and the lack of any scientific literature on these occurrences, it has been thought advisable to publish a brief preliminary description of this district. Development work has not been very extensive in the vicinity, and the results of the investigation are interesting mainly from the standpoint of the mineralogist and geologist.

The deposit is located in the Plomosa mining district, Yuma County, Ariz., in the southern part of the Dome Rock Mountains, some 8 miles due southwest of Quartzite, at a place locally known as Cinnabar. Vicksburg, on the Arizona and California Railroad, is the most accessible station, and in an air line is just 28 miles a little north of west of Quartzite, the stage road between the two places being a few miles longer.

During the summer months the heat is more intense in this vicinity along Colorado River than in any other part of the United States. Timber for use as fuel and water for domestic purposes are obtained in the vicinity, though neither is found in great abundance.

The topography is characterized by broad, flat valleys with mountain ranges rising abruptly from the deserts. The Dome Rock Mountains have an average elevation of 1,500 feet, being approximately 1,000 feet above the surrounding country. The spur in which the cinnabar occurs forms the highest branch of the mountains, one of its peaks rising to an elevation of over 2,700 feet. The dip of

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[a] These deposits, according to H. W. Turner, have been known for over thirty years. See The mineral industry during 1908, Quicksilver, p. 743.

the strata in the vicinity of the deposits is in general between 15° and 45° NE., and the strike is to the northwest, but there are many pronounced local changes in both dip and strike.

The rocks in this locality are arenaceous shales, presumably of pre-Cambrian age, which have been metamorphosed into quartz-mica schists. To the unaided eye most of them appear fine grained, with a satiny sheen, ranging in color from light silver-white through gray, brown, and red to a dark, almost black tone. The colors are due in general to the kind of mica and the amount of chlorite and epidote present and in part to the degree of oxidation of the contained iron. Mica is prominent, and although the crystals are not large they are conspicuous enough to be recognized without the use of a strong lens. Because of their abundance, the rocks are fairly soft, feel greasy, and are readily scratched with a knife blade. On microscopic examination of thin sections it is found that the general composition of the schists is the same; all of them contain much quartz, feldspar, and mica, part of the mica probably resulting from the decomposition of the feldspars. Epidote is present in almost all the schists, and some of them are highly chloritic. Near the veins the wall rocks show calcite and epidote in abundance, with some zoisite.

The country rock in which the deposit worked by the Colonial Mining Company occurs is unlike most of the schists in the vicinity in that it contains small crystals of magnetite scattered throughout the rock in large quantities.

In a prospect owned by the French American Mining Company, located a short distance from the one just mentioned and in a similar series of rocks, there are, associated with pure white quartz, small quantities of tourmaline, gold, and copper glance, all except the last apparently of primary origin. Siderite associated with gold was noted, and cinnabar is said to occur with the tourmaline in the quartz, although none was to be seen at the time of the writer's visit to the property. The vein strikes N. 55° W. and dips about 15° SE., cutting directly across the schists, which dip 20° to 30° N. 60° E. A variety of the schist next to the vein is highly impregnated with tourmaline; another schist in the vicinity is extremely silicified, and very impure limestones occur near by. The association in this vein of primary quartz, tourmaline, and gold is indicative of deposition under great heat and pressure.

The vein worked by the Colonial Mining Company strikes S. 55° E. and is practically perpendicular. It occupies a fault zone which shows intense brecciation of the country rock. The gangue is highly siliceous and is cut by small stringers of calcite and siderite, the former occurring in places in conspicuous quantities, but being entirely absent in the croppings of the vein, where silica with a little black oxide of manganese forms the ledge. In width the vein varies from a few inches to several feet; parallel breccia planes of small magnitude, which accompany the main fault in places, tend to widen the deposit. The ore shoot in the property is said to pitch to the southeast.

Cinnabar is very sparsely distributed throughout the gangue and is supposed to be found mainly on the northeast side of a very plastic, iron-stained gouge which has resulted from the extreme movement in the fault zone. The ore in places is conspicuously marked by the green carbonate of copper, and Turner[a] has reported gold and silver in ores from this deposit. The presence of magnetite near the vein is a feature worthy of note; its alteration has probably formed the red and yellow stains so common in the brecciated vein material and gouge.

Considering the facts that late eruptions are absent in the vicinity, that the deposit is entirely oxidized, that copper stains are prominent, and that values of gold and silver occur in the vein, it seems highly probable that the cinnabar has been derived from mercurial tetrahedrite.[b]

The Colonial Mining Company has a vertical shaft about 300 feet deep with three levels, constituting in all some 1,500 feet of development work.[c] During parts of 1908 a 30-ton Scott tile furnace was operated on the property, and the recovery of a small amount of mercury was reported.[d] High absorption of the metal by the bricks of local manufacture used in the condensers is reported by the management to have so lowered the percentage extracted that metallurgical operations have not proved profitable.

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[a] Turner, H. W., The mineral industry during 1908, Quicksilver, p. 743.

[b] For this suggestion pertaining to the origin of the cinnabar the writer is indebted to Mr. Waldemar Lindgren, who has noted the occurrence of this mineral in gold-quartz veins of the Granite district, Blue Mountains, Oregon, containing also pyrite, chalcopyrite, and arsenopyrite. See The gold belt of the Blue Mountains of Oregon: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 683.

[c] These figures are only approximate.

[d] McCaskey, H. D., The production of quicksilver: Mineral Resources U. S. for 1908, pt. 1, U. S. Geol. Survey, 1909, p. 692.

SOME OCCURRENCES OF MOLYBDENITE IN THE SANTA RITA AND PATAGONIA MOUNTAINS, ARIZONA.

By F. C. SCHRADER and J. M. HILL.

LOCATION AND GENERAL DESCRIPTION.

The Santa Rita and Patagonia mountains constitute one of the most prominent mineral-bearing desert ranges of the Southwest. Beginning near the transcontinental line of the Southern Pacific Railroad about 20 miles southeast of Tucson, the range extends southward in Pima and Santa Cruz counties, with a length of 45 miles, to the international boundary, which it crosses about 12 miles east of Nogales. The northern two-thirds of the range, extending to Sonoita Creek, which cuts across it, is known as the Santa Rita Mountains and the remainder as the Patagonia Mountains.

The range is generally rugged and near the middle part of its course culminates in Old Baldy, at 9,432 feet above the sea. It is drained by Santa Cruz River, which flows in a northwesterly direction via Tucson into the Gila, which in turn joins the Colorado at Yuma.

In a reconnaissance of the mineral deposits of the mountains during the season of 1909 the occurrences of molybdenite (sulphide of molybdenum, MoS_2) herein described were encountered at the following more or less widely separated localities, as indicated on the accompanying map (fig. 12): Helvetia, Madera Canyon, Providencia Canyon, Duquesne, and near the international boundary Of these the most important is Helvetia.

DESCRIPTION BY LOCALITIES.

HELVETIA.

Helvetia, the most important mining camp in this part of Arizona, is situated 27 miles southeast of Tucson, in the northern part of the Santa Rita Mountains, on the west slope at an elevation of about 4,300 feet. (See fig. 12.) Here molybdenite occurs at two localities—the Leader mine and the Ridley mine.

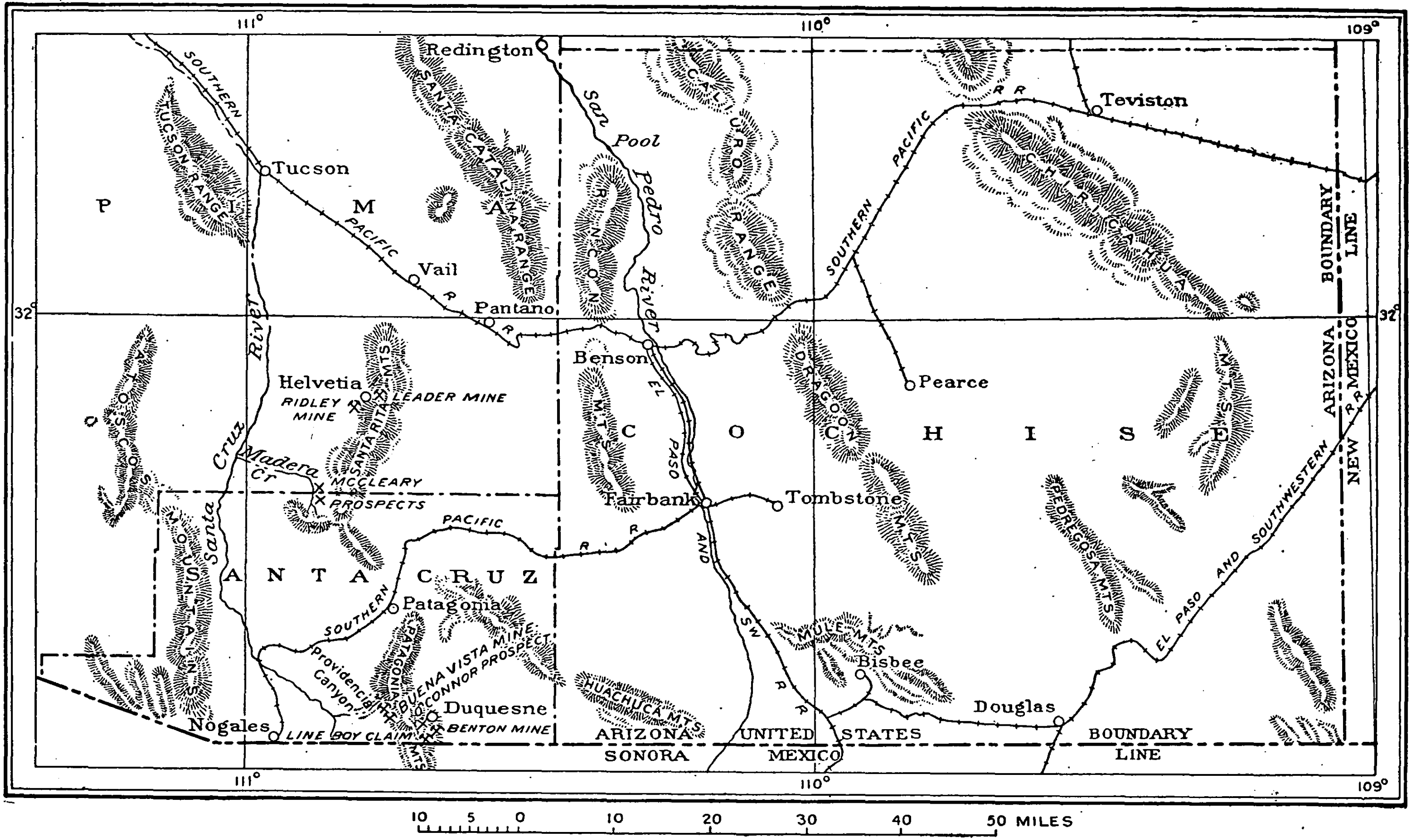

FIGURE 12.—Index map of southeastern Arizona, showing location of molybdenite deposits in Santa Rita and Patagonia mountains.

LEADER MINE.

The Leader mine, one of a group of copper mines owned and operated by the Helvetia Copper Company, is situated east of the town and a few hundred feet above it, at an elevation of about 4,700 feet, in altered Paleozoic limestone, close to the northeastward dipping contact with underlying granite. Both pre-Cambrian and post-Carboniferous granitic rocks are present. The latter include aplite dikes as well as granite porphyry.

The workings in the main are on what is known as the tunnel level, which follows the contact for some distance, extending in a northerly direction. The molybdenite occurs at a point about 150 feet in from the mouth of the tunnel, in dull-brownish and greenish to yellowish mineralized garnetiferous silicified limestone and quartz.

The rock is more or less massive. It varies from fine to medium grained and is composed essentially of pale-greenish garnet, which corresponds to grossularite and occurs in grains and imperfect crystals. The mineral next in abundance is quartz, which seems to be of two periods. The remaining secondary metamorphic minerals observed are calcite, magnetite (or ilmenite) and epidote, which are present only in small amount. The latest mineral in general is quartz. After the rock had been severely crushed and fractured the cracks and openings became filled with quartz, which occurs in macroscopic and microscopic lenses, irregular bodies, and veins. The smaller veins have in general a direction roughly parallel with the ore bed and connect variously with the larger bodies or lenses, in places forming a closely woven reticulating meshwork, with garnet filling the interspaces.

At the tunnel level a tabular vein or seam of copper ore with quartz gangue inclines eastward at an angle of about 40° and is opened on the incline by what is known as the Molybdenite winze. In the vicinity of the level the vein is only a few inches in width, but with it, on either side, is associated from 1 to 3 feet or more of the above-described mineralized limestone, which contains chalcopyrite, pyrite, coarse calcite, and quartz, and which is a low-grade copper ore.

In the incline at a depth of 35 or 40 feet below the level, however, conditions change. Here molybdenite occurs in both the vein and the inclosing rock, mingled with the chalcopyrite and pyrite. In the next 8 or 10 feet below the dip flattens somewhat, the chalcopyrite and pyrite decrease greatly, and there is a more than corresponding increase in the amount of molybdenite, so that the deposit is there a relatively pure molybdenite ore, and seems to constitute a body or ore bed at least 3 or 4 and probably 6 or 7 feet in thickness. Owing to the presence of water in the shaft sunk at the end of the incline, examination could not be made across the entire bed. So far as observed there seemed to be no detrimental intermingling of chalcopyrite.

The molybdenite occurs in lenses, irregular bodies or bunches, and crystal aggregates embedded in and associated with both the rock and the quartz. It is mostly fine-grained, but some of the crystal plates range up to one-half inch or more in maximum diameter.

Bodies of the molybdenite inclosed in the middle of some of the quartz veins indicate that deposition of this ore probably continued after that of the quartz, with which the molybdenite seems to be in the main contemporaneous. Like the quartz, it was probably deposited by thermal solutions that accompanied or followed the intrusion of the aplite dikes or granite porphyry.

A considerable amount of molybdenite can be seen on a large dump of low-grade copper ore at the entrance to the mine, and a smaller pile of 8 or 10 tons of molybdenite ore is reported to average 6½ per cent of molybdenum. At the time of visit in 1909 the company was planning to mine the deposit commercially and expected to produce ore with a very much higher percentage of molybdenum.

RIDLEY MINE.

The Ridley mine, owned and worked for copper by C. B. Ridley, of Helvetia, is located in the foothills a mile southwest of Helvetia at an elevation of about 4,060 feet. The topography in this vicinity is gentle. The country rock is the pre-Cambrian (?) granite and it is freely intruded by dikes and masses of aplite which, as shown by the croppings to the north of the mine, are associated with the vein. The mine is situated on a tabular quartz vein that contains the ore and dips about 50° E. It is developed by an incline on the vein to a depth of 150 feet and contains short drifts on two levels, one of which is near the bottom of the shaft and the other 55 feet above it. The vein varies in thickness from 2 to 5 feet and averages about 4 feet. Some of the quartz is drusy. The better ore occurs in the lower part of the mine. Here it is mostly contained in a 10 to 18 inch pay streak on the hanging-wall side of the vein. It consists of alternating bands of quartz and sulphides—pyrite, chalcopyrite, argentiferous galena, and sphalerite—and is said to run about 6½ per cent in copper and 30 ounces in silver and $1.50 in gold to the ton.

In the south drift on the lower level a little molybdenite is scattered through the ore, and in the sump at water level, between the pay streak and the granite hanging wall, occurs a band from one-eighth inch to 4 inches in width, composed of sericitic mica, quartz, pyrite, and fine-grained molybdenite. In places this material seems to constitute a good molybdenum ore. Its concentration, however, may be difficult owing to its mixture with mica.

MADERA CANYON.

Madera Canyon drains the northwestern part of the Old Baldy section of the Santa Rita Mountains, about 10 miles south-southwest of Helvetia and 35 miles south of Tucson. In the foothill part of its course, where the creek and wagon road cross the Pima-Santa Cruz county line, a short distance above White House, as indicated on the accompanying map (fig. 12), occur a group of molybdenite prospects commonly known as the McCleary prospects, from the name of the owner. They range from about 4,500 to 5,000 feet in elevation and trend nearly north and south along the creek, extending half a mile on either side of the county line. The deposits probably have a much wider extent in an east-west direction, for the prospects here described have only accidentally been brought to light by the erosion of the creek across a seemingly small portion of the area.

In this part of its course the creek, a fine, clear mountain stream, about 2 feet wide by 3 inches in depth, flows in a trench but 5 to 15 feet deep. The topography is gentle and the prospects are all easily accessible.

The country rock is pre-Cambrian (?) granite. It has been fractured by dynamic disturbances, and along the more prominent of the resulting joints and fault fissures occur quartz veins containing the prospects. These veins vary from 1 foot to 12 feet or more in width and are mostly compound veins or stockworks. They are in the main associated with intrusive aplite or allied dikes, with which, as at Helvetia, the deposits are probably genetically connected.

The most important exposures, as shown in prospect shafts and tunnels, will be described in downstream order from south to north.

The most southerly of the prospect holes is situated on the west side of the creek at an elevation of 4,990 feet. It is on a small, somewhat iron-stained quartz vein that carries pyrite, chalcopyrite, and flaky molybdenite and dips 70° N. A 20-foot dike of aplitic granite forms the hanging wall.

Just south of the road forks, in the creek bank, at an elevation of 4,765 feet, in a fine-grained phase of the granite, a 4-foot vein of iron-stained honeycombed quartz dipping steeply to the north is opened by a shaft which was filled with water at the time of visit, but is reported to be 40 feet deep. On the surface the vein exposes a little flaky molybdenite and a very minor amount of pyrite and chalcopyrite.

On the east side of the creek, about 200 feet from the road, at an elevation of 4,675 feet, the granite is traversed by a stockwork several feet in width, composed mainly of massive iron-stained dark smoky quartz veins. It strikes N. 60° E. and the dip is vertical or steep to the north. The quartz is in part drusy or comby. It is concentrated along the north or hanging-wall side of the fissures, where it is from 6 inches to 2 feet in width and contains a little pyrite and a less amount of chalcopyrite. Associated in part with the pyrite and chalcopyrite and occurring also independently of these minerals, exposed at many places on the joint planes, are flakes of molybdenite that are locally concentrated in masses one-fourth inch thick and covering an area of about a square inch. Flaky aggregates and small bodies of pure molybdenite also occur in the druses and otherwise inclosed in the quartz, as at Helvetia. Associated with the larger masses of the molybdenite and also with limonite on the joints near the surface is a soft yellowish earthy material which looks like clay, but which on examination was found to be ferrous iron sulphate. At the mouth of the 10-foot tunnel driven on this prospect, dipping steeply to the southeast, occurs what seems to be a dike of fine-grained aplitic granite, with which the molybdenite is probably genetically connected.

The most northerly and apparently the most important prospect of the group is on the east side of the creek, at an elevation of 4,560 feet. Here in the granite is exposed a stockwork of quartz veinlets 3 to 7 feet wide. It dips about 60° NNW. and is traceable for a distance of 1,500 feet eastward from the opening. The granite between the veinlets is very much altered. It is soft, is of a yellowish-red color, due seemingly to iron staining, and contains pyrite crystals and flakes of molybdenite. The quartz forming the veinlets of the stockwork is smoky and coated with limonite and a little molybdenite. Some walls of open fissures are coated or glazed with a black sinter-like substance, which is mostly silica but contains manganese and molybdenum. It is particularly abundant on the south or foot wall.

PROVIDENCIA CANYON.

GENERAL DESCRIPTION.

Providencia Canyon heads about 2 miles northwest of Washington, in the southern part of the range, drains a considerable portion of the western slope, and joins the Santa Cruz 6 miles northeast of Nogales. The molybdenite prospects here described are in the foothill portion of its course, in the general region of the Golden Rose and Buena Vista mines, 10 miles north-northeast of Nogales, 5 miles west of Washington, and about 5 miles north of the international boundary, at elevations between 4,200 and 5,000 feet.

The topography is rough, being of the type formed from an area of igneous rocks scored by canyons and gulches in an arid climate, but the canyons or washes form avenues of approach to the mines.

The country rock is pre-Cambrian (?) granite, faulted and intruded by dikes and masses of quartz diorite generally, with granite porphyry occurring near by. As in Madera Canyon, it has suffered considerable dynamic disturbance, and the resulting fault fissures locally contain mineral-bearing quartz veins or lodes. The granite also locally contains metallic minerals in considerable amount.

In the northwestern part of the triangular area bounded by Sycamore Canyon on the south and east and Providencia Canyon on the northwest, just southeast across Providencia Canyon from the Golden Rose mine, the granite is uniformly impregnated with evenly disseminated small macroscopic crystals, aggregates or masses, and grains of chalcopyrite and pyrite, and contains sparingly molybdenite, having much the same habit as the other minerals. These mineralogical conditions are very constant throughout the mile or more of the northwest slope of the mountain examined opposite the Golden Rose mine, where in prospecting for copper the ground has been opened at intervals by shafts and tunnels from 10 to 80 feet in depth, and the same conditions are reported to prevail over most of the area above described, which occupies 2 square miles or more and rises 800 feet above the canyon.

From cursory examination these minerals seem in all respects to be primary constituents of the granite, but as such occurrence is unusual, decision on this point must await further examination.

Hess,[a] from investigations of the same minerals in other fields, concludes that the minerals are probably not primary and that the molybdenite in the places he cited was deposited possibly by a gaseous solution that had greater power than a liquid solution to penetrate the dense granite.

BUENA VISTA MINE.

The Buena Vista mine, owned by the Banco del Oro Mining Company, of Magdalena, Sonora, Mexico, is located about three-fourths mile southeast of the Golden Rose mine and the locality above described. It is in the pre-Cambrian (?) granite, on a fault or shear zone, with intrusive quartz diorite outcropping on the ground and granite porphyry occurring near by.

The zone comprises half a dozen or more fault fissure veins and associated lodes of more or less mineralized crushed rock, all of which dip about 60° SSE. The veins range from 6 inches to more than 6 feet in width. The two most important are about 100 feet apart. The vein filling is quartz with here and there associated calcite. The mine contains about 2,000 feet of work. It is developed principally by three tunnels on suitably spaced levels between approximately 4,700 and 5,000 feet in elevation. Two of the tunnels are drifts on the main vein. The other is a crosscut which opens a parallel vein.

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[a] Hess, F. L., Some molybdenum deposits of Maine, Utah, and California: Bull. U. S. Geol. Survey No. 340, 1908, pp. 231-239.

In the lower drift, which is 415 feet in length, the main vein contains about 5 inches of white quartz and calcite that carries chalcopyrite, pyrite, and a little flaky molybdenite. The ore is separated from both walls by gouge. In the face of the crosscut tunnel, which is 45 feet above the lower tunnel, is a 4-foot zone of crushed granite and quartz carrying pyrite, chalcopyrite, and a little flaky molybdenite.

DUQUESNE.

The well-known mining camp of Duquesne, south of Washington, lies on the east slope of the Patagonia Mountains, about 2 miles north of the international boundary and about 15 miles east-northeast of Nogales. At the southwestern border of the camp, about one-fourth mile west of the Belmont mine, on ground owned by Captain O'Connor, of Duquesne, occurs ore which shows galena, chalcopyrite, pyrite, and a little molybdenite, associated with drusy quartz. The deposit is in the country-rock granite just west of the contact of this rock with limestone. The granite is intruded or cut by masses of granite porphyry. Both rocks are much shattered and are traversed in all directions by a large number of the drusy quartz veins. The property is developed by several shafts, but these could not be entered at the time of visit, as they were full of water.

SAN ANTONIO CANYON.

Molybdenite is contained in two openings, the Benton mine and the Line Boy prospect, near the international boundary, in San Antonio Canyon, at the east foot of the Patagonia Mountains, about 2 miles south of Duquesne and 15 miles east of Nogales. The more important of these is the Benton mine.

BENTON MINE.

The Benton mine, owned by Dennis Coughlin and partners, of Duquesne, is situated about three-fourths mile northeast of post 113 of the international boundary line, on open ground, at an elevation of about 5,200 feet. It is developed principally by a 155-foot tunnel. The country rock is granite, intruded by granite porphyry and aplitic granite. The granite porphyry contains the values of the mine, which consist of low-grade copper and gold ore. The ore occurs chiefly in a dike of this rock 60 feet wide, which is impregnated with pyrite, chalcopyrite, and a little flaky molybdenite. Its contact with the granite is marked by a sericitic zone a few feet in width.

LINE BOY PROSPECT.

The Line Boy prospect, owned by Captain O'Connor, of Duquesne, is located just north of post 113 of the international boundary, about three-fourths mile southwest of the Benton mine, at an elevation of about 5,400 feet. It is developed to a depth of 80 feet by three shafts and a tunnel.

The country rock is gray granite, intruded by a north-south dike of granite porphyry 300 feet in width. The ore deposits are contained in the granite, which near the dike is impregnated with pyrite, chalcopyrite, molybdenite, and a little bornite. The metallic minerals are particularly abundant along the contact of the two rocks and are concentrated in joint planes and fissures, locally with a little associated quartz. In one place occurs a 3-foot band of fine-grained, friable, and relatively pure specularite.

The molybdenite occurs also unassociated with the other sulphides, in the form of comparatively pure lumps or crystals, in places one-eighth of an inch thick and more than half an inch in diameter, in a coarse siliceous, sericitic phase of the granite. It also, with quartz in about equal amount, forms veinlets of considerable continuity that traverse less acidic portions of the granite and range from microscopic width to one-sixteenth inch. It is also present in small amount in microscopic to very small macroscopic veinlets or seams traversing a dense phase of the granite. The veinlets are parallel, ten or twelve being contained in a single thin section made for microscopic study. They contain and are associated with microscopic druses.

ORIGIN OF THE DEPOSITS.

At all the localities here described the molybdenite, whether found in veins, as impregnations in the rock, or in other forms, occurs in granite or in quartz veins cutting the granite. All the deposits, besides being intimately associated with considerable quartz, are also more or less intimately associated with granitic intrusive rocks—aplite, granite porphyry, and allied acidic rocks. From the constancy of these conditions it seems probable that some genetic relation exists between the deposits and the intrusive rocks, and that the deposits were probably formed by precipitation from thermal solutions whose circulation accompanied or followed the intrusions.

FUTURE PROSPECTS OF THE DEPOSITS.

The only one of the above-described localities at which molybdenite seems to be present in workable quantities is at Helvetia, notably in the Leader mine. However, as all the deposits occur under geologic conditions favorable for molybdenite and are still in the prospect stage, it is possible that with development some others may prove to be of economic value. At the time of visit the Madera Canyon prospects were being exploited for molybdenite. An important point in the selection of deposits for development is the absence of chalcopyrite, for this mineral is difficult to separate from molybdenite and thus reduces its market value.

GENERAL OCCURRENCE OF MOLYBDENITE.

According to Crook,[a] the molybdenite at fifty or more localities in different parts of the world which have been described occurs in a great variety of rocks, including practically all the main groups, but its occurrence with granite is by far the most usual and typical. Hillebrand[b] also states that molybdenite accompanies the more acidic rocks and is a well-known constituent of some granites.

According to Crook, "the association with sulphides and oxides is that most characteristic of the occurrence of molybdenite in quantity in veins." In small quantities the mineral is not at all uncommon in the fissure veins of the Cordilleran States. The deposit at Crown Point, Wash.,[c] economically one of the most important in the United States, is a quartz vein in which molybdenite occurs in association with chalcopyrite.

USES AND PRODUCTION OF MOLYBDENITE.

Molybdenite is important as the main source of molybdenum, whose chief use in recent years is that of an alloy in the manufacture of steel. Other uses[d] of molybdenum in its different compounds are, as ammonium molybdate, to determine phosphorus in iron; as fireproofing material; as a germicide; as a disinfectant; as sodium molybdate, to color pottery and porcelain blue and to dye silks and woolens; as molybdenum tannate, to color leather; and, as "molybdenum indigo," to color india rubber.

According to Hess,[e] the price of molybdenum ordinarily ranges between 20 and 30 cents a pound for material carrying 92 per cent of molybdenum sulphide. The production of molybdenite ore in the United States is small, being in ordinary years less than 50 tons carrying 92 per cent of molybdenum sulphide.

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[a] Crook, A. R., Molybdenite at Crown Point, Wash.: Bull. Geol. Soc. America, vol. 15, 1904, pp. 283-288.

[b] Hillebrand, W. F., Distribution and quantitative occurrence of vanadium and molybdenum in rocks of the United States: Bull. U. S. Geol. Survey No. 167, 1900, p. 53.

[c] Landes, Henry, Ann. Rept. Washington Geol. Survey, 1901, vol. 1, pp. 41, 92, 93. Crook, A. R., Bull. Geol. Soc. America, vol. 15, 1904, p. 285. Pratt, J. H., Mineral Resources U. S., 1899 to 1902, U. S. Geol. Survey.

[d] Hess, F. L., Molybdenum: Mineral Resources U. S., for 1908, pt. 1, 1909, pp. 745-747.

[e] Op. cit., p. 747.

NOTE ON THE OCCURRENCE OF TUNGSTEN MINERALS NEAR CALABASAS, ARIZONA.

By J. M. Hill.

In the latter part of June, 1909, the writer made a short visit to the tungsten deposits about 3 miles south and a little east of Calabasas, Ariz., a station on the Nogales branch of the Southern Pacific Railroad, 10 miles north of Nogales. Information on this occurrence was also obtained from Messrs. Taylor, Peck, and Reagan, of Nogales, the two latter men owning claims in the vicinity.

The presence of wolframite was first noted about 1906, and a few prospect holes sunk at that time led to mild excitement. Little work has been done on the deposits. The deepest shafts are about 30 feet and the greater number are less than 10 feet in depth. Mr. Reagan has shipped about 1,000 pounds of ore which he states assayed more than 50 per cent tungstic acid, and about 400 pounds of ore of the same grade is still on the ground, together with several hundred pounds of lower-grade material.

The low north end of the tongue of land between Santa Cruz River and Nogales Wash is underlain by a very coarse, in many places porphyritic, granodiorite of light-gray color, that weathers to a flesh pink or dull red. In this rock are pink orthoclase crystals up to half an inch in diameter; the striations on plagioclase are plainly visible, and blebs of quartz and some dark micaceous mineral can be distinguished.

The granodiorite is cut by intrusive rocks of two types. One of small extent and of little importance so far as the ore deposits are concerned is a fine granular rock composed of orthoclase, quartz, some plagioclase (possibly andesine), and an insignificant amount of biotite.

The dikes that are most closely associated with the wolframite deposits are of the same type, but apparently of two ages of intrusion, possibly very close together. One set strikes N. 75° W. and dips at rather high angles to the north. The other and later system strikes N. 25° W. and is vertical or has a very steep dip to the west.

None of these dikes are over 6 feet across and most of them are between 2 and 4 feet. Some of them are traceable for 1,500 to 2,000 feet, but the greater number are shorter. The whole tongue is a grill of dikes in which those trending east and west are the more numerous. At one place four dikes, each about 2 feet wide, were seen within 100 feet, all striking N. 75° W. These were crossed by two north-south dikes.

The rock is a greenish-black, dense, fine-grained lamprophyre. Under the microscope it appears holocrystalline with trachytic texture. The most important constituents are an undeterminable plagioclase with index of refraction probably less than Canada balsam, long needle-like altered greenish crystals of hornblende, and a minor amount of quartz. The rock is largely altered to chlorite and a little epidote and contains some hematite, probably derived from magnetite, which is fairly abundant in the rock. It is cut by veinlets of calcite. Some phases are rather coarsely porphyritic, and in these the weathered surfaces are pitted, the casts being coated with iron oxide or filled with calcite.

The contacts of these dikes with the granodiorite are extremely sharp. The latter is apparently little changed except for a fraction of an inch. Along this belt, though the original constituents of the granodiorite are still visible, there is also a great deal of epidote and a chloritic mineral developed from both feldspars and ferromagnesian minerals. For one-fourth of an inch from the contact the intrusive rock is very dense, fine grained, and black; inside of this there is a belt of varying width, dependent on the size of the dike, that is much epidotized and chloritized; and in the center the rock is unaltered.

The deposits are veins showing beautiful comb structure, and in places repeated bands of quartz and wolframite. The usual order from the wall inward is quartz, wolframite. Here and there this order is reversed, and it may be that the deposition was more or less simultaneous, as wolframite crystals are seen in some of the quartz layers, and vice versa. Postmineral movement is shown by the gouge-covered wall, but the veins were not much crushed by this disturbance. In a number of places the quartz is cemented to the wall by a thin layer of greenish siliceous material, which is very dense, like a silicified shale, and may be the intrusive rock that has been altered by the solutions which formed the veins.

The principal gangue mineral is quartz, but there are some small crystals of calcite. The walls and gouge are in many places iron stained.

The only metallic minerals are wolframite, a dark reddish-black heavy mineral with metallic luster and brownish streak, and a very minor amount of scheelite. The wolframite is in part fairly well crystallized, but mostly rather massive. In the crystallized form, in the larger veins, the crystals have apparently grown into an open space that has later filled with white vitreous quartz. The wolframite near the surface is partly altered to iron oxide, which shows the form of the original crystal.

Most of the veins are under 10 inches in width, though some up to 2 feet were noted. The latter, however, are largely quartz. The veins occur both in the dikes and in granite near the dikes, and apparently the association between the wolframite and the intrusive rocks is very close.

Wolframite, however, is not found in all the veins nor in all parts of a single vein. It seems to lie in pockets in the larger quartz veins and to be more concentrated where these pinch. In the smaller veins the deposition of wolframite was apparently more general, as bands about one-eighth of an inch thick are fairly continuous along some of these veins. No large pockets were seen, the largest being about 4 by 3 feet along a 6-inch vein.

At the Reagan property, one-fourth of a mile east of the railroad and 2½ miles south-southeast of Calabasas, there are several open cuts and two shafts on a group of three veins. The country rock is granodiorite, very much altered and weathered. This is cut by two dikes of the dark rock described above, striking N. 75° W. The veins are apparently later than the dikes, which they offset a few feet. These veins all strike N. 25° W. and stand almost vertical. The central one is 30 feet west of the east vein and 60 feet east of the west vein.

The two outside veins are small and well banded and contain minor amounts of wolframite. The "tungsten" ore is usually next the wall rock, and the vein has a central band of comby quartz. The central vein varies from 1 to 2 feet in width and consists largely of quartz in which are pockets and stringers of wolframite. The deposition seems to have been repeated, as the banding from the wall inward is quartz (0.2 inch), wolframite (0.3 inch), quartz (0.25 inch), wolframite (0.1 inch), and quartz. The banding is not at all regular, however, wolframite locally filling the entire space inside of the first quartz bands. Scheelite occurs as minute crystals in the quartz near the bands of wolframite.

A 30-foot shaft at the Reagan property could not be entered, so conditions at that depth could not be studied. The veins as seen, however, to depths of 15 feet showed a slight pinching and rather less wolframite at the bottom. From the few prospects visited no generalization can be attempted as to the probabilities of ore at greater depth.

The deposits as a whole do not seem particularly encouraging. There are a large number of veins, but apparently most of them are nearly or quite barren. In the others wolframite is present in such small quantities and the pockets are so widely scattered as to hardly pay for mining.

SOME CHROMITE DEPOSITS IN WESTERN AND CENTRAL CALIFORNIA.

By E. C. Harder

INTRODUCTION.

Chromite is widely distributed through areas of serpentine and associated basic rocks in various parts of the United States. Such rocks are found at a few localities in the old crystalline region east of the Appalachian Mountains from New England to Georgia, at various points in the Rocky Mountains, throughout the extent of the Sierra Nevada and Coast Range in California, and at a few points in the Cascade Mountains. Chromite, being one of the accessory minerals in serpentine rock, probably occurs in a disseminated condition in all these regions, but its concentration is very local. Deposits are found in Massachusetts, Pennsylvania, Maryland, North Carolina, Wyoming, and California.

Chromite is the only commercial ore of chromium. Theoretically its composition is $FeO.Cr_2O_3$, with 32 per cent of ferrous oxide (FeO) and 68 per cent of chromic oxide (Cr_2O_3). Practically, however, the content of chromic oxide varies down to 10 per cent in the ores, though generally ranging between 40 and 60 per cent, and the ferrous oxide content varies from 10 to 50 per cent. Alumina and magnesia are almost invariably present, and in places they form a considerable proportion of the ore, alumina being present in quantities varying up to 30 per cent and magnesia in quantities varying up to 20 per cent. Ferric oxide is commonly present in small quantities. Alumina and ferric oxide replace chromic oxide and magnesia replaces ferrous oxide.

Chromite deposits are of two kinds—(1) pockets or lenses in serpentine or associated basic rocks, formed during the intrusion and cooling of the original magma by the segregation of chromite particles, and (2) chrome sands along watercourses, formed by the mechanical concentration of chromite particles derived from the weathering of serpentine, in which they occurred as disseminated granules or in pockets and lenses. Nearly all the deposits worked commercially have been of the first type.

The chromite deposits of Pennsylvania and Maryland were operated at intervals between 1827 and 1880, but have since yielded little or no ore. Chrome ore was discovered in California in the early seventies, but there was no production until 1880. Since then, however, nearly all the chromite produced in the United States has come from this State. Wyoming became a producer in 1908. No production has been recorded from North Carolina or Massachusetts, but the deposits have been occasionally exploited.

The chief producing counties in California have been San Luis Obispo, Shasta, Alameda, Del Norte, Placer, Glenn, and Tehama; minor quantities have been produced in Napa, Sonoma, and Calaveras counties. A total production of about 37,700 long tons has been reported from California from 1880 to 1908, inclusive. At the present time the only chrome deposits in California which are being worked are those of Shasta County. Deposits in San Luis Obispo, Alameda, Placer, and Calaveras counties were visited by the writer during a brief reconnaissance trip through western and central California during the fall of 1909.

DESCRIPTION OF DEPOSITS.

SAN LUIS OBISPO DISTRICT.

GENERAL DESCRIPTION.

The San Luis Obispo district is located on the coast of California about halfway between San Diego and San Francisco. It is on the west slope of the Coast Range, which in this district is represented by the Santa Lucia Range in the northeastern part and the San Luis Range or Los Osos Mountains in the southwestern part. The direction of the ranges is northwest and southeast, the Los Osos Mountains being near the coast and separated from the Santa Lucia Range by the Los Osos and San Luis valleys. Los Osos Valley runs into the ocean on the northwest at Morro Bay, and thence northward the Santa Lucia Range follows the coast. Northeast of the Santa Lucia Range is the Santa Margarita Valley, and beyond this are other parallel ranges.

The oldest rock formation in the district is granite of pre-Jurassic age, forming a large mountainous area northeast of the Santa Margarita Valley.[a] Next in age is the Franciscan formation (Jurassic), which consists of sandstone, conglomerate, shale, and amphibolite schist, and contains numerous jasper lenses. In the San Luis folio this is called the "San Luis" formation, but that local name has now been abandoned in favor of the older and better-known term Franciscan. It is intruded by basalt and diabase of slightly later age. This series of rocks is very irregular in its distribution. Above the

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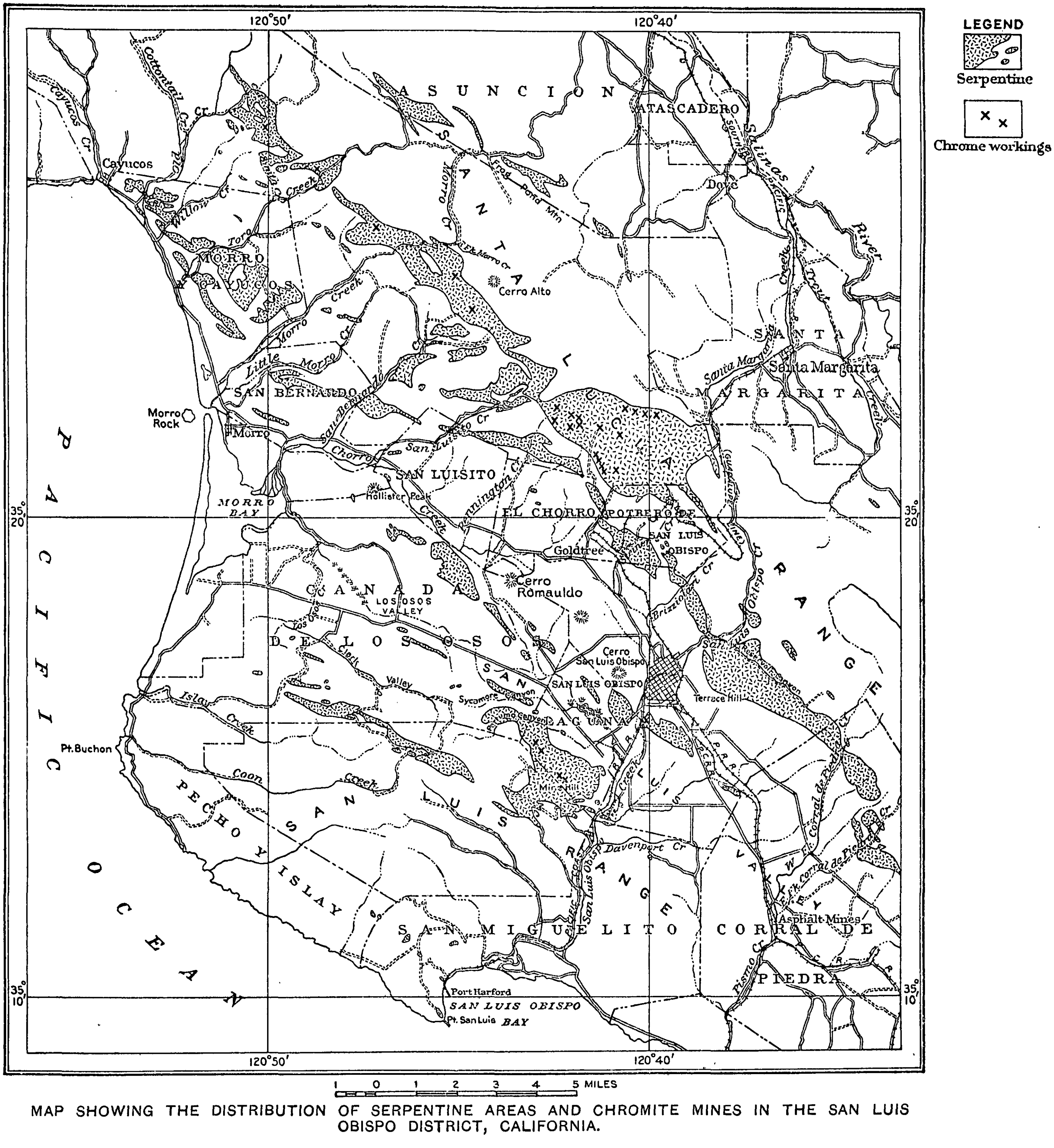
[a] Fairbanks, H. W., San Luis folio (No. 101), Geol. Atlas U. S., U. S. Geol. Survey, 1904.



MAP SHOWING THE DISTRIBUTION OF SERPENTINE AREAS AND CHROMITE MINES IN THE SAN LUIS OBISPO DISTRICT, CALIFORNIA.

Franciscan formation is the Lower Cretaceous Knoxville formation, consisting of dark shale and sandstone. This formation was called 'Toro" formation in the San Luis folio, but that local name has also now been abandoned in favor of the older and better-known term Knoxville. The Franciscan formation, and to a less extent the Knoxville formation, are intruded by granophyre, serpentine, and diabase. The serpentine areas are irregular and of varying size and occur throughout the Santa Lucia Range and in the Los Osos Mountains. They contain all the chromite deposits of the district. Younger sediments ranging from late Cretaceous to Pleistocene in age and Miocene intrusive rocks, consisting of andesite, rhyolite, and diabase, occur in various parts of the district.

Indications of chrome ore can be seen locally in the serpentine areas along the Santa Lucia Range and Los Osos Mountains and elsewhere within the district and they continue northwestward beyond the district. (See Pl. I.) The principal deposits, however, occur on the southwest slope of the Santa Lucia Range from 5 to 20 miles north and northwest of San Luis Obispo and in the Los Osos Mountains about 3 or 4 miles southwest of that town. There are a few deposits in the northeast slope of the Santa Lucia Range about 4 miles east-southeast of Santa Margarita[a] and on the west slope of Pine Mountain,[b] in the northwestern part of San Luis Obispo County but outside of the district proper.

In general the ores occur in lenses or pockets, of which many are rather irregular but nearly all are more elongated in two dimensions than in the third. They vary in width from a foot or less to 15 or 20 feet and in length up to several hundred feet. The greatest depth reached in the excavations observed by the writer was about 30 feet. In most places small branches run off from the main lens or pocket at varying though generally small angles. The main lens narrows and widens somewhat irregularly. Locally lenses are grouped along certain zones which may extend for a distance of half a mile or even a mile. As shown later, such zones generally extend along contacts. On the other hand, single deposits may be widely scattered.

The main lenses or pockets of chrome ore are made up of smaller bunches and veins of ore separated by serpentine which is but slightly impregnated with chromite. The wall-rock serpentine adjacent to the deposit is also slightly impregnated with chromite, which becomes more abundant as the deposit is approached. Similarly the bunches of chromite generally contain varying amounts of serpentine, though in places there are small masses perhaps 5 or 6 inches in diameter of almost pure chromite. In places, as in the Los Osos Mountains, the serpentine is badly weathered near the surface, having in consequence

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[a] Fairbanks, H. W., op. cit.

[b] Structural and industrial materials of California: Bull. California State Min. Bur. No. 38, p. 269.

a cellular structure due to unequal solution. Some portions of the rock are much decomposed and sandy; others are quite fresh. As a rule the rock is least decomposed around specks and bunches of chromite. The chromite is more resistant to erosion than the serpentine, and therefore where present is more or less concentrated near the surface.

The chromite of the district is of the glossy black crystalline variety and is generally found in small rounded granules in the serpentine. These granules vary from one-fiftieth of an inch or less to one-third of an inch in diameter and occur at varying distances apart, after the nature of phenocrysts in a porphyritic rock. Where the granules are small the mineral is finely crystalline; where they are larger it is more coarsely crystalline. In spots the particles are so close together that little or no serpentine remains, and in such places the ore is very coarsely crystalline.

Many of the deposits occur in the serpentine near the contact of older rocks into which the serpentine has been intruded. Such rocks may surround serpentine areas or may occur as masses within the serpentine. Hence deposits may be found extending around the borders of serpentine areas or may occur near included older rock masses within serpentine areas. Other deposits apparently have no such connection with older rocks and are scattered through the serpentine. In many of the areas the included rock masses are fine-grained biotite schist, and locally chromite deposits are found along their contacts.

MORRO CREEK.

Several chrome deposits that have been operated lie in a serpentine area crossing Morro Creek in a northwest-southeast direction, just below its junction with East Fork about 12 miles northeast of San Luis Obispo. Ore is found at several localities north of Morro Creek, but the most important deposits are to the south. These are reached by way of a road up Morro Creek to its junction with East Fork and thence by a trail into the hills. The deposits are on the southwest slope of the Santa Lucia Range a short distance below the summit. The hills are covered with a thick growth of chaparral and chamiso brush, with here and there clumps of manzanita, scrub oak, and yucca. Trees are rare in this part of the range except in the valleys, where live oak, white oak, and a few digger pine occur.

The principal workings are a mile south of Morro Creek, to the right of the trail. They consist of three irregular trenches arranged end to end in a direction about N. 45° W. The workings are 150 feet or more long, from a few feet to 30 or 40 feet deep, and up to 20 feet wide. The trenches follow a series of chromite lenses and pockets extending along the north contact of a lenticular mass of fine-grained biotite schist which is from 15 to 25 feet wide and is traceable throughout the length of the workings. At a few places the biotite schist touches the south wall of the trenches, but in general it is several feet away.

The chromite occurs in a nearly vertical zone from a foot or less to possibly 10 or 15 feet in width and extending at least for the length and depth of the trenches. (See fig. 13.) At one or two places the deposits pinch out for a few feet, so that the ore zone probably consists of several lenticular pockets arranged end to end. Smaller pockets lie in the wall rock alongside of the main series and are probably connected with them by stringers. Considerable fissuring has taken place along the chromite zone, as shown by numerous slickensided surfaces. The chromite as well as the serpentine has taken part in this movement, showing that the ore was formed previous to the fissuring. This fissuring is characteristic of serpentine wherever it is found as an alteration of basic olivine rocks, such as peridotite and gabbro, and is supposed to be due to pressure accompanying the increase in volume which results from this alteration. It follows, therefore, that the chromite was formed before the alteration to serpentine took place and was probably part of the original gabbro or peridotite intrusion.

There is no sharp line between the ore and the serpentine. Chromite occurs in small specks in apparently barren wall rock, and close to the deposits it is disseminated rather abundantly. Serpentine also occurs in all the chromite pockets in varying abundance, depending on the closeness of spacing of the chromite particles.

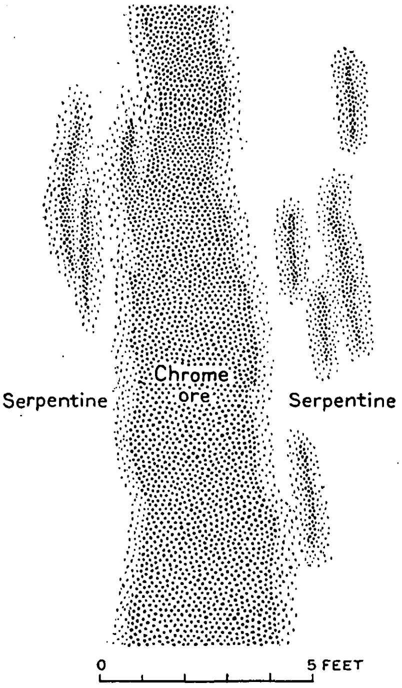

FIGURE 13.—Vertical section through a lenticular pocket of chrome ore south of Morro Creek, 12 miles northeast of San Luis Obispo, Cal.

Only a small quantity of ore remains in sight on the walls of the trenches, though about 10 or 15 tons of it lies on the dump. The floors of the trenches were covered with débris, so that it was impossible to determine whether or not the deposits continue below the present workings.

There is another group of less extensive workings consisting of open cuts about a mile southeast of the deposits described above and on the same slope. Others are found elsewhere in the same area, but were not examined.

PENNINGTON CREEK.

In the large serpentine area east of the head of Pennington Creek there are numerous pockets of chrome ore. Most of them are small, but they occur abundantly scattered through the area. They may be reached by way of a road going up to the head of Pennington Creek or by way of a road running into the mountains west of the horseshoe curve on the Southern Pacific Railroad.

Most of the workings are on an upland flat a short distance southwest of the main summit of the Santa Lucia Range, and on the sides of stream valleys cut into it. Very little ore is now in sight, though undoubtedly numerous deposits are undiscovered. The located deposits are all apparently exhausted. They were worked by small surface cuts and short tunnels, in but few of which was any ore visible in place, though at one tunnel about 10 tons of low-grade ore remained on the dump.

From the shape of the workings it appears that the ore occurs in small irregular pockets which locally seem to be scattered promiscuously through the serpentine area, and elsewhere are arranged along definite zones. Where ore is still visible it is of low grade, being intermixed with considerable serpentine, in which it occurs in granules of varying size. The granules are largest where the least serpentine is present—that is, where they are closest together—and as they become larger they become more coarsely crystalline.

MINE HILL.

The deposits in the Los Osos Mountains are on Mine Hill, about 4 miles southwest of San Luis Obispo. They are best reached by way of an old road which leaves the main highway at the Jasper place, near the Pacific Coast Railway. The workings consist of several groups of open cuts and tunnels scattered along the top of a brushy ridge for a mile or more.

The principal group of workings is about a mile northwest of the Jasper place. It consists of a tunnel and three or four large open cuts. The ore occurs in small specks and bunches disseminated through weathered and decomposed serpentine. Little or no pure chromite occurs, all the ore carrying a varying quantity of serpentine. Near the surface the serpentine is cellular, as a result of solution, the part remaining being that around chromite particles. A short distance below the surface the serpentine is gray, soft, and sandy between the ore specks, while that around the ore is compact and dark green. Where no ore is present the serpentine is all soft and grayish.

The other workings scattered over the ridge are chiefly small open cuts in local groups. The occurrence of the ore here is the same as described above. The serpentine everywhere seems to be soft and decomposed.

COMMERCIAL IMPORTANCE.

Large quantities of chromite have been shipped from the San Luis Obispo district, though the mines have been idle for many years. Most of the deposits operated are exhausted, but there are undoubtedly many others to be discovered. Prospecting is extremely difficult, as the serpentine areas for the most part are thickly covered with chamiso, chaparral, and brush oak, which not only conceal the soil but are penetrated with the greatest difficulty by prospectors. The activity was greatest about twenty-five or thirty years ago, and in 1890 it was estimated[a] that 11,000 tons had been shipped from the district. A small concentrating mill was once operated in San Luis Obispo, but is now out of use.

MENDENHALL CHROME MINES, LIVERMORE.

The Mendenhall chrome mines consist of several groups of workings on Cedar Mountain, Alameda County, about 12 miles southeast of Livermore. The deposits are best reached by way of the Mendenhall Springs road along the southwest slope of Arroyo Mocho. There are two groups of workings, several hundred yards apart, just west of the crest of the ridge extending northward from the summit of Cedar Mountain. Both consist of several open cuts and tunnels. A magnesite mine is near the chrome workings.

Cedar Mountain consists largely of serpentine which is intrusive into sandstone and shale of the Franciscan formation (Jurassic), the latter forming most of the eastern slope of the hill. The ore occurs in irregular lenticular pockets and stringers in more or less decomposed serpentine. Where the serpentine is much decomposed it is soft and broken and has a brown stain. The chrome ore that occurs in this rock is generally soft and friable and of a dull grayish-black color, but that in the fresh serpentine is glossy black in color and contains very little intermixed serpentine. Some masses of fairly compact ore are found within pockets of soft ore, as if they were not yet thoroughly disintegrated. Pockets of soft ore are homogeneous—that is, there are no particles of serpentine visible within the mass—and the contact with the decomposed serpentine surrounding them is very gradual. On the other hand, the contact between the fresh serpentine and chromite grains is sharp, and small particles of serpentine are visible throughout the chrome masses. However, the percentage of the serpentine in this ore is very much smaller than that in the average

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[a] Structural and industrial materials of California: Bull. California State Min. Bur. No. 38, p. 269.

ore from the San Luis Obispo district. Bright-green chrome ocher, a clay stained with chromic oxide, occurs at many places in the soft decomposed ore and along cracks in the fresh ore.

The workings at each of the localities cover an area about 100 by 50 or 60 feet. Single pockets are generally less than 10 feet long. Very little ore is in sight in the workings, and that is of low grade. Some low-grade ore also remains on the dumps. More than 3,000 tons of chrome ore is said to have been mined here, but operations stopped many years ago, probably because of the exhaustion of high-grade ore.

CHROMITE DEPOSITS NEAR VALLEY SPRINGS.

GENERAL DESCRIPTION.

The chromite deposits near Valley Springs occur in the central portion of the narrow belt of discontinuous serpentine areas extending in a northwest-southeast direction through southwestern Eldorado, Amador, Calaveras, and Tuolumne counties, along the lower foothill region of the Sierra Nevada. The portion of the belt near Valley Springs [a] is parallel to and just west of the Mother Lode district. This central portion is for the most part not more than a few miles wide, but to the northwest and southeast it widens and branches.

The serpentine is older than late Cretaceous, being intrusive into a variety of Carboniferous and Jurassic rocks which occur with it in parallel bands. The basal formation consists of Carboniferous (Calaveras) quartzites, argillites, and schists, which are intruded by amphibolite schists, diabase, and porphyrite. With them are associated slates of Jurassic age (Mariposa). This entire series has been compressed and complexly folded and faulted, the disturbances producing their schistosity and their distribution in northwest-southeast bands. They are locally covered by later Tertiary sediments and beds of fragmental rhyolite and andesite and are intruded by late Cretaceous igneous rocks of various types.

Chromite deposits occur at intervals along the serpentine belt in this district and continue to the north and south. The Valley Springs deposits are in several groups south, east, and north of Valley Springs, Calaveras County.

VOGELSANG RANCH.

The chrome deposits on the Vogelsang ranch are about a mile south of Calaveras River and about 5 miles southeast of Valley Springs. They consist of a series of lenses of varying size in serpentine arranged along a line trending approximately N. 45° W. Chromite can be traced for 600 or 700 feet along the strike; in this distance five or six lenses outcrop. All have their larger diameter parallel to

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[a] Turner, H. W., Jackson folio (No. 11), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

the strike and are separated from one another by barren stretches of several hundred feet. The largest lens has a maximum width of 10 to 15 feet and is 40 or 50 feet long; the second largest is 3 feet wide and 30 feet long. The width of the largest lens is shown by surface ore outcrops, but partings of serpentine may occur in it. The other deposits range down to a foot or less in width and to 5 or 10 feet in length. (See fig. 14.)

The lenses are nearly vertical or dip steeply to the northeast, this being the same dip as that of the schistosity of the associated rocks. They occur in the serpentine 25 to 50 feet from its contact with amphibolite schist, the string of deposits running along northeast of this contact and nearly parallel with it. The amphibolite schist has a well-developed schistosity, and thin slabs of it have resisted erosion and rise from a foot to 3 feet above the soil all along the contact, looking like gravestones. In strike and dip this schistosity is approximately parallel to the contact and to the chromite zone.

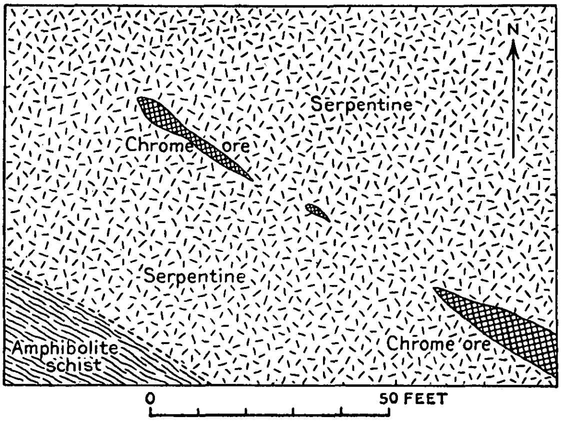

FIGURE 14.—Horizontal plan showing part of the chromite-bearing zone at the Vogelsang deposits, 5 miles southeast of Valley Springs, Cal.

The ore is very pure, glossy black, and coarsely crystalline. It is hard, heavy, and massive and can be removed in large fragments. Smooth fracture planes occur in it here and there and along some of these there are thin stringers of serpentine. In the mass of the ore, however, serpentine is almost or entirely absent, the ore thus being of high grade. The lenses are very irregular in their occurrence. One lens was found to pinch out altogether at one end about 4 or 5 feet from a point where it was 3 feet wide, while the other end continued for about 20 or 25 feet, decreasing gradually in width.

The contact of the chrome and serpentine is sharp, little or no chrome occurring in the wall rock and little or no serpentine in the ore. The serpentine is slickensided and schistose and of greenish-blue or gray color, the hanging-wall rock being apparently more decomposed than the foot wall.

A little ore has been removed for use as a furnace lining in the copper smelter at Campo Seco, but the deposits remain practically untouched. Their depth can therefore not even be estimated, but probably 500 to 1,000 tons of ore is in sight.

PINE TREE CHROME MINE.

The Pine Tree chrome mine is about 1½ miles north of the Vogelsang deposits and about half a mile north of Calaveras River, in the same serpentine area that contains the deposits just described. It consists of a narrow open cut 30 or 40 feet long, in serpentine. Several hundred feet northeast of the cut are outcrops of massive and schistose amphibolite with areas of dark-red stained jasper. No ore is visible in the cut, all having been removed and used for lining furnaces at the Campo Seco copper smelter, but fragments on the dump show it to have been an intimate mixture of chromite and dark-green massive serpentine.

OTHER DEPOSITS.

Several small occurrences of chrome are found about 5 miles north of Valley Springs, south of Mokelumne River, in a continuation of the same serpentine area that contains the mines described above. Other deposits are reported from isolated serpentine areas on the west slope of the Bear Mountains, 10 miles northeast of Milton[a] on the land of Captain Wright, on the Pool ranch, and on the Tower ranch, in Salt Spring Valley about 9 miles east of Milton.

FLAGSTAFF HILL CHROME DEPOSITS.

The Flagstaff Hill chrome deposits are in Eldorado County, 8 miles south of Auburn, in the northwestern part of the serpentine belt in the central portion of which the Valley Springs deposits occur. A large lenticular area of serpentine crosses Flagstaff Hill[b] in a northwest-southeast direction, and a number of smaller lenses lie northeast of this area, on the east slope of the hills north of Flagstaff Hill. The inclosing rock is amphibolite and amphibolite schist.

The principal deposits of chrome are in one of the small serpentine lenses about 2 miles north of Flagstaff Hill and about halfway up the east slope of the ridge. Several trenches have been dug, but the ore remains on the dumps and apparently none has been shipped.

The ore is in every way similar to that of the San Luis Obispo district, occurring in serpentine as granules and small particles varying in size and closeness of spacing. Most of the ore is fine grained and varies from high grade to low grade, according to the amount of serpentine present. It occurs in small indefinite pockets which trend approximately north and south and grade into the surrounding serpentine.

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[a] Turner, H. W., Jackson folio (No. 11), Geol. Atlas U. S., U. S. Geol. Survey, 1894; Structural and industrial materials of California: Bull. California State Min. Bur. No. 38, p. 267.

[b] Lindgren, Waldemar, Sacramento folio (No. 5), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

THE ORIGIN OF CHROME ORE DEPOSITS.

PREVIOUS INVESTIGATIONS.

The origin of primary chromite deposits—that is, those occurring as pockets and lenses in serpentine and associated basic rocks—has been discussed by various investigators.[a] Some of these, such as Von Groddeck and Power, have advanced hypotheses that chrome ore deposits have a fairly recent origin, being formed during the natural process of oxidation which accompanies the hydration and weathering, resulting in serpentinization. Meunier, on the other hand, as a result of chemical study, believed that they may have originated by pneumatolytic processes shortly after the intrusion of the magma. Most commonly, however, chromite deposits have been described as products of magmatic differentiation formed by the segregation of chromite particles during the intrusion and cooling of the magma. This view is held by Vogt, Pratt, Hall and Humphrey, Cirkel, and many others.

Chromic iron ore deposits may be likened in many ways to titaniferous iron ore deposits, the former occurring in peridotite (dunite, saxonite, wehrlite, etc.), and its alteration product, serpentine, while the latter occur similarly in gabbro, anorthosite, and associated rocks. The peridotites carry chromic oxide in varying though nearly always recognizable amounts,[b] but titanic oxide is present only sparingly. On the other hand, gabbros carry definite amounts of titanic oxide, but the chromic oxide present in them is negligible. Pyroxenites, the intermediate rocks between the gabbros and the peridotites, carry small quantities of both chromic oxide and titanic oxide, the former, however, being generally in excess. This suggests that chromite is present as an original constituent in peridotites as ilmenite is present in gabbros, magnetite occurring in both.

Von Groddeck advocated the hypothesis that chromite deposits, because of their intimate association with serpentine, were formed during the serpentinization of the original rocks such as peridotites and dunites. He believed that during the process of hydration of the magnesian silicates the iron present, which generally separates out

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[a] Pratt, J. H., and Lewis, J. V., Corundum and peridotites: North Carolina Geol. Survey, vol. 1, 1905, Chromite, pp. 369–390.

Pratt, J. H., Chromite or chromic iron ore: Mineral Resources U. S. for 1900, U. S. Geol. Survey, 1901, pp. 897–898.

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Von Groddeck, Lehre von den Lagerstätten der Erze, 1879, p. 146.

[b] Vogt, J. H. L., op. cit., p. 387.

as magnetite, would, if chrome minerals such as chrome diopside, picotite, and others were present, unite with the chromic oxide in these to form chromite. Vogt and Pratt, however, have shown that chrome occurs with peridotite as well as with serpentine, thus making Von Groddeck's hypothesis untenable.

Power, in his study of the New Caledonia chrome deposits, finds that besides being disseminated in small grains through the serpentine the chrome is concentrated along joints and water channels that could not have existed in the igneous mass at the time of solidification; he therefore concludes that even though chromite is apparently almost insoluble there must be some natural agent capable of decomposing it so that it may be redeposited. He makes the following statement:[a]

> The serpentine, as previously mentioned, occurs in bands; the longer axis of the chrome ore lenses corresponds with the general strike of these bands. The chromite does not occur in one solid mass, but is found in joints in the serpentine and in the sandwiched beds. One may find grains of chromite peppered through the serpentine even outside the limits of the workable deposits; the ore itself does not shade off gradually into serpentine but shows a sharp line of demarcation. Now, if this chromite were due to differentiation in the molten magma one would expect the ore to pass gradually from rich to poor and thence insensibly into serpentine; instead of this, however, we find it occupying joints which could not have existed until the rock had solidified. That chromium, in the form of chromite or picotite, was an original constituent of the eruptive rock is shown by microscopic slides which give examples of ores of these minerals—which one it is difficult to determine—partly in olivine and partly in serpentine due to the alteration of olivine, the chromite grain itself showing no signs of alteration. That it is difficult to satisfactorily demonstrate how the chromite got transferred to joints considering its difficultly soluble nature we admit; still we find the chrome iron ore occupying natural water channels in the rock, sometimes with a thin coating of chrome ocher, showing that there is still some natural agent in force capable of decomposing the chromite.

Although hypotheses of recent deposition account for a few isolated occurrences of chrome ore which are otherwise difficult to explain, they do not fit the predominant and characteristic occurrences. For these the theory of magmatic segregation is the only tenable one, though undoubtedly in some places later decomposition and alteration has modified the nature of the deposits. The following exposition of the origin of the chrome-ore deposits in North Carolina by magmatic segregation is given by Pratt and Lewis:[a]

> The large deposits of chromite in North Carolina occur in peridotite rock near the contact of this rock with the inclosing gneiss and where there is but a small amount of chromite, either in pockets or in grains or crystals. These are more abundant near the contact and diminish in number toward the center of the mass of peridotite. * * *
>
> The constant occurrence of the chromite in rounded masses of varying proportions near the contact of the peridotite with the gneiss and its occurrence in the fresh, as well as the altered, peridotite indicate that the chromite has been held in solution in the molten mass of the peridotite when it was intruded into the country rock, and that it separated out among the first minerals as this mass began to cool.

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[a] Op. cit.

As has been said, the peridotite (dunite) magma, holding in solution the chemical elements of the different minerals, would be like a saturated liquid, and as it began to cool the minerals would separate or crystallize out, not according to their fusibility but their solubility in the molten magma. The more basic portions being, according to the general law of cooling and crystallizing magmas, the less soluble would be the first to separate out. These would be the oxides containing no silica—in the present case the chromite, spinel, and corundum. These minerals would solidify or crystallize out where the molten magma first began to cool, which would be at the contact of the mass with the country rock; convection currents would tend to bring new supplies of material to the outer boundary, which would deposit its chromic oxide as chromite.

The more fluid a molten mass of rock becomes the more favorable will be the movements and other conditions in this molten mass to the bringing about of these changes, and it is in these very basic magnesian rocks that we find the best illustration of the separation and concentration of the more basic minerals.

This would account for all the irregularities of the chromite deposits—their pockety nature, the shooting off of apophyses from the main masses of the chromite into the peridotite, the widening and pinching of the chromite "lodes," and the apparent nonrelation or nonconnection of one pocket of chromite with another. There has not been sufficient work done in the North Carolina chrome mines to demonstrate exactly the position and relation of the chromite deposits to the gneiss or other country rock, and in the description of other chrome mines but little light has been thrown on this point. The chromite would be concentrated near the borders of the peridotite in rounded masses, with offshoots penetrating into the peridotite. The line of contact near the gneiss would be sharp and nearly regular, while with the peridotite the contact would be very irregular. The pockets of chromite found in the midst of a peridotite formation, which at the present time are isolated and have no connection with each other, were at the time of their formation part of the chromite concentrated near the border of the peridotite, but the rapid erosion to which these rocks have been subjected has worn them down to their present condition. Again, there would be a somewhat gradual passage from the chromite to the pure peridotite.

Hall and Humphrey, in connection with their work on the chromite deposits in the Transvaal, examined the ores microscopically and found that the chromite grains show perfect crystal outlines, their edges in many places encroaching on other crystals. They say:[a]

> In all the thin sections examined the chromite is found in small, well-defined grains, possessing very good crystal outlines, and this evidently points to the conclusion that the ore particles were among the first constituents to crystallize out. The same also holds good in those cases where the grains apparently envelop large crystals of enstatite or hypersthene and wrapped round them to produce a kind of network resembling the well-known mesh structure seen in highly serpentinized olivine rocks; for although such an appearance seems to indicate that the central rhombic pyroxene belongs to a phase of crystallization preceding that of the granular chromite, one frequently finds along the edge of the former some of the grains of the ore partially surrounded by enstatite and lying in a little indentation running into the latter. Since these two minerals constitute practically the entire rock, the residual mother liquor left after the separation of the chromite must have had a composition agreeing closely with that of the particular rhombic pyroxene met with, so that finally the magma would consolidate as a whole, thus producing the rude kind of cellular structure alluded to.
>
> The gradual though rapid transition from the purer ore, within the veins, to an enstatite rock, or hypersthenite, still containing a fair amount of chromite, but with a much larger proportion of feldspathic material, as well as the absence of a sharp line

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[a] Op. cit.

of division between ore and country rock, clearly points to the conclusion that these deposits are of igneous origin and must be regarded as due to local concentration of scattered chromite grains as one of the factors in the differentiation of the magma of the Bushveld plutonic complex.

The mode of origin of these chromite deposits is, therefore, similar to that of numerous occurrences associated with basic igneous rocks in other countries.

Cirkel, in a recent study of the Canadian chrome deposits, indorses the magmatic segregation theory with the following statement: [a]

> As to the Canadian chromite deposits, it is quite evident that according to microscopical investigations the present serpentine is a derivative from olivine or peridotite, the dehydrated magnesian rock. The formation of chromite is explained by the oxidation of chromium (which is supposed to have been originally present in the rock) to chromic oxide, and the association of the latter with iron protoxide, which has also been formed through the oxidation of the iron which formed an accessory mineral of the rock. Of course the actual formation of chromite must have been effected during the cooling or solidification of the magma under conditions which can not be sufficiently explained; pressure and different temperatures very likely have facilitated these transformations; at any rate it is quite certain that according to the law of solubility chromite must have crystallized first out of the magma, and this crystallization or accumulation was apparently greatest where the cooling was quickest—that is, at the contact of the serpentine with some other rock. This does not mean, however, that chromite is mostly found close to the contact of serpentine with the country rock through which the original peridotite penetrated, for we find to-day excellent chromite deposits away from such contacts. It is evident also that the manner in which the crystallization or accumulation in different parts of the serpentine took place is responsible for the great irregularity of the deposits, the pockety nature and the lack of connection between the deposits, and also for the disseminated form in which the ore occurs. These irregularities were further accentuated through the shifting and displacement through which the rock had to pass after the deposition of the mineral, for we observe that the ore bodies sometimes are abruptly cut off and displaced through slickensides.

Vogt,[b] after a careful and comprehensive study of the chrome deposits of northern and central Norway, comes to the following conclusion with regard to their origin:

> Because of the regular association of chromite deposits with the peridotite; because of the gradual petrographic change from the normal peridotite to chromite peridotite with constantly increasing chromite; because of the absence of pneumatolytic minerals; and lastly, because of the fact that the chromite of the chromite peridotite was formed before the cooling of the surrounding MgO-FeO-silicate magma, we draw with certainty the conclusion that the chromite deposits are basic segregations in the peridotite.
>
> At times these chromite concentrations have cooled in situ, while at other times they have broken through surrounding rock in veins or "schlieren."

THE CALIFORNIA DEPOSITS.

The California chromite deposits examined by the writer may be grouped under three heads—(1) deposits of hard black ore mixed with serpentine and grading into the surrounding serpentine, (2) deposits of hard black ore containing little or no serpentine and hav-

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[a] Op. cit.

[b] Op. cit., p. 393.

ing a sharp contact with the surrounding normal serpentine, and (3) deposits of more or less disintegrated soft gray ore in decomposed serpentine.

To the first class belong all the deposits near San Luis Obispo, those at Flagstaff Hill, and some of those near Valley Springs. They may be described as concentrations of chromite particles formed while the magma was fluid, and cooled and consolidated without accompanying deformation. These are typical magmatic segregations, the origin of which is well described by Pratt in the extract given above. Pratt, however, attempts to explain only those deposits which occur near the contact of the intruded rock. In California numerous large deposits occur within the serpentine masses at considerable distances from the borders, and therefore further explanation is necessary.

Various processes of physical chemistry are active in the differentiation of magmas, and three of these are important in the concentration of chromite deposits—(1) fractional and selective crystallization, causing a separation of the most basic constituents from the rest of the magma; (2) pressure due to gravity, causing a concentration of heavy minerals in the lower portion of the magma reservoir; (3) convection currents which carry new material to the cooler portions, especially along the contacts, and tend to coat them with early crystallizations. All these processes are active in the formation of the deposits along the contact with older rocks, but only the first two play an important part in the formation of deposits away from the borders.

When a magma begins to cool the basic constituents tend to crystallize out first, because they are the least soluble. In a peridotite magma these would be largely chromite with some spinel and perhaps magnetite. They would separate out first where cooling began first, principally near the periphery of the reservoir or around included rock masses. As a result of unequal cooling in different parts of the magma convection currents would be set up, bringing hot lavas to the cooler portions of the mass. The chromite in these convection currents would join the chromite already crystallized in the cooler zone and thus the deposits would begin to grow. A layer of molten rock for a varying distance from the contact with the intruded rock would probably become so viscous immediately after the intrusion of the magma that but little concentration could occur in it; thus the barren zone between the contact and the ore lenses would be accounted for.

While this concentration along the contacts was taking place there would doubtless be a settling of heavier particles in other parts of the reservoir, due to gravity, soon causing a concentration in the lower portion. Both Vogt and Kemp[a] have considered this process as the principal one in the formation of titaniferous iron-ore deposits. If the magma were perfectly homogeneous and had the same temperature and gaseous content throughout, this concentration would doubtless be regular over the entire lower portion of the reservoir. However, any slight variation in the above-named properties or in basicity would cause a localization of concentration and such local points once established would act as centers of concentration, thus resulting in the segregation of basic minerals, in this case largely chromite, into deposits. Convection currents and other movements in the magma would at first interfere with the settling due to gravity, but after centers of concentration were once established such movements would aid in their growth. The result of these processes operating in a peridotite magma would be a local development of chromite deposits along contacts and in the lower part of the reservoir. Later movements of the magma, however, would doubtless alter the position and location of many of the centers of concentration, so that deposits might occur anywhere in a peridotite mass. Further eruption might even take place after such differentiation.

Chromite occurrences of the second type were seen at only one locality—that of the Vogelsang deposits near Valley Springs. They are duplicates of the Norwegian deposits described by Vogt[b] as "schlieren" and veins resulting from later movements in the magma. After the concentration of large deposits of chromite, before or after partial consolidation of the main mass of rock, the magma may be subjected to external pressures resulting in the squeezing of some parts of it into other parts and in a general deformation of the entire mass. During this process pure chromite masses or, as described by Vogt, mixtures of chromite with enstatite or olivine may be squeezed between masses of normal peridotite that may be fluid or partly consolidated. Thus perfectly sharp contacts would be established. Elsewhere the masses of chromite may be simply deformed by shearing and squeezing without much change of position. These processes would produce many of the chromite veins which have been by some investigators attributed to later deposition by ore-bearing waters.

Doubtless further deformation of the ore bodies takes place during the serpentinization of the inclosing peridotite. This change, due to the hydration of the magnesian silicates, is accompanied by a great increase in volume (33 per cent, according to T. Sterry Hunt, if there is no loss of silica), causing the development of immense

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[a] Vogt, J. H. L., Om dannelse af jernmalmforekomster, Kristiania, 1892. Kemp, J. F., Titaniferous iron ores of the Adirondacks; Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 417-419.

[b] Vogt, J. H. L., Beiträge zur genetischen Classification der durch magmatische Differentiationsprocess und der durch Pneumatolyse entstandenen Erzvorkommen: Zeitschr. prakt. Geologie, 1894, Chromeisenerz, pp. 384-393.

pressures which result in widespread shearing, faulting, and slickensiding. During the alteration of olivine and pyroxene to serpentine the iron present in these minerals separates out as magnetite and becomes disseminated through the serpentine. Adjacent to chromite deposits the magnetite may join the chromite and cause a dilution of the latter locally.[a]

Deposits of the third type are formed by weathering from either of the above-described types and are illustrated by the Mendenhall occurrences near Livermore. Here disintegration of the chrome-ore deposits has taken place near the surface with partial decomposition, resulting in the so-called "gray chrome ore." The wall-rock serpentine is decomposed and disintegrated to a much greater extent than the ore, and the ore deposits have probably been deformed considerably because of slumping. Numerous small bright-green specks of chrome ocher occur in the ore masses, bearing witness of at least a partial solution and subsequent hydration of the chromite.

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[a] Lindgren, Waldemar, personal communication.

AN OCCURRENCE OF MONAZITE IN NORTHERN IDAHO.

By F. C. Schrader.

LOCATION AND TOPOGRAPHY.

The occurrence of monazite here described is located in the southeastern part of Nez Perce County, Idaho, about 120 miles southeast of Spokane and 60 miles east of Lewiston. The nearest railroad station is Greer, 28 miles to the west, on the Clearwater branch of the Northern Pacific Railway. The locality is some 1,500 feet higher than Greer and is reached by a wagon road, following the famous Lolo trail that crosses the Bitterroot Range. The deposits are about 10 miles east of the village of Weippe and the same distance south of the mining camp of Pierce, in the western border of the Clearwater National Forest. The northern part of the field may also be reached by a wagon road joining the main road at Brown Creek, about 5 miles beyond Weippe.

The deposits examined are on Musselshell Creek, a tributary of Lolo Creek. The latter flows into Clearwater River, which joins Snake River at Lewiston. Musselshell Creek drains a part of the western border of the Clearwater Mountains at an elevation of 3,000 to 4,000 feet above sea. These mountains are shown by Lindgren[a] to be carved from an old uplifted westward-sloping plateau, now deeply dissected into a rough topography characteristic of eroded granitic rocks. The canyons, valleys, and gulches are deep and the ridges high and sharp. The region is heavily timbered and has a considerable annual precipitation. In the western portion, however, near the region where the mountains give way to the younger Columbia River basalt plateau (fig. 15), the topography becomes less rugged. Here the upper part of Musselshell Creek occupies a narrow valley about one-fourth of a mile in width from ridge to ridge and sunk to a depth of several hundred feet below the summits of the adjacent hills, which represent roughly the general level of the plateau or upland.

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[a] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904.

GEOLOGY.

The country rock in this portion of the mountains, as shown in figure 15, has been sketched by Lindgren as pre-Tertiary granite and its closely allied rocks, quartz monzonite and diorite, of massive structure, in which are embedded bands or local bodies of old metamorphic gneiss and schist. The granite itself, a normal light-gray medium-grained rock, of great constancy in petrographic character, is found on analysis to stand very close to quartz monzonite.[a]

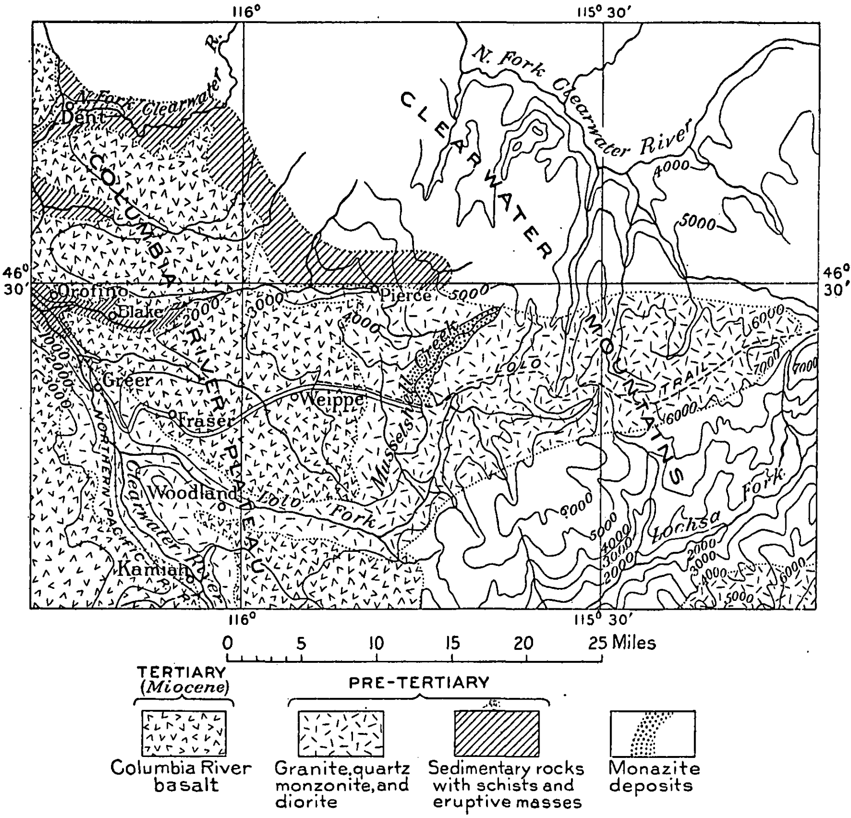

FIGURE 15.—Sketch map showing location of monazite deposits on Musselshell Creek, Nez Perce County, Idaho. (Adapted from Pl. I, Prof. Paper U. S. Geol. Survey No. 27.)

In favorable places on the ridges and side slopes of the valleys disintegration of these rocks has covered the surface with granitic residual soil or loam several feet thick. The bottom of the valley, 250 feet wide, is covered by a sheet of recent alluvium about 8 feet in average thickness. The upper 3 or 4 feet of this alluvium underlying the creek bottom or valley flat is usually composed of humus, soil, loam, muck, sand, and clay in various amounts; the lower 4

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[a] Prof. Paper U. S. Geol. Survey No. 27, 1904, pp. 17-20.

feet consists essentially of recent stream gravels and sand, resting upon the granite bed-rock floor.

The gravels are mainly granitic and, together with their sand and mineral content, are derived from the parent rocks in the immediate vicinity. They range from fine to coarse. Although stream-laid and to a moderate degree waterworn, on the whole they are more subangular than rounded.

Associated with these recent gravels, particularly on the rim rock and extending thence to higher ground, are also local deposits of ancient river gravel or "old wash." This ancient gravel is composed almost wholly of waterworn or well-rounded pebbles of quartz and dense quartzite and contrasts strongly with the recent gravel deposits. It is known to exceed 11 feet in maximum thickness.

Both the recent and the old gravels contain low-grade deposits of placer gold, which have been worked at different points with varying success from time to time during the last half century. The most extensive workings are those of the Musselshell Mining Company, at Musselshell Falls, near the middle of the field, a few miles above the Lolo trail.

MONAZITE DEPOSITS.

The monazite occurs as placer sand chiefly in the gravels above described. It was recently recognized by the Musselshell Mining company in operating for gold. The deposits were examined by the writer for a distance of about 7 miles, extending from the Lolo trail crossing northeastward along the creek nearly to its head, as shown in figure 15.

Owing to its high specific gravity, which is generally over 5, the monazite in the recent gravels, like the placer gold with which it is associated, is more concentrated in the lower part of the gravel and on the underlying bed rock than in the upper part of the gravel. The sand seems to be more plentiful in the ancient gravels than in the recent. For this reason these ancient gravels seem to be worthy of exploitation to bed rock, for their monazite as well as their gold content.

Likewise owing to its high specific gravity the monazite tends to remain with and is difficult to separate from the gold and heavier black-sand minerals, such as ilmenite, magnetite, garnet, and zircon. It is, however, more widely distributed than the gravel and the gold, for it is found also, though in less concentrated form, in the talus, disintegrated granite, and residual soil in the gulches and on slopes rising several hundred feet above the creek. What is commonly reported to be the best monazite prospect in the field is about a mile east of the falls of Musselshell Creek, on fairly high ground, in the southern part of the property known as the Little John claim. This deposit is apparently on one of the upper gulches of Gold Run Creek, a tributary to the Musselshell in the southern part of the field. Search in this locality failed to reveal any opening, but it was probably concealed by a considerable depth of snow that lay on the ground at the time.

It is probable that the monazite extends not only throughout the length of Musselshell Creek valley, but that it may have a much wider extent and may occur also in adjoining valleys. This inference is supported by a letter received from Mr. I. D. Cleek, superintendent of the Oro Grande Placer Mining Company at Pierce, and an experienced operator in the Musselshell and Pierce districts, who states that the monazite is much more plentiful at Pierce than on Musselshell Creek.

The monazite sand on Musselshell Creek is yellowish brown, with a greenish tinge in places, and has a resinous luster. It is fine grained, with the grains predominantly subangular and in large part exhibiting bright faces.

Eleven samples of the sand were collected at intervals to show its general distribution throughout the field. These were concentrated by David T. Day by means of magnetic machinery and by washing, and were found to contain from 7½ to 45 per cent of monazite, averaging about 29 per cent. Subsequently chemical analyses were made of the nonmagnetic portions of four of the samples by R. C. Wells, with results which conclusively identify the mineral monazite.

Analyses of monazite sands from Musselshell Creek, Nez Perce County, Idaho.

[Analyst, R. C. Wells.]

	No. 5. (162).	No. 14 (163).	No. 19 (164).	No. 21 (165).
P_2O_5	10.9	8.9	15.5	8.7
ThO_2	1.20	1.15	1.85	.88

The more interesting constituent revealed by the analyses is the thoria, for the commercial value of the monazite depends wholly on its available thoria content. The average in these samples was 1.3 per cent. The thoria is extracted chemically and is used in the manufacture of mantles for incandescent gas lights.

Computation from the content of phosphoric acid (P_2O_5) shows that the sands range from 31.8 to 55.36 per cent monazite, and average about 40 per cent. Estimates made by D. B. Sterrett of the percentage of monazite in the samples not analyzed agreed rather closely with the determinations based on the chemical analysis.

When cleaned to 90 per cent, the usual commercial grade, the sands contain approximately 3 per cent of thoria, which is about the average of a large number of samples from northern Idaho reported to have been analyzed by the Welsbach Light Company. On a basis of pure monazite the sands would contain 3.3 per cent of thoria.

As some of the phosphoric acid on which computation of the monazite is based may be derived from impurities present in the sands, the above-stated percentage of monazite in the samples analyzed is probably too high and that of thoria correspondingly too low. No allowance being made for this fact nor for the monazite lost during concentration both in the field and in the laboratory before the sand reached the chemist, and the sand of 90 per cent grade being rated at a value of 5 cents per pound, tests on the gravels show that they carry values in monazite ranging from 1 to 7 cents a cubic yard, or an average of about 3 cents. It is difficult to place a correct value on cleaned monazite carrying so low a percentage of thoria, as the companies manufacturing thoria compounds generally obtain sands carrying 5 per cent or more of this oxide. The present market price for monazite is 12 cents a pound for sand carrying 90 per cent of monazite and 5 per cent or more of thoria. The value of monazite with a smaller percentage of thoria is not proportionately less, as the cost of extraction of this oxide is considerably greater when the thoria content is low than when it is high.

Although at this figure the deposits are not workable for the monazite value alone, it is possible that the monazite can be saved with profit as a by-product in connection with gold-placer operations, and such saving may enable some ground to be handled with a margin which could not be worked for its gold content alone. As the value of the mineral, the extent of its occurrence, and the facilities that exist for saving it are not generally known, no effort has yet been made to save the monazite in mining operations in this part of the State.

Monazite is usually mined by concentration in sluice boxes, much the same as placer gold. Owing to its high specific gravity it is easily saved by ordinary methods of washing on the Wilfley or any similarly constructed table. As magnetic iron, titanic iron, garnet, and similar minerals associated with monazite respond to magnetic attraction a fairly clean separation can be effected with the Wetherill electro-magnetic separator.

ORIGIN AND GENERAL DISTRIBUTION OF MONAZITE IN IDAHO.

The following note on the known and inferred distribution of monazite in Idaho may prove of value to operators in regions where this mineral, hitherto unrecognized, may be present in commercial quantities.

Monazite was first reported in the Western States from Idaho Basin, Boise County, in southern Idaho, by Lindgren[a] in 1896. It

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[a] Lindgren, Waldemar, Mining districts of Idaho Basin and Boise Ridge, Idaho: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 677-679.

is widely distributed in the gravels of this locality, and its commercial exploitation has recently been undertaken on a considerable scale by the Centerville Mining and Milling Company at Centerville, with reported promising results.

In 1905, as a result of investigations made by the Geological Survey of the useful minerals contained in the black sands of the Pacific slope, sands containing monazite were received or reported from various localities, mostly in Idaho and Oregon. The Idaho localities are as follows:[a]

- Ada County:
  - Boise.
  - Boise Basin.
  - Snake River.
- Boise County:
  - Centerville.
  - Grimes Creek.
  - Red Fox claim.
  - Placerville.
  - Lardo.
  - Garden Valley.
  - Marsh.
  - Idaho City.
- Canyon County:
  - Payette River.
- Idaho County:
  - Elk City and district.
  - Resort.
  - Florence.
  - Marshall Lake district.
  - Baker Gulch, Crooked River.
  - Penmans Fork, Big Creek.
  - Syringa.
  - Camp Howard district.
- Lemhi County:
  - Leesburg.
  - Leesburg Basin, Arnet Creek.
  - Leesburg Basin, Wards.
- Lincoln County:
  - Minidoka.}
  - Shoshone.} Snake River.
- Nez Perce County:
  - Orofino.
  - Dent.
  - Lewiston (Clearwater River).
  - Salmon River.
  - Pierce City and district.
- Owyhee County:
  - Oreana, Snake River.
- Shoshone County:
  - Rhodes Creek.
  - Near Dent.
- Washington County:
  - Meadows.
  - Central Idaho, Salmon River.
  - Snake River.
  - John Day Creek.

Lindgren concluded that the monazite in the Idaho Basin was derived by disintegration from the local granite, of which it forms an original constituent. Similarly, the monazite of Musselshell Creek, recently examined by the present writer, seems without doubt to be derived from the pre-Tertiary granite and associated rocks. Many of the heavy minerals found in the sands of the gravels may be observed macroscopically or with a pocket lens in these rocks.

According to Lindgren, who has investigated both fields, the granite of Idaho Basin and the granite on Musselshell Creek are very closely allied if not the same rock. Both areas seem to be part of the same great granitic batholith that extends north and south through all of central Idaho, with a length of 300 miles, and eastward through the

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[a] Day, D. T., and Richards, R. H., Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906, pp. 1194–1201.

Bitterroot Range into Montana, with a width of 50 to 100 miles, "constituting one of the largest granitic batholiths of the continent."[a]

The manner of occurrence and the distribution of the monazite deposits on Musselshell Creek and in Idaho Basin and the distribution of the reported localities, all within or near the granite batholith area, are suggestive of a genetic relation between the monazite and the granite. Accordingly, it seems possible that the general distribution of monazite in Idaho may be roughly coextensive with the batholith area and the eruption of these granites into the included and inclosing older rocks. The monazite deposits without the area of the batholith may also have their origin in the smaller eruptive masses, probably offshoots from the same batholith, intruded in the outlying schists and sedimentary rocks. Deposits occurring under such conditions resemble those of the Carolinas in the southern Appalachians. The occurrence of monazite around Dent, on the North Fork of Clearwater River, in the northwestern part of Idaho (see fig. 15), furnishes a good example of this type.

If the above inferences are correct, it would seem that a knowledge of the distribution of granitic rocks of this class, whether occurring as batholitic masses or local intrusive bodies, may be utilized in searching for monazite deposits. If, as reported by the Centerville Mine and Milling Company, monazite sand of 90 per cent grade from Idaho Basin contains 4½ to 5 per cent of thoria,[b] it seems reasonable to infer that sand containing similar thoria values may yet be found elsewhere in the Idaho field.

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PLATINUM IN SOUTHEASTERN NEVADA.

By HOWLAND BANCROFT.

INTRODUCTION.

Early in the month of June, 1909, the writer, at the request of David T. Day, made an investigation of the Key West and Great Eastern prospects in Clark County, Nev., a short sketch of which has already been published.[a] Since that time a more detailed study of the specimens has been made and assays for gold, silver, platinum, and nickel have been furnished by competent analysts. Because of the necessary brevity of the former sketch and of the interest connected with the results of the assays made since its publication, it has been thought advisable to prepare a more detailed account of the results of the investigation.

Sincere thanks are due to the officers of the Key West Company for much information pertaining to the properties examined. To Mr. Waldemar Lindgren the writer is especially indebted for valuable assistance in the preparation of this paper.

LOCATION.

The prospects examined are located in the Copper King mining district, Clark County, Nev., about 16 miles a little west of due south of Bunkerville, a small Mormon settlement on Virgin River. (See fig. 16.) The most direct route to the prospects, however, is not by way of Bunkerville, for a wagon road crosses the river several miles southwest of that place and goes practically direct to the deposits. In an air line it is just 24 miles S. 75½° E. from the Moapa station on the San Pedro, Los Angeles and Salt Lake Railroad to the district. The distance by the most direct wagon road at present is probably between 35 and 40 miles, but could no doubt be shortened 4 or 5 miles by picking out another route. The prospects are situated about 8 miles west of the Nevada-Arizona boundary line.

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[a] Mineral Resources U. S. for 1908, pt. 1, U. S. Geol. Survey, 1909, p. 783.

GENERAL DESCRIPTION.

Reference to the St. Thomas topographic sheet of the United States Geological Survey will show the type of the country traversed between Moapa and the district examined. Moapa is located where the old California trail crosses Muddy Creek, at an elevation of 1,663 feet.

The country between Moapa and Virgin River is a desert plateau about 2,500 feet in elevation. There is hardly any vegetation, a total lack of water, and no habitation between the two places. Certain parts of the valley of Virgin River present a very acceptable and pleasing sight after the long ride across the desert. The river at the crossing has an elevation of 1,100 feet. The prospects are situated in the rough foothills of the Virgin Range about 8 or 9 miles from the river crossing and 2,500 feet above it. The range itself is

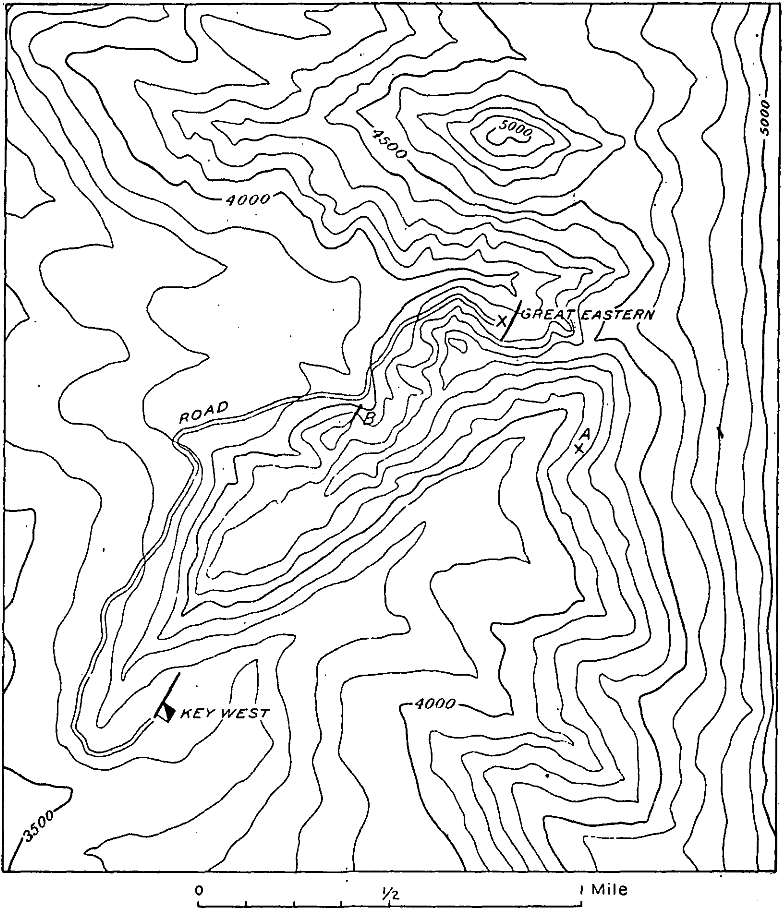

FIGURE 16.—Approximate sketch of a part of the Copper King mining district, Clark County, Nev.

precipitous, its highest point, Virgin Peak, attaining an elevation of 7,500 feet. Apparently it is formed mainly of thick sedimentary limestone strata.

Because of their altitude the temperature at the deposits is considerably lower than at Moapa. Early in June, 1909, it was fairly comfortable at the Key West when the heat was almost unbearable at Moapa, the thermometer there registering over 116°. During the spring, fall, and winter months the climate is said to be nearly perfect, little or no snow falls in the valleys, and there are frequently long periods of clear, pleasant days.

The nearest running water is in Virgin River, 8 or 9 miles distant. The water from the Key West shaft and from the Great Eastern adits has been utilized in the past for domestic use and also in the boiler on the Key West property with no apparent ill effects, as the writer has been informed. Whether the prospects would afford enough water to run a mill or reduction works of any kind is rather doubtful. According to reports on the property the Key West makes 8 gallons of water a minute at a depth of 300 feet. This is 11,520 gallons of water a day. The writer is not familiar with the amount of water developed in the Great Eastern properties, but it is certainly enough for domestic use.

Timber is scarce in this vicinity and the freight on fuel from Moapa would be very expensive, almost prohibiting the erection of a smelter at the property with the present transportation facilities.

GEOLOGY.

Between Moapa and Virgin River little rock in place can be seen in crossing the plateau. This desert table-land is covered in many places with small fragments of limestone and sandstone, with here and there an outcrop of the former. In places this seems to resemble a cracked asphalt pavement, being very flat and smooth and presenting a network of small fissures. Some 4 miles out of Moapa is an outcrop of reddish sandstone. Beyond and above this, as far as the Virgin Valley, all of the rock seen in place is limestone. The rocks of the high bluffs on the west of Virgin River and apparently the rocks which underlie the whole plateau between Muddy Creek and the river are reddish sandstones of Paleozoic age.

On approaching the Key West from the Virgin, the underlying rock is seen to be a pinkish coarse-grained gneiss of granitic composition, having orthoclase feldspar and quartz in about equal amounts, with a little hornblende. Overlying this is a limestone conglomerate a few feet thick composed of rather small fragments. Above this is a pinkish limestone of considerable thickness which assumes a yellow color on weathering. This formation extends to a point within 2 miles of the Key West, where it has been entirely eroded and the underlying gneiss comes into view. About 2 miles east of the Key West the limestone reappears and is apparently of great thickness, forming very steep cliffs on Virgin Mountain. Thus a narrow strip approximately 4 miles in width of probably pre-Cambrian rocks has been exposed by the erosion of the overlying Paleozoic sediments.

The rocks in the immediate vicinity of the Key West and Great Eastern properties consist of coarse-grained gneisses apparently of granitic origin, showing distinct gneissic structure. The country rock of the deposits shows on microscopic examination of thin sections about an equal amount of quartz and feldspar, with some hornblende and a very small amount of biotite, occupying close parallel zones which emphasize the general gneissic structure. Much of the feldspar is altered to white mica (sericite or paragonite) and here and there epidote and calcite are present in small amounts. These gneisses are probably of pre-Cambrian age. The prevalent direction of schistosity seems to be northeast, with a very steep dip to the northwest. These rocks, standing almost vertically and with the accompanying jointing parallel to the shearing planes, form in places prominent ridges. Along these ridges can be seen distinctly the successive intrusions of various basic rocks, with aplite and pegmatite, all of which are common to the vicinity. The two latter rocks are evidently later than the metamorphism of the region. The most schistose of the basic intrusive rocks is almost black, the feldspar it contains making all the more prominent the perfect lamination displayed. The phenocrysts of feldspar and hornblende are small, and although the general appearance of the rock is somewhat similar to that of the ore-bearing dikes, it can readily be distinguished from them in its comparatively large content of feldspar. This hornblende schist seems to be part of the earlier series and bears evidence of considerable metamorphism. A thin section of this rock shows hornblende, plagioclase feldspar, and some quartz. The feldspars are altered in part to white mica, and the titaniferous magnetite, which has filled some of the interstices between the hornblende, has altered to leucoxene. A little pyrite is present in the magnetite; both these minerals are secondary, the magnetite filling interstitial spaces rather than crystallizing, as it would if primary.

The pegmatite is very coarse grained, having orthoclase and quartz crystals over half an inch in length and containing a large amount of mica. The aplite is of medium grain and contains much mica.

Dikes of extremely basic composition are the most interesting feature of the geology of the area and these will be described in some detail, as they represent the ore-bearing formation. As may be seen by referring to figure 16, these dikes are intruded into the gneisses in a number of places with no apparent regularity except that of direction of strike. The trend of the intrusive rocks is approximately northeast and southwest, which follows the strike of the gneiss, the dikes in general seeming to conform to the structure of the older rocks.

The extent of outcrop of the basic dikes on the surface is generally 100 feet or more, and they vary in width from 10 to 50 feet. They are rather commonly faulted both horizontally and vertically, as indicated by the fault in the Key West property and by the displacements seen in the country rock in the vicinity.

The Key West and Great Eastern prospects are the two most prominent workings in the vicinity. The former is located on the southwest end of Virgin Mountain at an elevation of 3,660 feet and the latter about a mile northeast of this place at an elevation of 4,175 feet.

PETROGRAPHY OF THE DIKES.

The ore bodies in both the Key West and the Great Eastern are simply very basic intrusions having the composition of peridotite. The Great Eastern dike, from which it was possible to obtain fairly fresh specimens, is medium grained and dark colored, almost black, showing megascopically the presence of brownish mica and pyrrhotite. A thin section shows on microscopic examination that the rock is holocrystalline; the chief minerals are augite, olivine, biotite, and enstatite, their relative abundance being in the order named. This would constitute an enstatite-mica picrite, a variety of peridotite. The rock also contains magnetite, pyrrhotite, and chalcopyrite, which are apparently of primary origin and are intimately intergrown. These minerals constitute a small relative proportion of the whole dike, but are nevertheless rather conspicuous. Chromite was also recognized. The olivine has been in part decomposed, quartz, iron-stained serpentine, and magnetite resulting. This magnetite has no apparent relation to that associated with the pyrrhotite and chalcopyrite, however, but is scattered through the interstices of the altered olivine. A specimen of the rock from this dike analyzed for the United States Geological Survey showed the presence of a trace of platinum and 0.26 per cent of nickel, but no gold or silver.[a]

Other assays made by R. H. Officer & Co., of Salt Lake City, the results of which were given by Mr. Darling, superintendent of the Key West property, show 1.5 per cent of copper, 0.9+ per cent of nickel, and 0.25 ounce of platinum for the Great Eastern dike. A recent assay made by Ledoux & Co., of New York City, of a dike cut in the lower Great Eastern adit, the results of which were kindly furnished by the Key West managers, shows the following analysis:

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[a] Nickel determination by chemical laboratory, United States Geological Survey; platinum, gold, and silver by Ledoux & Co.; no assay for copper made.

Analysis of dike in lower Great Eastern adit.

Silica	24.88	Copper by electrolytic assay	2.01
Iron	19.35	Nickel	5.38
Alumina	4.21	Cobalt	.04
Lime	4.51	Platinum metals, 0.17 ounce.	
Magnesia	13.94	Gold, trace.	
Sulphur	18.02	Silver, trace.	

From a small open cut (location B on fig. 16) a specimen of another basic dike was taken. On microscopic examination this proved to be a typical hornblendite, the hornblende minerals being about 3 millimeters long and forming a holocrystalline rock. An assay showed a trace of platinum, but no nickel, gold, or silver. The presence of platinum in such a fresh rock, showing no signs whatever of metallic contents even in a thin section under the microscope, is worthy of remark. As little or no work has been done on this open cut it is impossible to give any details of the extent of the dike.

Another open cut (location A on fig. 16) is upon a dike composed almost entirely of biotite mica and pegmatite, which occupies a shear zone in the country rock. This dike probably contains no valuable metals, although no assays have been made of the material.

The Key West dike has been exposed by more workings than any other in the vicinity. However, the upper portions of the dike and the ore on the dump from the lower portions (under water at the time of the writer's visit to the camp) are extremely decomposed and altered, so that no detailed description of the constituent minerals of the dike can be given. It is reasonable to suppose, however, that the Key West and Great Eastern dikes were once of similar mineralogical composition. In the Great Eastern workings apparently there has been much more alteration, oxides and sulphides of copper having been deposited in large quantities.

Only a small amount of pyrrhotite is present in the ore from the Key West workings. This is probably due to the fact that on hydrometamorphism, such as has taken place in this dike, pyrrhotite changes to pyrite,[a] a mineral of which there is a great abundance, of both primary and secondary origin.

Assays made of the Key West ore show that the decomposed dike near the surface contained 0.1 ounce of platinum to the ton and 1.47 per cent of nickel, no gold or silver being present. One specimen of ore which contained an apparent high percentage of sulphides assayed 0.12 ounce of platinum to the ton and 5.6 per cent of nickel, with no gold or silver, copper content not being determined. This specimen shows extreme brecciation, and is composed of quartz fragments

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[a] See Lindgren, Waldemar, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 181, for description of similar alteration.

cemented by pyrite and chalcopyrite. The sample which gave the highest platinum assay of all those which the writer had tested, 0.55 ounce to the ton, came from an ore body found only between levels 2 and 3, where the Key West dike is supposed to be faulted and a new ore body comes in. These levels being under water at the time of the visit to the property, the rock could not be seen in place, and the specimen was selected from the ore dump as a "picked sample." This specimen contained, besides the platinum, 4.66 per cent of nickel, with a trace of gold, and no silver. This rock may have been a peridotite originally, but is so altered that the primary constituents are impossible to determine, sulphides now forming a large part of the rock. Calcite seems to have filled all the cavities left by the alteration of the amphiboles or pyroxenes.

DEVELOPMENTS AND PRODUCTION.

The Great Eastern has been developed by crosscuts only on two levels. In all there is some 600 feet of work on the prospect. No shipment has been made from this property.

On the Key West there is a little over 3,000 feet of development work. This includes two shafts, the main one being down 312 feet, three levels, winzes, and drifts. As the lower levels of the Key West were under water, information on the workings below the 120-foot level was given by Mr. S. W. Darling, superintendent of the Key West. From this property, which has not been operated for over six years, one carload (91,600 pounds) of ore has been shipped, the contents of which are shown by the following analyses, furnished by the Key West management:

Analyses of ore from Key West prospect.

	North American Lead Co.	Ledoux & Co.
Silica (true SiO_2)	34.87	
Iron	10.59	
Lime	9.41	
Magnesia	15.33	
Alumina	6.55	
Copper	2.30	3.50
Nickel	1.79	1.86
Cobalt	.08	
Sulphur	6.90	
Gold per ton (2,000 pounds)	Trace.	Trace.
Silver per ton (2,000 pounds) ounce	Trace.	.35
Platinum metals per ton (2,000 pounds) do	.13	.15

NOTE.—The sample contains a small trace of lead—no zinc and no arsenic; it also contains 0.3 per cent of titanic oxide.

CONCLUSIONS.

The basic dikes described contain in appreciable quantities primary magnetite, pyrite, chalcopyrite, platinum, and pyrrhotite, the last probably being nickeliferous. In the Key West dike the pyrrhotite has been largely changed to pyrite through the action of infiltrating solutions. As stated in the writer's earlier and briefer report on this district, if these properties were near a railroad or the ore could be treated on the ground, it is quite probable that they would be able to produce bullion. Under present conditions, however, working expenses would be very high.

THE VIRGINIA RUTILE DEPOSITS.

By Thomas Leonard Watson and Stephen Taber.

INTRODUCTION.

Rutile is the only one of the comparatively large number of titanium-bearing minerals that has been utilized as a source of titanium. It occurs in rocks belonging to each of the three major divisions—igneous, sedimentary, and metamorphic. Its known distribution in commercially workable deposits is limited to three widely separated localities. These are (1) the Amherst-Nelson counties area in Virginia, (2) the Kragerö area in southern Norway, and (3) a recently discovered area about 40 miles northeast of Adelaide in South Australia. So far as the writers have information the Virginia area is the most extensive of the three.

Recent detailed field studies, including mapping, of the Virginia area by the Virginia Geological Survey[a] indicate practically an unlimited supply of rutile, which can be concentrated to yield a product of very high grade, much of it containing more than 99 per cent of TiO_2. Prior to the opening of the Virginia rutile deposits in 1900 the small domestic demand for the mineral was supplied from Chester County, Pa. Since 1902 the Virginia deposits have supplied all the rutile used in this country, and much of the product has been shipped abroad. With the development of new uses of titanium—the two most important being in the manufacture of ferrotitanium for the production of special grades of steel and in the manufacture of arc-lamp electrodes—and the consequent increasing demands for rutile the prospect for the future of rutile mining in Virginia seems decidedly encouraging.

Some of the more important facts relating to the geology and development of the ore deposits in the Virginia rutile district, obtained by the writers from a recent careful study of it, form the basis of this preliminary paper.

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[a] A detailed report on this important and interesting area will be published shortly as Bulletin III-A of the State Survey.

THE VIRGINIA RUTILE AREA.

LOCATION.

The rutile area of Amherst and Nelson counties lies in the west-central part of the State, along the middle western edge of the Piedmont Plateau and near the southeastern slope of the main Blue Ridge, within the foothills. It occupies the south-central part of Nelson County and the contiguous northeastern portion of Amherst County to the south, but much the largest part of it lies in Nelson County, which includes all developments thus far made. The area lies from 5 to 7 miles northwest of the Southern Railway and is accessible from Arrington and Tye River, the two nearest stations. Its position is shown in the index map (fig. 17).

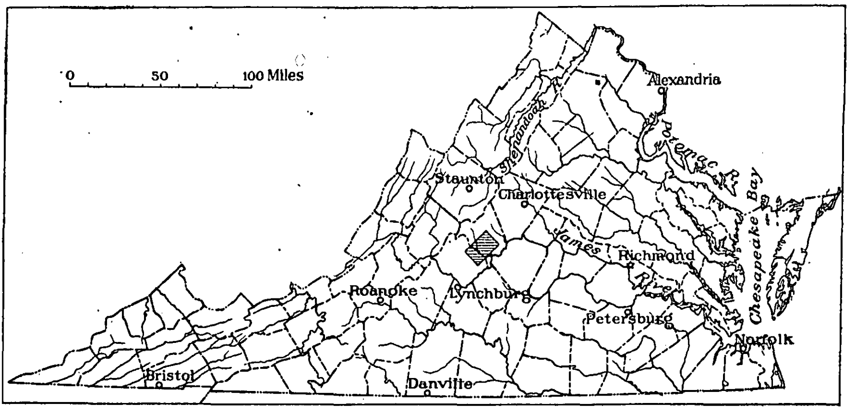

FIGURE 17.—Index map showing location of Virginia rutile area.

TOPOGRAPHY.

The area mapped includes approximately 170 square miles lying within the middle western portion of the crystalline region of Virginia. The rutile-bearing formation, however, covers less than one-fifth of the total area mapped, occupying a narrow lowland belt that has a general northeast-southwest direction approximately 16 miles in length and not exceeding 2½ miles in greatest width. Its general elevation averages about 700 feet, but the surrounding country immediately to the north, east, and west rises as peaks and ridges 1,000 to 2,000 feet and more above sea level. The drainage is in general toward the southeast into James River. Tye River and its tributaries drain the largest and most important parts of the area, and Buffalo River and its northeastern tributaries drain the extreme southwestern part. Figure 18, a reconnaissance topographic map of the area, shows the outline of the rutile-bearing formation and serves to indicate in a general way the larger topographic relations outlined above.

GENERAL GEOLOGY.

The rocks in the rutile area are igneous in origin, are intensely metamorphosed, and are readily divisible into a number of distinct types which show certain marked kinships to one another, especially in mineral composition. They form a distinct comagmatic area characterized by the prominence of apatite and the titanium minerals—ilmenite, rutile, and in a few places titaniferous magnetite; by a peculiar blue opalescent quartz; and by pyroxene (chiefly hyper-

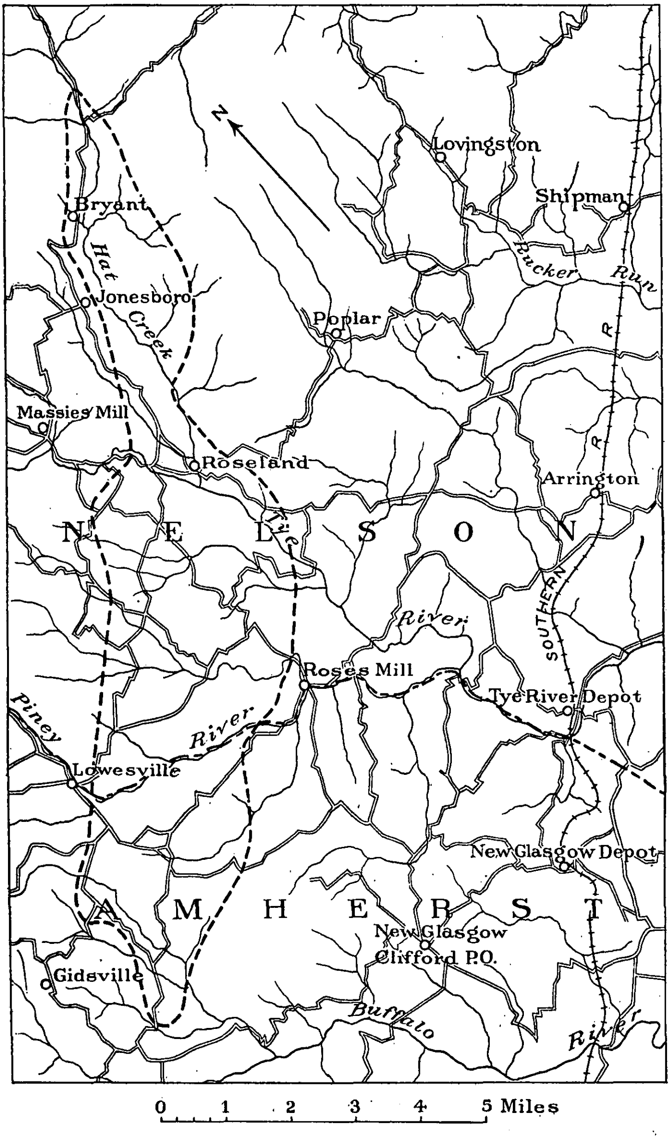

FIGURE 18.—Topographic map of Virginia rutile area. Rutile-bearing formation inclosed by heavy broken lines.

sthene) or secondary hornblende derived from the pyroxene as the dominant ferromagnesian mineral. Biotite, an important constituent in the surrounding gneisses and schists, is practically absent from the ore-bearing rocks. It occurs, however, as a minor constituent in a part of these rocks and is generally present in the nelsonite dikes, but its relations in each situation are such as to suggest probable secondary origin. In general the dominant minerals in one type make up the minor accessory minerals in the other.

The rocks are holocrystalline in texture and for the most part are even granular, ranging from very coarse grained in portions of the quartz-feldspar-hornblende formation (pegmatite) to very fine grained in some of the nelsonite and diabase dikes. They show pronounced though unequal effects of dynamic metamorphism, both in hand specimens and in thin sections under the microscope. Megascopically the most pronounced effect of metamorphism visible in most of the rocks is the development of complete or partial schistose structure. Microscopically, metamorphism is manifested chiefly in mashing—granulation, fractures, and optical disturbance of certain essential minerals—in recrystallization, and in the complete or partial change of pyroxene (hypersthene) to secondary hornblende. Other changes of a different order and kind involve the production of secondary minerals from the essential ones, chief among which may be mentioned the formation of bastite from hypersthene, leucoxene from the titanium minerals rutile and ilmenite, and sericite from feldspar. In some of the rocks biotite, chlorite, epidote, and osteolite are noted as alteration products.

PRINCIPAL ROCK GROUPS.

Named in the probable order of their differentiation, including the surrounding rocks, the principal rock types of the area mapped are (1) metamorphic igneous gneiss, including schists, (2) pegmatite, (3) gabbro, (4) nelsonite, (5) diabase. In places the rocks of types 2, 3, and 4 appear to be approximately contemporaneous.

GNEISS.

The inclosing or country rock of the area is a pronounced foliated biotite gneiss which shows in many places a considerable development of schists of various composition. Gneiss is the dominant type in this complex of metamorphic rocks and has wide general distribution beyond the limits of the rutile area throughout the Blue Ridge region of central western Virginia. It exhibits some textural and mineralogical variations, but the prevailing kind is a medium to dark gray rock, varying from a fine to medium-coarse, even-granular to porphyritic texture. The minerals recognizable with the naked eye are feldspar, quartz, and biotite.

The microscope shows the gneiss to be a metamorphosed igneous rock, derived from an original quartz monzonite, a conclusion confirmed by the analysis given below. The original porphyritic texture which characterized certain parts of the gneiss is still readily recognized, and the feldspar phenocrysts plainly show the effects of pressure metamorphism. The typical gneiss consists of quartz, oligoclase, orthoclase (partly perthitic), some microcline, biotite, ilmenite, apatite, and zircon. The principal secondary minerals are chlorite, epidote, sericite, kaolin, and leucoxene. Pressure effects are plainly marked in the thin sections in granulation of the quartz and feldspar, especially the former, and the filling in of the interareas with a fine mosaic of the two minerals; and in fracturing and wavy extinction of the same minerals.

The chemical composition of the typical gneiss is indicated in analysis No. 1 on page 208. The essentially equal percentages of the alkalies, K_2O and Na_2O, and the content of SiO_2, Al_2O_3, and CaO indicate a rock of quartz monzonite character. Attention is directed to the more than appreciable amounts of TiO_2 and P_2O_5 in the analysis, each of which is above the usual average for rocks of this type—a striking feature in the composition of the rocks of the district and one which emphasizes the definite genetic relationship of the different types.

THE RUTILE-BEARING ROCK (PEGMATITE.)

The rutile-bearing rock is the most extensive of the rock types in the immediate district. (See map, fig. 18.) It is a coarsely crystalline metamorphic igneous rock composed essentially of feldspar and blue quartz with, in many places near the border portion, secondary hornblende derived from pyroxene (chiefly hypersthene), rutile, and some associated ilmenite and apatite. The ratio of these minerals is variant, but feldspar is everywhere the dominant one. The central portion of the rock mass consists almost exclusively of feldspar, usually with some quartz. Hornblende is as a rule a prominent constituent near the border portions of the rock mass and is virtually absent from the central portions. In some places quartz enters as a prominent constituent of the rock; in others little or none is visible. Its deep-blue opalescent color contrasts strikingly with that of the other minerals, and it varies from grains of almost microscopic dimensions to masses many inches across. Merrill states that at one of the openings worked by the American Rutile Company in 1902 quartz was the dominant mineral, and masses weighing several tons were procured.[a]

The textural relations of the feldspar and quartz to each other and of the hornblende where present are, over many parts of the rock

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[a] Merrill, G. P., Rutile mining in Virginia: Eng. and Min. Jour., vol. 78, 1902, p. 351.

mass, similar to those of a coarse pegmatitic granite. The more feldspathic or dominant facies of the rock corresponds in chemical and mineral composition to a soda-rich syenite (laurvikose); the hornblende facies is in close agreement with granodiorite (tonalose). That the rock has been subjected to intense metamorphism is plainly shown in the granulation of the feldspar and quartz, in the partial segregation of the hornblende and rutile, and in the more or less distinct schistose structure.

Microscopic study of a large number of thin sections of the rutile-bearing rock shows the feldspar to be of several kinds—plagioclase, orthoclase, and a variant but subordinate amount of microcline. Of these, plagioclase near oligoclase is present in largest amount. It occurs usually in stout tabular individuals, the lamellæ of which are rather commonly bent and curved and in places broken across from pressure effects. Granulation and fractures are strongly marked. Much of the orthoclase is intergrown with a second feldspar, probably albite, as microperthite. The quartz, apart from its prevailing blue color in hand specimens of the rock and the abundance of hairlike inclusions of rutile, presents no unusual features. Effects of pressure are shown in the quartz similar to those in the feldspar, granulation, fractures, and wavy extinction being the most marked. The hornblende is light bluish in color and fibrous in structure, and it is clearly secondary in every section examined, being derived from pyroxene, chiefly hypersthene.

In addition to the rock-forming minerals, rutile associated with some ilmenite and in places with apatite occurs here and there as a prominent constituent, making up locally more than 30 per cent of the total rock mass. The general character and mode of occurrence of the rutile are described on a later page. In distribution the rutile, including both the pegmatite and nelsonite rutile, is essentially limited to the feldspar-quartz-hornblende rock and is confined largely to the border portions of the rock mass.

A chemical analysis, made of an average sample of the rutile-bearing rock collected from the American Rutile Company's openings near Roseland, is given on page 208 (No. 2) and will afford a general idea of the composition of the rock.

DIKES.

The district contains numerous dikes of many kinds of igneous rocks, all of which are genetically related, and with the exception of diabase nearly all gradations in composition are indicated between the extremes of the different types. Three principal types of these rocks are recognized—(1) gabbro, (2) nelsonite, and (3) diabase. Between the gabbro and nelsonite occur nearly all gradations in mineral composition, from typical hypersthene gabbro (norite) containing subordinate apatite and ilmenite to typical nelsonite containing little or none of the silicate minerals. The dikes are most abundant within the rutile-bearing feldspar-quartz rock, but they are by no means confined to it and in places are observed beyond the limits of this formation, in the outside gneiss-schist complex. They vary greatly in width, ranging up to 70 feet and more, and in many places show almost as great variation in strike, although most of them conform to a general northeast-southwest direction.

Gabbro.—The gabbro is a rock of medium-dark color and even-granular texture. The constituent minerals are feldspar and orthorhombic pyroxene, chiefly hypersthene, with subordinate ilmenite, apatite, and a little quartz, and secondary hornblende, bastite, leucoxene, and in the more altered phases, biotite. The ratio of pyroxene to feldspar varies. The feldspar is plagioclase, usually with much orthoclase. The gabbros are noticeably metamorphosed, at many localities showing well-developed schistose structure. In the more altered rocks of this type pyroxene is partly changed to secondary hornblende and bastite. With increase of the ore minerals, apatite and ilmenite, and decrease of the silicate minerals, the gabbros pass through gabbro-nelsonite into nelsonite. In some places the gabbro apparently grades into the pegmatite.

The chemical composition of a much metamorphosed schistose gabbro, occurring south of but near the American Rutile Company's mines, is shown in analysis 3 on page 208. This analysis is noteworthy for the high percentages of TiO_2 and P_2O_5, a characteristic feature in the composition of the rocks of this area that is commented on elsewhere in this paper.

Nelsonite.[a]—Nelsonite, including the several facies based on variations in mineral composition noted below, is the most abundant dike rock occurring in the district. In length the dikes range up to 2,100 feet, as exposed on the surface, and in width up to 65 feet or more, but as yet few of the dikes have been prospected in depth. Variation in mineral composition gives rise to several different facies of nelsonite, the normal one of which is an even-granular mixture composed essentially of ilmenite and apatite, with or without rutile. Except in a few places rutile is practically absent. Ilmenite or apatite may be the dominant mineral in the normal facies of the rock; probably ilmenite is dominant in most of the dikes. At several localities, notably at the General Electric Company's mines and the openings on the Bourne place, near Rose's Mill, and on the Giles tract, near Roseland, ilmenite is almost or entirely replaced by rutile, the rock being composed chiefly of rutile and apatite, with some ilmenite. Secondary hornblendes derived from pyroxene, biotite, and quartz are noted as sporadic minerals. Pyrite, partly secondary, is a constant

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[a] Name proposed by the senior author. See Mineral Resources of Virginia, 1907, p. 300.

minor constituent of the rock. The ratio of titanium minerals to apatite varies, the rocks ranging from one composed largely of the dark minerals with but little apatite to one composed practically all of apatite. Magnetite replaces the titanium minerals in some of the dikes occurring in the vicinity of Lovingston, and elsewhere beyond the limits of the rutile area proper, accompanied by apatite and biotite.

The prevailing texture of the nelsonite is even granular, usually with remarkable uniformity in granularity and composition of the rock from center to walls of the dike. In places in some of the dikes there is an appearance of imperfect banding or crustification of the titanium minerals and apatite, but this is exceptional and can not be interpreted as indicating vein origin as against dike origin for these bodies. The rock is penetrated by several sets of closely spaced joints, so that it breaks into small blocks when struck with the hammer.

A second facies of the rock is observed in parts of the area, which shows a predominance of the dark ferromagnesian minerals, more especially hypersthene and secondary hornblende, over the ore minerals. This facies of the rock also contains essential feldspar, chiefly plagioclase with some orthoclase, and an occasional quartz grain. It is composed chiefly of pyroxene (hypersthene) and feldspar (plagioclase and orthoclase), subordinate apatite, and ilmenite or magnetite. In some places the pyroxene is partly or entirely altered to hornblende. For this facies of the rock the name gabbro-nelsonite is proposed.

The dikes of nelsonite, composed essentially of the ore minerals, have been prospected at many places in the area, chiefly near Roseland, Bryant, and Lovingston, for phosphate (apatite), and near Rose's Mill, on Piney River, by the General Electric Company for rutile.

Analyses of the nelsonites from this area are given on page 208 (Nos. 4, 5, and 6).

Diabase.—Diabase dikes of varying width occur in many places in the area. They are confined chiefly to the rutile-bearing rock, but are observed here and there beyond these limits penetrating the surrounding gneiss. They are fine-grained dark-colored rocks, which show under the microscope typical ophitic texture and the principal minerals plagioclase, augite, and magnetite. In common with other rocks of the area they show more or less distinct evidence of metamorphism. Analyses of the diabase are not available at this time.

CHEMICAL COMPOSITION OF THE ROCKS.

In the accompanying table are assembled, for convenience, the six analyses of the rock types found in the area. These analyses will give a fair idea of the composition of the rocks. They have been arranged in the order of decreasing SiO_2 and increasing TiO_2 and P_2O_5.

Analyses of rocks from the rutile area of Amherst and Nelson counties, Va.

[William M. Thornton, jr., analyst.]

	1.	2.	3.	4.	5.	6.
SiO_2	63.40	59.84	54.80	33.83	....	....
Al_2O_3	15.94	20.59	14.28	5.19	....	....
Fe_2O_3	2.01	.55	3.08	11.38	2.70	....
FeO	3.91	.71	7.55	15.08	29.14	1.19
MgO	1.33	.76	2.52	8.57	.50	....
CaO	3.75	4.48	6.57	8.22	16.05	21.23
Na_2O	3.53	5.23	2.61	1.28	....	....
K_2O	3.30	2.57	2.00	.50	....	....
H_2O-	.06	.18	.16	.45	.03	.97
H_2O+	.76	.75	1.23	.75		
TiO_2	1.33	3.75	4.15	10.00	37.68	59.30
P_2O_5	.55	.35	.70	4.84	12.48	16.15
MnO	.07	.02	.02	.26	Tr.	....
CO_2	Tr.	Tr.	Tr.	....	....	....
Cl	....	....	....	.04	Tr.	....
F	....	....	....	.55	1.03	1.30
S	Tr.	....	.02	.25	1.17	.67
	99.94	99.78	99.69	101.09	100.78	100.81

1. Biotite gneiss, Roseland road, 1 mile north of Colleen.
2. Rutile-bearing feldspar-quartz-hornblende rock (pegmatite), American Rutile Company's openings, one-quarter of a mile south of Roseland.
3. Foliated gabbro, about 120 yards south of the southernmost opening of the American Rutile Company's mines, near Roseland.
4. Gabbro-nelsonite, 1 mile south of Roseland.
5. Rutile-bearing ilmenite-apatite nelsonite, General Electric Company's mines, 1½ miles northwest of Rose's Mill.
6. Ilmenite-bearing rutile-apatite nelsonite, Bourne place, 1 mile northwest of Rose's Mill.

THE RUTILE ORE.

Two distinct types of rutile occur in the district and each has been mined. In the first type, designated pegmatite rutile, the rutile occurs chiefly as disseminated grains of various sizes and in the form of wavy lines produced by dynamic metamorphism, in the coarse-grained feldspar-quartz-hornblende rock. In the second type, designated nelsonite rutile, the rutile occurs in the even-granular rock having dikelike characters and composed normally of apatite and ilmenite.

Pegmatite rutile.—The pegmatite rutile is red to reddish-brown in color, has a metallic-adamantine luster, and is remarkably pure. The rutile grains vary in size from very minute granules, almost microscopic in dimensions, up to masses weighing several pounds. The mineral is irregularly distributed through the rock, ranging from sparsely disseminated grains to aggregations which make up 30 per cent or more of the entire rock mass. Segregations of rutile in irregular wavy lines or stringers composed of disconnected rutile grains are noted in places. The rutile occurs similarly in each of the three rock-forming minerals—feldspar, quartz, and secondary hornblende—but is most abundant in the feldspar, and locally is associated with some ilmenite. So far as mining operations extend, the rutile associated with the feldspathic portions of the rock is generally free from ilmenite or other metallic minerals, but that associated with the quartz and hornblende is more likely to be mixed with ilmenite. Apatite is here and there closely associated with the rutile. Microscopic study of thin sections strongly indicates that the rutile is an original constituent of the rock in which it occurs; but in places it has undergone more or less segregation as a result of the intense metamorphism affecting the rutile-bearing rock. No evidence has been developed from either the field or the laboratory study for regarding the rutile as of secondary or subsequent origin.

Although it is prospected in a number of localities in the district, the mining of pegmatite rutile is limited to the American Rutile Company's mines on Tye River, a quarter of a mile south of Roseland.

Nelsonite rutile.—The nelsonite rutile is limited in occurrence to the dikes composed essentially or entirely of the ore minerals, ilmenite and apatite, the normal phase of the rock. The rutile-bearing dikes show all gradations in the ratio of rutile and ilmenite, from a granular mixture composed of dominant rutile and apatite with little or no ilmenite to one composed of ilmenite and apatite with or without subordinate rutile. Gradations between these two extremes are observed in the same dike. The rock with dominant rutile and apatite in a given position in the dike may gradually pass with increasing depth into a phase of the rock composed essentially of ilmenite and apatite. Accessory pyrite, in part at least secondary, is a constant constituent of the rock.

The norms calculated from the analyses (p. 208) of a representative ilmenite-bearing rutile-apatite nelsonite and of a representative rutile-bearing ilmenite-apatite nelsonite show the following percentages of the three principal minerals:

Percentages of rutile, ilmenite, and apatite in representative nelsonites.

	Rutile.	Ilmenite.	Apatite.
Ilmenite-bearing rutile-apatite nelsonite	57.9	2.6	38.3
Rutile-bearing ilmenite-apatite nelsonite	6.9	58.5	29.6

The rutile of the nelsonite dikes is uniformly darker in color, both in hand specimens and in thin sections, than the rutile of the pegmatite. Although no analyses of the two kinds of rutile occurring in the district are available at present, the darker color of the nelsonite rutile can probably be attributed to the presence of iron. In some of the workings of the General Electric Company's mines, near Rose's Mill, there occurs a series of titanium minerals containing mixtures of titanium and iron oxides ranging from rutile to ilmenite.[a] Although no analyses of this series of intermediate minerals have been made, it is probable that some of them will prove to be ilmenorutile, a variety of rutile containing up to 10 per cent and more of ferric oxide.

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[a] Hess, F. L., Mineral Resources U. S. for 1908, pt. 1, U. S. Geol. Survey, 1909, p. 743.

Rutile-bearing nelsonite dikes have been exploited at several localities in the district, chiefly in the vicinity of Rose's Mill and Roseland. Nelsonite rutile was recently mined in the vicinity of Rose's Mill by the General Electric Company.

HISTORY OF MINING DEVELOPMENT.

Ilmenite, scattered over the surface in many places as sand and bowlders of varying size, derived chiefly from dikelike bodies by weathering, early attracted attention to the district as a possible source of iron ore. In 1878 some development work was done on the Warwick farm, where a shaft was sunk to expose one of the large nelsonite dikes outcropping on the south side of Piney River in Amherst County, but the work was soon abandoned. Further developments in the district were not attempted until some years later, when attention was again drawn to the nelsonite dikes because of their phosphate content in the form of the mineral apatite.

In 1889 considerable development work was begun in the vicinity of Bryant, on Hat Creek, and resulted in the uncovering of many ore bodies. Since 1889 considerable prospecting for phosphate (apatite) by open pits, cuts, and shafts has been done at numerous localities within the district, chiefly near Roseland, Bryant, Rose's Mill, and Lovingston. Three-quarters of a mile northwest of Roseland a number of diamond-drill holes were bored on the Giles tract to ascertain the size and quality of the apatite-ilmenite nelsonite dikes. Prior to 1907 several cars of phosphatic rock were shipped from openings on the Dillard farm, near Lovingston.

No systematic attempt was made to exploit the rutile deposits of the district until 1900, although the occurrence of the mineral was known earlier. In 1900 the American Rutile Company began operations in the pegmatite rutile on the east side of Tye River, a quarter of a mile south of Roseland, and several shipments of the ore were made to Charlotte, N. C., for concentration. In 1902 the company erected a mill at Roseland for crushing and concentrating the ore, which is mined from open cuts in the bluff near the river.

The ore, of which there is a large quantity in sight, occurs in the coarse-grained feldspar-quartz-hornblende rock (pegmatite), probably averages about 5 per cent of the rock, and is remarkably pure. The rocks on this property, as well as over the district in general, are covered by a varying depth of residual decayed rock which contains large quantities of rutile in places, especially in the soil overlying the ore bodies. Some of these residual deposits could undoubtedly be worked to advantage by hydraulic mining, as there is usually an abundance of water close at hand.

The mines of the General Electric Company were opened in 1907 on dikes of nelsonite rutile on the Warwick farm, 1½ miles northwest of Rose's Mill. The development work comprises several hundred feet of tunneling, including drifts, and two shafts, the deeper of which was sunk to a depth of 100 feet. Rutile, in association with apatite and locally with ilmenite, occurs as an original mineral in the dikes, which range in thickness up to 5 feet. In some places the rutile is very pure but of darker color than the pegmatite rutile; in others it grades by increased percentages of iron into ilmenite. Rutile has not been found on this property in the feldspar-quartz-hornblende rock (pegmatite) in deposits sufficiently segregated to be of workable grade. The ore has been mined by stoping and shipped to Allentown, Pa., for concentration.

Mining operations are in progress at present on the property of the American Rutile Company a quarter of a mile south of Roseland.

Figures for the total output of the district are not available, but since 1902 the Virginia deposits have supplied all the rutile used in this country, and much of the product has been shipped to Europe in competition with that from Norway and elsewhere.

USES OF TITANIUM.[a]

Titanium compounds have had a moderate use for many years, but it is only since the development of the high-temperature electric furnace and the discovery of rutile in workable quantities that the manufacture of titanium products on a commercial scale has become possible. Pure metallic titanium, because of its high melting point and affinity for oxygen, has found little use in the arts or industries, but alloyed with other metals and in various chemical compounds it is rapidly becoming an important element.

The products into which titanium enters as an important constituent may be classified as follows:

Metallic alloys, such as ferrotitanium, cuprotitanium, etc.
Incandescent media for lighting purposes, including gas mantles, arc-lamp electrodes, and filaments for incandescent electric lamps.
Mordants and dyes for leather and textiles.
Refractory coloring material for use in ceramics and the manufacture of artificial teeth.
Miscellaneous.

Metallic alloys.—Titanium forms alloys with several of the metals, its alloy with iron, ferrotitanium, having the greatest commercial importance. Ferrotitanium is added to iron and steel in order to remove the oxygen and nitrogen; titanium unites with these objectionable elements to form stable compounds that pass off in the slag, the energy of combination being so great as to perceptibly raise the temperature of the molten metal. Iron and steel treated in this

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[a] Compiled from various sources.

way have a freedom from blow holes and other imperfections and greater strength, elasticity, and wearing properties. Titanium steel is claimed to be especially adapted to making rails, and 35,945 tons were rolled in 1909. Cuprotitanium, an alloy with copper, is said to improve brass and copper castings in a similar manner.

Incandescent media.—The use of titanium in the metallic state or in combination with other elements to form incandescent media for lighting purposes is one of the most important that have been developed. Titanium gives a spectrum rich in lines, but it is believed that its efficiency in lamps is largely due to selective radiation and temperature effect rather than preponderance of certain colors.

Titanium compounds have been employed in making gas mantles, though not yet on a commercial scale. Incandescent lamps with filaments containing titanium are said to have been placed on the market a few years ago, but owing to the cost of production by present methods they have not become a commercial product. They are claimed to have many advantages over the ordinary lamp with carbon filaments, such as longer life, better quality of light, and higher efficiency. It is asserted that they give a greater light for the same expenditure of energy than any electric luminant hitherto known. They are not as sensitive as other lamps to variations in voltage and are able to resist high temperatures. Experiments are being conducted with the object of reducing the cost of these lamps and many patents covering methods of manufacture have been issued in the United States and foreign countries.

Arc-lamp electrodes containing titanium have been in use for a number of years and are now manufactured on a considerable scale. Experiments conducted by a large electric company are said to prove that of all substances available for use as electrodes those containing titanium give the maximum efficiency in candlepower per watt consumed. At present the most extensively used electrode containing titanium is that of the so-called magnetite arc lamp. This electrode is composed of magnetite, 15 to 20 per cent rutile, and some chromite. The magnetite gives conductivity to the electrode when cold and furnishes particles that, while not luminous in themselves, make the arc stream a good conductor; incandescent particles of rutile carried into the arc stream by the electric current give the high lighting efficiency; and the chromite is added to increase the life of the electrodes. Ferrotitanium has been used in the manufacture of electrodes and more recently titanium carbide has attracted the most attention. The suboxide of titanium has also been used. The carbide and suboxide are probably the most efficient electrodes discovered. They are, as a rule, used only for the cathodes, the anodes being made of copper or carbon.

In a carbon arc nearly all of the light radiates from the incandescent electrodes; no light is derived from the terminals of titanium electrodes, but they give a long, intensely luminous arc stream. The titanium arc lamps have a better distribution and color of light, much higher efficiency, and a lower cost of maintenance.

Mordants and dyes.—The use of titanium in the manufacture of mordants and dyes is a comparatively recent development. Titanium oxalate and titanium ammonium oxalate used with a tannin compound give a golden-yellow color of great durability and by the addition of other substances any desired shade may be obtained. Titanous chloride has been used to some extent as a mordant, and titanous sulphate is now being employed as a stripper and mordant. They yield bright, fast colors, intermediate in shade between those produced by chromium and aluminum. The double pyrosulphates of titanium and the alkali metals have recently been obtained and may be applied to textiles and other substances without injury to texture or material. The titanium oxalates and the double tartrates and lactates of titanium and an alkali metal are used in leather dyeing. Titanium ferrocyanide is employed as a substitute for the poisonous Schweinfurth green and other arsenical pigments.

Refractory colors.—In the porcelain industry rutile is used alone to impart a beautiful soft yellow color under the glaze, or with other substances to produce secondary colors. Few colors are available for underglaze painting, as they must resist the high temperatures of the kiln. The purest grades of rutile furnish the only coloring matter suitable for use in the manufacture of artificial teeth, the production of which in the United States has been estimated at 8,000,000 annually.

Miscellaneous.—Among other uses for titanium products may be mentioned the following:

Titanium sesquioxide and its salts are employed as reducing agents, sodium titanous sulphate and titanous chloride having been found most useful. Titanium dioxide is used in the manufacture of a protective paint for iron and steel. In analytical work titanium sulphate may be employed in determining the presence of fluorine. Metallic titanium and oxygen combine with great energy, producing an instantaneous dazzling light; it is used for this purpose in pyrotechnics. It has been proposed to employ the titanium nitrides as a source of nitrogen for use in fertilizers and other nitrogen compounds. Titanium readily combines with the nitrogen of the atmosphere to form nitrides, which yield ammonia on heating in the presence of hydrogen. Sometimes crystals of rutile are found sufficiently clear for gem purposes.

NOTES ON TUNGSTEN DEPOSITS NEAR DEER PARK, WASHINGTON.

By Howland Bancroft.

During a geologic reconnaissance of northeastern Washington in the summer of 1909 some tungsten prospects near Deer Park were examined. In view of the wide interest in deposits of this metal it has been thought advisable to issue a brief preliminary description of these prospects.

The properties are located in Stevens County, Wash., 30 miles a little west of north of Spokane, in the SE. ¼ sec. 16, T. 30 N., R. 42 E. This is about 10 miles almost due north of Deer Park and 5 or 6 miles northeast of Loon Lake, both of which are stations on the Spokane Falls and Northern Railway, a branch of the Great Northern Railway. There is a good wagon road from Deer Park to a point within 2 or 3 miles of the deposits, and from this point a road has been constructed to the properties.

The topography of the region is characterized by broad valleys and gentle slopes. Glacial débris is scattered over most of the mountains, and the valleys are choked with it. The country is well timbered and watered.

The deposits are located at an elevation of 3,500 feet near the head of a small gulch on the southeast side of Big Blue Grouse Mountain. A continuation of the mountain extends eastward for about a mile and forms Little Grouse Peak. These two peaks constitute the southwestern extension of the dividing range between Burnt Canyon and Ecks Creek and are a part of the Calispell Range. The top of Big Blue Grouse, the highest mountain in the immediate vicinity, is probably not over 3,800 feet above sea level; the elevation of the valley in which Deer Park and Loon Lake are located is approximately 2,200 feet.

The rocks in the vicinity of the deposits are principally arenaceous shales, probably of Paleozoic age, metamorphosed to quartz-mica schists of various colors. The original bedding planes of the rocks do not appear to have been greatly changed, being very even, with fairly uniform structure. The rocks are deeply oxidized and the various colors, from white to red and yellow, seem to be due to the amount and degree of oxidation of the iron present in the schists. The dip of the rocks is about 30° to 60° SW., and the strike is to the northwest, with many minor and in places abrupt changes in the direction of both.

A short distance to the northeast granite has been found, but no contacts of this rock and the schist were visible, so that the true relations of the two can not be positively stated. The schists are said to dip away from this granite in all directions, the granite probably being an intrusive mass.

The Tungsten King properties have been opened by two short prospect tunnels located about 50 feet apart vertically, an 80-foot inclined shaft situated 250 feet above the lower tunnel, and several shallow open cuts on various parts of the claims. The workings are scattered, and so far no large shipments have been made.

The ores occur in lenses of quartz which follow in general the bedding planes of the shales with small fissures similarly filled cutting across the country rock. A number of these quartz lenses are opened in the workings, and as exposed along the outcrop they show a thickness of 1 to 6 feet. The outcrops are largely covered by débris, but a few of the quartz lenses can be followed on the surface for a hundred feet or more.

The gangue is composed entirely of quartz, generally white, but here and there smoky and in many places iron stained.

A partial analysis of the tungsten mineral, made by R. C. Wells, of the United States Geological Survey, showed the presence of 23.9 per cent of MnO, which indicates a typical hübnerite. The crystals of hübnerite are commonly twinned and form in places along the walls of the vein in bunches over an inch thick, with smaller crystals scattered through the quartz in an irregular fashion. They are also present in most of the outcrops of the lenses. The country rock seems to be quite free from hübnerite. In general the quartz lenses are rather lean. Here and there, however, fairly massive bunches of hübnerite can be seen; the most conspicuous of these, noted in July, 1909, was at the foot of an inclined shaft where a small shoot 2 inches wide extended across the bottom of the vein for a distance of 6 feet. The quartz veins have been broken and fractured since the deposition of the minerals, and minute fissures extend across the ledges and country rock.

The other metallic minerals present are pyrite and argentiferous cosalite, of which the latter might possibly be economically important.

Although in places the hübnerite and cosalite occur together, this association is not common, the bismuth mineral, it is said, being found mainly in the lenses which are down in the gulch and not occurring in the workings high up on the hill, although there seems to be no logical reason for its absence in these outcrops. Just as the hübnerite is found scattered through the quartz, so also is the cosalite, though apparently not so generously distributed. The crystals are long and fibrous and have about the hardness of gypsum, the weathered surfaces of the bismuth mineral being rather yellow and resembling antimony oxide. A picked specimen of ore contained, according to an assay made by Ledoux & Co. for the United States Geological Survey, 27.20 ounces of silver and $2.48 in gold to the ton. A specimen of cosalite was examined by R. C. Wells, of the Survey, who transmitted the following analysis. The second column represents the analysis reduced to gangue-free basis, without moisture.

Analysis of cosalite.

Moisture	0.17	
Gangue	2.19	
Bismuth	45.25	46.44
Lead	33.66	34.54
Sulphur	16.58	17.01
Silver	.80	.82
Copper	1.16	1.19
	99.81	100.00

The above composition is intermediate between that of galenobismutite and cosalite, but nearer cosalite, whose theoretical composition is $2PbS.Bi_2S_3$ (S 16.1, Pb 41.8, Bi 42.2). Galenobismutite has the formula $PbS. Bi_2S_3$ (S 17.08, Pb 27.6, Bi 55.40). Mr. Wells thinks it doubtful if the molecular ratio has any definite meaning in minerals of this character and says: "Possibly the two sulphides, PbS and Bi_2S_3, are capable of forming solid solutions of one in the other, or have been precipitated together from a state of colloidal solution."

Pseudomorphs of hematite and limonite after pyrite are present in large numbers in the wall rock and in the quartz lenses. These crystals vary from those of microscopic size to 2-inch cubes, the pyrite being in all stages of alteration. In places the pseudomorph itself is nearly decomposed and only the skeleton of the crystal remains. These cubes are developed on a larger scale in the vein than in the wall rock and seem to extend only a foot or so into the inclosing walls. In the immediate vicinity of the quartz ledges the country is locally silicified and highly stained with iron oxides.

The origin of the deposits is probably due to the waters which accompanied the intrusion of the granitic rock a short distance to the northeast.

Considering the scattered character of the ore and the haul of 10 miles to the railroad station, it is possible that concentration at the property might be advisable.

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

The principal publications by the United States Geological Survey on the rarer metals are those named in the following list.

These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Publications marked "Exhausted" can not be procured from the Government. No publications on Alaskan occurrences are listed here.

BECKER, G. F. Geology of the quicksilver deposits of the Pacific slope, with atlas. Monograph XIII. 486 pp. 1888. $2.

——— Quicksilver ore deposits. In Mineral Resources U. S. for 1892, pp. 139-168. 1893. 50c.

BLAKE, W. P. Nickel; its ores, distribution, and metallurgy. In Mineral Resources U. S. for 1882, pp. 399-420. 1883. 50c.

——— Tin ores and deposits. In Mineral Resources U. S. for 1883-84, pp. 592-640. 1885. 60c.

BOUTWELL, J. M. Quicksilver. In Mineral Resources U. S. for 1906, pp. 491-499. 1907. $1.

CHRISTY, S. B. Quicksilver reduction at New Almaden [Cal.]. In Mineral Resources U. S. for 1883-84, pp. 503-536. 1885. 60c.

COLLIER, A. J. Chromite or chromic iron ore. In Mineral Resources U. S. for 1906, pp. 541-542. 1907. $1.

——— Tin ore at Spokane, Washington. In Bulletin 340, pp. 295-305. 1908.

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

——— Platinum. In Mineral Resources U. S. for 1907, pt. 1, pp. 731-732. 1908. $1.

——— Platinum. In Mineral Resources U. S. for 1908, pt. 1, pp. 781-791. 1909.

DAY, D. T., and RICHARDS, R. H. Investigations of black sands from placer mines. In Bulletin 285, pp. 150-164. 1906. 60c.

EMMONS, S. F. Platinum in copper ores in Wyoming. In Bulletin 213, pp. 94-97. 1903. 25c.

GALE, H. S. Carnotite in Rio Blanco County, Colorado. In Bulletin 315, pp. 110-117. 1907.

——— Carnotite and associated minerals in western Routt County, Colorado. In Bulletin 340, pp. 257-262.

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

GRATON, L. C. The Carolina tin belt. In Bulletin 260, pp. 188-195. 1905. 40c.

——— Reconnaissance of some gold and tin deposits in the southern Appalachians. Bulletin 293. 134 pp. 1906.

HARDER, E. C. Chromic iron ore. In Mineral Resources U. S. for 1908, pt. 1, pp. 751-770. 1909.

HESS, F. L. Some molybdenum deposits of Maine, Utah, and California. In Bulletin 340, pp. 231-240. 1908.

——— The Arkansas antimony deposits. In Bulletin 340, pp. 241-256. 1908.

——— Note on a tungsten-bearing vein near Raymond, California. In Bulletin 340, p. 271. 1908.

——— Minerals of the rare-earth metals at Baringer Hill, Llano County, Texas. In Bulletin 340, pp. 286-294. 1908.

——— Tin, tungsten, and tantalum deposits of South Dakota. In Bulletin 380, pp. 131-163. 1909.

——— Note on a wolframite deposit in the Whetstone Mountains, Arizona. In Bulletin 380, pp. 131-163. 1909.

——— Antimony. In Mineral Resources U. S. for 1908, pt. 1, pp. 709-711. 1909.

——— Bismuth. In Mineral Resources U. S. for 1908, pt. 1, pp. 713-714. 1909.

——— Selenium. In Mineral Resources U. S. for 1908, pt. 1, pp. 715-717. 1909.

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