MINERALS AND ASSOCIATED ROCKS AT COPPER MINE HILL, RHODE ISLAND

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ABSTRACT

Copper Mine Hill, Rhode Island, consists of a series of green schists with beds of quartzite and limestone which have been intruded by riebeckite granite. At and near the contact of the granite are mineral deposits of the contact metamorphic type which were once worked for copper. These deposits are described, as are veins of several types.

LOCATION AND HISTORY

Copper Mine Hill is located in the town of Cumberland which is in the northeast corner of Rhode Island (Plate I). This town has long been known for the great variety of its minerals and is said to have been named for Cumberland, England, because of its minerals and mines. Among the mining and quarrying ventures are the old coal mines at Valley Falls, metal mines at Copper Mine Hill and elsewhere, old iron mines and the present "trap rock" quarry at Iron Mine Hill, granite quarries at several places, the quarry for quartz at Diamond Hill, and a few small limestone pits. Jackson[1] states that over fifty prospect pits or mines were found on Copper Mine Hill alone, and suggested that some of them were dug on the assumption that the chalcopyrite was gold. We did not find fifty holes, but no doubt many were small and some have been filled.

We have been unable to learn much about the history of the mines at Copper Mine Hill, although we searched through most of the published histories and interviewed members of old families in the region in the hope that they might have old records of the mining. Jackson's report in 1840 refers to the mines as "ancient mine holes."[2] Robinson's *Catalague of American Minerals* issued in 1825 states that the mining was done forty to a hundred years previously,[3] while an article by the same author written in 1824 states that the mining was done forty to forty-five years prior to that date.[4] We have thus far been unable to go further into the history of these mines.

It has been stated in the earlier writings that the shaft at the main mine was from 70 to 100 feet deep and that there was a tunnel 250 feet

[1] Jackson, Charles T., Report on the geological and agricultural survey of the State of Rhode Island, p. 55, **1840.**

[2] *Op. cit.*, p. 55.

[3] Robinson, Samuel, *A Catalogue of American Minerals*, p. 84, **1825.**

[4] Robinson, Samuel, Notice of miscellaneous localities of minerals: *Am. Jour. Sci.*, 1st series, vol. **8**, pp. 230–232, 1824.

long. It is not possible to enter the old workings now, but the dumps afford some opportunity to study the type of ore. The north wall at the opening of the main mine exposes some of the geological relationships, which may be seen also at some of the smaller pits.

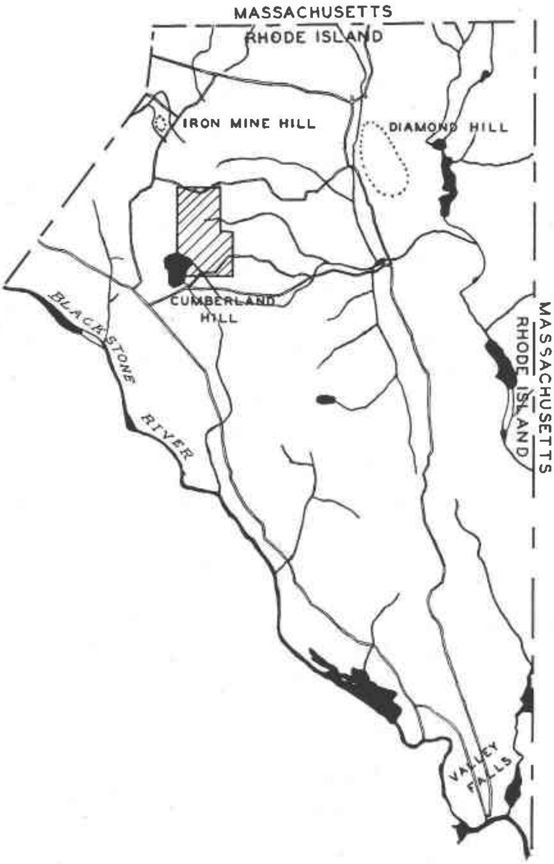

Plate I. Map of Cumberland, Rhode Island, showing location of area described in this paper. Not all of the roads are shown. (Approximate scale, two miles to the inch.)

There are several recent cuts on the west slope of the hill, where some of the minerals may be seen in place. Quarry 2 (Plate II), especially, shows some of the garnet rock in place and furnishes the only good specimens of the quartz-epidote-adularia veins. These recent quarrying operations have been for the purpose of obtaining uniform green schist and have, therefore, avoided most of the interesting mineralogical phases.

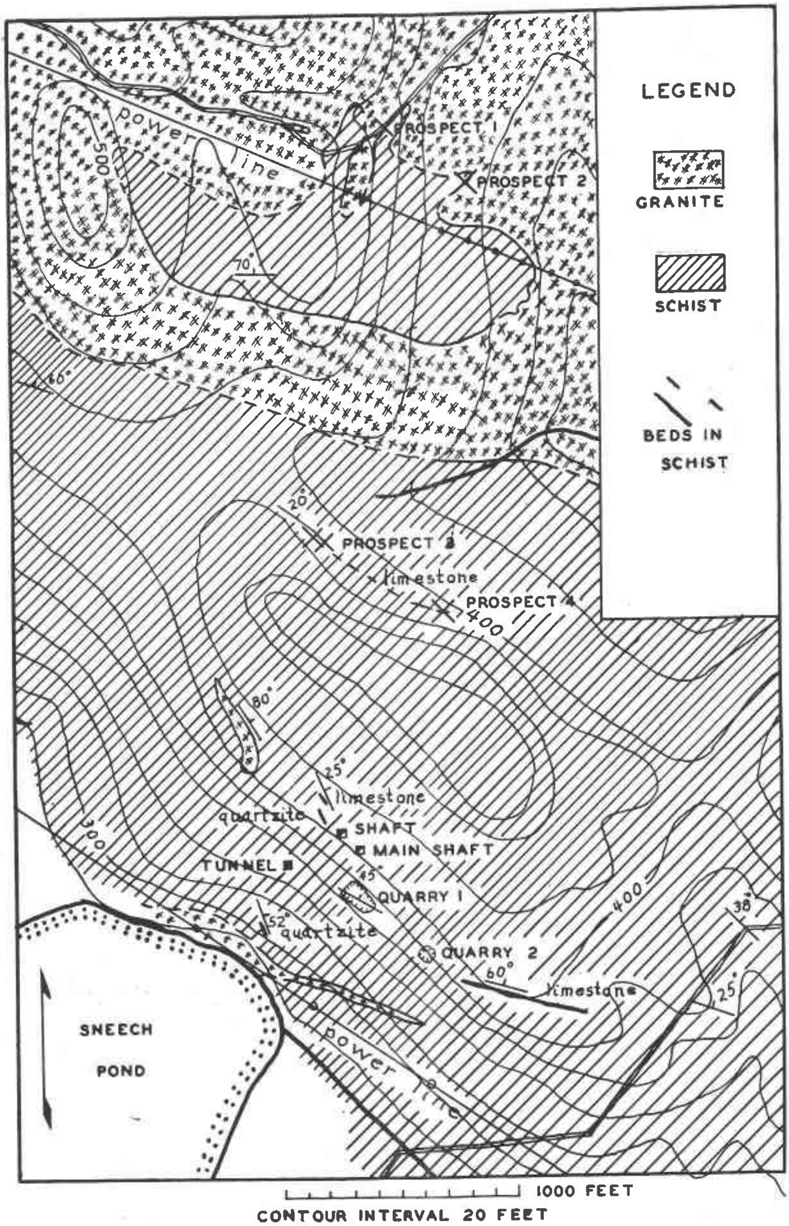

PLATE II. Geological Map of Part of Copper Mine Hill, Rhode Island.

Map

A portion of the topographic map of the Providence Quadrangle of the United States Geological Survey was used as a base for geological mapping, but the lack of detail on this map and the dense covering of brush over a part of the area made mapping rather difficult. These difficulties were largely overcome by W. R. Benford of the Department of Engineering of Brown University who made a traverse by transit and stadia across the area. We hereby express our sincere thanks to Mr. Benford for this assistance.

Previous Work

No published paper has been primarily concerned with these ore deposits. The minerals were listed by Robinson in 1824 and 1825, and Jackson described the minerals in 1840.[5] Emerson and Perry[6] described these deposits briefly in their report on the granites and green schists of Rhode Island. Warren and Powers' paper in 1914 covered this area, but they paid little attention to the ores.[7] Fisher and Gedney[8] listed some of the minerals in 1926.

Schist

The oldest rocks in this area are green and gray colored schists with associated limestone and quartzite. This series is included in the Ashton schist of Warren and Powers,[9] and in the Marlboro formation of Emerson and Perry.[10] It is believed to be of Algonkian age.

The schists of Copper Mine Hill are fine-grained. The color varies from gray to green, to almost black. In places the rock has a slaty structure. Such rock is generally rather light in color. Certain of the darker phases are massive in structure. Nodules, veins, and streaks of epidote abound, especially in the massive portions. The main minerals in the body of the rock, as determined mainly from thin section, are actinolite, epidote, chlorite, and quartz. There are also many aggregates of a fine textured material that are probably of a sericitic nature. Biotite is common, but generally is not a main constituent. Magnetite is abundant in small grains and pyrite is present sparingly.

[5] Jackson, *op. cit.*
Robinson, *op. cit.*

[6] Emerson, B. K., and Perry, J. H., The green schists and associated granites and porphyries of Rhode Island: *U. S. Geol. Survey, Bull.* **311**, pp. 13–15, 1907.

[7] Warren, C. H., and Powers, Sidney, Geology of the Diamond Hill-Cumberland District in Rhode Island-Massachusetts: *Bull. Geol. Soc. Am.*, vol. **25**, pp. 435–476, 1914.

[8] Fisher, Lloyd W., and Gedney, Edwin K., Notes on the mineral localities of Rhode Island. I. Providence County: *Am. Mineral.*, vol. **11**, p. 336, 1926.

[9] Warren and Powers, *op. cit.*

[10] Emerson and Perry, *op. cit.*, pp. 13–15.

Quartzite and Limestone

Associated with the schist are several small beds of quartzite and limestone. The quartzite occurs in small lenses, 25 to 50 feet long and 10 to 20 feet thick. It is white to light gray in color and is rather sugary in texture.

Beds and small lenses of limestone are present in the schist at several places. Evidence of limestone is found at most of the ore bodies, but generally replacement has been so complete that not much limestone remains. The long bed 200 feet southeast of Quarry No. 2 has not been greatly affected by mineralizing solutions. It is a white, crystalline, somewhat dolomitic limestone with numerous crystals of tremolite. Along the contact of this limestone bed with the schist are alternating bands of brown garnet and actinolite. Most of the limestone contains some talc and a serpentinous mineral which resembles the "bowenite" of other limestone bodies in Rhode Island. According to Selfridge this should be called antigorite [11] Much of this bed has been removed, presumably for lime.

The beds of quartzite and limestone are parallel to the schistosity of the green schist. On the north wall of the excavation, at the main shaft, the limestone has the appearance of being at the crest of a tightly compressed anticline. Elsewhere there are small disconnected lenses of limestone which probably represent fragments of a broken and sheared bed.

There is considerable uncertainty about the origin of the green schists of Rhode Island, some of which are considered to have been sedimentary and some igneous. The intimate association of the schist with limestone and quartzite suggests that the whole series at Copper Mine Hill was sedimentary.

Granite

Intruding the schist series of Copper Mine Hill is a riebeckite granite which is probably related to the Quincy granite of Devonian or early Carboniferous age. It is medium to fine-grained and is in places somewhat porphyritic. The color is light gray to gray. There is some tendency toward a banded structure. Megascopically, the rock is composed of light gray to bluish feldspar, areas of sugary quartz, black amphibole and pyroxene, and small amounts of biotite. Here and there may be seen patches of bright purple fluorite. Thin sections reveal that the main minerals are microperthite in large grains, areas of fine-grained quartz, riebeckite, and aegirite. Some thin sections have considerable biotite. Minor constituents are astrophyllite, purple fluorite, magnetite, musco-

[11] Selfridge, George C., Jr., An *x*-ray and optical investigation of the serpentine minerals: *Am. Mineral.*, vol. **21**, pp. 500–501, 1936.

vite, and concentric grains of what Warren and Powers called a leucoxenic alteration.[12]

There is some irregularity in the shape of the granite intrusions, but they are mainly along the schistosity of the schist, and the granite appears to be in sills dipping to the northeast.

Gash Veins in Granite

The granite is cut by numerous gash veins and lenses of quartz up to a foot in width. This type of vein is almost entirely confined to the granite. Many of the veins contain nothing but quartz, but purple fluorite, ilmenite, and a very few poor crystals of dark green beryl have been found.

Tourmaline Veins

There are a very few small veins of black tourmaline. One occurs in the schist about 200 feet north of the main mine. It is about one inch wide, cuts through almost at right angles to the schistosity, and is composed almost entirely of minute crystals of black tourmaline. Some quartz accompanies the tourmaline. Another such vein was found cutting the granite.

Mineral and Ore Deposits

Relationships

The broader relationships of the ore bodies are revealed in part, but exposures are not of the kind to show many of the details. At all of the ore bodies there are indications that the ores are related to limestone, the evidence being partially replaced blocks of limestone on the dumps, and beds of limestone exposed in the mine workings. There is also evidence to show that the ores are related to the granite intrusions. At Prospects 1 and 2, the ores are at the granite contact. Prospects 3 and 4 are over 400 feet from any outcrop of granite, however. They may be related to an unknown granite intrusion in the schist beneath, or their location may have been determined by a permeable zone in the schist. The limestone beds associated with these prospects may have been such a permeable zone. The ores of the main mine are not very near any large body of granite. There is a small sill to the southwest, near Sneech Pond, and it probably cuts under the main mine. With sills of granite so common here it is very likely that all these ores are near some granite intrusion, and the general relationships suggest that the deposits are of the contact metamorphic type. This is further indicated by the minerals to be described later in this paper.

[12] Warren and Powers, *op. cit.*, p. 465.

Most of the study of the minerals of the ore deposits was made on specimens from the dumps of the old prospect pits and mines. Several of the minerals are in place at Quarry 2, however. The opaque minerals were studied by reflected light and the others were identified with the petrographic microscope.

Tremolite

The limestone usually has tremolite, whether associated with ore deposits or not, and much of it must have originated in the dynamic metamorphism which affected the rocks before the formation of the ores. Some may have originated as a result of the contact metamorphism by the riebeckite granite, however. In the limestone the tremolite is in small needles up to a quarter of an inch long. At the dump of the main mine are large pieces of a magnetite-tremolite rock. The tremolite is present in large streaks through the magnetite and as individual crystals scattered through it. The needles are arranged in parallel fashion. The color is a faint green and the optical properties indicate that it is a tremolite near actinolite in composition.

Epidote

Epidote is one of the most widespread minerals at Copper Mine Hill. It occurs in the body of the schist and as nodules and veins in the schist, in places which seem not to have been affected by contact metamorphism. It also occurs in the contact metamorphic deposits and in quartz-epidote, calcite-epidote, actinolite-epidote-calcite, and quartz-epidote-adularia veins. The epidote has about the same optical properties in all these occurrences. The intermediate index of refraction is near 1.76, the optic angle large, and the optic sign negative. It seems to be an iron-rich variety.

Actinolite

Actinolite is present as one of the minerals of the schist, as an important mineral of the contact metamorphic rock, and in veins. The veins include actinolite, actinolite-quartz, and actinolite-epidote-calcite veins. It is all dark green in color. In some of the veins the fibres are rather long and good specimens may be obtained.

Pyroxene

At Quarry No. 2 may be found quarter-inch crystals with octagonal cross-section. They have been altered to amphibole with optical properties near those of actinolite and must, therefore, be examples of uralitization. The crystals were originally embedded in calcite, but in places the calcite has dissolved, leaving the crystals projecting into cavities.

Diopside

At Prospects Nos. 1 and 3 white diopside occurs in radial groups with the individual crystals up to an inch in length. The optical properties of this mineral indicate that it is near pure diopside. It was not found at any of the other localities.

Hornblende

Brilliant black crystals of hornblende occur with calcite in veins at Prospect No. 3, and with epidote in veins at several other places. The intermediate index of refraction is near 1.65, the optic angle is moderately large, the optic sign is negative, and the maximum extinction angle in the vertical zone is about 25°.

Garnet

Garnet is one of the most abundant minerals in the contact rocks. It usually forms a massive rock and shows crystal faces only when found in cavities, which seem to have been formed by the solution of calcite. The garnet is mainly light brown, although the color varies somewhat, even in single crystals. The crystals are usually lighter in the interior. The interior portions may have a distinct greenish cast. The darkest garnet is dark reddish brown and occurs in veinlets. The index of refraction is higher than 1.77. Chemical tests indicate it to be andradite, with the lighter colored parts varying toward grossularite. The darker garnets contain more iron.

Chlorite

Chlorite is one of the main constituents of the green schist. It also occurs in the limestone at the main mine, where it seems to have been formed by contact metamorphism. Flakes up to 1½ inches across are arranged in a zone in the limestone near the contact with the schist. The mineral is light green and has a pearly luster. The index of refraction on cleavage flakes is about 1.575, but is variable. The optic angle is small and the optic sign is negative. These properties indicate penninite.

Quartz

Quartz is an important constituent of the green schist, it is present in the veins associated with the granite, and it occurs in many other types of veins, but it is not abundant in the contact rocks and there is very little silicification of the older rocks.

Magnetite

Magnetite is a very abundant and widespread mineral in the contact zone. Magnetite rock is found in large masses on the dumps, especially at the main mine. It is associated with almost all the minerals here, but especially notable are the masses of magnetite-tremolite rock and the magnetite-chlorite rock. It is fine-grained and massive.

Molybdenite

At the main mine dump, molybdenite was found associated with crystals of magnetite in fragments of greenstone. Many pieces of the old chalcopyrite ore contain flakes of molybdenite. It is also associated with garnet at Quarry No. 2. It seems to be later than magnetite and earlier than chalcopyrite.

Pyrite

Pyrite is not an abundant constituent of the ores, but is rather widespread in occurrence. Some is massive and some shows crystal faces. In the ores it is later than magnetite and earlier than chalcopyrite.

Chalcopyrite

Chalcopyrite is so scarce at the main dumps that one wonders why this was ever called a copper mine, but on a rock surface near the main shaft is an accumulation of rusty, two-inch pieces of ore which contain considerable altered chalcopyrite and some molybdenite. These pieces are probably all that remain of the casks of ore which Jackson said were present in 1840.[13] Small amounts of the chalcopyrite may be found at the other prospects, but it is usually much altered and is not very abundant. It is also found in calcite-epidote veins in the schist at Quarry No. 1.

Bornite

Bornite was found in irregular veins at Quarry No. 2. It was also found at Prospect No. 2. It is not entirely clear whether this mineral is primary or secondary.

Sphalerite

One specimen from a bornite vein at Quarry No. 2 contained considerable dark sphalerite.

[13] Jackson, *op. cit.*, pp. 55–56.

Knebelite

Jackson describes a forty-foot bed of a "remarkable ore of manganese" and states that the ore mineral is knebelite.[14] Emerson and Perry quote Jackson's description, but give no indication that they ever saw the bed. We were unable to find such a bed "near the pond." A short distance southeast of the southeast corner of our map is a small deposit of manganese oxides, however.

Quartz-Epidote-Adularia Veins

At Quarry No. 2 are several quartz-epidote-adularia veins from one inch to several inches wide cutting approximately at right angles to the schistosity. The epidote is bright pistachio green in color and was probably the first mineral formed, although it was in part contemporaneous with the quartz. The quartz forms crystals which project into the center of the veins. Adularia, which is the latest mineral in the veins, forms crystals up to $1\frac{1}{2}$ inches across. It is flesh-colored and opaque on the outside, but rather glassy inside. Probably these veins represent a later lower-temperature mineralization. Other evidence for a later mineralization of lower temperature are the small veins west of Sneech Pond which contain galena, sphalerite, chalcopyrite, smoky quartz, white fluorite, and bright purple fluorite.

Secondary Minerals

In the tremolite-magnetite rock, and in the garnet-magnetite rock, antigorite occurs as an alteration of tremolite, probably the result of hydrothermal action.

Polished sections of the opaque minerals reveal minute veinlets of covellite replacing bornite. Small amounts of chalcocite were found with the bornite and covellite. Textural relationships do not indicate whether the bornite is primary or secondary.

A thin coating of botryoidal, white opal was observed on a few joint planes and lining small cavities in the garnet rock at Quarry No. 2. A fragment of the ore from the dump at the main mine contains opal filling the spaces between the fragments of a piece of brecciated chalcopyrite.

The characteristic weathering products, limonite, malachite, and azurite were seen at many places in the area.

Summary and Geologic History

This area was at one time composed of a series of rocks which were metamorphosed to green schists, quartzite, and crystalline limestone.

[14] Jackson, *op. cit.*, p. 54.

The minerals of the green schists are the result of this metamorphism, as probably is some of the tremolite, serpentine, and talc in the limestone. These rocks are considered to be of pre-Cambrian, probably Algonkian, age.

In Devonian or early Carboniferous time the green schist series was intruded by sills of granite, and contact metamorphic deposits were formed. The silicate, oxide, and sulphide minerals formed are characteristic of high-temperature contact-metamorphic deposits. In general, the silicates were formed first, the oxides next, and the sulphides last. Probably several types of veins containing quartz, beryl, tourmaline, fluorite, and ilmenite were formed at about this time.

Veins of low temperature types, such as the quartz-epidote-adularia veins, were formed somewhat later. Common weathering products were formed still later, probably in post-glacial time. The number of minerals found here is about forty.