MOLYBDENITE NEAR RAMONA, SAN DIEGO COUNTY, CALIFORNIA.

By F. C. CALKINS.

INTRODUCTION.

Molybdenite is said to have been discovered at several places in San Diego County, Cal. The occurrence that has received most notice was visited by the writer in December, 1915. It lies about 6

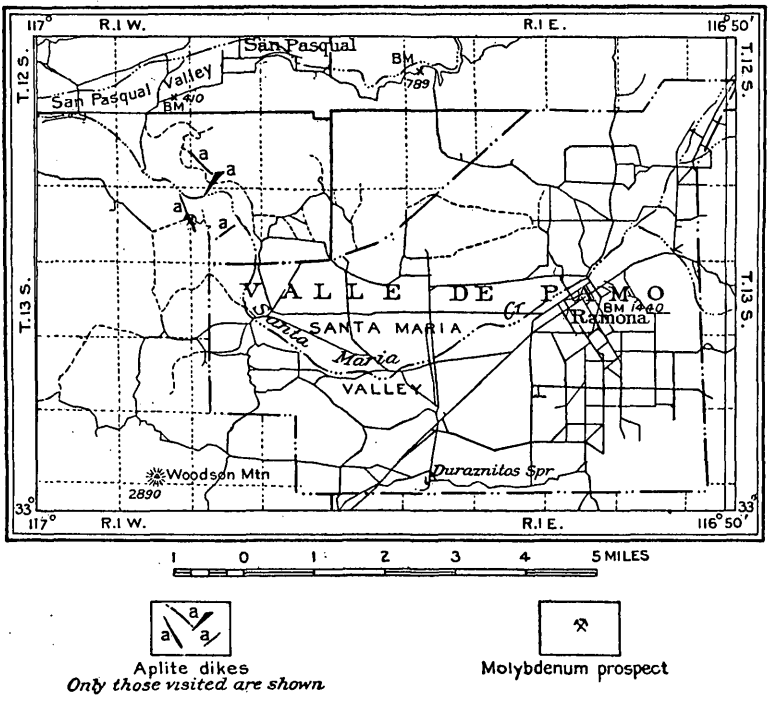

FIGURE 11.—Map showing location of aplite dikes and molybdenum prospect near Ramona, San Diego County, Cal.

miles west of Ramona, on property held by the Molybdenum Syndicate (Ltd.), of San Diego. (See fig. 11.) Ramona lies by road 37 miles northeast of San Diego, whence it may quickly be reached by any one of two or three automobile stage lines. A carriage or auto-

mobile may be taken within less than a mile of the prospect, the remainder of the distance being covered by an old road that was in disrepair at the time of visit.

Ramona lies in one of the many basin-like valleys which stand at various levels amid the mountains east of San Diego and whose origin and relations present an interesting physiographic problem that can not be discussed in the present paper. Santa Maria Creek passes from the Ramona basin to the much lower one of San Pasqual through a gorge of remarkably steep gradient. The molybdenum prospect is situated on undulating ground that overlooks this gorge from the south.

Natural vegetation is scanty about Ramona. No native trees except scrub oak grow nearer than some of the higher summits that form the sky line. Brush grows thickly on the shadiest slopes, but the surface is for the most part barren to a degree that favors easy prospecting.

GEOLOGIC CONDITIONS.

The dominant rock about Ramona, as well as westward to the foot of the mountain range, is one that would commonly be called a biotite granite. Its color is gray with a tinge of olive-green; its texture is moderately coarse. Feldspar is its most abundant mineral, but quartz is also abundant, and small flakes of black mica occur in moderate quantity. Microscopic study shows that the rock is not a typical granite, inasmuch as the alkali feldspar is very subordinate to the soda-lime feldspar.

This granitic country rock is cut by many dikes of aplite. The aplite is made up of the same constituents as the granite, but as it contains less biotite, it is light in color, being pale gray to nearly white when fresh; in places, however, it is stained with red oxide of iron. The microscope shows that it contains a large proportion of microcline. Aplite is harder and less readily weathered than granite and therefore commonly stands forth in relief on the surface. This is strikingly true of the aplite in the hills about Ramona, where many dikes, especially one on the crest north of the Santa Maria Creek gorge, appear at a distance like walls built by human hands.

MOLYBDENITE.

The molybdenite occurs in one of the aplite dikes, which trends north-northwest and has been traced about 1,500 feet southward from the brink of the gorge of Santa Maria Creek, on whose south wall it is exposed. Its width varies from less than 50 to about 200 feet. The molybdenite is very unevenly distributed through the rock. The greater part of the dike is barren or nearly so, but the mineral is conspicuous in the few shallow cuts and pits lying

between the road and the top of the hill to the south that constitute the only developments on the prospect. The aplitic matrix of the molybdenite is here of uneven texture; its greatest part is of medium grain, but it is interspersed with irregular masses, a few inches in diameter, that are coarser, like pegmatite. Quartz, partly reddened with iron oxide, is especially abundant in the pegmatitic bodies, and it is these bodies that contain the molybdenite.

This mineral is strongly characterized by its lead-gray color, metallic luster, and flexibility, and by its softness, which is such that it marks paper like a lead pencil. It forms more or less imperfect isolated crystals, some of which approximate hexagonal tablets in form. The crystals rarely exceed half an inch in diameter. The sulphide appears to be unaltered, as a rule, a few feet beneath the surface, although in the northernmost opening, a trench in a crushed zone that cuts across the dike, there has been some alteration to molybdite (hydrous ferric molybdate), which has partly replaced molybdenite and has tinged the rock with greenish yellow. At the surface of the outcrops the aplite contains numerous little cavities which are not found in the freshest rock taken a few feet below the surface and which appear to have been left on the removal of the molybdenite by weathering. On the other hand, molybdenite is frequently found in the rock at the very surface.

The molybdenite is clearly an original constituent of the aplite, to which it is confined. Its occurrence in the coarser parts of the rock indicates that the coarse crystallization and the mineralization were both due to local concentration in the magma of the more mobile constituents. To its mode of origin is due its uneven distribution.

A large sample of the rock is said by the owners to have assayed about 2 per cent of molybdenite. Although the Geological Survey has made no assay of the material, it may safely be said, as a result of the field examination, that very little, if any, of the aplite contains as much as 2 per cent of molybdenite. The dike is for the most part barren or nearly so, and its tenor as a whole can not exceed a small fraction of 1 per cent. A bulletin of the Bureau of Mines giving the results of quantitative tests of this ore, as well as of a great number of others, is now in press.[1]

POSSIBLE FUTURE DISCOVERIES.

The possibility of further discoveries of molybdenite near Ramona deserves consideration. A few hours was devoted to an examination of three other dikes that crop out within view of the prospect in positions indicated on the map (fig. 11). No molybdenite was found, but in places the occurrence of cavities that resemble those left by the

[1] Horton, F. W., Molybdenum, its deposits and uses: Bur. Mines Bull. 111 (in press).

removal of molybdenite suggest that the mineral may be present a few feet beneath the surface. There was little evidence that any of the dikes examined contains the mineral abundantly. It is possible, however, that workable deposits may be found in some of the many similar dikes that rib the neighboring hills. The quest for such deposits would be less difficult than most prospecting, for the dikes are easily followed, and the presence of molybdenite at any point where indications of it appeared to exist could usually be verified or disproved by making a shallow excavation. Small cavities in the rock, the greenish-yellow stain due to molybdite, and particles of molybdenite itself are among the indications to be looked for.

It is not certain that the ore would everywhere be confined to aplite. Molybdenite inclosed in granite is said to have been discovered between Ramona and Foster.

It may not be amiss to warn prospectors against oversanguine estimates of the richness of any deposits that may be found. Molybdenite is a mineral that makes a strong showing because of its bright metallic luster and its general occurrence in broad, thin flakes. Because of this prominence and because of its comparatively low specific gravity (4.7 to 4.8) its abundance in a rock is likely to be much overestimated when judged by the eye alone.

AN OCCURRENCE OF NICKEL ORE IN SAN DIEGO COUNTY, CALIFORNIA.

By F. C. CALKINS.

INTRODUCTION.

As no ores are mined for nickel at present within the United States, a peculiar interest attaches to deposits that hold out some promise of being valuable primarily for their nickel content. A hasty visit to such a deposit in San Diego County, Cal., was made by the writer in December, 1915.

The deposit is the property of the Friday Copper Mining Co., in which Beecher Sterne, of San Diego, is one of the principal owners. It lies near the main highway about 4 miles south of Julian, a village about 60 miles northeast of San Diego, with which Julian is connected by two or three automobile stage lines.

The Friday claim was located about 30 years ago, in the belief that it contained a vein of copper, and owing to the slowness with which development went forward the nickeliferous character of the ore was not discovered for some years. It is worth remarking that the famous Copper Cliff mine, at Sudbury, Ontario, and the Gap mine, in Lancaster County, Pa., had in this respect a similar history. The workings at present consist of a shaft about 250 feet deep and several drifts. The drifts at about 200 and 250 feet from the surface are each about 200 feet long; the others, which are shorter, are blocked by rock falls.

GEOGRAPHIC AND GEOLOGIC CONDITIONS.

The Julian district lies in the heart of a zone of not very rugged mountains for which no general designation is in popular use, but which it seems proper to consider as part of the peninsular range that forms the backbone of Lower California. The west base of this range lies a few miles east of San Diego. Julian is near the divide between the Pacific and Salton Sea, at an altitude of about 4,200 feet above sea level; some of the neighboring summits rise rather gradually to altitudes exceeding 5,000 feet. The climate at

these altitudes is sufficiently cool and moist to favor the general growth of an open forest of oaks and pines, from which a supply of mine timber may be derived. Some of the slopes, however, are covered with dense brush. Although the district is remote from railways, it is favored by fairly good roads and by cheap automobile transportation.

The rocks that form the mountains about Julian and west of it are chiefly igneous. From the west foot of the range to a point some distance east of Ramona they are almost exclusively granitic. Farther east metamorphosed sedimentary rocks form considerable areas, though they remain subordinate to the igneous intrusives, which, between Ramona and the Friday mine, are chiefly granodiorite or diorite.

In the immediate vicinity of the mine occurs a body of igneous rock, unlike any that was noted to the west, whose area of exposure is strongly characterized by a rusty-red soil, interspersed with bowlders and small outcrops of dark rock. Broken surfaces of fresh rock reveal a greenish-gray medium-grained crystalline mixture of several minerals. Feldspar is subordinate to dark silicates, of which olivine is shown by the microscope to be the chief, accompanied by pale amphibole and by augite or diallage. The rock may be classified as amphibole-bearing olivine gabbro, though the specimen examined verges closely on peridotite because of the subordination of its feldspar. The olivine in a specimen taken from the immediate vicinity of the ore body is remarkably fresh. A minor constituent of special practical interest, because it forms the greater part of the ore, is pyrrhotite, small grains of which are sprinkled evenly through the rock.

The gabbro at the mine is in contact with a dark-gray fine-grained mica schist, evidently derived by metamorphism from a clay shale. The dip of the schist layers, in the few places where it has been observed, is steeply southward. Very little was learned, in the brief time available, concerning the form and extent of the gabbro mass. Its area appears to be at least a square mile and may be many times as much. The surface of its contact as exposed in the mine workings is steep in general but irregular in detail and is partly determined by faults.

ORE BODY.

MINERAL COMPOSITION.

The ore of the Friday property consists mainly of pyrrhotite but contains pyrite, chalcopyrite, and an iron-nickel sulphide and is accompanied by small quantities of amphibole and of a carbonate that is probably calcite. When the ore is viewed with the naked eye,

pyrrhotite alone is conspicuous. The pyrrhotite possesses an unusually perfect cleavage, or parting, which shows that some crystal individuals are as much as 2 inches in diameter. The other sulphides are better discerned on polished faces, particularly on those that have been etched for a few minutes with boiling hydrochloric acid ($\frac{1}{1}$), which corrodes and darkens the pyrrhotite, to which the other minerals, remaining bright, then present a contrast, while they also differ in color from one another. Pyrite, which presents a somewhat rough brass-yellow surface, occurs in a proportion estimated to exceed 10 per cent. It forms a very irregular network and has clearly originated through the replacement of the pyrrhotite by solutions or gases (perhaps H_2S) that have permeated a multitude of fractures. Much less abundant are chalcopyrite, which is bright in luster and deep-yellow in color, and a smoothly polished silvery white mineral whose identity is not quite certain. This mineral has been shown by chemical test to be a sulphide of nickel and iron, but its crystal system could not be ascertained. It is altogether free from the tinge of brownish yellow that characterizes pentlandite. It differs from gersdorffite (NiAsS) in its freedom from arsenic and in its lower degree of hardness. It seems most likely to be polydymite (Ni_4S_5, with iron replacing part of the nickel, or $Ni_3Fe_2S_5$).

The cupriferous and nickeliferous sulphides occur for the most part in contact with each other and form together irregular bodies about 5 millimeters in maximum diameter, which exhibit some tendency to alignment; the supposed polydymite also forms thin veinlets cutting pyrrhotite but not pyrite. The age relations of the minerals are not quite clear. The phenomena suggest that the cupriferous and nickeliferous sulphides are nearly contemporaneous and older than the pyrrhotite, though some of the nickeliferous mineral appears to have been redeposited in fissures. The pyrite is pretty plainly the latest of the sulphides, though it has replaced the pyrrhotite alone without penetrating the others.[1] Scattered grains of amphibole and of chlorite are inclosed in the sulphides, and all the minerals are cut by a network of calcite veins. Both the silicates and the carbonate are best observed in thin section.

The fresh sulphides were found only at considerable depth below the surface. The outcrop of the vein is a spongy gossan consisting chiefly of limonite, and a small amount of material rich in malachite was found between this and the unoxidized ore. Oxidation, which is perhaps especially favored by the closely spaced partings in the

[1] The order pyrite, pyrrhotite, pentlandite, chalcopyrite was observed in ores from Sudbury and elsewhere by William Campbell and C. W. Knight (On the microstructure of nickeliferous pyrrhotite: Econ. Geology, vol. 2, p. 350, 1907). On the other hand, A. L. Du Toit (Report on the copper-nickel deposits of the Jusizwa, Mount Ayliff, East Grinqualand, Cape of Good Hope: Geol. Comm. Ann. Rept., vol. 15, p. 110, 1910) found the sequence chalcopyrite, pentlandite, pyrrhotite.

pyrrhotite, attacks vigorously the ore thrown on the dump and develops enough heat to char wood. Its chief products, in the first stage, are sulphates, which are readily dissolved, so that much of the nickel and copper must have been lost from the accumulated ore.

The ore can not be said to have a gangue in the proper sense of the term. The minerals intimately mingled with the sulphides are almost negligible in quantity, though the ore is more or less mingled with country rock at the margins.

TENOR.

No assays or chemical analyses of the ore have been made by the Geological Survey, but several have been supplied by the company. These, on their face, indicate a wide variation in the nickel content, the percentages reported ranging from 2.94 to 22.95. The higher figures, however, are not confirmed by the appearance of the ore that was examined. It seems, on the other hand, as if considerable reliance might be placed on the figures given in two fairly detailed analyses by well-known eastern firms, namely, 4.34 and 4.12 per cent. Both these analyses report gold and silver to be absent, though the assays giving the highest figures for nickel report them as present in weighable amounts. Copper, according to the assays, ranges from a trace to 2.4 per cent. Platinum, whose possible presence in traces at least is suggested by the geologic relations of the ore, apparently has not been looked for.

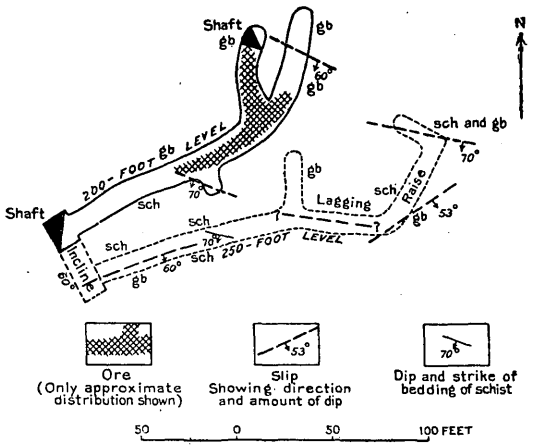

FIGURE 12.—Sketch map of principal workings of Friday mine, near Julian, San Diego County, Cal. gb, Gabbro; sch, schist.

FORM AND RELATIONS.

Regarding the form of the ore body and its detailed relations to the country rock, only partial evidence was gathered by examination of the one accessible drift in which the ore is exposed. Its observed distribution is rudely indicated in figure 12, though some portions of it may have been overlooked. The observations indicate that the ore forms a chimney-like body of steep inclination, partly bounded by slips. The mass does not appear to be sharply defined except where there is indication that it is faulted. It lies near the contact of gab-

bro and schist but is partly inclosed in gabbro. It is cut by a thin dike of pegmatite containing conspicuous crystals of common black tourmaline.

The lowest drift, which follows a zone of fissuring, has failed thus far to uncover the ore, which appears to have been cut off by some of the fissures that are followed or crossed by the drift. As these dip steeply southward, it seems probable, inasmuch as the majority of steep faults are normal, that the ore is to be looked for at a greater depth on the south side of the zone of fissuring.

PROBABLE ORIGIN.

By its mineral constitution and its geologic situation at the contact of a basic intrusive rock with older sediments, the Friday ore body belongs to the numerous class of nickeliferous deposits, of which the Sudbury district of Ontario[1] contains the most noted and productive examples. The deposits at Sudbury are regarded by the authorities most familiar with them as having been formed by gravitative concentration from a molten magma. A huge blister-like body or laccolith many miles in breadth, of norite, a rock that is closely related to gabbro, was injected at the base of a series of horizontal strata. As the magma gradually crystallized, particles of sulphides were formed all through it and, by reason of their heaviness, sank in great part to the floor of the magma chamber before their settling was finally arrested by solidification of the cooling magma. The norite laccolith was afterward bent or subsided in the center, so as to take the form of a spoon, and its edges were exposed by erosion, so that the ore bodies became accessible. Those of simplest character, which appear to be the direct result of settling, dip toward the center of the spoon. Their lower sides, in contact with the floor of the laccolith, are sharply bounded, but their upper sides grade into the norite, which, like the gabbro of the Friday mine, contains visible particles of pyrrhotite. Besides these simple marginal deposits, there are others complicated by faulting and by redeposition of the ores, and there are also "offset" deposits lying entirely without the main body of norite.

The data obtained by a brief examination of the Friday mine are hardly sufficient in themselves to establish clearly the nature of its ore body, but the resemblance of this body in some essential features to those at Sudbury suggests a similarity of origin. The igneous origin of the Friday ore is strongly indicated by three outstanding facts. First, the penetration of the ore by pegmatite shows that ore deposition was completed before the close of igneous activity. Second, the deposit differs from those of secondary origin by the total

[1] Coleman, A. P., The nickel industry, with special reference to the Sudbury region, Ontario: Canada Dept. Mines, Mines Branch, 1913.

absence of contemporaneous gangue minerals, such as quartz and calcite; the small amount of carbonate found in the ore, being of later deposition, has no bearing on its origin. Finally, pyrrhotite, the principal constituent of the ore, occurs in the gabbro close to the ore body in association with perfectly fresh olivine. If the sulphides had been deposited from solutions, these solutions would certainly have attacked that very unstable silicate.

FUTURE DEVELOPMENTS.

A suggestion has already been ventured (p. 81) regarding the direction in which the ore body is to be looked for in depth, on the assumptions that it actually persists downward and is normally faulted. When it is considered, however, that either or both these assumptions may be erroneous, and that the ore body, being probably igneous, is likely to be irregular in form, the risk of wasting effort in unsuccessful exploration appears rather greater than usual. This argues, to some extent, in favor of exploration by the diamond drill, a method that is much employed in the Sudbury district.

It is possible that the surface in the Julian district, where prospectors have been accustomed chiefly to search for gold, has not been thoroughly prospected for the nickeliferous deposits. Search for outcrops of gossan along the margins of the gabbro mass might be rewarded by further discoveries.

A word, finally, should be said in favor of shielding ore dumps, so far as possible, from moisture, whose decomposing action may finally reduce the ore to worthless limonite.