UNITED STATES DEPARTMENT OF THE INTERIOR

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Strategic mineral investigations [unnumbered]

GEOLOGY OF THE ELIZABETH COPPER MINE, VERMONT

By

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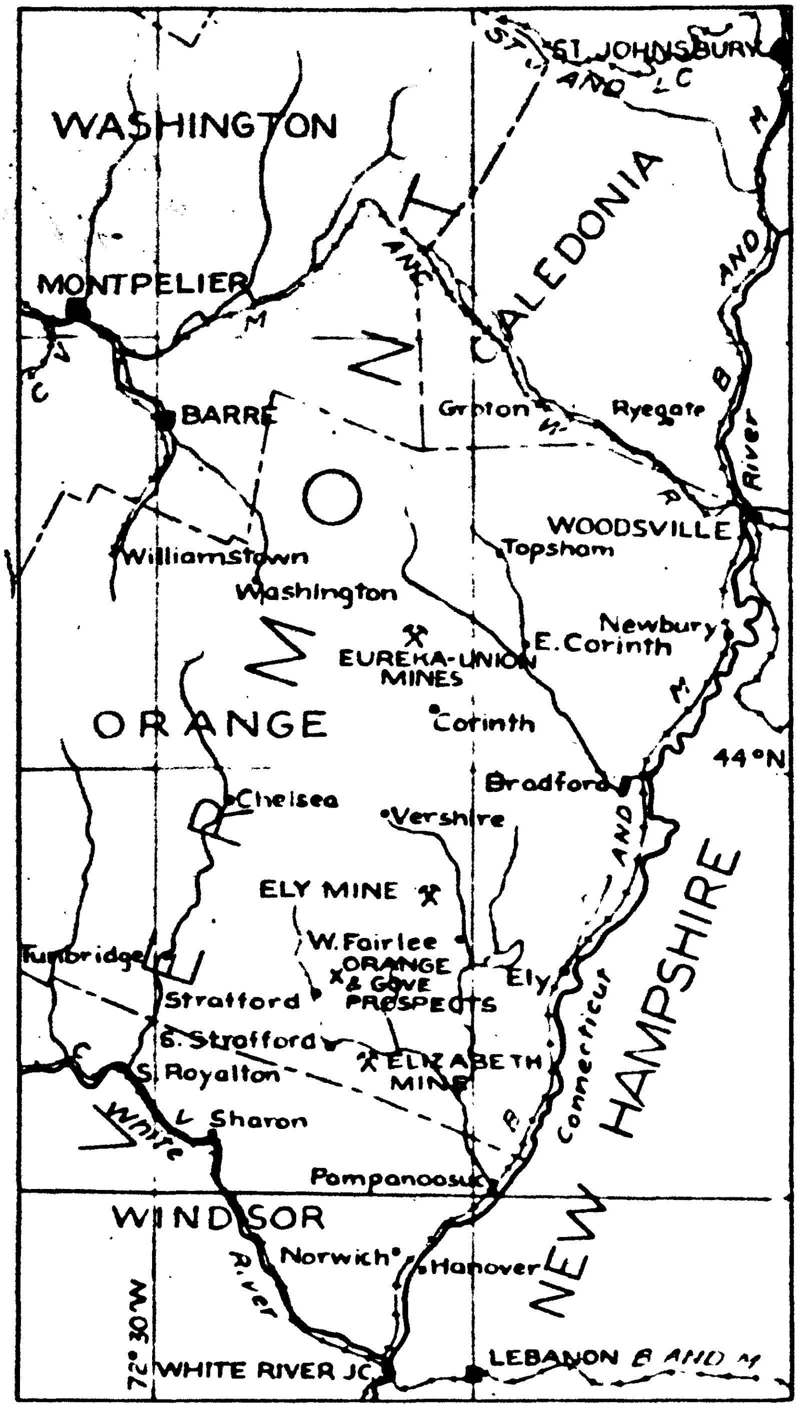
STRATEGIC MINERALS INVESTIGATIONS
PRELIMINARY MAP FIGURE 1



INDEX MAP OF EAST-CENTRAL VERMONT
SHOWING LOCATION OF COPPER MINES

0 10 20 Miles

Geology of the Elizabeth Copper mine, Vermont

By Walter S. White

Introduction

The Elizabeth mine, owned by the Vermont Copper Co., Inc., lies a mile and a half southeast of the village of South Strafford, Orange County, Vermont (fig. 1). The mine was examined during the winter of 1942-43 by members of the Geological Survey, United States Department of the Interior, in the course of a comprehensive study of the Orange County copper district which was begun in September 1942. The study forms a part of the Survey's program of providing geologic information that will aid in developing known deposits of strategic minerals, and in the search for new deposits. A detailed report on the whole district is still in preparation, but it is hoped that some of the problems affecting local mining operations will be clarified by making available a brief geologic account of the newly reopened Elizabeth mine, illustrated by a detailed plan of the mine (pl. 2) and a geologic map of the vein (pl. 1A).

The field work was carried out by a party in my charge, under the general direction of Mr. Ralph S. Cannon, Jr., whose advice has been most helpful. Able assistance was rendered by John H. Eirc and I. Gregory Sohn, who did a large part of the underground mapping. Mr. G. E. Espenshade of the Geological Survey spent six weeks in the field and contributed much information and valuable experience.

The Bureau of Mines, United States Department of the Interior, conducted a drilling program at the mine in cooperation with the Geological Survey, and the geological data obtained by the drilling are included in this report. Complete assay data of bore holes have been provided by Messrs. James E. Bell and H. P. Hermance, project engineers of the Bureau of Mines. Mr. H. M. Kingsbury, mining geologist for the Vermont Copper Co., Inc., and other officials of the company have done all in their power to facilitate the investigation.

Bibliography

The geology of the Elizabeth mine has been briefly described by several writers. The more noteworthy papers on the mine are as follows:

Anderson, C. S., Mining and milling in the Vermont copper district; Eng. and Min. Jour., vol. 131, pp. 208-210, 1931. Article written following the last shutdown prior to present operations. This is the only report that describes the

mine in its present stage of development, as only the upper workings had been opened when the earlier descriptions were written.

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Smyth, L. and Smith, P. S., the copper deposits of Orange County, Vermont; Eng. and Min. Jour., vol. 77, pp. 677,678, 1904.

Weed, W. H., Notes on the copper mines of Vermont: U. S. Geol. Survey Bull. 225, pp. 190-199. 1903.

Weed, W. H., Copper deposits of the Appalachian States; U. S. Geol. Survey Bull. 455, pp. 18-33, 1911. Contains same information as Bull. 225 with some additional data.

History and production[1]

The copper deposit of the Elizabeth mine was discovered in 1793. It was at first mined only for copperas, and the vein was worked for copperas in the open cut at least as late as 1875. As a source of metallic copper, the ore was first mined and smelted by Isaac Tyson in 1830, and it was intermittently mined thereafter, mainly from the open cut, for over 50 years. The first serious attempt at underground mining was made in 1886, when a vertical shaft was sunk for the purpose of following the ore down the pitch to the north. The main adit was completed in 1898. In 1907 the property was sold by the Tyson family to August Heckscher (Anahma Realty Co.). During the next ten years extensive development and exploration were carried on, including diamond drilling along the vein to the south, but the only real mining was done in 1918 and 1919; about 24,000 tons of ore were mined during those years, and the mine was then shut down. The American Metals Co., operating under lease, mined 20,000 tons of ore in 1926-1927. In 1929-1930, the National Copper Co., also operating under lease, mined about 50,000 tons before the drop in copper prices forced the closing of the mine.

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[1] Compiled from references listed in the bibliography, principally the paper by Anderson, and from information supplied by Mr. H. M. Kingsbury of the Vermont Copper Co., Inc.

The property is now owned by the Vermont Copper Co., Inc., organized in 1942 for the purpose of developing this and other old mines in Orange County (fig. 1). A new 500-ton mill is being built, and the mine is being newly equipped and developed for production. The company expects to begin shipping copper concentrates early in the summer of 1943.

From records of production since 1917, and from approximations based on the size of the older workings, the total production of sulfide ore from the property is roughly estimated at 400,000 tons. The 94,000 tons mined since 1917 contained on the average 2.2 percent of copper.

Geology

The rocks in the vicinity of the Elizabeth mine are metamorphosed sediments, probably of Ordovician or Devonian age. Their general distribution is shown in plate 1A. The most abundant rock is quartz-mica schist, consisting essentially of quartz, muscovite, and biotite. All gradations from mica schist containing relatively little quartz to almost pure quartzite are found. Small garnets are common in these rocks, and crystals of kyanite occur locally.

Interbedded with the quartz-mica schist are layers, up to 50 feet in thickness, of schist that contains abundant crystals of hornblende in addition to quartz and biotite. The layers locally grade into schist without hornblende, and there is a good deal of hornblende-free schist in the area extending for 2000 feet north of the South mine (plate 1A) that is mapped as hornblende schist. This rock was probably formed by metamorphism of sediments rich in carbonates of iron and magnesium. Associated with the hornblende schist is a garnet-muscovite schist, in which some of the garnets are over an inch in diameter. Long crystals of hornblende, largely altered to biotite, are common in this rock. A gneissic rock, well banded in layers of coarse and fine crystals and containing abundant rounded crystals of oligoclase feldspar, occurs in the open cut and in the southern workings of the Elizabeth mine. This gneiss is probably a metamorphosed volcanic rock. The layers have clearly undergone all the deformation recognizable in the associated schists.

All the rocks have been highly deformed. Their bedding is much folded on a small scale, and they are characterized by a well-developed schistosity, which strikes about N. 7° E. (due north on the grid adopted by the company), and has an average dip of 63° E. Detailed observations on the attitude of the schistosity are plotted in plate 1A and plate 2. The bedding, as determined both from field observations and from comparing the position of a zone of hornblende schist at the surface with its position in depth, strikes more easterly and dips more steeply than the schistosity. This discordance is probably due to folding on a large as well as a small scale, as is suggested in cross-sections A-A' and C-C', plate 3. Both the major and the minor folds plunge for the most part gently northward, though horizontal crests and even southerly plunges were observed (plate 1A, in the open cut and to the south). The rocks are so uniform and the schistosity so well developed that the bedding has had no important mechanical effect in localizing the vein zone and the ore shoots.

Apart from minor faults, the latest stage of deformation is represented by the fault along which the Elizabeth vein extends. The footwall of the vein, being parallel to the schistosity of the underlying rocks, has a general strike of N. 7° E. and an average dip of 63° E. The majority of individual measurements of dip give values close to the average, but they range from 35° to vertical. The fault is presumably a reverse fault, but neither the direction nor the amount of movement on it is known. The schistosity of the hanging wall has been warped, probably by drag along the fault. A broad synclinal roll in the schistosity, locally broken off by a small reverse fault on the east limb, lies close to the top of the main ore body (see cross-sections, pl. 3), and similar rolls of smaller size may be observed locally within the ore body. These rolls generally plunge from 5°-15° N., but in places their crests are horizontal. They and the fault zone followed by the vein are the only structural features that influenced the localization of the ore.

The Ore Deposit

The ore at the Elizabeth mine consists of a massive aggregate of pyrrhotite and chalcopyrite with a gangue of silicate and carbonate. The approximate mineral composition of ore mined in 1929-30, according to C. S. Anderson[1]; was as follows: quartz 15 percent, feldspar 15 percent, mica 10 percent, pyrrhotite 53 percent, and chalcopyrite 7 percent. The ore commonly contains about 0.5 percent of zinc, in the form of sphalerite, and in a few places there are small grains of pyrite associated with vein quartz. Carbonate, though not mentioned by Anderson, is locally an abundant gangue mineral, and tourmaline is common. Pale actinolite, or perhaps tremolite, was seen at a number of places, and hornblende may be abundant where the wall rock is hornblende schist. Except for the carbonate, tourmaline, actinolite, and a monor proportion of vein quartz, it is believed that the gangue minerals were not introduced or formed by alteration but represent unreplaced wall rock. All gradations may be observed from massive sulfide without gangue to schist with scattered grains of pyrrhotite or chalcopyrite, and vestiges, or "ghosts", of the schistose structure of the wall rock are common even in the most massive sulfide.

There may be some correlation between the nature of the vein and the composition of the wall rock. From the results of the drilling by the Bureau of Mines, it appears that the hornblende schist is an unfavorable host rock for replacement by sulfides. Where hornblende schist on the hanging wall extends through the vein zone to the footwall, as in holes BM 12, 18, and 21, there are only a few scattered thin veins and

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[1]Anderson, C. S., op. cit., p. 208.

disseminations of sulfide; and in holes BM 7 and 13, where hornblende rock lies on the hanging wall, the unreplaced country rock within the vein zone is schist without hornblende. On plate 1B, the intersection of one layer of hornblende schist with the hanging wall of the vein zone is plotted on the basis of drilling data. The lower part of this zone is probably unfavorable for ore deposition.

The ore occurs in a vein zone striking, as already said, about north-south and dipping, on the average, 63° E. The sulfide seems to follow a braided fault zone, or series of subconcordant fractures, related to a single fault. The zone is known to be mineralized for a strike length of about 1½ miles and for a vertical range of over 1000 feet. Only a minor part of the zone contains ore of minable width and grade, and in places the zone cannot even be recognized (see tabulation of drill hole data, pl. 1B). At most places the vein zone consists of a number of thin stringers, partly parallel to and partly cutting the schistosity, with sulfide more or less sparsely disseminated through the intervening schist. The width of the zone varies considerably. The vein zone proper is rarely more than 80 feet wide, although traces of sulfide may be found at least 200 feet east of the footwall of the vein. The greatest width of minable ore observed was 65 feet, but a greater width may have been mined in some parts of the open cut that are now covered by dumps.

At a few places along the vein, as in the Elizabeth mine, the mineralization was sufficiently concentrated in relatively narrow channels to produce ore shoots of economic width and grade. At such places the vein zone generally contains little or no unreplaced schist and has sharp contacts with the enclosing wall rocks. The footwall, in most parts of the Elizabeth mine, is well defined and consists of a smooth plane above unaltered and uniformly dipping schist. No slickensides, fault gouge, or other indications of fault movement were observed on the footwall, but such features would probably have been destroyed by the recrystallization and replacement which accompanied ore deposition. Immediately above the footwall there may be massive sulfide, or as much as 6 feet of strongly altered schist containing tourmaline, carbonate, actinolite, and disseminated sulfide. On the hanging wall, at many places the boundary is gradational and is marked by interfingering of schist and sulfide stringers, by an abundance of disseminated sulfide in the schist, and locally--as on the east side of the open cut--by intense alteration of the wall rock. The average width[1] of the vein in the Elizabeth mine, determined by measurements along the level workings, is about 12 feet.

The ore shoot followed by the Elizabeth mine plunges about 15°N. Its outline as viewed in a vertical longitudinal projection of the vein zone is shown in plate 1B. The top of the ore body is closely related to the synclinal roll formed by drag on the hanging wall, as is shown in sections

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[1] The horizontal width, rather than the thickness, of the vein is given becasue it can be used directly in conjunction with the area in vertical longitudinal projection to calculate volume.

B-B' and D-D', plate 3. This roll appears to have behaved as an obstruction to copper-bearing solutions moving up the dip in the plane of the vein, causing them to move upward at a low angle toward the south and concentrating the flow in the part of the vein immediately below. The average width of the vein beneath this roll is about 20 feet. The synclinal roll becomes smaller, and ceases to act as an important channelizing agent, at the depth of the 600 level, which it intersects at about 12980 feet N (see pl. 2). North of the intersection, well above the roll, there are many stringers, whereas the rock above the roll in the upper parts of the mine is barren. Near the north end of the 600 level, the veins or vein aggregates locally attain minable widths and some of the small stringers are very rich, but, because of the erratic distribution of the sulfide veins, considerable exploration will be necessary to develop substantial ore bodies in that vicinity. The thick veins of good ore penetrated by the old drill holes DDH 19 and 20 (see pl. 1B) suggest, however, a possible renewal of the conditions observed in the upper parts of the mine, and they seem to justify further exploration down the pitch.

The lower boundary of the ore shoot is an assay wall[1], along which the vein pinches to a foot or two in width or splits up into a number of scattered stringers too low in grade to mine. Pinches can be observed at the south end of the 400 and 600 levels, and typical examples of splitting may be observed farther north along the 600 level.

Within the main ore body, far below the top, there are some pinchings and swellings not controlled by a synclinal roll. A thick pod of ore, up to 25 feet in width, may be observed in three places, one at the south end of the 600 level, one near the inclined shaft in the north part of the 500 level, and one in the sublevel just south of the 500-level stopes (pl. 2). It pinches markedly both to the north and to the south. It appears to lie in a roll in the footwall that plunges gently north, and it may have been formed near a channel created by adjustments during fault movement along a gentle roll in the fault plane. In general, however, no close relation between the attitude of the footwall and the thickness of the vein was found, and there is some apparent conflict between evidence obtained at different places.

The large ore body indicated by holes BM 7 and 13 is believed to be limited along its lower margin by the unfavorable hornblende schist in the hanging wall. Although the ore has not been blocked out, it probably has the form of a shoot pitching gently to the north, and it may be similar in general shape to the pod just north of the lower part of the inclined shaft. Evidence is inadequate to determine the presence or absence of a synclinal roll along the upper boundary.

In the South mine, a long pit largely filled with water, some massive sulfide is still exposed in the hanging wall. Drill holes DDH 1 and 2, which penetrate the vein nearby, failed to intersect minable ore, but

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1. In general a cut-off of 6 feet of ore containing 2 percent copper, or its equivalent, is being used to determine assay walls.

between the drill holes there may be an ore shoot of small tonnage, pitching about 35^{o} north, more or less parallel to the plunge of some broad folds in the schistosity.

There may be a shallow ore body of unknown dimensions from 1100 to 1700 feet north of the South mine. Its presence is suggested by meagre surface exposures in old trenches and by drill holes DDH 3 and 4. Because of a thin surficial zone of secondary chalcocite, the trenches cannot be adequately sampled without considerable blasting to obtain unenriched material. The longest trench, however, exposes over 40 feet of minable material, consisting partly of massive sulfide and partly of schist with abundant disseminated chalcopyrite. Other trenches and small pits give only poor exposures, but some massive sulfides can be seen in the walls and dumps.

Ore Reserves

Ore reserves at the Elizabeth mine include (1) ore measured and indicated by mine development and drilling prior to 1942, (2) ore indicated by recent Bureau of Mines drilling and geologic evidence, and (3) ore inferred from drilling and geologic evidence. The estimate of total measured ore reserves given by Anderson[1], which was used as a basis for the mining venture, was 233,000 tons averaging 2.07 percent copper. This total includes all the ore shown as "measured" in plate 1B and also about 12,000 tons in a block that includes the narrow veins exposed in the south ends of the 400 and 500 levels and penetrated by the old drill holes DDH 29 and 30. As this 12,000-ton block lies below the probable lower limit of the ore body, it should be deducted from Anderson's total. A large part, also, of a block extending to the surface between the open cut and the shaft at 11370N probably should be deducted, as it lies above the top of the ore projected on the basis of geologic data. This block is credited with 17,600 tons in the old estimate, but it may not contain more than 5000 tons of minable ore. About 25,000 tons in all, therefore, should be deducted from Anderson's estimate, leaving a measured ore reserve of 208,000 tons. This figure is believed to be correct within 10 percent.

A block containing about 150,000 tons of ore with an average grade of 3.4 percent copper is indicated by the Bureau of Mines holes BM 4 and 6, by the old holes DDH 17 and 18, and by projection of geologic data from adjacent mine workings. The average grade as calculated from the four drill holes is exceptionally high; more information would probably lower the figure.

Downward projection of the thick pod of ore exposed in the south end of the 600 level indicates the probable existence of a block containing about 35,000 tons of ore with at least 2 percent of copper.

On the basis of holes BM 7 and 13, a large ore shoot may be assumed to lie below and parallel to the lower limit of the main Elizabeth shoot. The

1. Anderson, C. S., op. cit.

maximum limits of this lower shoot in the direction of dip are will defined by drill holes and mine workings, and its vertical dimension in longitudinal projection may be conservatively estimated as about 125 feet. The horizontal distance between the ore intersections of drill holes BM 7 and 13 is 600 feet. Although it may seem questionable whether the ore can be assumed to persist throughout so great a distance, the assumption seems reasonable in view of the known continuity of the main Elizabeth ore body along the pitch. As the lower vein is about 20 feet wide in drill holes BM 7 and 13, its average width may well equal that of the vein in the Elizabeth shoot, which is 12 feet. The total tonnage thus indicated is 90,000 tons, or, extrapolating slightly beyond the drill holes, roughly 100,000 tons, and the average copper content in the two drill holes is 2.2 percent. Until more data are obtained, however, this ore body must be considered less certain than the other bodies of indicated ore.

In addition to the measured ore, then, drill holes and geologic data indicate about 285,000 tons of ore containing 2.8 percent copper.

New and old drill holes have demonstrated the continuity of the mineralized zone below and north of the 600 level. The drill holes within the area of light stippling in plate 1B all intersected minable widths of ore. Holes DDH 19 and 20 intersected thick veins of relatively rich ore. About 200,000 tons of ore containing over 2 percent of copper may be inferred to lie in this block, a third or half of which might well be called indicated ore. The fact, however, that the vein zone on the 600 level consists of scattered small veins and irregular lenses, rather than of a single vein comparatively uniform in width, makes it necessary to exercise caution in estimating the ore below until the existence of workable ore bodies is more certainly known. For example, a drill hole that intersected the vein on the 600 level at 13155N (pl. 2) would give a far different impression from one that intersected it 15 feet to the north or south.

A block containing 15,000 tons of ore with over 2 percent of copper may be inferred from projection of the trough of the synclinal roll at the top of the ore shoot above the workings near the main adit (11740N).

To summarize, the ore reserves at the Elizabeth mine are estimated as follows:

Classification	Tons	Grade (%Cu)
Measured ore	208,000	2.07
Indicated ore	285,000	2.5
Inferred ore	215,000	2 +
Total	708,000	2 +

Future exploration and possibilities

The first exploratory work that is done in the future at the Elizabeth mine should be directed toward the development of the main ore shoot down the pitch, and toward opening up the new ore shoot indicated by holes BM 7 and 13. The most probable direction for the extension of the latter ore shoot appears to be up the pitch.

Large increases in the reserves of the Elizabeth mine might possibly be obtained in one or both of two directions: down the pitch to the north, or down the dip. Extension down the pitch holds the greater promise, despite the unfavorable tendency towards splitting up of the vein noted on the 600 level. The main ore shoot of the Elizabeth mine is situated at a place where solutions moving up the dip of a fault zone appear to have been diverted and concentrated beneath the trough of a fold plunging gently northward. If the location of the shoot was determined by this fold and diversion channel, it seems unlikely that similar features occur directly down the dip, for they would have tended to prevent access of solutions to the main shoot. The ground above the best part of the main shoot is in fact completely barren. The upper, or south end of a similar shoot might, however, be found at considerable depth below the northern part of the main shoot, where mineralization appears to have been less intense. Should future development down the pitch encounter a zone in which the vein is absent, another shoot might well be found down the dip, though perhaps at prohibitive depth. Smaller ore shoots, such as that revealed by holes BM 7 and 13, might lie beneath the southern part of the main Elizabeth shoot, for their existence would not necessarily preclude that of the main shoot. But inasmuch as the vein zone between the Elizabeth and South mines is everywhere mineralized, though only sparsely, the chances for the existence of another shoot as large as the main Elizabeth shoot are not considered good.

There are remote possibilities of finding other large shoots, one at some distance south of the South mine, and another at shallow depth north of the present workings of the Elizabeth mine, where the fold at the top of the main shoot either disappears or ceases to act as an impermeable barrier. These possibilities can best be tested by geophysical methods, for in both areas the cover of glacial drift is too deep for trenching.