BULLETIN 57

Geologic Series

# Copper Mines and Mining in New Jersey

by

HERBERT P. WOODWARD

DEPARTMENT OF
CONSERVATION AND DEVELOPMENT
STATE OF NEW JERSEY

Trenton, N. J.

1944

Plate 1. Ruins of surface structures at the Arlington mine, Bergen County, N. J. (Source: Mining World).

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## LETTER OF TRANSMITTAL

MR. CHARLES P. WILBER, *Director,*
*Department of Conservation and Development,*
*Trenton, N. J.*

SIR:

I am transmitting herewith the manuscript of a new report on the copper ores of New Jersey and the many attempts to mine them. The report is particularly timely in that many inquiries are being received in respect to the value of these ores and the possibility of using them to supplement the supply of copper from the dwindling western copper deposits in the present emergency.

The State is indebted to Dr. Herbert P. Woodward, Acting Dean and Professor of Geology at the University of Newark,* who, at the request of the writer, made the investigations and took the time to prepare this report as a contribution to the State in which he lives. It is also indebted to Major William Lee Phyfe for permission to use certain information incorporated in the report and obtained by him during the preparation of a college thesis on the "Copper Deposits of New Jersey".

I take pleasure in recommending the publication of this report as Bulletin 57 of the Geologic Series.

Yours very truly,

MEREDITH E. JOHNSON,
*State Geologist.*

* Dr. Woodward has since taken leave of absence to serve as a commissioned officer in the Allied Military Government.

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ABSTRACT

This report summarizes previously published information about the copper ores and copper mines in New Jersey; contributes additional information concerning the nature of the ores and efforts to mine them; discusses the geologic setting of the deposits and their origin; and includes sound advice relative to any future development.

# INTRODUCTION

## NATURE OF THE REPORT

It has been nearly 40 years since publication of the last report specifically dealing with the copper ores and mines of New Jersey. At that time interest in local copper was stimulated by a flurry of speculative activity that directed many hopes toward the possible commercial development of these ores. By 1910, however, the copper fever had mostly abated, for few, if any, hopes were actually realized. After the lapse of two generations it is now thought that another report, reviewing the subject in the full perspective of its historical background and in the unbiased light of present and possible future values, will be of substantial worth.

The writer's attention was first turned to these old copper mines in 1929, when his home was near one and his office not far from another. Since that time he has visited most of the workings, and has followed the early development of some of these mines through an interesting historical exploration.

The first report on this subject was prepared in 1840 by H. D. Rogers, who made a careful study of the mines then known. Each subsequent writer, from Cook through Weed, Keith and Lewis to the present author, has drawn heavily upon the work of his immediate predecessors, and the writer has produced less of a new contribution to the subject, than a restatement and interpretation of data previously prepared.

The present report, therefore, is submitted as a digest or synthesis of what has already been written concerning the copper ores of New Jersey, together with certain new contributions designed to bring all known information up-to-date. For the original studies of earlier writers, the reader is referred to the following publications:

1839 Beck, L. C., Notices of native copper. .. ; Am. Jour. Sci., 1st Ser., vol. 36, pp.107-114.
1840 Rogers, H. D., Final report on the geology of New Jersey; pp. 147, 148, 158-165, Philadelphia.
1854 Whitney, J. D., The mineral wealth of the United States; pp. 326-328, Philadelphia.
1868 Cook, G. H., Geology of New Jersey; pp. 218-224, 644-680, Newark, N. J.
1902 Weed, W. H., Copper deposits of New Jersey; Ann. Rept. State Geologist of New Jersey for 1901, pp. 125-139.
1906 Keith, N. S., The copper deposits of New Jersey; Mining Mag., vol. 13, pp. 468-475.
1907 Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, pp. 131-164.
1907 Lewis, J. V., The copper deposits of the New Jersey Triassic; Econ. Geology, vol. 2, pp. 242-257.
1911 Weed, W. H., Copper deposits of the Appalachian States; U. S. Geol. Survey Bull. 455, pp. 38-57.
1911 Apgood, F. W., Description of copper deposits of New Jersey; Mining World, vol. 34, pp. 298-301.
1927 Richter, F. E., Copper-mining industry in the United States; Quat. Jour. Econ., vol. 41, pp. 236-91, 685-717.

Through the courtesy of Meredith E. Johnson, State Geologist of New Jersey, the writer has had access to the original files of that office dealing with copper ores and copper mining for the period from about 1895 to the present, and considerable historical information was found in these documents, including matter published by several of the evanescent mining companies, much correspondence with company officials, and several company reports on the geology of different prospects.

## ACKNOWLEDGMENTS

The writer has drawn heavily upon the geologic literature cited above, and herewith expresses his indebtedness to these authors for information and opinion. He has discussed portions of the present report with Mr. Johnson, State Geologist, to whom he is indebted for encouragement and advice. Dr. Edward Fuhlbruegge, Professor of History at the University of Newark, has shared the writer's interest in the historical background of the copper mines, and has supplied both information and counsel. Harriette B. Woodward also contributed research on the history of some early mining operations.

The author expresses gratitude to Mr. O. Ivan Lee of Jersey City, who kindly loaned him a manuscript with photographs and a sub-surface map of the Schuyler mine at Arlington. Manuscript under-graduate theses on the same mine by Miss Edith Ferguson of the University of Newark and Mr. Norman Bodinger of the Newark College of Engineering have also been useful.

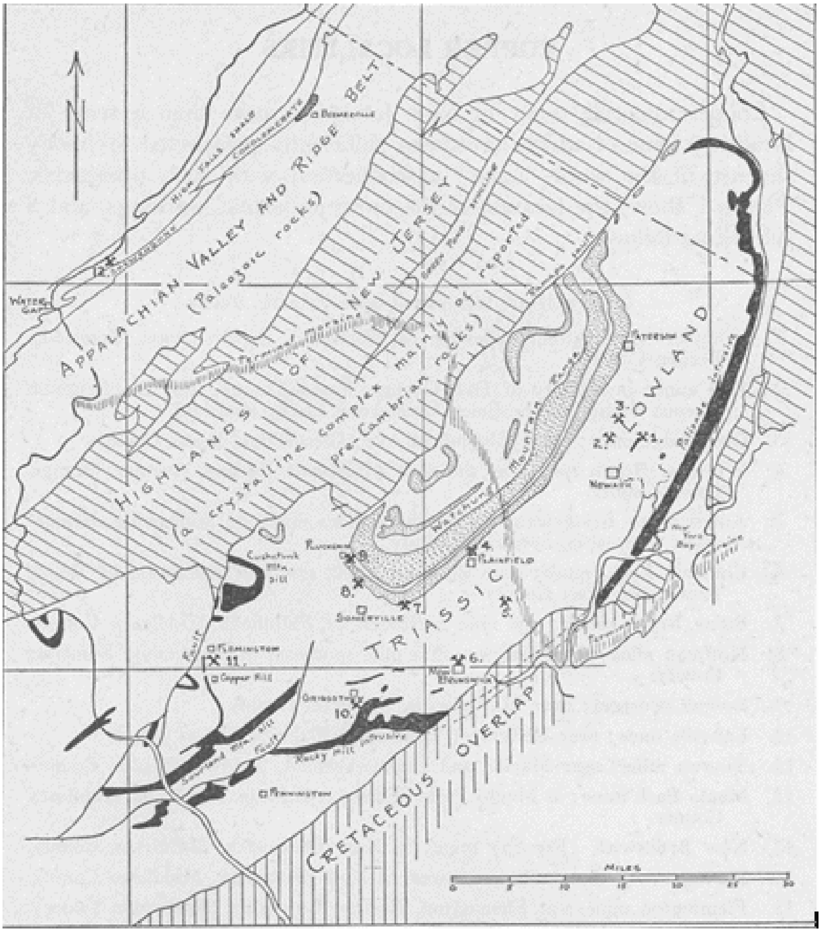


Figure 1. Generalized sketch map of northern New Jersey. The broad features of the three major geomorphic regions are indicated, and the outcrops of Triassic igneous rocks are shown. Triassic intrusives are shown in solid black; Triassic basaltic flows are stippled. Numbers refer to the more important copper mines or prospects, as follows:

1. Schuyler mine
2. Dod mine
3. Glen Ridge mine
4. Green Valley prospects
5. Menlo Park mine
6. New Brunswick mines
7. Chimney Rock mines
8. American mine
9. Hoffman prospect
10. Griggstown mine
11. Flemington mines
12. Pahaquarry mine

## COPPER LOCALITIES

Copper minerals occur in New Jersey at more than a score of localities, some of which have been sufficiently prospected to justify the use of the word "mine" in connection with such operations. Figure 1 shows the location of the more important workings, and a full listing follows:

### *Copper Mines Associated with Triassic Rocks*

1. Schuyler (Arlington, Belleville or Victoria) mine; Union Township, Bergen County.
2. Dod mine; in the city of East Orange, Essex County, near the Brighton Avenue Station of the Erie (Greenwood Lake) Railroad.
3. Glen Ridge mine; along Bloomfield Ave., Glen Ridge, Essex County.
4. Wigwam Brook mine; at the foot of Mount Vernon Avenue, Orange, Essex County.
5. American or Bridgewater mine; three miles north of Somerville, Bridgewater Township, Somerset County.
6. Chimney Rock mines; near Chimney Rock, one mile northwest of Bound Brook, Somerset County.
7. Stony Brook mines; one mile northwest of Plainfield, Middlesex County.
8. Hoffman mine; three-quarters of a mile southeast of Pluckemin, Somerset County.
9. Bolmer prospect; near Martinsville, Somerset County.
10. Feltville mine; near Feltville ("Deserted Village"), Union County.
11. Totowa mine; near Marion and Union Avenues, Totowa, Passaic County.
12. Menlo Park mine; at Menlo Park (Edison), Raritan Township, Middlesex County.
13. New Brunswick (French) mine; in New Brunswick, Middlesex County.
14. Raritan mine; three miles southwest of New Brunswick, Middlesex County.
15. Flemington mines; at Flemington, Raritan Township, Hunterdon County.
16. Neshanic mine; near Flemington, but in Delaware Township, Hunterdon County.
17. Griggstown or Franklin mine; in Franklin Township, Somerset County, one mile south of Griggstown.

### *Copper Deposits not in Triassic Rocks*

18. Pahaquarry mine; along Delaware River in Pahaquarry Township, Warren County. In Silurian rocks.
19. Banghart prospect; near Glen Gardner, Lebanon Township, Hunterdon County. In crystalline rocks.
20. Davis prospect; on Jenny Jump Mountain, Independence Township, Warren County. In crystalline rocks.
21. Aaron Howell prospect; at northeast end of Jenny Jump Mountain, Independence Township, Warren County. In crystalline rocks.

# COPPER MINERALS

Copper minerals found in New Jersey range through a wide variety and include at least all of the following: native copper, chalcopyrite, chalcocite, covellite, bornite, cuprite, hydrocuprite, tenorite, chrysocolla, brochantite, malachite, azurite, and possibly conichalcite and pseudomalachite.

## NATIVE COPPER

Native copper occurs in sheets, threads and other particles in many New Jersey copper deposits, being especially common at the American, Chimney Rock, Hoffman, New Brunswick and Menlo Park mines. Some metallic copper occurs as sheaths that encrust amygdules in the basal igneous flow of First Mountain. Elsewhere it is found as thin sheets or nodules in veins and fissures crossing igneous and sedimentary rocks alike. It is most common in the latter. Where found in Triassic sediments, native copper occurs chiefly as minute grains, nodules and small ragged masses in a great variety of forms and sizes. Some sheets have been found several feet in perimeter and more than one-half inch thick; and a single nugget weighing 128 pounds has been reported.

Native copper is the dominant ore mineral in deposits that are located some distance from intrusive Triassic igneous rocks, whereas it is much rarer in deposits situated near intrusive bodies as at Arlington and Griggstown. It is common in copper deposits that are disseminated through red Triassic shales where it is believed that ferric iron was partly responsible for its precipitation.

From its types of occurrence and general behavior, the metallic copper is believed largely to be of hypogene origin, and to have originated in the hydrothermal activity of ascending solutions or vapors associated with Triassic igneous rocks. There are some small masses of native copper at the American mine that may have been locally reduced from chalcocite during secondary or supergene alteration.

Probably the native copper is nowhere important as an ore, although it supplies spectacular mineral specimens and so far has been the chief product of the American mine near Somerville.

Mention should be made here, perhaps of minor quantities of native silver[1] that occur with native copper at the Arlington, American and Chimney Rock mines. The metal is in the form of wire silver, and occurs in tiny strings and threads that are very rare and difficult to detect. Probably both silver and copper were formed tinder similar conditions of precipitation.

Assays of New Jersey copper indicate that it is generally slightly argentiferous, attesting the presence of more silver—although a very small total—than the few visible shreds of white metal suggest. Probably the volume of silver actually present, however, has been considerably exaggerated.

Native silver has also been reported at Griggstown, Flemington and Pluckemin, and assays reporting native gold have been submitted by various mine owners.

### CHALCOPYRITE

Chalcopyrite, the compound sulphide of iron and copper, $CuFeS_2$, is more common in Triassic deposits of other eastern states (see pages 117-122) than in New Jersey, where it has little economic importance and nowhere constitutes a major part of the copper ore. It has been reported at Arlington, Flemington, Griggstown, Raritan and Somerville, New Jersey, as well as at the Davis and Banghart prospects which occur in gneisses of pre-Cambrian age.

The mineral occurs chiefly as small grains and individual crystals irregularly scattered through veins, fissure fillings or fault breccias; it is accompanied by such other sulphides as pyrite, chalcocite, covellite and bornite. It is also sparsely disseminated through Triassic sandstones and shales and is found in altered sediments close to the diabasic intrusives. It is rarest in deposits distant from igneous intrusions, and occurs sparsely in the diabase itself, as at Fort Lee and Snake Hill. It may also be present in small amounts in the surface flows of First Mountain.

Most Triassic chalcopyrite is believed to be of hypogenic origin. It is thought that the mineral was precipitated directly from ascending magmatic solutions which derived their metal from magmas that crystallized into the diabase of Triassic age. Alteration to supergene minerals by meteoric waters has largely destroyed most of the primary chalcopyrite which is now found only where it has escaped this alteration.

[1] Schaeffer, C. A., Native silver in New Jersey copper ores ; Eng. & Min. Jour., vol. 33, p. 90, 1882.

## CHALCOCITE

Chalcocite is the sulphide of copper alone and has the chemical formula. It is probably the most important source of copper in the New Jersey copper deposits, forming the richest ore pockets at all prospects.

At the Schuyler mine it occurs in small branching veins and seams in sandstone above an intrusive diabase sheet, and is also thinly disseminated through the body of overlying sedimentary rocks where it has been altered in part to oxidized copper minerals. At the American mine it occurs with calcite along joint fractures and in masses scattered through bleached spots in an altered shale below Watchung basalt. At Griggstown the chalcocite likewise occurs in a "hornfels" along the upper margin of a small intrusive diabase sheet. The mineral is found mainly in fractures and fissures in the baked shales, and there is little or none in the diabase. Occurrences at Chimney Rock and Stony Brook are analogous with those at the American mine.

Chalcocite forms the main mineral at the old Glen Ridge and East Orange mines, where it is disseminated in Triassic sandstone and penetrates or partly replaces bituminous plant material that may have aided in concentrating the sulphide. It occurs in baked shale at the Raritan mine, but is found in little-altered shale at Feltville. It is associated with somewhat brecciated sandstone and basalt in the Hoffman prospect.

Chalcocite is also the ore mineral of a cupriferous Silurian sand-stone at the Pahaquarry mine. Here the sulphide finely impregnates gray sandstone in irregular areas through a fairly thick vertical section of rock along a wide lateral extension of the exposed outcrop. The mineral occurs in thin seams along joint and bedding-planes, and is believed to have replaced portions of the sandstone so as to form fairly rich but irregularly distributed nodules of ore.

Chalcocite crystallizes in two systems. If formed below 91°C., it crystallizes in the orthorhombic system and forms striated prisms; above 91°C. it crystallizes in the isometric system and forms octahedra. These facts have a bearing on the origin of the mineral, for all supergene or secondary mineral formation is assumed to take place below temperatures of 91°C. Hence it is probable that all isometric chalcocite—formed *above* 91°C.—is of hypogene or primary origin. On the other hand not all orthorhombic chalcocite is necessarily supergene ; for it is likely that hypogenic chalcocite is always developed during the later stages of mineralization, and might be precipitated when the ascending solutions are cooled below 91°C. Primary or hypogene chalcocite has been identified at the Bristol, Connecticut, copper mine, [1] which is probably analogous with certain New Jersey copper deposits. (See pages 119-120.) Its presence in New Jersey ores has not been established, but it seems likely that some chalcocite in the latter was directly deposited from heated cupriferous solutions.

It is believed that chalcocite was produced with other sulphide minerals during the original mineralization at certain New Jersey deposits. Its source may have been ascending solutions of a type that would normally precipitate sulphide minerals. This is suggested by the prevalence of chalcocite in those deposits nearest intrusive bodies, and its relative rarity in deposits located some distance from the intrusions. On the other hand, it is thought that most of the primary or hypogenic chalcocite has been subsequently altered to supergene minerals, including among others, secondary chalcocite. This is evinced at the American mine, where some ore bodies that contain chalcocite are themselves partially encrusted with sooty or capillary chalcocite, the latter being patently derived from the former[2]. At the same time, there is no clear external evidence that even the sulphide bodies so encrusted are necessarily hypogenic in origin, for they, in turn, may have been produced during still earlier epochs of supergene alteration.

From the evidence of its numerous occurrences in New Jersey, one must conclude that this mineral is secondary at most if not all localities. It is found mainly in fractures, crevices, joint-planes and bedding-planes. It is significant that it is rarely found where native copper is abundant.

## COVELLITE

Deep indigo-blue covellite (CuS) is a rare New Jersey mineral, being reported chiefly from the Schuyler mine, where a few fragments may now be found on the mine dumps. It is believed that this mineral, which intimately occurs with chalcocite, has been secondarily developed from the other sulphide, although the two may have had contemporary origin. At no point is it sufficiently common to attain commercial importance.

[1] Bateman, A. M., Primary chalcocite; Bristol copper mine, Connecticut; Econ Geology, vol. 18, pp. 122-166, 1923.

[2] Weed, W. H., Copper deposits of the Appalachian States; U. S. Geol. Survey Bull. 455, pp. 49-50, 1911.

## BORNITE

Bornite, a sulphide of copper and iron having the chemical formula $Cu_3FeS_3$, is also a rare New Jersey mineral, although it is known at the American, Raritan and Griggstown mines. At the American-Bridgewater mine it occurs in the zone of supergene minerals near the surface,[1] and has not been reported at depth. Its presence at Griggstown is somewhat uncertain, and the writer found no bornite in his own collections from this locality.

It is believed that bornite may have been produced during the epoch of primary mineralization, when heated magmatic waters carrying copper in solution are believed to have deposited hypogene bodies of sulphide minerals in New Jersey localities. This original bornite, however, is thought to have been largely altered to supergene ores, as the mineral is now rare and is reported at only a few mines. Indeed, probably all bornite now found belongs to a late generation of supergene deposits. The mineral is not an important ore.

## CUPRITE

Cuprite, or red copper oxide, occurs at several New Jersey mines, specifically at Flemington, Griggstown, New Brunswick, and the Hoffman, Schuyler and American mines. In most occurrences it consists of tiny clusters of capillary crystals coating or protruding from small pores or amygdules. Elsewhere it may cover the walls of fissures or other rock surfaces. At no place is the mineral common or found in large bodies, and its conspicuous red color is its chief means of identification. It is clearly of supergene origin, probably being derived from native copper by surficial meteoric waters in the zone of oxidation.

Some specimens of cuprite appear to contain the related orange-red *hydocuprite,* as at the American mine, and at Flemington.

## TENORITE

Gray copper oxide, or tenorite, is rare at New Jersey copper localities. being reported only from Griggstown and Stony Brook. It is of supergene origin.

[1] Weed, W. H., op. cit., p. 52.

## CHRYSOCOLLA

This conspicuous mineral occurs at all New Jersey copper mines, where its bright blue-green color has been frequently mistaken for the darker green of malachite. Chrysocolla is a common constituent of the oxidized zone, and has resulted from supergene alteration of native copper and sulphide minerals to hydrous copper silicate, $CuSiO_3 .2H_2O$. It occurs as crusts, coatings and stains both upon rock surfaces and along joint-planes. It permeates red shales and sandstones of the Triassic series, and its green color also has been noted on igneous rocks at the various mines. Probably it can nowhere serve as an ore, but its omnipresence has led many operators to anticipate a richer ore body than is actually present. This mineral was one of the last to develop, and was produced where meteoric waters charged with silica encountered copper minerals.

## BROCHANTITE

The green basic copper sulphate, brochantite, is reported only from Arlington,[1] where it occurs with selenite in the form of tiny capillary crystals lining small openings in the ore rock. No doubt it is actually more common than the single reported occurrence, perhaps being elsewhere identified as malachite.

## MALACHITE AND AZURITE

Malachite, the green carbonate of copper, and less commonly, azurite, the blue carbonate, have been widely noted at local copper mines. The former occurs at the Flemington, Somerville, Raritan, Stony Brook, New Brunswick, Arlington, Griggstown, Hoffman and Pahaquarry mines ; the latter at Arlington, Totowa, Stony Brook, Somerville and New Brunswick. Lewis[2] has reported and the writer's observations confirm, that considerably less malachite is actually present than earlier observers reported ; for much of the common green discoloration is due to chrysocolla.

The two basic copper carbonates occur as stains and incrustations on fissure and joint surfaces, and are disseminated through, or impregnate, porous rocks in the ore zones. The minerals are obviously supergene in origin, as is attested by their composition and distribution.

[1]Manchester, J. G., The minerals of New York City and its environs ; Bull. New York Mineralog. Club, vol. 3, p. 64, 1931.

[2]Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, p. 135, 1907.

They are not present in sufficient quantity to serve as a major constituent of any ore body; and if they represent copper that has been redeposited from hypogene minerals, their very presence may indicate a reduction from the former value of such deposits.

Azurite is much rarer than malachite, being represented in available collections only by a few small specimens.

### CONICHALCITE

Certain green botryoidal incrustations, particularly at the Schuyler mine, may consist of conichalcite, a hydrous arsenate of copper and calcium oxide, but precise determination of this mineral has not been reported.

### PSEUDOMALACHITE

This mineral may also occur at Arlington, but constitutes no important part of the ore. If present, it is of supergene origin.

## COPPER DEPOSITS OF THE TRIASSIC AGE

With the conspicuous exception of the Pahaquarry mine, which is in Silurian rocks, and of a few minor occurrences of chalcopyrite in pre-Cambrian rocks, all copper mines and copper-bearing minerals of New Jersey are found in the area of Triassic (Newark) outcrop. These deposits represent a distinct and somewhat unique type of occurrence, of which the New Jersey mines are probably the best-known examples. The following paragraphs are designed briefly to describe the origin of such ores, and are followed by a section describing the historical development and geologic relations of the more important workings. Brief comments upon similar mines in other eastern States are also added.

### GEOLOGIC SETTING

#### *Triassic Basin*

The northern portion of New Jersey falls essentially into three geomorphic provinces : the Triassic Lowland, the New Jersey Highlands (an extension of the New England Upland), and the Appalachian Ridge and Valley Province. These units show marked contrast in type of bedrock, character of topography, and complexity of geologic structure ; and the effects of these phenomena upon settlement, culture and habitation have been different in the three regions. (See figure 1.) Practically all of the copper mines lie in the Triassic Lowland, which is also the site of the most flourishing industrial development and contains the densest population.

The Triassic Lowland, or structural basin, is a long relatively narrow tract that extends from Hudson River southwestward into east-central Virginia. Its width varies considerably, being greatest in eastern New Jersey where the lowland has its maximum development. In general, the Triassic basin maintains the strike of the New Jersey Highlands into which the Triassic sediments are partly infaulted. The occurrence of easily eroded rocks (the Newark Series) in this basin has been responsible for comparatively low ground, so that the physiographic term "lowland" is an appropriate geomorphic designation. Indeed, extensive portions of the Triassic area, such as the Hackensack Meadows in northeastern New Jersey, are partially flooded or stand near sea-level. The term "Somerville peneplain" has been used to describe the fairly level erosion surface developed upon

Triassic sediments. The regularity of this peneplain is interrupted by low ridges or hills—notably the Watchung Mountains ; the Palisades ; Cushetunk, Round and Sourland Mountains ; and Rocky Hill. These elevations mark outcrops of igneous rock associated with the Newark Series.

On the east and southeast the Triassic is overlapped by Cretaceous and younger sediments, the Triassic-Cretaceous boundary being roughly followed by U. S. Highway 1 and the line of the Pennsylvania Railroad. The Triassic Lowland merges imperceptibly with the equally low Atlantic Coastal Plain, for there is no conspicuous demarcation between the two provinces.

To the north and northwest the basin is bounded by higher ground at the edge of the New Jersey Highlands where the crystalline rocks of which they are composed show bold relief above the weaker Newark sediments. Most of this boundary in New Jersey is the trace of a great fault, commonly called the Ramapo fault, of which the dropped side is to the southeast, the upthrown side being at the north-west. The course of this boundary strikes roughly northeast and the trace of the fault is a partial crescent with the concave side facing northwest. Toward this boundary and into the plane of the fault—which probably inclines at a high angle—sediments of the Triassic series clip at relatively low angles that rarely exceed 20 degrees.

Numerous minor faults occur throughout the basin, most being high-angle strike faults of variable magnitudes. On a still smaller scale are minor displacements or fractures that provide fissures and channels for underground circulation. Most of the latter are too small for areal mapping, and acquire importance only where they act as sites for mineralization. In at least its major features, the structural pattern of the Triassic Lowland is both uncomplicated and familiar. Probably its minor features contain elements that still demand further close scrutiny and some commonly held conclusions about the basin will perhaps be modified after more intensive study of these smaller features.

## TRIASSIC SEDIMENTARY ROCKS

The sedimentary rocks of the Newark series are chiefly fine-grained red shales with some sandstones and conglomerates ; there are also darker argillites, black shales and various types of conglomerates, some of the latter probably representing cliff talus consolidated along the marginal fault. It has been common practice to recognize three main sedimentary units, an upper member mainly of red shale called the Brunswick formation ; a darker, medial rock known as the Lockatong argillite ; and a basal member called the Stockton sandstone or conglomerate.

The Brunswick formation contains most of the copper deposits. It is composed mainly of red shale with scattered beds of a fine-grained brown or red-brown sandstone that is widely known in the building trade as "brownstone" and was a fashionable building stone at the close of the 19th century. The rocks are predominantly red in color, whether shale or sandstone, but various shades of purple and other hues also occur. Mostly the shales are soft and argillaceous, showing monotonous uniformity through considerable rock thickness ; but some shales are micaceous and a very few are dark or contain coaly material. The sandstones vary in texture from very fine to medium coarse, and there are a few conglomerates in the western and northern parts of the Triassic basin. Many of the sandstones are highly arkosic and not a few are micaceous. The chief minerals of the sandstones are quartz and partially weathered feldspar; and although they suggest the weathering of some igneous source rock, the absence of gneissic or granitoid pebbles in the conglomerates is conspicuous.

Exposures of the Brunswick formation are found mainly along ridges where the harder sandstones protrude through the glacial or other overburden. Shale exposures are few and occur chiefly along streams. A mild but definite control upon topography is maintained by sandstones and shales of this formation, for the former produce low ridges that follow the strike and stand a few tens of feet above subsequent valleys developed upon shale belts. The Brunswick formation is commonly assigned a thickness between 6,000 and 8,000 feet ; it seems to occupy nearly one-half the volume of the Newark series.

The Lockatong formation, which is generally given a thickness of 3,500 feet, is a fine-grained dense argillite that was probably hardened by the precipitation of colloidal silica in an extremely fine mud or clay. Parts of it are very brittle and break with a conchoidal fracture, and most of it is dark colored, showing black, dark-purple or bluish-gray colors. Some beds are definitely carbonaceous, but there is a general absence of the true black shale that characterizes certain Paleozoic sediments of much older age. Like the Brunswick shale, the Lockatong formation contains many evidences of exposed deposition, including mud cracks, ripple-marks and even reptilian footprints and trails.

The basal Stockton formation is essentially a sandstone composed of quartz grains and a great deal of feldspar. It contains several rock types including more or less arkosic red-brown sandstone, yellow micaceous feldspathic sandstone, typical Triassic "brownstone" and soft red argillaceous shale. These varieties are indiscriminately inter-bedded, and the total lithic character of an exposure changes markedly in short lateral distances. The best Stockton outcrops are those along Delaware River near Stockton and Wilburtha, north of Trenton, where the formation is thought to be 3,000 feet thick

In summary, the Newark series contains a thick succession of clastic and argillaceous rock, showing evidence of hasty deposition and shallow-water or eolian origin. The prevailing red color has been generally attributed to deposition under semi-arid conditions in a basin of intermontane type. The Newark thickness, although large, is not exactly known, although a total of 12,000 to 14,000 feet is usually assigned. The few fossils attest an early Triassic age, possibly late early Triassic, but successful separation of the series into recognizable paleontologic horizons still awaits further field and laboratory studies.

## TRIASSIC IGNEOUS ROCKS

At least two types of igneous material are intimately associated with the Newark series, and have so long been colloquially called "trap rock" that it is difficult to avoid the term and unnecessary to qualify it.

Diabase, in part olivine diabase, forms one of the two varieties of Triassic igneous rocks, and occurs in sills or dikes that were intruded into the sediments after the latter had been deposited. It is evident from strong metamorphism at the contacts of the larger intrusive bodies, as well as from minor stringers and apophyses that protrude upward and downward from the diabase sills, that the main mass of the rock was interposed as a highly heated wedge which forced its way between layers of sediments, lifting the overlying strata and partly engulfing masses of the roof that broke or were melted from the country rock. Profound alteration of sediments along each igneous contact indicates that the diabase retained its heat for a long period, for at some places this alteration extends across several hundred feet of sediment. Shales suffered greater thermomorphism than sandstone, being hardened into a dark or purplish material for which the old name "hornfels" is still appropriate. These "baked" shales are conspicuous features both above and below margins of the intrusive sheets.

Probably the most conspicuous diabase sill crops out along Hudson River to form the spectacular Palisades of the New York City landscape; it is called the Palisade intrusive. This great sill, which is 500 to 1,000 feet thick, is the easternmost Triassic igneous rock in the basin, and crops out in a broadly curving crescent whose concavity faces northwest. The trace of the sheet disappears beneath Cretaceous rocks near Carteret, New Jersey, but it is known that the same sheet reappears at the surface to form Rocky Hill and other continuations northwest of Princeton. A separate intrusive underlies Sourland Mountain, and a third body forms Cushetunk Mountain, south of Lebanon. Including its buried portion between Deans and Staten Island, the Palisade diabase forms a single, continuous sheet, extending for about 100 miles, that corresponds in curvature with the circumference of a great circle whose radius would be about 75 miles. (See figure 1.) Several smaller intrusive bodies are also known in the basin.

Basalt, of extrusive origin, forms the other main Triassic igneous rock, and is believed to have originated as a molten lava which welled upward from fissures (now concealed) through the Triassic sediments, to pour out upon the surfaces of strata deposited only a short time previously. The lower surface of the basalt is commonly vesicular or porous, and the openings are now filled with amygdaloidal minerals of which certain zeolites, calcite and, less commonly, cupriferous minerals, are representative. This lower surface is wholly conformable with the sediments over which it flowed, and the thermal effects are marked only for a few inches directly below the basalt. These contact metamorphic effects somewhat resemble those along the margins of intrusive diabase ; but the top contact of the basalt produced no such metamorphism, for the unaltered overlying sediments were deposited upon the cooled basalt and not intruded by it. In mineralogical, chemical and physical character, the basalt strongly resembles the intrusive diabases, differing chiefly in its finer texture.

At least three distinct generations of basaltic flows occurred during Triassic sedimentation, each being completely buried by succeeding sedimentary rocks. These flows now form the Watchung Mountains and the Long Hill-Hook Mountain range, whose strikes follow smaller western arcs within the greater curve of the Palisade intrusive. The outermost ridge formed by the first flow is known as First Mountain; the parallel ridge to the northwest is called Second Mountain. The third and youngest flow constitutes Long Hill and Hook Mountain with an irregular, disconnected surface trace that crops out near the fault at the northwest Triassic boundary.

Each of the three basalt flows was multiple in character, as is attested by several distinct outpourings of basalt that may be identified in each main body. Apparently these smaller extrusions were so near in time of formation that there was no opportunity for deposition of mud and sand between them, although thin streaks of sediments locally intervene between separate flows. Many interesting igneous features are associated with the Watchung basalts, including pillow-type lava and columnar jointing, the latter also being conspicuous in the Palisade intrusive sill.

Contact metamorphism, or "baking," of the shales beneath basalt flows of the Watchung Mountains differs vastly in degree from that beneath the intrusive Palisade diabase. Whereas the heat of the molten intrusive affected sediments as much as 500 feet from the diabase, shales underlying the basalt flows are usually unaltered two feet away from the contact, and are wholly unaffected 8 or 10 feet below the flow. This difference in depth of alteration is patently a function of the quantity of heat involved, the flows cooling rapidly, and the diabase retaining a high temperature for a much longer time.

Although the relative ages of the three basalt flows can be simply determined, there is no sure way to establish the exact time relations between the basalt flows and the diabase intrusives, although both were produced in Triassic time. There is reason to believe that the intrusions of diabase occurred after the outpouring of basalt, possibly taking place during the epoch of deformation that faulted both the sedimentary bedrock and the intercalated or buried flows of trap.

Several analyses follow to show the chemical character of the Watchung basalts and Palisade diabase.

ANALYSES OF TRIASSIC IGNEOUS ROCKS[1]

| | Watchung Basalt | | | | Palisade Diabase | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $SiO_2$ | 50.19 | 51.82 | 51.36 | 49.68 | 50.81 | 53.13 | 51.03 | 50.34 |
| $Al_2O_3$ | 14.65 | 14.18 | 16.25 | 14.02 | 9.42 | 13.75 | 11.92 | 15.23 |
| $Fe_2O_3$ | 3.41 | 0.57 | 2.14 | 4.97 | 1.68 | 1.07 | 1.52 | 2.82 |
| FeO | 6.96 | 9.07 | 8.24 | 9.52 | 9.10 | 9.10 | 10.85 | 11.17 |
| MgO | 7.95 | 8.39 | 7.97 | 5.80 | 15.01 | 8.57 | 12.08 | 5.81 |
| CaO | 9.33 | 8.60 | 10.27 | 6.50 | 10.65 | 9.47 | 9.22 | 9.61 |
| $Na_2O$ | 2.64 | 2.79 | 1.54 | 3.49 | 1.18 | 2.30 | 1.50 | 2.93 |
| $K_2O$ | 0.75 | 1.26 | 1.06 | 1.41 | 0.40 | 1.04 | 0.39 | 1.02 |
| $H_2O$ | 3.04 | 1.70 | 1.33 | 2.43 | 0.98 | 0.90 | 0.71 | 0.26 |
| $TiO_2$ | 1.13 | 1.17 | ... | 1.39 | 0.74 | ... | 0.93 | 1.56 |
| $P_2O_5$ | 0.18 | 0.17 | ... | 0.21 | 0.16 | ... | 0.08 | 0.20 |
| Total | 100.30 | 99.85 | 100.28 | 99.60 | 100.16 | 99.77 | 100.38 | 101.09 |

1. Basalt, from Hartshorn quarry, near Springfield, N. J.
2. Basalt, Hatfield & Weldon quarry, Scotch Plains, N. J.
3. Basalt, Watchung Mountain, Orange, N. J.
4. Basalt, Morris County Stone Co. quarry, Millington, N. J.
5. Diabase, west end George Washington Bridge, N. J.
6. Diabase, Jersey City railroad cut, Jersey City, N. J.
7. Diabase, Englewood Cliffs, N. J.
8. Diabase, Rocky Hill, N. J.

## ORIGIN OF THE DEPOSITS

The New Jersey copper deposits are the best-known examples of a group of similar occurrences in Triassic rocks from Nova Scotia to Virginia. Probably Michigan copper is essentially similar in origin, while mines at Coro Coro, Bolivia; the Faroe Islands; White River and Copper River, Alaska; Nova Zembla and Arctic Canada fit into analogous patterns.

[1] Analyses 1-4, 6-8, Lewis, J. V., Petrography of the Newark igneous rocks of New Jersey; Ann. Rept. State Geologist of New Jersey for 1907, pp. 121-2, 161-2, 1908.

Analysis 5, Walker, Frederick, Differentiation of the Palisade diabase, New Jersey; Bull. Geol. Soc. America, vol. 51, p. 1080, 1940.

Essential features of this type of occurrence include associations of Native copper with red shales and sandstones, and copper sulphides with Basalt or diabase affiliated with the sediments. The main factors to be discussed in considering mineral gneiss are the source of the metal, the agent and manner of its transportation, and the casues of its precipitation.

In presenting the following discussion, the writer has assembled and reported information available without making any essentially original contribution to the problem. The hypothesis of mineral origin stressed below differs only in minor details from that offered by Lewis[1] in 1906, to whom credit should be given as being one of the first to assign ascending magmatic solutions as the transporting agent in cupriferous mineral accumulations.

There is a large body of geologic literature bearing upon the origin of copper deposits of this general type particularly including the famous Michigan copper ores. Many of these references contain material of significance in considering the origin and deposition of copper from solution, and the following citations may be noted as pertinent to the problem under discussion in addition to those referred to in the accompanying text :

1871 Henwood, W. J., On the native copper of Lake Superior ; Royal Geol. Soc. Cornwall Trans., vol. 8, pp. 385-489.

1898 Wadsworth, M. E., The origin and mode of occurrence of the Lake Superior copper deposits ; Am. Inst. Min. Eng. Trans., vol. 27 pp. 669-696.

1899 Clements, J. M., A contribution to the study of contact metamorphism ; Am. Jour. Sci., 4th ser., vol. 7, pp. 81-91.

1900 Blandy, J. F., The origin of the native copper in the Michigan deposits ; Eng. and Min. Jour., vol. 70, pp. 278-279.

1906 Stokes, H. N., Experiments on the solution, transportation and deposition of copper, silver and gold; Econ. Geology, vol. 1, pp. 644-650.

1906 Hussak, E., Ueber das Verkommen von gediegen Kupfer in den Diabasen von Sao Paulo: Centralbl. Mineralogie, pp. 333-335.

1908 Moffit, F. H., Notes on copper prospects of Prince William Sound, Alaska; U. S. Geol. Survey Bull. 345, pp. 176-178.

1910 Knopf, Adolph, The copper-bearing amygdaloids of the White River region, Alaska: Econ. Geology, vol. 5. pp. 247-256.

1911 Brauns, R., Native copper in basalt; Zeitschr. Krystallographie, p. 493. 1911 Lindgren, Waldemar, Genesis of copper with zeolites in basic rocks; Min. and Eng. World, vol. 35, No. 27, p. 1311.

1911 do., Some modes of deposition of copper ores in basic rocks; Econ. Geology, vol. 6, pp. 687-700.

1911 Menche, A. H., The development of the copper mines of Lake Superior and their geologic relations; Michigan Geol. Survey Pub. 6, vol. 2, pp. 887-931.

1911 Van Rise, C. R., and Leith, C. K., The geology of the Lake Superior region; U. S. Geol. Survey Mon. 52, 641 pp.

1913 Douglas, James, The copper-bearing traps of the Coppermine River ; Canadian Min. Inst. Trans., vol. 16, pp. 83-144.

[1] Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, pp. 131-164, 1907.

1913 Voit, F. W., Zeitschr. prakt. Geologie, Jahrg. 21, p. 42.
1915 Hore, R. E., Michigan copper deposits ; Michigan Geol. Survey Pub. 19, pp. 19-161.
1919 Butler, B. S., Primary (hypogene) sulphate minerals in ore deposits; Econ. Geology, vol. 14, p. 581.
1919 Woods, T. S., The porphyry intrusions of the Michigan copper district; Eng. and Min. Jour., vol. 107, pp. 299-302.
1920 Spurr, J. E., The copper ores of Lake Superior; Eng. and Min. Jour., vol. 110, pp. 355-357.
1923 Watson, T. L., Native copper deposits of South Atlantic States compared with those of Michigan: Econ. Geology, vol. 18, pp. 732-751.
1928 Lindgren, Waldemar, Deposits of native copper with zeolites in basic lavas ; Mineral deposits, 3d ed., pp. 497-515, New York.
1929 Butler, B. S., and Burbank, W. S., The copper deposits of Michigan; U. S. Geol. Survey Prof. Paper 144, 238 pp.

## *Critical Features of New Jersey Copper Deposits*

Certain features that are common to all Triassic copper deposits of New Jersey and other eastern States not only supply criteria which bear upon the origin of the ores, but they also erect requirements that must be met by any satisfactory theory of genesis. Some of these features should be carefully noted.

### *Location*

Practically all Triassic occurrences of copper minerals in eastern States lie close to outcrops of trap rock, and exceedingly few occur in sediments far removed from igneous bodies. Indeed, this association is so conspicuous that nearly all authors have postulated a genetic connection between the igneous materials and the copper deposits.

Some of the ores openly follow intrusive diabase contacts, or are disseminated in their zones of exomorphic alteration as at Griggstown, Arlington and Flemington. The copper minerals may lie on one or both sides of the intrusive, but are most common along its *upper* contact or in sediments *above* the igneous bodies. Some of the ores occur in or near extrusive contacts, as in the belt of prospects along Watchung Mountain near Somerville. Here and in all analogous occurrences, the ores have collected *below* the flow rocks whose relative impermeability may have blanketed solutions that might elsewhere have ascended into higher levels.

At a few localities, such as the mines in East Orange, Menlo Park and New Brunswick, there are no known igneous exposures in the immediate vicinity. Nevertheless, as the dip of the Newark sediments is relatively low, intrusive igneous bodies may be postulated to lie at no very great depth both at New Brunswick and Menlo Park ; and the eroded Watchung flows, if restored, would pass not far above the East Orange-Glen Ridge deposits.

### Mineral Associations

In Triassic copper localities close to intrusive bodies, the dominant vein mineral is chalcopyrite in fissures that penetrate the diabase, with chalcopyrite and chalcocite occupying veins and fissures that ramify through altered sediments close to the intrusives. These minerals are likewise characteristic of ores disseminated in zones of hydrothermal alteration.

In deposits situated at a distance from the intrusives as at Somerville, native copper is the dominant mineral, although some chalcocite is usually present. Chalcopyrite and bornite are rare if not commonly absent at these localities.

The gangue minerals associated with the ores fall into relatively few groups, being chiefly quartz, calcite, prehnite and zeolites. There are few sulphates. Probably these minerals, whether filling amygdules or fractures, cannot be regarded as essential to the formation of the copper minerals, but they indicate something of the conditions under which the latter were formed. Near the diabase intrusions, both ore and gangue probably belong to the same general epoch of mineralization ; at the base of extrusive flows, most of the gangue is older than the cupriferous deposits.

### *Structure*

It is significant that most of the Triassic copper ore in New Jersey occurs at positions of structural irregularity : along faults or other fractures ; at the uncomformity of an extrusive contact ; or in brecciated or altered rock along intrusive contacts. At most cupriferous localities it is possible to determine structural channels along which movement of mineral-bearing solutions occurred. These channels are invariably sites of richest ore accumulations, a fact that indicates mineralization during their use. Fissures and faults which extend from the area of intrusions were inaugurated during the invasion of magma into the country rock. Such fissures readily carried off volatile components of the magma, and governed movements of the mineralizing solutions. Where they reached surface levels, such channelways later gave downward passage to meteoric waters that were influential in supergene alteration of minerals previously formed.

## *Hypotheses of Origin*

There is no doubt that the copper ores are younger than the rocks in which they occur (i.e., they are definitely epigenetic), having been introduced into the bedrock after it was formed. Two separate theories have been proposed to account for their introduction. One assumes transportation by surface or meteoric water at relatively low temperatures, moving in consequence of surface drainage. The other hypothesis calls upon magmatic waters heated by and moving from igneous intrusions. Loosely described, meteoric waters descend, whereas magmatic waters are ascending agents of transportation. The two theories are completely contrasting and require different means of deposition.

### Deposition by Descending Meteoric Solutions

This general hypothesis was invoked by Weed[1] in 1902 to account for the origin of New Jersey copper ores, and was given specific particulars to explain ore occurrences at the American mine near Somerville. Weed ascribed these ores to the influence of percolating surface waters producing partial alteration of the trap rock.

Briefly stated, this theory assigned the basalt ("diabase") of First Watchung Mountain as a primary source of copper, and Weed quoted tests which showed a percentage of 0.025 copper in the trap rock at Somerville. He noted abundant joints and fractures in the basalt, and described these as channels for infiltrating surface water. The latter, Weed supposed, attacked ferromagnesian minerals of the trap wherein copper was supposed to occur in the form of chalcopyrite. Copper taken into solution was carried downward as the slowly circulating waters moved in response to variations in base level. The hypothesis called for the metal to be carried as a sulphate or, perhaps, in alkaline carbonate solutions. Moving ultimately downward, the solutions encountered sandstones and shales wherein their copper was lost by reaction with organic matter. Secondary alteration produced the supergene minerals at a later stage.

Certain physical and chemical objections can be raised against this hypothesis. The trap rock of First Mountain is far too little altered to account for the ores which underlie it ; and in any case, the solution of so much copper could not occur without simultaneous solution of other minerals whose loss should be apparent in the rock itself. There are several localities where ore minerals occur *above* the associated trap rock, as at Arlington, and the hypothesis of descending water poorly accounts for such a position. In addition, the thin sheet of diabase at Arlington is wholly inadequate to supply the volume of copper minerals found nearby. There is no obvious source of organic material postulated by the assumed presence of

[1] Weed, W. H., Copper deposits of the Appalachian States; U. S. Geol. Survey Bull. 455, pp. 38-57, 1911.

humic acids in the meteoric waters, and the general lack of organic remains in the Newark series does not indicate precipitation of copper minerals as suggested by Weed. Moreover, minerals that accompany the copper and are believed to be of equivalent age, are moderately high-temperature minerals and not those formed by cool surface solutions. Finally, concentration of copper on the *under* side of relatively impermeable barriers is fairly direct evidence that the solutions came from below after the rocks had assumed their present attitude.

Thus it seems necessary to relinquish the hypothesis of descending meteoric waters, and the alternative theory of ascending magmatic water may be next considered.

*Deposition by Ascending Magmatic Solutions*

In 1906 J. V. Lewis[1] reviewed and rejected Weed's earlier idea of ore deposition by surface waters, proposing a "magmatic hypothesis" in which he attributed the copper deposits to hot mineralizing solutions deriving both their heat and metal from igneous intrusions, particularly the Palisades-Rocky Hill trap sill and its offshoots.

Lewis based his argument on the close association of ores with intrusive sills, dikes and apophyses, and their general position *above* those intrusives with which a genetic association was postulated. He believed the thick mass of the Palisades intrusive sheet offered an ideal source of heat and copper salts for all Triassic copper localities in New Jersey. He correlated the time of formation with intrusion of the parent sill, an event that took place after extrusion of the Watchung flows. Lewis postulated that magmatic waters emanating from the sill carried copper in solution, possibly as acid solutions of cuprous sulphate in which the metal came from igneous rock. These cupriferous solutions permeated the bedrock over wide areas at and shortly following the time of igneous intrusion, utilizing fissures and fractures as convenient channelways. Where obstructed, or at other favorable sites for deposition, the waters lost their cuprous minerals ; and the flow sheets of the Watchung Mountains acted as such an overhead barrier, permitting rock layers immediately thereunder to become impregnated with copper. Supergene alteration at a much later date aided in developing the variety of copper minerals present.

It will be seen that this hypothesis conforms with observed facts far better than the theory of descending cool solutions, for which reason it is herein given acceptance.

[1] Op. cit., pp. 156-164.

### *Source of the Copper*

If it is assumed that the Triassic copper bodies were formed by descending meteoric waters, then the copper must have been derived from the uppermost basalt flows, or from other trap bodies so located that circulating waters could leach and carry downward their copper salts. It is true that these flows contain small particles of copper and that possibly the amount of metal so disseminated in the flows is volumetrically adequate to supply the various ore bodies. On the other hand, the flows hold copper in minutely disseminated state, and it is difficult to postulate that solutions could attack and extract this one material without leaving a more conspicuous trace of the removal of other more soluble constituents of the flows. Therefore, the extrusive rocks must be considered to be a quantitatively capable but qualitatively improbable source for New Jersey copper.

If the deposits were produced by ascending solutions, then the intrusive sills—particularly the Palisade trap—may be called upon as a source. Copper in small amount is found in this diabase, and the body of the rock is favorably located to provide the necessary hot solutions and metallic content. Intrusion of the molten rock into Newark sediments caused the fracturing needed to permit upward escape of volatile materials ; the copper and other minerals are such as could be supplied by emanations from the magma; and the heat of the igneous invasion could well attain temperatures needed to produce vapors and solutions whose pressure would carry them far into the bedrock where precipitation ultimately occurred.

### *Transportation of Copper*

On the assumption that the ores were deposited from heated solutions, one must conclude that fluids transporting the copper were hot either because they came from a heated source, or because they flowed through or past heated rock. The first assumption implies that the solutions were active during entry of the parent molten material ; the second suggests that the circulation which became heated had a separate origin from that of the igneous rock. There seems to be no need to dissociate the cupriferous solutions from the epoch of igneous intrusion, and it is believed that the transporting fluids originated in as well as emanated from the magma that invaded the country rocks.

Thick bodies of diabase now lie as intrusive sheets between Triassic sediments which they have thrust apart, lifting bodily the overlying materials under tremendous pressure. Hence, when the magma was intercalated into the Newark series, its mobile constituents must also have had tremendous hydraulic or vapor pressure. There is every reason to assume that this pressure far surpassed that produced even at great depth by the hydrostatic head of surface-controlled waters. Thus the volatile copper-bearing solutions had driving energy sufficient to force them through rocks that would be relatively impervious under meteoric conditions of circulation. Of course, the solutions would seek and follow lanes of easiest access, and would flow most readily through the more permeable or broken rocks and channelways. Hence minerals deposited from such solutions should be most abundant in avenues of simplest access to the surface. Nevertheless, until such lanes of escape could service all of the mobile vapors, some of the latter inevitably would seep under pressure into unbroken or normally impervious layers, where cupriferous minerals might be disseminated in such spaces as could be produced by solution or metasomatic action.

The main direction of transportation must eventually have been upward, although locally the fluids may have spread laterally or downward as well. Wide-spread layers of highly impermeable rock, such as the Watchung flows, would act as temporary barriers to this upward ascent of mineralizing solutions, and zones of mineral deposition are expectable beneath such bodies. Even these flows, however, probably halted only temporarily the ascent of the solutions, and the latter ultimately broke through joints and fractures in the dense basalt to gain higher levels. There is no existing evidence that the ascending waters reached the actual ground surface and emerged as mineral or hot springs, but it is not improbable that some may have so escaped.

### *Precipitation of Copper*

The problem of accounting for precipitation of native copper and copper minerals from ascending heated solutions[1] must take into consideration the distribution of these minerals, their types of deposit and the geologic structure of their containing rocks.

Disregarding the chemical character of the solutions, one may invoke two physical factors to assist in mineral precipitation: loss of temperature, and the relief of pressure that fluids must undergo upon attaining shallower levels than those of their source. The resulting

[1] See also Wells, R. C., Chemistry of the deposition of native copper from ascending solutions ; U. S. Geol. Survey Bull. 778, 1925.

chemical effect of these physical factors is precipitation because of saturation. Possibly relief of pressure also permits escape of certain gases—perhaps carbon dioxide—whose pressure might tend to make solutions more acidic ; but it is not clear that any particular minerals of the New Jersey copper deposits were precipitated solely by relief of pressure. From solutions which contain cuprous sulphate, native copper would be precipitated by cooling, and it seems likely that this reaction took place. No large-scale deposition through cooling is postulated, however, and precipitation from physical causes is likely to have been merely an adjunct of precipitation by chemical reactions.

In his excellent discussion of New Jersey copper ores, Lewis[1] concluded that the metal had been deposited from cooled solutions containing cuprous sulphate which had been reduced from cupric sulphate by the action of minerals or waters containing ferric iron. The bleaching of ore beds near copper pockets he attributed to leaching of hematite by acid sulphate solutions. His hypothesis assumed precipitation by the reducing action of ferric iron.

A difficulty standing in the way of complete acceptance of this hypothesis is the distribution of copper minerals ; for sulphides are prominent in or near intrusive contacts, while native copper is more prevalent in occurrences distant from the diabase bodies. Inasmuch as the ferric iron of Newark sediments is commonly reduced to ferrous iron near diabase intrusions, and as this reduction presumably occurred before invasion of metallogenic solutions, then the territory along the intrusions was not an active reducing field when invaded by the cupriferous solutions. Indeed, as sulphides were deposited in such locations, it may be reasoned that the solution was not charged with cuprous sulphate or cupric sulphate, as postulated by Lewis, but rather was one which would normally deposit copper sulphide.

Although the nature of such a solution is not precisely understood, it is clear at thousands of ore deposits that these solutions exist and that they must be the common and not the unusual type. Such a solution would definitely produce native copper as a precipitate if oxidized under the right conditions ; and the presence of native copper where precipitation occurred in red ferric shales seems to verify the supposition that the solutions were of this type.

[1]Op. cit., p. 162.

It is believed, therefore, that the copper of Triassic deposits was carried upward by heated magmatic emanations of a type that would normally precipitate copper sulphide minerals. Where these solutions invaded chemically inactive intrusives, or in fairly open channels or fissures through fractured bedrock, sulphide minerals were those most commonly precipitated, although some local oxidation produced minor bodies of native copper. Where the solutions invaded unaltered red beds of the Newark series, or where the zone of thermomorphism was very narrow—as beneath the surface basalt flows the ferric iron contained in the sediments readily yielded its oxygen and was reduced to ferrous iron ; sulphur was oxidized, and native copper was formed. Locations richest in ferric iron were places most favorable for precipitation of native copper ; those low in ferric iron would be favorable for the precipitation of sulphides.

Weed[1] first noted and others have confirmed that the red color of many New Jersey ore-beds is strongly bleached around pockets of native copper or copper minerals. He postulated the presence of organic material, possibly humic acid, as the cause of this reduction of ferric to ferrous iron. Lewis, on the other hand, supposed that the reduction was a result of acidity of the solutions themselves, possibly indicating carbonic acid. The hypothesis that copper sulphide solutions acted as the reducing agent which destroyed the ferric iron appears to fit the facts in a satisfactory manner, and at once explains the bleaching of the rocks and the precipitation of the native copper. Indeed, the ability of metallic sulphides to take up oxygen is probably greater than the ease with which ferrous iron minerals succumb to oxidation.

The following analyses show both bleached and unbleached ore-rock at Somerville, New Jersey, and from the Kearsarge lode, Michigan. The decrease in ferric iron ($Fe_2O_3$) in the bleached rock of both localities is marked. Note its high percentage in "normal" Triassic shale and relatively low percentage in "normal" basalt.

[1] Weed, W. H., op. cit., pp. 44 et seq.

ANALYSES SHOWING BLEACHING OF ORE-BEDS[1]

| | Somerville, N. J. | | | Kearsarge, Mich. | | |
|---|---|---|---|---|---|---|
| | Basalt | Unbleached rock | Bleached rock | Unbleached rock | Bleached rock | Triassic shale |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| $SiO_2$ | 51.36 | 57.24 | 50.15 | 57.7 | 62.8 | 57.02 |
| $Al_2O_3$ | 16.25 | 24.31 | 19.07 | 14.2 | 16.6 | 19.60 |
| $Fe_2O_3$ | 2.14 | 6.21 | .... | 11.2 | 2.1 | 8.73 |
| FeO | 8.24 | .... | 3.57 | 1.1 | 0.5 | 1.93 |
| MgO | 7.97 | 3.20 | 1.74 | 3.5 | 4.2 | 0.76 |
| CaO | 10.27 | 5.80 | 14.64 | 6.7 | 7.5 | 6.78 |
| $Na_2O$ | 1.54 | .... | tr | ... | ... | 0.19 |
| $K_2O$ | 1.06 | .... | tr | ... | ... | 0.75 |
| $H_2O$ | 1.33 | 3.08 | 7.44 | 0.7 | 1.0 | 4.01 |
| $CO_2$ | .... | .... | .... | ... | 0.6 | ... |
| Cu | .... | tr | 3.01 | 0.06 | 0.05 | tr |
| Total | 100.28 | 99.84 | 99.62 | 92.5 | 95.4 | 99.76 |

1. Basalt, Watchung Mountain, Orange, N. J.
2. Purple unbleached altered shale or ore-bed, American mine, Somerville, N. J.
3. Bleached spots in same bed, American mine.
4. Dark hard oxidized rock, Kearsarge lode, Ahmeek mine, Michigan.
5. Bleached equivalent associated with copper, do.
6. Unaltered Triassic red shale, American mine, New Jersey.

The absence of sulphate minerals in New Jersey copper deposits raises a question as to disposal of the sulphur. Some of the latter, of course, remained as sulphide and was so precipitated. A little gypsum and brochantite are reported at the Schuyler mine, but it is believed that most oxidation products of sulphur were carried away either in the form of gas or as soluble materials subsequently disposed of by later solution. Finally, one may return to cooling of the

[1] Analyses 1, 2, 3, 6. Weed, W. H., Copper deposits of the Appalachian States; U. S. Geol. Survey Bull. 455, p. 48, 1911.
Analyses 4-5. Butler, B. S., and Burbank, W. S., Copper deposits of Michigan U. S. Geol. Survey Prof. Paper 144, p. 134, 1929.

solutions as an accessory in the precipitation of the copper, for the loss of temperature may have contributed its share in bringing the native metal out of the oxidized solutions.

It is not meant to draw a sharp distinction between total absence of oxidation in intrusive contact zones and complete reduction in the redbeds. Obviously both sulphides and native copper occur at both positions. The attempt is made, however, to discriminate between the dominant type of mineral produced, and to emphasize the precipitation of native copper in the (original) ferric environment of Newark sediments.

The exact nature of the sulphides is still not definitely known. Chalcopyrite, bornite, chalcocite and covellite all occur in these deposits. The first two should be mainly primary or hypogenic except as later altered. Presumably the chalcocite and covellite found in a reduced ferric environment are supergene. Possibly some unaltered chalcocite is hypogenic, as seems to be the case at Bristol, Connecticut.[1] Sufficient tests have not been made of New Jersey minerals to determine if there is any chalcocite still unaltered that was deposited directly from the original cupriferous solutions.

### *Supergene Alteration*

As postulated, the hypogene or primary minerals of New Jersey copper deposits were sulphides and native copper. Although no deposit has been followed to considerable depth—only the American mine attains a depth of 600 feet below the surface—there is no indication of (a) prominent leaching of minerals above the water-table, (b) increase of sulphide minerals with depth, or (c) development of any zone of secondary sulphide enrichment. These facts are of significance in prospecting for copper, for it must be understood that ores in this State are not necessarily richer below ground than at the surface, and no enriched zone can be expected below the water-table.

It is possible, however, to observe a wider variety of copper minerals near the surface than at depth. These secondary, or supergene minerals, occur in the oxidized zone mainly above the present water-table, where circulating surface waters have reacted with pre-existing copper minerals. Copper has been dissolved from the sulphides or from the native metal and transferred to other sulphides, carbonates or the copper silicate. Malachite and azurite have been formed where

[1]Bateman, A. M., Primary chalcocite: Bristol copper mine, Connecticut; Econ. Geology, vol. 18, pp. 122-166, 1923.

solutions were rich in carbonic acid ; chrysocolla has resulted where copper-bearing solutions have reacted with silicic acid ; native copper, cuprite and tenorite have been formed by the further reduction or oxidation of various copper compounds ; while brochantite has been derived by the oxidation of sulphides.

Supergene minerals are conspicuous in New Jersey copper deposits where their high colors give a false impression of large bodies of ore. Probably they enrich the deposit in no important respect, as they merely indicate transfer of copper already present into a more conspicuous form. They are secondary in manner of formation, were formed under low temperatures by circulating meteoric solutions, and are supergene in origin having no connection with the igneous process by which the hypogene ores were produced. There are few localities where they contribute volume to workable ores, and if they represent primary minerals secondarily disseminated, their presence may actually detract from the former value of the copper accumulation.

Ore deposits, particularly those of copper, situated in the eastern part of the United States differ conspicuously from western deposits in the lack of a zone of secondary enrichment. This difference, it is believed, can be traced to two factors, climate and long-continued erosion followed by glaciation. Secondary enrichment operates best under an arid climate where the distance from ground surface to the water-table is great. In the east where the water-table is close to the soils, there is little opportunity for leaching and downward transportation of copper from upper levels.

That there ever was any zone of sulphide enrichment in eastern deposits is very doubtful in view of the long-continued erosion during humid climates when the water-table was seldom far below ground. Glaciation and denudation have removed most of the original residual soils, and if enriched copper deposits were once present, they have been destroyed long ago. Triassic copper of New Jersey must be made useful, if at all, without the prospect of enriched zones of ore at depth. The deposits cannot be expected to change materially below ground from their character near the surface.

### *Summary of Origin*

New Jersey copper deposits owe their metal to ascending magmatic solutions having a common origin with the intrusive Triassic rocks. It is thought that these solutions moved upward under high initial pressure, carrying copper in such form that it would be precipitated as sulphide minerals under normal conditions. In more open channels, and in the hydrothermally altered zones adjacent to intrusives, the chief minerals to be deposited were sulphides, little native copper being formed. Elsewhere, in the presence of ferric iron, as in the red Newark sediments, the solutions were oxidized, and the dominant resulting mineral was the native element. The primary minerals are thus native copper and the sulphides, chalcopyrite and bornite. Some chalcocite may be primary, but it has not been so proven.

Supergene oxidation has resulted in the transfer of some copper to other minerals such as cuprite, tenorite and even secondary native copper. New sulphides have been produced, chiefly chalcocite and a little covellite. Carbonates, malachite and azurite, and the silicate, chrysocolla, are also products of secondary alteration. There is no indication of any leaching or sulphide enrichment.

## TRIASSIC MINES AND PROSPECTS OF NEW JERSEY

For the small amount of copper that has come from the mines of New Jersey, a relatively large amount of money has been spent in more or less fruitless organization and expansion of copper-mining companies, most of which has contributed little to the economic welfare of the State or to the body of geologic knowledge concerning the copper deposits.

Each of the more important workings is discussed below and for some—particularly the Schuyler mine—their long and involved historical background of success and failure is recorded in full detail. Much additional information can probably be obtained to document the human side of these mining operations, but it is believed that sufficient data have been assembled to show the general pattern of New Jersey copper mines and their history.

The location of most of the mines described herein is shown in figure 1.

### *Schuyler Mine*

(Also known as the Arlington, Belleville, or Victoria mine)

*Location*

This historic copper mine lies beneath Schuyler Avenue and environs at the west edge of the Hackensack Meadows. It is a short distance north of the Belleville Turnpike and within the limits of

North Arlington, Union Township, Bergen County. (See figure 2.) It is close to Newark, being only four miles northeast of Broad and Market Streets, and it is only eight miles due west of Columbus Circle, New York City. The Victoria shaft of this mine is reportedly near the northeast side of Arlington Avenue, between Avon Avenue and Elm Street. (See figure 3.) Many of its other shafts were sunk near what is now the intersection of Schuyler Avenue and Exton and Arlington Avenues. The main workings were located approximately one mile east of the junction of Second River and Passaic River, Belleville.

Other minor prospects were once excavated on the Kingsland estate north of the Schuyler mine, but no serious mining was attempted there and an old sandstone quarry at the edge of the meadows near Kingsland, 1.5 miles northeast of the Schuyler mine, is the only present relic of these diggings. Chalcocite and chrysocolla occur at this quarry in small, unimportant amounts.

Because of the unusual historic interest attached to the Schuyler mine and its proximity to New York City, its long early history and development are here recounted in some detail. The excellent article by William Nelson, "Josiah Hornblower and the first steam-engine in North America" (New Jersey Hist. Soc. Proc., 2nd ser., vol. 7, pp. 175-247, 1883), has served as the most important single reference on the history of the Schuyler mine.

*Discovery*

Phillip Pieterse van Schuyler sailed from Holland to Beverwyck, now Albany, New York, in 1650, and received permission to "plant a village" on Esopus River in 1662, the year his sixth son, Arent Schuyler, was born. The latter came to New York as a young man, and subsequently established a trading post along the Minisink Trail. In 1693, he removed to Pequannock, then included in Bergen County, New Jersey. With Major Anthony Brockholst, Arent Schuyler purchased 5,500 acres of land on both sides of Pompton River for "mining purposes", also buying land in Orange County, New York. In 1697 he built a substantial home near Pompton Lakes along what is now part of the Pompton Turnpike and U. S. Highway 202. This house, part of which is still standing, is owned by the Colfax family and is known as the Colfax-Schuyler house.

On July 4, 1668, Captain—later Major—William Sandford of the Barbadoes Island obtained Crown grant to a tract of 30,000 acres, of which one-third was meadowland, situated between the Passaic and Hackensack Rivers, and extending north from their junction

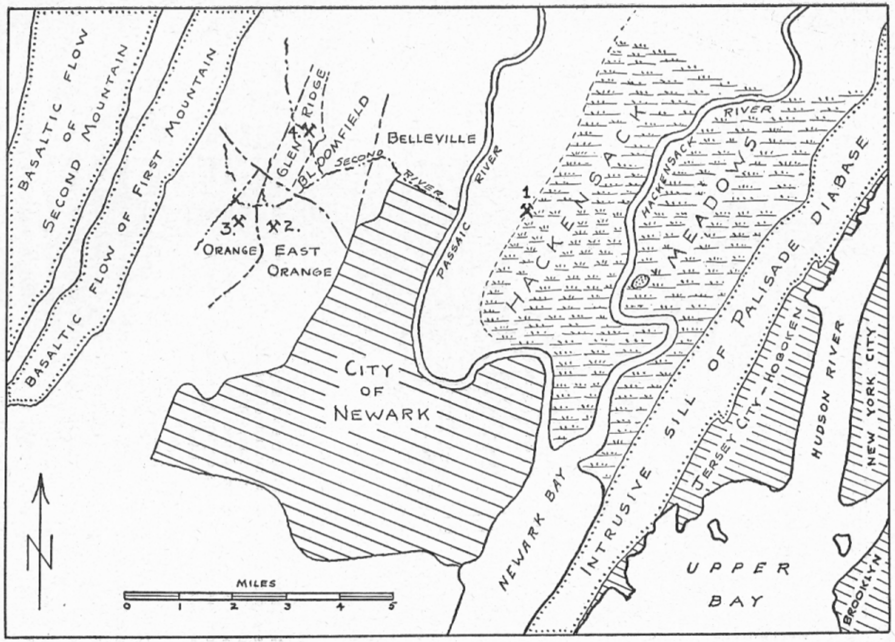


FIG. 2. Generalized sketch map of the metropolitan area of New Jersey, showing the surface outcrops of the basaltic flows of First and Second Watchung Mountains. Numbered copper mines or prospects are as follows: 1. The Schuyler or Arlington mine; 2. the Dod mine; 3. Wigwam Brook prospect; 4. the Glen Ridge mine. All of these mines are located in what is now a residential suburban district.

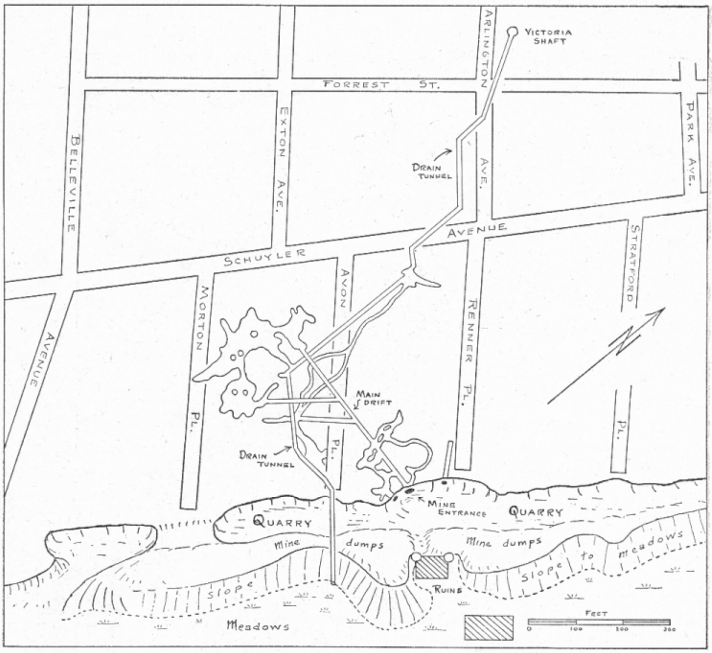


FIG. 3. Generalized sketch map of the vicinity of the Schuyler or Arlington copper mine. There is no present surface indication of the old Victoria shaft at street level, and considerable areas over the large chambers near Morton Place are partially caved. The reduction plant of the Arlington Copper Company is mostly in ruins, save the building on the meadow floor, which is currently occupied. Location of the underground workings is based upon a published map by O. Ivan Lee.

for seven miles to Boiling Springs, now Rutherford Park. Sandford called the tract "New Barbadoes Neck" from his former home. He was presiding judge in Bergen County in 1673 and died in 1708. Major Nathaniel Kingsland, Sandford's close friend, soon took over the large upper (western) tract of Sandford's grant; and his son, William Kingsland, settled upon it, building a large mansion house on what is now the Hackensack road in Nutley.

Thirty years later, Captain Arent Schuyler, former Dutch trader and Indian agent, who had previously located at Pompton, purchased for 300 pounds and settled upon the lower, southern part of the Kingsland tract, building a notable stone and brick homestead upon the higher, westerly heights overlooking the Passaic. This land was then rough wild country, occupying a wooded ridge between the Passaic Valley on the west and a dense cedar thicket on the east that merged with the marshes of what are now the Hackensack Meadows. The purchase by Schuyler was made probably in, or just prior to, 1710, but the exact date is uncertain. It is sometimes reported that he obtained the land by "hard work", that he toiled there for many years, and that he was about to sell the place when his slave found copper ; but these reports seem more romantic than accurate.

There is some uncertainty about Schuyler's interest in the property in question. If it is true that he was concerned with mining lands as early as 1693, then his purchase of the Kingsland tract may have been premeditated for a mining venture, and ore may have actually been known at the time of his purchase, possibly discovered through previous systematic search. It should be observed that Dutch miners from Albany and Esopus, whence Schuyler had come, were already acquainted with the occurrence of copper on Kittatinny Mountain in western New Jersey (see pages 127-128) ; hence Schuyler may well have been on the lookout for copper deposits. If this reasoning is valid, then his surprise at the slave's mineral discovery, as well as the entire legendary details of that romantic event, are probably fictitious. At any rate, if he bought the land as late as 1710 and the slave found copper shortly thereafter, Schuyler lost no time in finding shows of ore; for shortly after 1710 copper was reported on the Schuyler estate.

The date of discovery is invariably assigned to the year 1719,[1] but it is clear that it occurred several years earlier, for General Robert Hunter, Governor of New York and New Jersey, reported to the Lords of Trade in England, November 15, 1715, as follows :[2]

> "There being a Copper Mine here brought to perfection as you may find by the Custom House books at Bristol, where there was imported about a Tonn in the month of July or August last, of which copper farthings may be coyned."

Probably the initial discovery was in 1712 or 1713. The legendary story is that one of Schuyler's slaves plowed up a heavy green-covered stone—evidently chalcocite and chrysocolla—which he

[1] Gordon, Thomas, Gazetteer of New Jersey; p. 11, Trenton, N. J., 1834.
[2] Documents relating to the Colonial History of New Jersey; New Jersey Archives, vol. 4, p. 222, 1882.

brought to his master as a curiosity. Schuyler sent it secretly to England for analysis, and was informed that it contained 80 per cent copper. The slave, continues the legend, was rewarded with his freedom, and was allowed three wishes which, after ponderous deliberation, were : (1) always to live with his master ; (2) to get a dressing gown like his master's ; and (3) to have all the tobacco he could use

Some little confusion surrounds the early history of this mine because of the name "Hanover" that seems to have been applied to the place of discovery ; or that may have been the familiar name for Schuyler's homestead. At any rate, certain early records speak of Schuyler's mine at "Hanover, New Jersey," and confuse some of its details with early iron workings at Hanover, Morris County. There is further confusion arising from the report of Peter Kalm,[1] who was sent to America by the Royal Academy of Sweden and who described Schuyler's mine as being situated at "Hanover". He reported of it in 1748 that :

> "Some Dutchmen who live in Philadelphia preserve the account among them that on digging in this mine, the people met with holes worked in the mountain, out of which some copper had already been taken."

Kalm also stated that the "Hanover" copper mine had been worked for many years prior to 1719 by Dutch settlers. Presumably this statement and the above quotation refer to the Pahaquarry copper mine which was worked by the Dutch about 1660; and the botanist Kalm, who was in America for only a short period, may well be excused for confusing locations in the wilderness of a strange continent. (See also page 129.)

It is not known that there was any previous copper activity at the Schuyler locality before 1712 or 1713, although as intimated above, there may have been some exploration by the prospective purchaser : not all of these early details are yet clear.

The Schuyler mine is variously described: (a) as the first mine of any kind operated in the United States by Europeans; (b) as the first copper mine in America; (c) as the oldest mine in New Jersey; and (d) as one of the earliest mines in North America. Probably the last statement is correct. Certainly it was not the first copper mine in either America or New Jersey, for a copper lode was discovered in Massachusetts[2] in 1632; the manufacture of pins from native copper had begun at Lynn, Massachusetts in 1666; while

[1] Kalm, Peter, Travels into North America ; vol. 1, p. 300, London, 1772.
[2] Rickard, T. A., A history of American mining pp. 7-8, New York, 1932.

copper ore had already been worked along Delaware River (Pahaquarry mine) as early as 1660. As to mining in general, seventeen tons of iron ore were smelted at Bristol, England, from 35 tons of "oare" shipped from Virginia in 1607-1608, and there may be evidence of still earlier mines worked by Europeans in the Colonies. Thus the Schuyler mine can claim priority neither as the first American mine operated by Europeans, nor as the first copper mine ; but its position as one of the oldest mines in the United States seems well founded. The Schuyler mine has also been described as the first mine of any "real value" that had been discovered in the Colonies after nearly a century of prospecting and this statement also seems warranted. The installation of one of the first steam engines to be erected in North America has given it additional historic importance.[1]

*Historical Development*

Discovery of Schuyler's copper caused much excitement, and the property was soon opened for work, which at first consisted of surface diggings only. Indeed, copper prospecting was stimulated all over the state, especially along the trap ridges of First and Second Watchung Mountains. Governor Hunter,[2] writing hopefully in 1720, reported "Copper, but rare," and again, uncertainly, "Some copper as 'tis said, but I never saw any". His annual report for 1721 noted "A great quantity of iron ore and some copper in New Jersey".

Frank Harrison, Surveyor of New York, wrote uneasily to the Lords of Trade on April 17, 1721, as follows :[3]

> "Copper Oare which now rises very rich and in great plenty in a New discovered mine of one Arent Schuyler in New Jersey. . There is shipt on board for Holland 110 casks of said ore, which we have not, as I can find, any law at present to prevent."

The shipment referred to left New York in April, 1721, bound for Holland. It contained ore that Schuyler's slaves had crushed, washed from the bedrock, and barrelled at the mine. It was unsmelted, as the colonists were not permitted to treat or refine any native ore. The barrels or casks were trundled across the Hackensack Meadows to the Hudson and thence shipped to Holland, the Dutch offering a better price for the ore than the English. This procedure grieviously

[1] Bishop, J. L., A history of American manufactures; vol. 1, p. 546, 1861.

[2] See footnote page 43.

[3] Documents relating to the colonial history of New Jersey; New Jersey Archives, vol. 5, p. 7, 1882.

irked the apprehensive Lords of Trade, who wanted Parliament to pass regulations forbidding it.[1] In 1730 an agreement was reached with Schuyler's son John whereby ships carrying this ore would first put in at England. Later, in August 1734, the New Jersey legislature curiously imposed a duty of 40 shillings per ton on all exported copper ore not shipped directly to England. This tax was adroitly avoided, however, by shipping the ore directly from New Jersey to New York, there unloading it, and thence sending it abroad in a second shipment from New York, on which no New Jersey export levy was required. All of this taxation and its evasion worked to the disadvantage of the buyers in Bristol, England, who condemned the colonial legislature for attempting to discourage the mining of copper by taxation. Finally the tax was lifted, and the ore moved more smoothly.

The early yield of ore from the Schuyler mine ran about 100 tons per year, and by 1731 the Bristol Copper and Brass Works of Bristol, England, had become the chief purchaser, paying the high price of 40 pounds per ton of ore. The latter is said to have averaged about 80 per cent metallic copper, but this estimate is probably a high exaggeration even for sorted ore. The original books[2] of Captain Schuyler show that the Bristol Company accepted 6,933 casks or 1,386 tons of ore before 1731 ; but as this was the period when the New Jersey tax was being evaded, it is possible that more ore was being shipped from the mine than reached Bristol. The diggings were manned by Schuyler's slaves who were poor and unwilling miners, and it was not until about 1754 that skilled Welsh and Cornish miners were imported to lend their experience to the mining venture. Most of these later miners settled in Second River (now Belleville). Schuyler's manuscript records of the mine remained in the family for nearly a century and a half, during which time some of them were copied. The originals, however, were destroyed on November 17, 1870, when fire burned the home of Arent H. Schuyler, in Belleville.

Captain Schuyler died in 1730, leaving three sons: Colonel Peter Schuyler, who later distinguished himself as a colonial soldier and military hero in the French and Indian War ; Adoniah, who moved to New York and became a merchant; and Colonel John Schuyler. The mine was left to the three sons, of whom John was the natural choice to continue its operation. Colonel John worked the mine

[1] Idem, pp. 7, 9, 267, 377.
[2] Gordon, Thomas, op. cit., pp. 123-4.

efficiently, sending much ore to England to be wrought, and it is likely that the mine had its most profitable period under his supervision. He built a magnificent mansion on the east bank of the Passaic below the present Belleville Avenue Bridge, where he established a precedent for colonial hospitality. His mining records were destroyed during the Revolution.

The mine yielded substantial profits and was a steady source of income to the Schuyler family who retained its active controlling interest until near the end of the century. Governor Montgomerie[1] of New Jersey and New York wrote as follows to the Duke of Newcastle, May 20, 1730, speaking apologetically of the Schuyler mine and of a request from the Duke to assist the Bristol Copper Works in getting the New Jersey ore:

> "I have had several conferences with the Proprietor of the Mines. I find him unwilling to enter into any contract here, and all I can bring him to promise is that when his Ships arrive in England with the Ore, the Company shall have first sight of it."

An account[2] of 1750 relates the following :

> "Schuyler's Copper ore is from a Mine in the Jersies but exported from New York. . The Cartage to Hudson's River is short, and their first agreement with the miner, was to allow him one-third of ore for raising and laying it above ground. . . . The richness of the Copper Mine made so much Noise in the world that a few years since, to engross this Ore for the benefit of Great Britain, it was by Act of Parliment enumerated ; but lately it has not been Wrought and Exported, as appears in the Quarterly Accounts of the Custom House of New York."

The mine was working in 1739, for an item appeared in a New York paper noting that a workman named Marsh was injured in a "premature mine blast". Another note of 1743 reported that one Malachi Vanderpoel fell into a 100-foot shaft at the mine and was killed. During this period, the ore was "done up in quarter barrels whereof six made a Tun."

During this period, the Schuyler mansion on New Barbadoes Neck became a social center of the middle colonies, a position which it maintained through the Revolution, during which period it was used in 1777 by Sir Henry Clinton as headquarters in the famous battle of Second River. Schuyler was responsible for the improvement of many roads in the area, particularly those used to transport his copper to the Passaic and to Schuyler's Ferry on the Hackensack. His brother, Colonel Peter, managed to dragoon a crew of sailors

[1]Idem, pp. 367-8.

[2]Douglas, William, Account of the British Settlements in North America; vol. 2, pp. 257-8, Boston, 1751.

from a British ship lying in New York harbor in 1759, and the men split cedar logs to build the "Corduroy road" that was later to become the present Belleville turnpike.

Captain William Owen[1] of the Royal Navy recorded a visit to the Schuylers on July 29, 1767 as follows :

> "We mounted our carriages, ferried over the Hackensack, and passing through a flat, marshy country, where we met with myriads of the largest and most Blood-thirsty Moskittos (sic) I was ever plagued with, we visited Schuyler's copper mines, and by 3 o'clock reached Colonel Schuyler's at Second River to dinner. . . .The house is a pleasant one situated on the banks of the Passaic. It is a large and commodious modern building, such as might suit a gentleman of 3 or 4,000 Pounds annually in England."

Other prospectors in the vicinity were not so successful. An English party of Bristol merchants had purchased prospecting rights in the area adjoining Schuyler's property, but their representatives were severely handicapped by the investors backing the company, who expected most of the profits and did none of the work. At least one member of the company, Abraham Soverhill, became so discouraged with his returns that he moved in April, 1745, from Orange, New Jersey, to Milton, Pennsylvania. In 1746, a wistful advertisement was placed in the New York papers[2] offering for sale :

> "Property belonging to the mine, including pots and kitties, utencels and two negro men who understand mining ; also the remaining part of the leace of said mine, which being near two years."

Even the Kingslands attempted to mine their estate north of Schuyler, but found nothing to match the values of the Schuyler bonanza. In 1749, Benjamin Franklin, then living on his farm at Burlington, New Jersey, subsequently wrote (February 13, 1750) to Jared Eliot :[3]

> "I know of but one valuable copper mine in this country, which is that of Schuyler's in the Jerseys. This yields good copper and has turned out vast wealth to the owners. I was at it last fall, but they were not at work. The water has grown to hard for them, and they waited for a fire-engine from England to drain their pits. I suppose they will have that at work next summer; it costs them a thousand pounds sterling."

It may be interposed at this point that the mine, although eminently profitable, was not a source of *immense* revenue even in Franklin's time. Probably it gave its owners several thousand pounds annually ; but even the shrewd Franklin, who apparently failed to

[1] Narrative of Captain William Owen, R. N.; Bull. New York Pub. Library, vol. 35, pp. 144-6, 1931.
[2] Urquhart, F. J., History of the City of Newark; vol. 1, pp. 174-5, Newark, 1913.
[3] Franklin, Benjamin, Writings (edited by A. H. Smith) ; vol. 3, p. 1, 1905.

visit the mine personally, seems to have accepted without question the story of "vast wealth" that was supposed to be pouring out of Schuyler's ground. Actually the Schuylers, in spite of their ostentatious living, were landpoor and were not abundantly wealthy.

The arrival of the steam-engine[1] from England marked an important event in the history of the Schuyler mine. This engine, which had been ordered by Schuyler in 1748 through his London agent at a cost of 3,000 (1,000 *fidé* Franklin) pounds sterling, was built especially for the mine by Jonathon Hornblower of Cornwall, England, an associate of Thomas Newcomen who invented the first steam-run mine engine. The date of its arrival in New York harbor was September 9, 1753, and the engine and boiler with pump and pipe accessories in duplicate and triplicate were later landed at Second River (Belleville) and thence hauled to the mine. The equipment came in the custody of Josiah Hornblower, younger brother of Jonathon, who sailed from England on the ship "*Irene*" specifically to supervise its erection. Apparently Hornblower's arrival in this country, and, indeed, his very mission, were prudently kept secret ; for the current British law prohibited exportation, even to its colonies, of artisans or machinery calculated to encourage industries that might compete with those of the mother country. No doubt this necessary secrecy partly accounted for the four-year delay in the arrival of the engine, which not even Colonel Schuyler's prestige and wealth were able to shorten.

Within a month after Hornblower's arrival at Belleville, the construction of an engine house at the mine was begun, and bills paid for carting, material and labor carry dates between October 1753 and March 1755. Although the engine is not supposed to have been under steam until March 1755, an item appeared in the New York Gazette of February 17, 1755, offering for lease the ferry at Second River, and advising that it was "within a mile of Messrs. Schuyler's and Lucas's mines which are both at work". Lucas was then operating the Dod mine in East Orange. (See page 70.) Although not in response to this advertisement, Josiah Hornblower subsequently purchased the ferry in 1760 and built a home nearby.

The new engine—generally called Hornblower's engine—was brought over to pump the deep pit later called the Victoria shaft. This excavation was one of the oldest—if not the first—deep mine shafts to be sunk in what is now the United States ; it was more than 100 feet deep in 1735. The engine was attached to a Cornish pump

[1] Nelson, William, Josiah Hornblower and the first steam-engine in North America; New Jersey Hist. Soc. Proc. 2nd Ser., vol. 7, pp. 175-247, 1883.

situated 100 feet below the surface at the bottom of the sump, and was capable of pumping 8 hogsheads of water per minute or 720,000 gallons per day. The capacity of the pump was less than that of the engine, being about 180,000 gallons per day. This engine was one of the first three steam engines, possibly the earliest, to be erected in North America, and was "destroyed" by fire in 1765, 1768 and 1773. Subsequently the remainder was broken up and disposed of, but a century later the historic old boiler was taken to Philadelphia and exhibited at the Centennial Exposition in 1876. Part of it was last known to be at S. J. Meeker's foundry in Newark, located near the corner of Clay and Ogden streets in1883. The original Cornish pump is believed still to lie at the bottom of the Victoria shaft, buried beneath two hundred feet of debris, mud and water. A section of its great valve was reported to be in place when the mine was last fully explored in 1901.

In 1761 Josiah Hornblower, who had effectively managed the mine for 5 years, leased it with John Stearndall for a term of 14 years, subsequently extending the lease for 8 more years. They contracted to pay one-seventh royalty to the Schuylers as a yearly rental. Hornblower's account books for this period show receipts from the mine as follows :[1]

| | |
|---|---|
| 1765 | $1,676.00 |
| 1766 | 4,357.00 |
| 1770 | 4,785.00 |
| 1771 | 7,787.00 |
| 1772 | 1,237.00 |
| 1773 | 2,855.00 |

During this period, the ore brought eight to ten dollars per hundred-weight, and the above records show that the proceeds were quite uneven. Part of this irregularity in profits resulted from Hornblower's varying interest in the mine ; part from a number of accidents that interrupted the mining.

Half interest in the property was assigned on March 23, 1765, to a Philadelphia group that included William Dowell, Judah Fouke, John Kid and William Parr. These men worked the mine with Hornblower and Stearndall until 1768, but at least one member of the company made no great profit, for in October 1768, a writ of *fieri facias* was posted against goods and chattels of the estate of the late John Stearn-dall, to be enforced by the sale of his share in the copper mine. Indeed, the partnership had started off badly, for in 1765 an irate discharged workman set fire to the engine house, destroying the engine and

[1] Nelson, William, op. cit., p. 204.

2,000 cords of wood and forcing the mine temporarily to close. Hornblower patched up the engine and operations continued until a second fire in 1768.

The New York Gazette of July 25, 1768, carried the following news item.

> "On Monday Night last, a very costly and valuable Engine for extracting Water out of Col. Schuylers Copper Mines at Second River, unhappily took Fire, and was, together with the buildings which inclosed it, entirely consumed. This is the second Time the Fire has destroyed their Engine, and as it is of great Value and many Labourers had their chief Dependence on this Work, which they will now probably know the want of, the Damage will be very sensibly felt; it is unknown how the Fire began, but it is said not to be without some suspicion of Design."

The mine lay idle in 1769, but was shortly reopened by Stearndali's New York associates who worked it until 1773, when the engine house caught fire for the third time, a few years prior to the visit of Lieutenant Isaac Bangs[1] of Massachusetts in 1776. Bangs, who was stationed in New York City, was apparently delegated to obtain timber with which to barricade New York harbor against the enemy. He crossed the Hackensack in his quest and was cutting cedar trees on the meadows near Schuyler's mine when he was taken around Schuyler's estate by a guide. He marvelled at the powerful engine, writing in his diary that the mine had been idle since the last fire "four years" before.

Shortly before the Revolution (1765) a company of English capitalists got permission to erect a smelter at the mine and offered Arent J. Schuyler, son of Colonel John Schuyler, 100,000 pounds for the estate. Although Schuyler refused the offer, he agreed to join them in rebuilding the engine and working the mine; but absorption of labor into the army and a general economic insecurity resulting from the war prevented any important development. As a consequence the mine was not worked for the 20 years following 1773, being idle during the entire Revolution as there were no adequate smelting facilities in the country to handle the ore. As a matter of fact even Schuyler's loyalty to the American cause was under some suspicion, for the Kingslands who lived on the next estate to the north were openly friendly to the British, and Arent Schuyler was temporarily jailed as a Tory who failed to state his sympathies for the colonial cause.

When the war was won and there were no further restrictions on the smelting or refining of copper, interest in the mine was again

[1]Bangs, Isaac, Extract from the journal of; New Jersey Hist. Soc. Proc. 1st Ser., vol. 8, p. 121, 1858.

renewed. On February 4, 1793, the New Jersey Copper Mining Association consisting of Jacob Mark, General Phillip A. Schuyler of Revolutionary War fame (friend of Washington ; son of Arent J. Schuyler), and (later) Nicholas Roosevelt, leased the mine for 21 years from Arent Schuyler, with the privilege of one renewal. The rent was to be one-tenth of the ore during the first term, and one-seventh during the second period. The lessees agreed "to erect and rebuild a sufficient steam Engine within 18 months, and to keep at least eight men at work for not less than eight months in the year".

The new company took over with somewhat more ambition than discretion. Before mining operations could be resumed, it was necessary to pump out the drowned workings, and another or several new steam engines were needed. It occurred to Roosevelt, who had considerable technical knowledge and mechanical ability, to construct these engines on the spot, rather than import them from England ; hence in 1794 the new company bought 6 acres from Hornblower on Second River to erect a dam and coal house. They established a foundry and machine shop, and induced the aging Hornblower who had lately been in Congress, from which he retired in 1786 to his home on the Passaic—to build them the first stamping mill in this country. The shops were named Soho by Roosevelt after Boulton and Watts' establishment in Soho, England, and the first steam engine manufactured in the United States was built here. The smelting works were in charge of Mr. Smallwood, who had come from England to install a Boulton and Watts engine at this plant and at the Philadelphia Water Works ; and who, instead of returning to England, remained with Nicholas Roosevelt in Belleville. The mill was located on the west bank of the Passaic and was later operated by the Hendricks Brothers as a copper-rolling mill. Hornblower's house was nearby.

At Smallwood's foundry, John Hewitt, later to live and die at Ringwood Manor, and a German named Rohde were respectively commissioned to make patterns and castings for Chancellor Robert Livingston's steamboat *"Polacca"* whose first trip was made October 21, 1798. In 1830 Rohde was still "operating a small foundry near Belleville" with ore from the Schuyler mine.

The prospectus[1] of the new company read in part :

> "The ore of the Schuyler's mine yields, in each hundred pounds of copper, from four to seven ounces of silver, and like most copper ores, a small portion of gold. . . . At the time when pure copper was sold in

[1] Black, G. F., The Belleville copper mine ; Am. Mineralogist, vol. 7, p. 157, 1922.

England at seventy-five Pounds Sterling per ton, the ore of the Schuylers' mine was shipped to England at New York at seventy Pounds (probably *not* Sterling, but about $175 New York currency) per ton."

The new company hopefully cleaned out the old copper workings and attempted to sell stock in the mining end of the business, but their labors were greatly handicapped by the death of Jacob Mark, principal stockholder, and by resignation of the dissatisfied superintendent, Hornblower, in 1794. It had become evident to Hornblower that the main interests of the company were with the engine plant and not with the mine, for the Belleville Engine Works were already occupying most of the attention of the Association. The onus of carrying mining operations forward was taken over by Nicholas Roosevelt, but his "many engagements" conspired to hamper successful management of the mine, and operations lagged. Miners were imported from Germany in the hope that the low wages which they asked would help offset the low copper values that the mine was now supplying, but the amount of copper obtained was disappointing, and the mine became merely a small adjunct to the building of steam engines.

Livingston persuaded the members of the Association to reorganize and admit him as a partner, and thenceforth the energy of the new Soho Company was directed to industry rather than mining, although Noah Webster[1] wrote in 1806.

"A copper mine, on the Passaic, a few miles north of Newark in New Jersey, has been wrought to advantage, and an association by the name of the Soho Company, has been incorporated for the purpose of prosecuting the benefits."

For several years, the company busied itself at Belleville in the construction of steam-engines and steamboats, but the entrepreneurs soon moved away to wider reaches along the Mississippi River. The plant on Second River was sold to the Hendricks family who organized the Hendricks Copper Rolling Mill to convert Schuyler's ore into copper bolts and wire. The plant prospered and was in the hands of this family until 1928, for many years housing an enterprising and extensive business. The last of the old buildings constructed by the New Jersey Mining Association was razed in 1938 to make room for a modern industrial project.

With the demise of the New Jersey Copper Mining Association, the Arlington mine passed out of the hands of the Schuyler family, and its subsequent history has not been impressive. The property

[1]Webster, Noah, Elements of useful knowledge ; 2nd ed., vol. 2, p. 86, New Haven, 1806.

lay idle for some time, and a report[1] written in 1822, apparently based on personal communications from Dr. J. Torrey and J. Pierce, stated that Schuyler's mines had not been worked "for several years", although some shafts were 300 feet deep and the "ore is considerably abundant." Another report of the same period noted that the "Schuyler mine, situated near Belleville, one mile north of Arlington, has been worked at interval since 1817, and has been extensively wrought, as the abandoned shafts and galleries testify."[2]

The grounds were leased in 1825 to another company which made a large investment in the enterprise. A new and more effective steam engine was installed in the shaft to make possible the mining of deeper beds. Two levels were prepared for operations, one new shaft was sunk, and three older shafts were widened and cleared, but the venture was doomed to failure. The pumping machinery broke down on the opening day, and thereafter refused to function properly. As the parties involved were unwilling to sink any more funds in the project, and as their lease required that the mine be operated, the stalemate resulted in the collapse of the company.

In 1833 the property was taken over by an English company and operations proceeded "with spirit" under the direction of William Tregaskis, mine superintendent. Again a new engine and pump were installed and the shafts were cleaned out. In honor of the coronation of Queen Victoria in 1837, Tregaskis named the deepest and oldest shaft the Victoria, a name by which it has been subsequently known. The company, however, soon became dissatisfied with the low copper content of the ore, and abandoned work in a few years.

During the next 20 years the mine ownership changed hands several times. The Passaic Mining Company took over the mine about: 1847 and they erected a steam engine and spent a large sum of money apparently without accomplishing a great deal. In 1855-1856 it was worked by a Philadelphia company, of which Theodore Moss was chief engineer. In 1859 the Brisk Company of Philadelphia held rights to the property but sunk no new shafts. The Victoria shaft was again cleaned, whereupon an elaborate robber's loot was found, representing mostly flat silver "stolen from Newark residences". Shortly thereafter the Consolidated Mining Company assumed management employing nearly 200 men. A shaft was sunk to a depth of 275 feet "with much ore", but too much water hampered operations.

[1] Cleaveland, Parker, Elementary treatise on mineralogy and geology; 2nd ed., vol. 1, p. 557, Boston, 1822.

[2] Russell, I. C., Geology of Hudson County, New Jersey ; Ann. N. Y. Acad.. Sci., vol. 2, pp. 33-5, 1882.

The company gave way to the New York and New Jersey Mining Company in 1863, following a serious cave-in that had been maliciously caused by a group of miners late in 1862.

This company operated with some success, utilizing from 150 to 200 men at the mine and mills. The main shaft was sunk to a depth of 347 feet, and seven others were in use. A long drain tunnel or drift was constructed from the meadow edge to the Victoria shaft, which was reported to have been eight feet wide and six feet high. It is said that a group of miners one day removed ore worth more than $10,000 from the upper end of this gallery. Unfortunately the pump broke unexpectedly in February 1865. The main shaft speedily filled with water, tools were abandoned, and the miners were forced to flee for their lives. The operators were discouraged by this accident and abandoned work, leaving the equipment—including the old Cornish pump of Hornblower's day—buried in mud and fallen timbers.

The property lay idle for 27 years until 1892, when the New York and New Jersey Mining Company tried to begin operations again. Lacking capital, they attempted foolishly to take out the mine pillars, a procedure which caused so many disastrous cave-ins that they soon abandoned work.

Early in the 1880's a sandstone quarry on the Westlake property, about one mile south of the Schuyler mine, encountered a small body of copper ore in red sandstone adjacent to dikes off-shooting the main Arlington diabase sill. This ore pocket, although quite rich, was soon worked out, the ore being sent to Bergen Point. As much as $12 of silver per ton was reported from the copper at Westlake's quarry. It was this flurry of excitement that probably led to the ill-fated attempt in 1892 to reopen the main mine.

In 1899 the property was in the hands of the McKenzie family of Rutherford, and William McKenzie was induced to consider reopening the mine. A "party of Boston capitalists" optioned the property from him, and engaged in preliminary operations in November, 1899, being chiefly concerned with cleaning the old shafts and timbering passages that needed support. On February 3, 1900, the Arlington Copper Company was organized by C. L. Dignowity of Boston and William C. Eakins of Chicago. The new company had a capitalization of $2,500,000, of which it is reported that McKenzie supplied a substantial portion. Officials of the company[1] were as follows :

[1]Kümmel, H. B., Mining industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1900, pp. 199-217, 1901.

William McKenzie of Rutherford, President
H.G. Bell of Rutherford, Treasurer
William C. Eakins of Chicago, Secretary
C. L. Dignowity of Boston, General Manager
Dr. N. S. Keith, Metallurgist
J. H. Granberry, Mining Engineer

The new organization started work with much flourish, cleaning and refurbishing the entire mine. Shafts and tunnels were reconditioned, the mine adits were electrified, and tracks were installed. Entrance was now effected into the mine by way of an incline from the meadow edge, and the Victoria shaft was drained to the 240-foot level. An elaborate and expensive reduction plant of "unique design" was erected on the meadow near the new mine opening, where a crushing plant and power house were also constructed. Large electrolytic tanks were built and the company used more than $250,000 of the investor's funds, it is reported, in this work.

This refining plant was specifically designed for the electrolytic extraction of copper by the Keith process.[1] (U. S. Patent No. 700941, Dec. 7, 1901), devised by Dr. Nathaniel S. Keith, metallurgist for the company. The method was plausible on paper and was reported to have been previously utilized with success, supposedly in Germany. The essentials of the process called for the ore to be crushed and pulverized at a mill specially constructed for this purpose. Next the powder was to be thoroughly roasted and treated with dilute sulphuric acid. The latter was supposed to dissolve the copper, which, when the solution was electrolyzed, would precipitate in native form. A recovery of 40 pounds of copper per ton of ore was promised, and the plant was designed to handle 125 tons of ore daily at a cost "not to exceed $2.70 per ton."

There was some excitement when the first batch of ore was run through the new refinery, but to the dismay at least of the investors, the new tanks refused to hold acid, and the copper failed to precipitate. Workings were halted in November 1901, two years after they had begun, to "await considerable alteration of the plant". The mine was still closed in 1903, but the company optimistically planned to "resume operations" in the spring of 1904, an awaited reopening that never materialized, for the plant was sold at auction in the fall of 1903, and was partially dismantled, having never produced a pound of copper.

[1]Further discussion of the Keith process may be found in Eng. and Mining World, vol. 75, p. 755, May 16, 1903; and Journal Franklin Institute, August 1905, pp. 148-155. In 1903 Dr. Keith organized the Metals Recovery Company of Camden, N J., of which H. D. Deshler was a director. Deshler was also an official of Montgomery Gold Leaf Mining Company, active at the old Pahaquarry mine in Warren County. (See pages 129-130.)

The property, then consisting of 93 acres, including the mine and abandoned refinery, was bought by James E. Pope of New York, who used one of the buildings for several years to refine tin which he was importing in crude form from Bolivia. The location, however, proved unsatisfactory, and this industry was discontinued after a few years. About 1906, an attempt was made to obtain brick clay from the property, but was largely unsuccessful. In 1923 Pope leased the mine to an amateur mushroom fancier, who had quantities of black loam hauled into one of the large mine chambers, and hired an Italian horticulturist to open a mushroom farm, [1] a project that also ended in a fiasco.

On May 9, 1926 a party from Hackensack, New Jersey, explored some of the mine passages in an attempt to investigate radio reception below ground. The reception was found to be poor, but the magnitude of the subterranean workings stimulated the active imagination of a reporter who followed the party and wrote of reaching a depth of "1,500 feet below ground" in a trip extending "more than a mile and a half from the entrance"—exaggerations that far surpass even the considerable dimensions of the actual openings.

Since 1926, the mine has been visited or explored by several interested parties, mainly as a curiosity of the metropolitan area. Among those entering the more accessible workings were the writer in 1929, Mr. O. Ivan Lee of Jersey City in 1932, and a party from the Newark College of Engineering in 1939. Mr. Lee spent some time below ground, and has prepared a sketch map of the outermost galleries.[2] (See figure 3.) Access into the mine was made through a small opening at the meadow edge near the ruins of the ill-fated refining plant. When last visited by the writer, this opening was sealed and the mine was closed.

Save for some mushrooms that received second place at the National Mushroom Growers Fair at Washington, the mine has produced nothing of value since the Civil War, and little enough since the Revolution. A trickle of mine drainage[3] emerges from the long main drain to feed a small spring on the meadow floor, the waters of which have been considered choice by residents of the locality.

[1]Kümmel, H. B., Mineral industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1922-23, p. 24, 1924.

[2]Lee, O. I., Ye ancient copper mine of Arent Schuyler ; Rocks and Minerals, vol. 12, pp. 99-109, 1937.

[3]Lee, O. I., Absence of copper in drainage water of the Schuyler copper mine; Rocks and Minerals, vol. 17, pp. 102-3, 1942.

*Workings*[1]

The original operations which followed discovery of the Schuyler copper were surface workings entirely, the ore being crushed, separated from the bedrock, washed and barrelled, and the concentrate shipped to England. After a few years, workings were carried underground and a few shafts were sunk. The latter soon encountered water, which became an increasing hazard in all subsequent operations. By 1748 the deepest shaft was well below the 100-foot level, and this pit was deepened shortly after 1833 to 347 feet, when three drifts were extended from its base. One was directed northwestward for 180 feet, a second extended southwest for a similar distance, and the third was directed north for more than 200 feet. Numerous galleries were opened at higher levels, the general mining pattern being one of rooms and chambers as in anthracite coal mining. Many vertical shafts were sunk to the surface of the diabase sheet, while tunnels, rooms and other drifts were excavated along this sloping foot-wall.

Three drain tunnels were constructed at this mine, of which the middle, or main, drain was 1,300 feet long, and drained the mine down to the 100-foot level. This tunnel had four shafts for cleaning and certain lower levels were drained to a depth of 240 feet by means of a raise, 500 feet long, that connected with the main drain. Two inclines were opened from the escarpment facing the meadows. One was 220 feet long and connected through still older workings with the old shaft. The other incline, directed toward the Victoria shaft, was only 80 feet long when it was abandoned. It is reported that as many as 42 separate surface shafts have been sunk on the original Schuyler estate.

Approximately 75 acres of property are honeycombed by underground workings, many of which are close to the present ground surface. Those near the southern end of the tract are dangerously near ground level, and many caved or collapsed as the ground settled when the supporting pillars were robbed in 1892.

The full extent of the underground passages is considerable. When the Arlington Copper Company took over in 1900, their engineers were amazed at the size of some of the drifts, reporting that "the dimensions of the mine chambers are indeed tremendous ; one especially is 75 feet wide with a length of 300 feet, and varies from

[1] See particularly Kiimmel, H. B., Mining industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1900, pp. 199-217, 1901; and Granberry, J. H., The Schuyler Mine, Kingsland, N. J.; Franklin Inst. Jour., vol. 164, pp. 13-28, 217-223, 1907.

12 to 30 feet in height. Most of the chambers are to be found above the drain tunnel."[1]

There is a persistent legend that one of the lower mine tunnels extended to the southwest beneath Passaic River to emerge as an opening in the basement of the Reformed Dutch Church situated on the west side of Passaic River at the corner of Main Street and Belleville Avenue. Hornblower had been a trustee of this historic church, and helped in its construction. It is postulated in the legend that secrecy regarding occurrences of silver ores was necessary during Colonial times, as such discoveries were "Royal" mines and could not be privately operated. The legend continues that copper was taken from the main mine opening, but that silver ores were smuggled out of the western passage into the church basement. The legend gained supposed proof by the alleged discovery of several skeletons buried in quicklime when contractors were constructing a brick wall behind the furnace in the basement of this church. These relics were presumed to be bodies of slaves who helped Schuyler and Hornblower work the silver ore.

At present there is remarkably little evidence at the surface of the mine to betray its mining history of more than 200 years, and some of the householders who live above the old chambers are still unaware of the mine passages beneath them. The old Victoria shaft is now completely concealed at the surface. There are grass-covered mine dumps along the escarpment facing the meadows, but these successfully merge with surface quarry dumps to lose their identity. The only entrance to the underground workings is a small opening now boarded up.

The electro-deposition plant of the defunct Arlington Company is the sole unit now standing of the once-extensive plant ; it is still used as a small factory and is located on the meadow near the mine. The fire-swept shell of the old power house adjoins the rusty frame of the mill, while the drying furnace on the nearby hill-slope preserves only its gaunt chimney. (See plate 1, frontispiece.) The circular foundations of the abandoned lixiviation tanks are almost covered by meadow grass.

Underground, one may follow the main drift for about 400 feet from the meadow-edge, and by side drifts to the left (south) may gain entrance to the largest accessible chamber, 300 feet long, 80 feet wide, and 12 to 30 feet high. Soft loam on its floor is a relic of mushroom farming. It is now possible to explore only those passages that are east of Schuyler Avenue and little is known about the western, deeper passages. (See figure 3.)

[1] Granberry, J. H., idem.

*General Geology*

The Schuyler mine is located at the west edge of Hackensack Meadows, approximately midway between the outcrop of intrusive Palisade diabase and First Watchung Mountain, which is the edge of an extrusive basaltic flow. (See figure 1.) It is three miles west of Snake Hill, an isolated stock of diabase that rises conspicuously above the low, partially flooded meadow-land. The mine property lies in a broad outcrop of Newark (Brunswick) shales and sandstones that strike south-southwest. Numerous low ridges and intervening linear valleys have been etched into mild relief upon the sandstones and soft shales of this Triassic formation, of which the regional dip and visible inclination of ledges near the old mine are approximately 10° N. 30° W.

The Triassic sediments of the locality include light-colored brownish-gray sandstones in which quartz and feldspar are chief constituents, and interbedded red shales, mainly soft and argillaceous. Shale predominates beneath the marshy country east of the mine ; sandstones are more prevalent in the rolling country to the west. A fairly prominent, albeit low, east-facing escarpment bounds the meadows at the west, and is formed by sandstone, together with a narrow intrusive diabase sheet near the mine. The Schuyler shafts were sunk vertically from the top of this low sandstone ridge, and the old inclined tunnels sloped westward from the meadow edge underneath the ridge. Probably the surface elevation of the old shafts is about 90 feet above sealevel ; the base of the escarpment is only a few feet above tide.

Triassic diabase which occurs at the Schuyler mine is a dense fine-grained blue-gray rock that is generally conformable with the sediments into which it is intercalated, and it holds the same west-ward dip. In the vicinity of the mine, which is near its northernmost exposure, the sill is about 20 feet thick ; at the southern end, possibly a mile south of the mine, it has narrowed to about 5 feet. The diabase body pitches westward beneath the surface to form the floor of extensive galleries in the old copper workings, where it is reported that the top of the sill, which serves as the mine foot-wall, is fairly smooth and conformable to the bedrock dip. There are a few irregularities where igneous rock cross-cuts some of the sediments, or where minor off-shoots extend upward into the overlying sandstone, but in the main, the sheet regularly parallels the sedimentary beds. (See figure 4.)

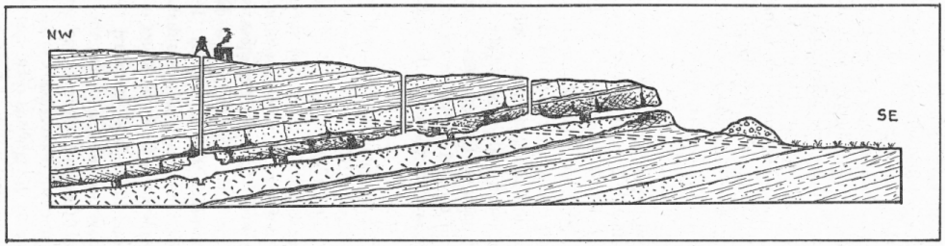


FIG. 4. Generalized cross-section through the old Schuyler copper mine at Arlington, New Jersey. The mine workings followed the upper surface of the thin Arlington sill, here about 20 feet thick. Mineralized zones follow the top contact of the sill in beds of sandstone. The numerous shafts are now concealed, and the locality is a residential suburb. The position of the main drain is indicated by dotted lines.

It is reported that the diabase surface was followed westward for more than one-half mile in underground mining operations, and that at one point a fault of strong throw was encountered.[1] It is likely that this displacement is the subsurface extension, or an associate, of the faults that are visible in the Arlington cut of the Erie (Greenwood Lake) Railroad, located about one mile southwest of the mine. These exposed faults, of which three are known, are nearly vertical displacements with the upthrown side on the west and with relatively small throw. The rock is considerably brecciated along the fault-planes which strike northeast. Their subsurface continuation could well intersect a tunnel driven some distance west from the main Schuyler workings.

The Arlington diabase sill is poorly exposed near the copper mine and elsewhere north of Belleville Avenue. In the cemetery south of the turnpike where there are minor exposures and float rock of diabase, there is some evidence that two smaller igneous bodies are associated with the main sill. It is reported that the latter is intersected by a minor fault and sends off a small subsidiary sill toward the east. For a distance of about one-fourth mile south of the cemetery, the sill has sparse exposures, and narrows to less than 5 feet in thickness. Its edge was encountered in the old Westlake quarry from which a small pocket of rich copper ore was mined in the early 1880's. (See figure 5.)

A short distance south of the quarry but north of the railroad, six feet of diabase occurs between two rather coarse sandstones, the latter being relatively little altered by intrusion. This exposure seems to be the southernmost outcrop of the Arlington sheet. Probably its total exposed length in a north-south direction is not more than a mile and a quarter. Its known maximum thickness is scarcely more than 20 feet, although it probably thickens down dip to the west, which is the direction from which it was intruded. Its connection, if any, with the main Palisade intrusion is not established, but it must be a related body and is probably a direct off-shoot of the larger sill.

Apparently the Arlington sill wedged eastward near the base of the sandstone beds and above soft shale, forcing the former upward and creating numerous fractures and fissures that served to control the location of cupriferous mineral deposition. Contact metamorphism is evident in sediments close to the igneous rock, but is inconspicuous a short distance from the contact.

[1] Darton, N. H., and others, U. S. Geol. Survey Geol. Atlas, New York City folio (No. 83), pp. 9-11, 1902.

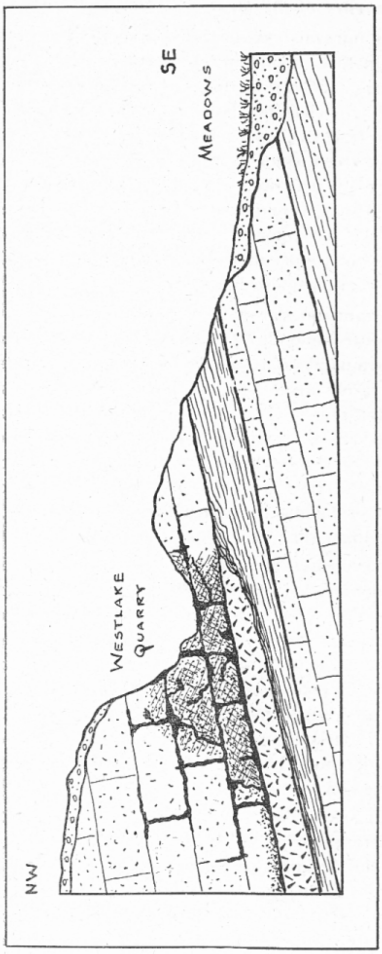


FIG. 5. Generalized cross-section at the old Westlake sandstone quarry, located about one mile southwest of the Schuyler mine. Copper ore was found in mineralized sandstone above the margin of the Arlington diabase sill, here about 6-10 feet thick. (After Darton.)

*Nature and Occurrence of the Ore*

The cupriferous minerals[1] at the Schuyler mine are chalcocite in small bodies or masses, abundant chrysocolla, minor amounts of malachite and azurite, and rare particles of cuprite and native copper. A little covellite, conichalcite, brochantite and possibly pseudo-malachite are also present. Chrysocolla is by far the most conspicuous mineral, its bright-green color pervading the bedrock and giving misleading promise of rich ore. Probably many thousand tons of copper-stained sandstone were moved in this mine under an erroneous impression that its green color invariably attested workable copper ore. In addition to the copper minerals, calcite, selenite, epidote, wad and tiny seams of coal have also been reported.

The most important mineral of the locality is chalcocite, which is the only potential ore mineral. It occurs chiefly in small branching fissure veins and seams in sandstone directly above the diabase sheet. These veins are rarely more than an inch wide; most are short, narrowing abruptly to pinch out the ore. Some pockets show mineral cleavage faces one-half inch or more across, but most of the chalcocite is granular or finely crystalline. Irregular masses of the mineral also occur in pockets, branches or seams that ramify through the sandstone benches or huddle in broken zones along thin dikes that off-shoot from the main sill.

Small faults have created brecciated zones that contain accumulations of copper sulphide and other minerals. Much of the chalcocite is arenaceous, containing scattered quartz crystals and sand grains. Tiny masses of the mineral, conversely, are widely scattered in sandstone beds some distance from the larger ore accumulations. A few small masses of covellite are associated with the chalcocite. None of the veins can be followed for more than a few feet, nor is there any ore body with well-marked boundaries. Thus in mining the chalcocite, much bedrock must be handled to obtain relatively small quantities of usable ore.

Chrysocolla is most conspicuous in the form of an incrustation on the fractured sandstone above the diabase. Mostly the coating is only a few millimeters in thickness but some crusts have been observed that are a quarter of an inch or more thick. A cross-section of some incrustations reveals separate mineral layers, probably representing pulsations in the flow of copper-bearing solutions through the rock. The rich, blue-green color of the mineral is in marked contrast to

[1] Manchester, J. G., The minerals of New York City and its environs ; Bull. New York Mineralogical Club, vol. 3, p. 64, 1931.

the gray-brown or green-gray sandstone upon which it forms a coating. Near the diabase and in fractured or fissured areas adjacent thereto, the sandstone is irregularly stained pale green, a color which results from the subtle infiltration of tiny amounts of chrysocolla into the cementing material or pores of the rock.

Malachite and conichalcite are also present as supergene minerals, but are in much smaller amounts than chrysocolla. Both, too, occur as incrustations, impregnations and other secondary accumulations. Many of the thicker crusts of myrtle-green conichalcite show typical botryoidal structures although on a minute plan. At some places alternate crusts of leaf-green malachite and blue-green chrysocolla were observed. Azurite is fairly rare, only one or two identifiable masses being observed. Pseudomalachite is reported, but was not identified by the present writer. Brochantite occurs with selenite as tiny capillary crystals lining some small cavities. The writer has not found native copper or cuprite in ore from this mine, but both minerals have been reported.

It has been the Schuyler family tradition that ores obtained by them always contained enough silver to pay the costs of smelting, and that at least part of the silver was returned to this country as English coin. No doubt this story has grown with the years, but the actual presence of wire silver has been authenticated,[1] and a sampling of the copper ores in 1900 reported an average of one-half ounce of silver per ton of copper ore. A rich specimen of ore from this mine was assayed at Rutgers University and yielded 4.4 ounces of silver per ton ; it also showed a definite gold bead.[2] Despite the actual presence of minor amounts of silver, it is believed that the silver values from this locality have been over-estimated since their initial discovery. Indeed, if old reports of the amount of silver were accurate, the mine could have been more profitably worked as a silver mine than as a copper mine.

The copper ore at the Schuyler mine is associated with two sandstone layers or benches that overlie the Arlington diabase sheet. (See figure 4.) The sandstones are irregularly stained with supergene copper minerals and lie close together, being separated by only a foot or so of red shale. The upper bed has an average thickness of about 12 feet; the lower is about 10 feet thick. The two have a reported total thickness of 38 feet at Shaft 2, and 63 feet at the old

[1]Darton, N. H., An occurrence of native silver in New Jersey; Am. Jour. Sci., 4th ser., vol. 30, pp. 80-81, 1885.
[2]Lewis, J. V., The Newark (Triassic) copper ores of New Jersey: Ann. Rept. State Geologist of New Jersey for 1906, p. 143, 1907

Victoria shaft. The long activity at the latter was a testimony to the thickness of sandstone and volume of ore there encountered. Most of the workings follow the top of the diabase upon which pillars of sandstone have been left as supporting columns for rooms and chambers from which ore and bedrock have been removed. Mining operations have been simple, for the ore is easily reached and crushed, and no great depths are involved.

Except for a few rich pockets of chalcocite, most of the copper values lie in small grains of chalcocite thinly disseminated through the sandstone, together with the carbonate and silicate incrustations that are more conspicuous to view than profitable to mine. The ore does not occur in veins or seams, and in order to reach it one must mine much barren sandstone and then mechanically separate the copper minerals from the body of this rock. Practically all of the material seen by the writer is low-grade ore, and most is not ore at all, but copper-stained stone.

The widely scattered pockets of ore occur in small fissures and crevices at or near the top contact of the Arlington diabase sill, or along small upward off-shoots therefrom. Some of these pockets supplied small bonanzas of copper ore, one being reported as having yielded ore worth more than $10,000 in one day. Unfortunately they are too sparsely distributed to make the locality profitable to mine except under the most advantageous circumstances.

Systematic sampling in 1900 is reported to have shown slightly more than 2 per cent copper in the upper sandstone and a little less than 2 per cent copper in the lower sandstone. The general average for workable ore is stated to be 2.5 per cent ; while a higher percentage, perhaps up to 6 per cent, is reported as a possibility if the ore is systematically sorted during mining. Granberry[1] calculated that not less than 5,000,000 tons of ore-bearing rock was accessible in 1906. Even if these estimates are accepted as reliable, the Arlington copper does not occur in such form that a fair comparison can be made between its low values and the working percentage of copper ores handled at profitable low-grade deposits of the far West.

*Ore Genesis*

The close association of Schuyler ore with the Arlington diabase sill strongly indicates a genetic relation, and the position of the ore *above* the sill is explainable by the assumption that primary mineral-

[1]Granberry, J. H., History of the Schuyler mine; Eng. and Min. Jour., vol. 82, pp. 1116-1119, 1906.

ization was the result of heated magmatic solutions that accompanied invasion of the igneous rock into the Newark series. Probably both the Arlington diabase and the Schuyler copper minerals had their origin in the Palisade intrusive sill which must underlie this locality at some depth, and which could serve as a source both for the local magma and for copper-bearing solutions. It is believed that these solutions utilized fissures and fractures as lanes of upward movement and deposited copper minerals in sulphide form, probably as chalcopyrite, bornite and, possibly, chalcocite. These were hypogene minerals, and their formation was a result of magmatic processes which occurred at moderate to high temperatures.

Much later, circulating surface waters ultimately reached these primary deposits, and transformed some of the copper from the sulphide to carbonate, silicate or other sulphide form, but no evidence has yet been noted that the deposit was actually enriched during this supergene alteration. Production of such secondary minerals probably so transformed the original hypogene deposits that most of the ore now found at the mine has been secondarily produced.

The absence of native copper at this mine is in strong contrast to its prevalence beneath the basalt flow at Somerville. It is believed that this difference is mainly a function of the abundant ferric iron of the red Triassic shales at Somerville, and its general absence from the gray-green sandstones at Arlington. Ferric iron would reduce the copper-bearing magmatic solutions permitting precipitation of the native metal, a process which took place freely at Somerville. Scarcity of ferric iron, such as marks the sandstone bedrock at Arlington, would result in the deposition of sulphides rather than free metal.

*Possible Future Development*

Because of the collapse of many shafts and tunnels at this mine, it is now practicable to enter only the eastern, shallower chambers, and it is therefore extremely difficult to augment the meager information available about the real value of the ore, or to ascertain its exact volume by direct inspection and sampling.

It has already been stated that the mine is believed to have been greatly overpraised from the very beginning. It is true that it brought a profitable return to Colonel John Schuyler, and that it was successfully operated by Josiah Hornblower ; but practically all other operators failed because of the low grade of available ore. Numerous small pockets of fairly rich chalcocite have been found in the past, and these have encouraged many operators to continue the unprofitable mining of the main ore body. The latter, however, is only a sandstone thinly impregnated with copper that apparently runs too low for economic extraction. The usable ore pockets are too meager and too widely dispersed to warrant the efforts necessary to reach and extract them.

Systematic core-drilling could be used to prospect the undeveloped portion of the mine, and information might thus be obtained to show the nature and quality of the available ore. Probably all of the tunnels and chambers would require a great deal of cleaning ; and the fact that the workings extend under what is now a residential district would call for careful timbering and shoring that were unnecessary when the openings were first undertaken. Indeed, the whole life and economics of the region have moved far from those conditions under which the property temporarily became a profitable mining district nearly two centuries ago.

Each company that has operated this mine has left it in worse shape than before, and although probably as much as 100,000 tons of rock and ore have been extracted, a large amount of money would still need to be spent before any ore could again be mined, or before any adequate assay of general ore values could be made. On the other hand, improvements in pumps, drilling machinery, hoisting and transportation equipment have materially reduced the costs of mining operations, while modern crushing and floatation equipment have similarly lowered milling costs. If as much as 5,000,000 tons of 2 per cent ore (as reported by Granberry) could be blocked out within a depth of 500 to 600 feet, it seems wholly possible that such ore could be profitably handled at the present price of copper (17 cents per pound), without making allowance for any recovery of silver. Transportation costs to smelter and markets would be almost negligible as compared with similar costs for western mines.

If any copper locality in New Jersey holds promise of profitable exploitation, the Schuyler mine seems to exhibit the most favorable conditions, yet it cannot be regarded as a prospect devoid of considerable hazard. One may well hope that a final inventory of the property can be made before it is completely written off the books as an outworn mineral locality of no further commercial value.

In any event, here is a body of cupriferous rock, once extensively mined, within eight miles of New York City, and three miles of Newark. Ample transportation facilities are at hand, and copper is likely to be in demand for a long time.

*Bibliography*

Because of the special interest in the Schuyler mine and its historical background, the specific articles that describe this property, in addition to those cited in the foregoing text, are listed below with brief comments.

1883 Nelson, William, Josiah Hornblower and the first steam-engine in North America; New Jersey Hist. Soc. Proc., 2nd ser., vol. 7, pp. 175-247. (This article is the first to assemble the early history of this mine. It has served as the chief source for all subsequent historical sketches of the property.)

1900 Anonymous, The Schuyler copper mine in New Jersey; Eng. and Min. Jour., vol. 69, pp. 134-136. (Includes three photographs and a map.)

1901-2 Various articles; Eng. and Min. Jour., March 23, 1901, p. 371; May 25, 1901, p. 49; Jan. 18, 1902, p. 119; May 3, 1902, p. 638; Sept. 26, 1903, p. 483.

1906 Keith, N. S., The copper deposits of New Jersey; Mining Mag., vol. 13, pp. 468-475. (Includes 4 photographs.)

1906 Granberry, J. H., History of the Schuyler mine, New Jersey; Eng. and Min. Jour., vol. 82, pp. 1116-1119. (Includes 3 photographs.)

1907 Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist for 1906, pp. 140-142. (Discusses the geology of the mine with maps and a section.)

1907 Granberry, J. H., The Schuyler mine, Kingsland, New Jersey; Franklin Inst. Jour., vol. 164, pp. 13-28, 217-223. (Largely a reprinting of Granberry's 1906 article; includes 5 photographs and 2 maps.)

1911 Weed, W. H., Copper deposits of the Appalachian States; U. S. Geol. Survey Bull. 455. (This is a reprinting, with little or no change, of an earlier article : Copper deposits of New Jersey; Ann. Rept. State Geologist of New Jersey for 1902, pp. 125-139, 1903.)

1922 Black, G. F., The Belleville copper mine; Am. Mineralogist, vol. 7, pp. 154-158.

1937 Lee. O. I., Ye ancient copper mine of Arent Schuyler; Rocks and Minerals, vol. 12, pp. 99-109, 1937. (Includes an account of a recent (1932) visit to the mine, with a map and several photographs.)

## EAST ORANGE-GLEN RIDGE MINES

*General Statement*

Three small copper mines were once operated in parts of colonial West Newark, now East Orange, Orange and Glen Ridge. These mines seem not to have been active since the 18th century, and are now scarcely more than historical relics. Their total production of ore was only a few hundred tons. (See figure 2.)

Two of the mines are located about 3 miles upstream from the Passaic along Second River and its tributary, Wigwam Brook. They are approximately 5 miles due west of the Schuyler mine and are situated in a broad outcrop of Brunswick shale and sandstone in which, so far as known, there is no nearby intrusive or extrusive igneous rock. The third mine is located along Bloomfield Avenue and Toneys Brook, near the north end of Hillside Avenue, Glen Ridge. This locality enjoyed a small flurry of excitement in the late

1880's, when copper was rediscovered in a sandstone quarry that encountered an old shaft of this colonial mine.

All of these prospects lie east of First Watchung Mountain and the basal contact of the flow sheet constituting that ridge, if projected eastward to the mine localities, would pass several hundred feet above the workings. It is possible, of course, that a change in the dip of this contact may have brought the now-eroded extension of the flow nearer the mine levels, but under any circumstance, the mineral deposits were probably formed some distance below the base of the sheet. The buried western extension of the intrusive Palisade diabase must lie below the area of these prospects, but it seems likely that it is at considerable depth, probably several thousand feet below the present surface. The copper minerals of these mines, therefore, may be more distant from igneous materials than those of most other New Jersey copper mines.

It may be noted that Second River served as an important colonial inland water route to the iron mines of Morris and Bergen counties (Ringwood mine), when considerable traffic then followed what is now a shrunken and abandoned waterway.

*Dod Mine*[1]

Copper was discovered in 1720 on property of John Dod, which was then located in West Newark, but is now included in the northern part of East Orange. It is alleged that discoloration of the waters of Second River led prospectors to this locality, but it is more likely that the discovery was an outcome of the epoch of intensive surface prospecting that quickly followed news of Arent Schuyler's successes at North Arlington. The first excavations were located on the northern bank of Second River approximately at the point where Brighton Avenue crosses the stream, a short distance from the present Brighton Avenue Station of the Erie Railroad. The old mine opening was apparently near the present Franklin firehouse.

At the time of discovery, John Dod owned 500 acres of land that extended from a line drawn a little west of the former site of Bethel Presbyterian Church northward and eastward toward Bloomfield; it included the site of the sawmill which formerly (1892) was located between Dodd Street and the Bloomfield Township line.

On February 24, 1720, Dod made an agreement with Gideon Van Winkle and Johannes Cowman, both of Newark, "to search and dig

[1] See particularly : Wickes, Stephen, History of the Oranges ; pp. 54-62, Newark, 1892: and Pierson, D. 1,., History of the Oranges to 1921; vol. 1,. pp. 35-40, New York, 1922.

for any mines, minerals, copper, or other metals whatsoever." Expenses and profits were to be shared equally, and the main region to be prospected was the tract of Dod's land known as "Rattlesnake Plain", which then lay between Dodd Street and the river. The original manuscript of this agreement was in the hands of Calvin Dodd, a great- grandson of John Dod, in 1892. After the copper had been discovered, and the first excavations had been made, Dod formed a partnership with, and assigned half of his interests to, Cornelius Clopper on November 13, 1720. This lease is now in the library of the New Jersey Historical Society.

At a Newark town meeting on March 4, 1721 Captain Samuel Harrison and Lt. Samuel Dod were appointed a committee to let out all public lands for prospecting. Although this hopeful action was a direct outcome of the discovery of Dod's mine—which was then at work—no new mines were located.

Early operations at the Dod mine were fairly successful, and some ore may have been sent to England for assaying or smelting. When the workings progressed underground, timber was obtained from nearby forests by "specially selected" men and horses, who took out the ore on their return trips. A small crushing mill was erected on Second River near the mine, and the whole venture began to yield a profitable, although modest, return.

On October 8, 1735 Dod made another agreement, this time with William Roe. Again, all expenses and profits were to be shared equally and Dod was to have interest in any "future engine and stamping mill". Roe was to pay Dod for one-eighth of the ore then ready for shipment. The partnership lasted until 1739, when Roe's rights reverted to Dod. During this period the tunnel was carried about 800 feet in a northeasterly direction, and the mine was producing "satisfactory" quantities of ore.

An Englishman, Frind Lucas, representing a party of British capitalists, made an agreement with Dod on October 18, 1739, to take over Roe's expired lease. Lucas undertook to use all necessary timber from Dod's property, and was granted permission "to carry up a drift and dead-water level for the venting and carrying off of the waters from the mine or course of ore in the lands aforesaid".

Lucas operated the mine as late as 1755, and probably until 1760. The ore was taken by drag and horse or oxen to Newark docks, whence it was shipped to England. Water flooding, however, stopped mining operations sometime before the Revolution, and the mine has not been worked since, although the Dodd family reserved mineral rights on their property as late as 1796.

By 1853 many of the old mine timbers were badly decayed and had insufficient strength to support the mine roof. A number of the old passages and tunnels collapsed during that year after an unusually heavy rain, whereupon Calvin Dodd explored part of the passages and reported that one chamber, although then full of rocks and submerged in water, was half an acre in extent. He also reported that the original entrance was large enough to admit a horse and wagon, and stated he followed some tunnels more than 700 feet toward the northeast.

Stephen Wickes visited the mine in 1872 before the entrance was closed, and verified the large size of some chambers. Fifty years later, the entrance was largely blocked with fallen debris and practically all trace of colonial mining had become obliterated. The last visible surface trace of mining activity was removed a few years ago when the course of Second River was cleaned and straightened by the Work Projects Administration. An old emergency entrance to the mine had been previously sealed in constructing foundations for the present Bethel Presbyterian Church.

There is little available information about the geologic relations of the Dod copper deposit. Apparently the chief ore mineral was chalcocite thinly scattered in veins and fractures in Newark sandstone and extensively altered to chrysocolla which stained considerable bodies of the containing rocks.

The Dod mine extended northeastward beneath a low hill whose surface extension may be traced to Bloomfield Avenue, where it crosses that turnpike between Hillside and Ridgewood Avenues, Glen Ridge. Another colonial mine was opened at this point on what may well be the northeastern continuation of the belt worked by the Dods. The Bloomfield Avenue workings are called the Glen Ridge mine, a description of which follows.

*Glen Ridge Mine*[1]

There was much early prospecting for copper on lands now included in Bloomfield, Glen Ridge and Montclair, during the period immediately following the opening of the Schuyler mine ; but most of the activity terminated with the prospecting, for little mining was attempted save at one relatively small mine.

A letter written by Alexander Williams,[2] schoolmaster at Glen

[1] See Wickes, Stephen, op. cit., pp. 57-58; also Urquhart, F. J., op. cit., p. 174.
[2] Folsom, J. F., Bloomfield, old and new; pp. 26-7, map opp. p. 185, Bloomfield, N. J., 1912.

Ridge, to Charles Orr, dated August 7, 1801, contained the following statement :

> "There is a copper mine about 300 yards from my school, which was lately wrought, and many tons of ore were obtained from it. It is now neglected"

Apparently this mine was located near the corner of modern Bloomfield and Hillside avenues, and the original shows of ore may have been found along the banks of nearby Toneys Brook. Tunnels apparently ran northeastward toward the cemetery, and possibly extended southwestward beyond the creek. It may be noted that a drift driven southwestward from this locality would extend directly toward the Dod mine, located less than a mile away.

The Glen Ridge mine was apparently operated for a short time by the New Jersey Copper Mining Association, of which Mark, Schuyler and Roosevelt were chief investors (see also pages 52-53), and it may have been their operations that were "lately" observed from the windows of Williams' school. Nevertheless, the mine was old when the New Jersey Copper Mining Association was established in 1793.

Thomas Cadmus, who was born near the mine in 1736, said that it had been worked before his recollection, probably as early as 1746, and it seems likely that the original operations go back to the generation of Schuyler's discovery. Apparently Cadmus was part owner of the mine in the period immediately preceding the Revolution, for it is reported that a Cornwall miner (possibly Josiah Hornblower) who had worked Schuyler's mine, made an effort to lease the Glen Ridge mine from Cadmus's widow about 1760-1766. She refused to sell the mine, and there is no information that it was worked from 1760 until after the Revolution. Travellers following what is now Bloomfield Avenue, commonly reported numerous "stone-heaps" along the turnpike during Revolutionary days, and for a generation afterwards. These heaps were old mine dumps, the last of which were removed for foundation stone before the Civil War.

Many evidences of this old mine have been encountered. Its main entrance seems to have been a tunnel on the east bank of Toneys Brook, from which point a double drift was driven northeastward for possibly 700 feet. The main tunnel was the only passage in which a man could stand upright, and its roof seems to have been about 40 feet below the surface of the ground. A second tunnel may have been driven at right angles to the main drift. Considerable timber was used for the supports of the roof, and as the tunnel was unusually crooked, it has puzzled explorers to explain how the timber was brought through the tortuous passages which wander, apparently aimlessly, in various directions. After heavy rains a shaft behind 171 Hillside Avenue collapsed on July 8, 1922, leaving a large hole.[1]

Some 60 years ago, in blasting sandstone at Bloomfield and Hillside avenues, quarrymen came upon a drift of this mine near the site of the present High School playgrounds and some copper ore was unearthed during the quarrying. At first, the small amounts of copper ore, revealed were not taken seriously, as the existence of the old mine was known and the ore was thought to have been exhausted. Shortly, however, the quarry penetrated a branch opening of the old mine, and a sizable "ledge" of ore was discovered, sloping westward and being about 20 feet wide and 12 inches thick at the east, and 4.5 feet thick at the west. The ore was hastily sampled and an assay was reported to contain 79 per cent copper and some silver. This discovery caused much local excitement, and several hundred tons of ore were taken out by the Glen Ridge Quarry and Mining Company, then operating the quarry. The ore was shipped by the Morris Canal to the Orford Copper Company at Constables Hook. The flurry of excitement quickly subsided, however, and no further serious copper mining was attempted.[2]

Many relics of the old miners were found including picks, wedges, shovels and a powder horn. Most interesting was an old pump, reportedly (1892) still in place. Many of these tools were found by Herman Cadmus who donated them to the New Jersey Historical Society. A hammer and pick together with a drill 15 feet long were found along Bloomfield Avenue, a short distance south of Ridgewood Avenue ; the drill was still imbedded in the rock when found.

The copper minerals found at this locality are chalcocite and chrysocolla, penetrating and largely replacing bituminous plant remains in black glossy masses resembling anthracite coal.[3] Gray sandstone is also stained by chrysocolla as at Arlington. No igneous rock is present, and there are no indications of faults. Copper minerals in exactly the same association are found in certain strata of the old sandstone quarries at Avondale, north of Newark and Belle-

[1] Folsom, J. F., and others, The municipalities of Essex County, New Jersey; vol. 2, p. 704, New York, 1925.

[2] For a contemporary account of this epoch, see article in the Newark Daily Advertiser of June 6, 1892.

[3] Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, pp. 154-5, 1907.

ville, and also in a quarry located about a mile and one-half northeast of the Schuyler mine on the old Kingsland estate. The geologic conditions at the Glen Ridge mine seem to duplicate those of the Dod mine in East Orange

*Wigwam Brook Mine*[1]

There is evidence of another mine that was dug during the same period along Wigwam Brook at the foot of Mount Vernon Avenue, Orange, 0.7 miles west of the Dod mine.

This mine included a deep shaft that was discovered in the middle 1800's by Judge Jesse Williams, who recognized it as an old mine opening. Some of the timbering which was removed about 1870 when the street was graded, was even then reported to be in sound condition. The bottom of the mine was not explored and the opening was sealed off.

Two other prospects on the "Ropes property", were also uncovered during the grading of that area about 1870. These were deep excavations, made in early times and now filled with successive layers of leaves and earth.

There is no evidence in the vicinity, nor in any available records, that any of these workings ever returned a reward, although there seems to have been considerable prospecting along Second River and Wigwam Brook.

### *American Mine*

(Formerly known as the Bridgewater mine)

*Location*

The American copper mine, once called the Bridgewater mine, is located on the southwest flank of First Watchung Mountain, about three miles due north of Somerville, Bridgewater Township, Somerset County. (See figure 6.) The mine property lies upon the ridge flank, and the mine entrance, now in ruins, has an elevation of about 370 feet above sealevel, or 200 feet above the rolling plain from which the Watchung Mountains rise. The dumps and abandoned mine entrance may now be reached from New Jersey Highway 31 along an abandoned road that leads east to the mine, or by a foot-path that leads north along the ridge from the road crossing the mountain about one mile south of the mine.

[1]See Wickes, Stephen, op. cit., p. 56; Pierson, D. L., op. cit., p. 36 ; and Urquhart, F. J., History of the City of Newark; vol. 1, p. 74, Newark, N. J., 1913.

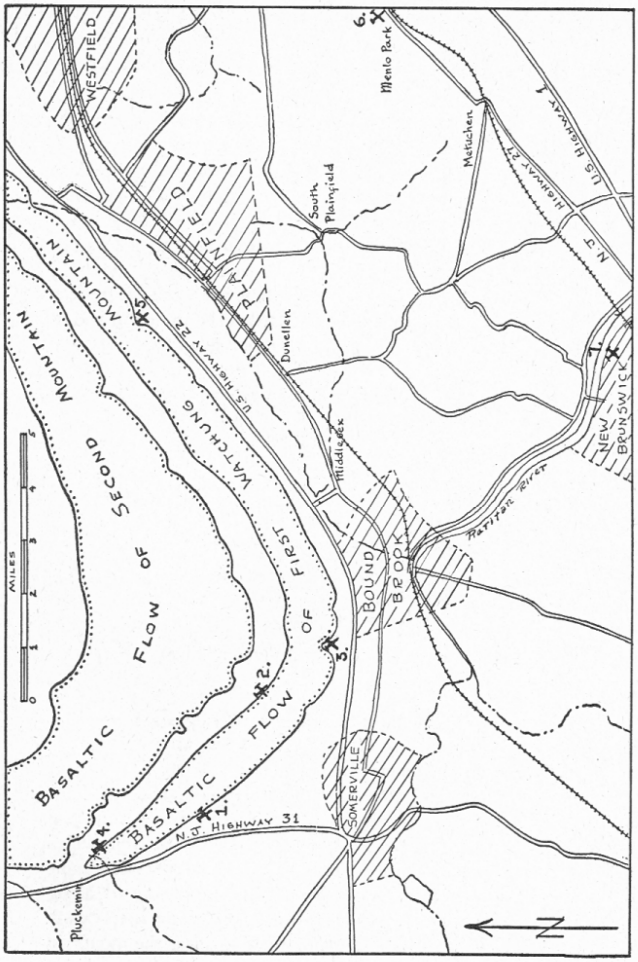


FIG. 6. Generalized sketch map of the Somerville-New Brunswick area, New Jersey, showing the location of several old copper mines and the surface outcrops of the basaltic flows of the Watchung Mountains. Numbered copper prospects or mines are as follows: 1. American or Bridgewater mine; 2. Bolmer prospect; 3. Chimney Rock mines; 4. Hoffman prospect; 5. Green Valley prospects; 6. Menlo Park mine; 7. New Brunswick (French) mine.

This is the deepest copper mine in the State, and the only one wherein there are openings that extend below the zone of surface oxidation. It has been the scene of another persistent attempt to mine copper in New Jersey.

The following references serve as valuable sources of both historical and geologic information about this mine :

1902 Kümmel, H. B., Mining industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1901, pp. 151-2.

1903 Weed, W. H., Copper deposits of New Jersey; Ann. Rept. State Geologist of New Jersey for 1902, pp. 131-9.

1907 Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, pp. 146-9.

1909 Kümmel, H. B., Mineral industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1908, pp. 131-132.

1911 Weed, W. H., Cooper deposits of the Appalachian States : U. S. Geol Survey Bull. 455, pp. 45-54.

*Historical Development*

Discovery of copper on Arent Schuyler's estate at North Arlington quickly stimulated search for this metal in other parts of the Triassic lowland, and there was much prospecting along the basalt ridges of First and Second Watchung Mountains which form a long crescent in northcentral New Jersey. The ridge-slopes in the vicinity of Bound Brook and Somerville were carefully combed early in the 18th century, and the many fragments of native copper that were picked up encouraged the search for more extensive orebeds. As much as 1,900 pounds of the native metal in various masses is said to have been discovered before 1754,[1] and one mass of 128 pounds when placed on exhibit attracted great interest. This nugget was owned by James Van Dyke of New Brunswick in 1837, and a portion of it was placed in a local geologic museum.[2]

As the locality of the American (Bridgewater) mine was regarded as an extremely promising prospect long before the Revolution, numerous small exploratory drifts were driven into the hillside. Some of these extended one hundred feet or more into First Mountain, but as no valuable copper minerals were encountered in quantity sufficient to treat by the crude methods then available, it seems likely that whatever money was spent in this early mining brought no substantial return.

It is widely reported that during Washington's New Jersey campaign, when the Continental army was encamped in the vicinity, a

[1] Morse, Jedidiah, Universal geography; vol. 1, p. 402, Boston, Mass., 1812.

[2] Beck, L. C., Notices of native copper ...: Am. Jour. Sci., 1st Ser., vol. 36, pp. 107-114, 1839.

strenuous effort was made to obtain copper, and that sufficient ore was mined to make a brass cannon. The latter, it is also said, was used to advantage in the seige of Yorktown. Except for these small operations, however, the locality was not actively prospected during the Revolution for which period the one legendary cannon seems to represent the total copper production. Nearly 50 years elapsed before any further mining was attempted, and the workings were described as "abandoned" in a report written in 1812.

In 1821 Augustus Camman, a native of Germany who had come to this country three years before, became interested in the mineral possibilities of the Watchung Mountains, and purchased three tracts of land along First Mountain. He then organized the Bridgewater Copper Company.[1] In 1824 he erected a small smelter at Chimney Rock, and put it in charge of two expert smeltermen whom he had induced to follow him from Germany. Apparently he also erected a second smelter at the foot of the mountain below the main workings, which were then called the Bridgewater mine. Despite Camman's diligent efforts the operations were not successful and the mine was closed in 1830 after considerable money had been expended with scant return. By 1840 the tunnels had largely caved and the mine was filled with rubbish and loose rock.

Camman's son Albert, with Peter I. Stryker, hoping to recover some of his father's fortune, organized the Washington Mining Company in 1835, and purchased 150 acres of land along First Mountain adjoining the Bridgewater Mine. An abandoned colonial opening was cleaned out and new operations were begun at what was called the Washington mine. A small volume of ore was mined, hand trimmed and shipped in barrels to Boston for smelting. The company later sold out to Boston interests, who operated the mine a short time until water-flooding became too serious to be overcome by their crude pumps. The operation closed, and like the Bridgewater property, the mines were abandoned to the ravages of time.

In both instances, as in the earlier colonial period, the mines absorbed much more capital than the output provided return. Both the Washington and Bridgewater mines were closed in 1844 and the smelters were abandoned. It is said that the latter were destroyed during the Civil War, but it is evident that they had been inactive for some time before the war. Interest in copper prospecting was

[1] Snell, J. P., History of Hunterdon and Somerset Counties, New Jersey; p. 680, Philadelphia, 1881.

directed elsewhere in the Watchung Mountains during the 1860's, and the Bridgewater mine and property were largely forgotten.

About 1880 the American Copper Company was organized and acquired several small mineral holdings along the slope of First Mountain, including woodlots of farms that faced the ridge between Bound Brook and Somerville. The new company also took over the old Bridgewater property, and its mine was reopened by A. H. Hovey in 1881.[1] Several tunnels were sunk and drifts were cleaned out, but as no new ore was found to warrant further operations, activity ceased in 1883 without important result or change except in name from Bridgewater to American mine.

In 1889 exploration was again begun and was carried on in a desultory fashion for a few years. Work on the Bridgewater property, now called the American mine, was again resumed in 1898, and active mining was in process in November 1899. These developments were carried on with renewed energy and a number of new tunnels were driven and a small concentrating plant was started.[2]

The American Copper Company, under the direction of J. C. Reiff, president, and Josiah Bond, general manager, erected an experimental smelter in 1901. This was a 20-ton brick and steel-jacketed plant designed for testing, and the surface equipment was subsequently enlarged to include a 50-ton mill, with crusher, screens, sizer, and two Wilfley tables; a 5-drill Rand compressor with power boiler; a hoist and pump ; drills and other apparatus. Several thousand tons of crude ore are reported to have been mined, several hundred tons of ore were run experimentally through the crusher, and a trial lot is alleged to have been smelted with "good results". Specimens of ore from this mine were exhibited by the Geological Survey of New Jersey at the Pan-American Exposition at Buffalo, New York, and much hope was held out for the success of the new endeavor.

Operations moved slowly, however, in 1903 and 1904. The shafts were deepened, and more ore was put through the crusher, but all operations were idle in 1905, although the mine was being kept dry in anticipation of further work. Shortly thereafter the company went out of business.

[1]Cook, G. H., Notes on copper mines; Ann. Rept. State Geologist of New Jersey for 1883, pp. 164-6, 1883.

[2]Kümmel, H. B., Mining industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1900, p. 208, 1901.

When the mine again became active in 1907-08,[1] it was in the hands of the Alpha Copper Company (formerly the Jersey Hecla Mining Company), and Alfred Swartz was its new mine manager. The experimental mill was enlarged, electricity was installed, and all of the machinery was overhauled and put into good condition.[2] It was experimentally demonstrated that 10 to 12 tons of crushed ore could be reduced to one ton of concentrated ores and that concentrates could be made with as much as 60 per cent copper. A little ore was carried through to a 35-ton reverberatory smelter which had been newly erected, and a few copper ingots were produced. Activity continued until late in December 1909, when the mine was shut down.[3] For a time the workings were kept dry, and a small force of men was employed in repairing the property, as it was hoped that operations would be renewed in the spring of 1910. The expected reopening, however, never came. The smelter, mill, and other mine buildings were soon dismantled and the machinery hauled away ; the tunnels and incline filled with water ; and the property fell into complete disrepair—a condition in which it now remains. The old mine dumps are partly brush-covered, the mine entrance is wholly closed, and only waste rock and tumbled ruins remain to document the long unproductive history of this copper locality.

*Extent of Workings*

As in the case of all New Jersey copper prospects, the first Somerville operations were wholly conducted from shallow trenches and surface excavations, no deeper pits being sunk until the surficial deposits had become exhausted. Probably none of the workings extended far underground at this locality until the period of the Revolution, when some tunnels are believed to have penetrated a hundred or more feet down the dip. These were reopened and extended in the early 1800's, and some may then have been several hundred feet long. As at Arlington, the early operators were unprepared for the volume of water encountered, and when their hand pumps were unable to cope with the flow, all deeper workings had to be abandoned.

Several new tunnels were sunk in the early 1880's, one of which, forming the chief Bridgewater shaft, was about 600 feet long, measured down the dip. Between 1900 and 1904, the mine was completely

[1]Kümmel, H. B., Mineral industry of New Jersey ; Ann. Rept. State Geologist of New Jersey for 1908, pp. 129-134, 1909.

[2]Kümmel, H. B., Copper mining in New Jersey ; Eng. and Min. Jour. vol. 87, p. 808. 1909.

[3]Kümmel. H. B., Notes on the mineral industry for 1909; Ann. Rept. State Geologist of New Jersey for 1909, pp. 106-7, 1910.

overhauled. The old Bridgewater shaft was cleaned out to the first bend, whence it was extended down dip for another 650 feet, making a total length of nearly 1,300 feet. The lower end of the incline must then have been close to 600 feet below the ground surface. The remainder of the Bridgewater shaft, together with most other old passages, was now abandoned. Next, numerous side drifts were cut at levels 30 feet apart on opposite sides of the main slope. Thus the distance between two levels on either side of the slope was 60 feet. Some of these side drifts were expanded into rooms and chambers, following the usual pattern of coal mining. The thick basalt flow formed an excellent hanging wall which, because of its great strength, required little or no timbering save in the highest levels. As the ore-bed was undercut beneath the basalt flow, mining operations were relatively simple. (See figure 7.)

A total of more than 2,040 feet of side drifts were excavated, and a tunnel to catch surface drainage was also constructed. This tunnel led water directly from upper workings, while drainage from lower levels was pumped up into it. The Spencer slope, located about 500 feet from the main slope, was also lengthened to improve ventilation of the latter. All in all, the underground workings were more extensive than those of any other copper mine in the State save those at Arlington.

*General Geology*

The American mine is situated on the south slope of Watchung Mountain about 3 miles north of Somerville. Openings for copper, of which this mine was originally one of many, occur well up the slope of the ridge at an elevation of about 370 feet above sealevel. First Watchung Mountain is produced by the gently tilted edge of a thick extrusive sheet of basalt whose outcrop traces a broad evenly curving crescent on a geologic map of the area. (See figure 1.) At the locality under discussion, the basalt dips gently toward the northeast, and the mine is situated below the southwest rim of the crescent which extends from Bound Brook northeastward for nearly 50 miles. The basalt sheet is intercalated between red sandstones and shales of the Newark series, and it is patent from many lines of evidence that it is the oldest of several lava flows that were broadly contemporaneous with the containing sedimentary series.

This basalt is a dense, very fine-grained bluish-black flow-rock that exhibits columnar jointing at many places, although not in the vicinity of the mine. It contains innumerable “blind” joints, whose

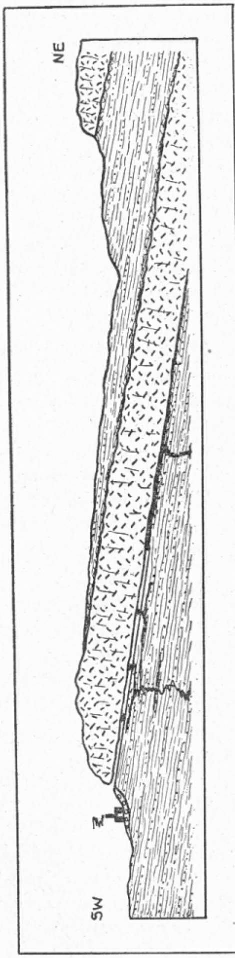


FIG. 7. Generalized cross-section at the American copper mine near Somerville, New Jersey. The main workings followed the under surface of the basaltic flow of First Watchung Mountain.

presence is betrayed by light red bands, possibly colored in part by cuprite, but mostly stained with ferric iron. These joints served as channels for circulating water that leached the adjacent basalt and deposited a concentrate of leached material along the joints. Discoloration stains show clearly the extent of this leaching and rim the numerous joints with prominent color bands. Some joints were only potential channels, apparently being too tight even for capillary fluid movement. The top surface of the sheet, where not deeply eroded, shows vesicular and amygdaloidal textures typical of surface flows. Most of the copper, however, occurs below the base of the flow where it occupies a bed of highly altered shale hardened along the igneous contact.

The lower surface of the basaltic sheet is also vesicular and amygdaloidal, its cavities being filled with quartz, manganocalcite, laumontite, other zeolites and, less commonly, nuggets or stringers of native copper. The presence of copper in the basal amygdaloids is partly a function of the porosity of rock immediately beneath the basalt, for where the lower rock is dense, one finds copper in the amygdules, whereas it is absent from the basalt where the underlying rock is more porous.

The trap rock shows considerable evidence of alteration at and for several inches above its base, but is relatively unchanged six inches away from the contact where its normal dark-gray color is apparently unaffected by endomorphic changes. Three inches from the bottom, however, the rock is light in color, and its amygdules increase in number as the contact is approached. Those nearest the boundary are irregular in shape, and many are bordered or encrusted by shells of native copper. Farther away from the boundary, most amygdules have the size and shape of small bird-shot ; these are commonly filled with calcite or zeolites and contain little native copper.

The lower portion of the basalt has been partially chioritized, apparently as a result of ordinary hydrometamorphism ; and the various color changes along the contact attest hydrothermal zonation and progressive degrees of endomorphic alteration near the chilled contact of the flow. The presence of the chlorite gives the rock a slightly greenish color when dry and a prominently dark-green color when moist. Comparison of analyses of the basalt at the contact with unaltered basalt found elsewhere along the mountain shows that the former has lost some of its magnesium and is low in silica. Probably the trap carries small amounts of copper, perhaps as primary chalcopyrite. Careful tests quoted by Weed[1] suggest an average percentage of about 0.025 copper. Josiah Bond, mining engineer and general manager of the American Copper Company, reported in 1902 that he had tested 213 fragments of basalt taken from various locations within and near the mine. He found an average of 0.013 per cent copper in the specimens tested, and noted that 4 specimens of basalt taken from glacial boulders averaged 0.014 per cent copper.

At the American mine the basaltic flow rests upon a bed, one to three feet thick, of dense, firm, nearly uniform purplish shale, altered by contact metamorphism to a "hornfels" that superficially resembles a vitrophyric andesite. Its purple color distinguishes it from red unaltered Newark shales, and in thin sections the rock shows a glassy base with small fractured feldspar crystals and scattered shreds of muscovite. It contains innumerable tiny lenticular gashes or cavities, as well as numerous other small irregular openings. There is no doubt that this rock was produced from red Newark shale by contact with the heated lava of the Watchung flow. From its content of copper minerals, the altered shale is known as the orebed.

Conspicuously scattered through the orebed are prominent areas wherein the purple color has been bleached white or gray. These blotches are irregularly distributed through the rock and tests show that they now contain ferrous iron that has been reduced from the brighter-colored ferric iron of the main rock. Although they are prominently marked, the splotches lack sharp boundaries, commonly showing a distinct transition halo one-eighth to one-quarter inch across. Practically all native copper or copper minerals found in the orebed occur in these white spots or bleached areas. In deeper workings, the light-colored patches chiefly hold small pellets or strings of native copper ; at higher levels, some of the copper occurs as oxide dust lining minute open cavities.

An analysis of the orebed shows that it chemically resembles a normal shale, but has lost both alkalies and iron, has gained aluminum, and contains much more magnesium than unaltered shale.

Beneath the thin orebed occurs normal red Triassic shale which, where weathered, is soft and friable ; in the deeper mine workings it is found to be hard and compact, and is composed of different layers that thin abruptly and vary in grain size, being separated by micaceous streaks and partings. Immediately below the ore zone, the

[1] Weed, W. H., Copper deposits of the Appalachian States ; U. S. Geol. Bull. 455, p. 50, 1911.

shales are very fine-grained and dense. There are many calcite crystals, apparently low flat rhombohedra, many of which have been dissolved to produce numerous small pores, some irregularly round or branching, others similar in shape to many of the smaller particles of native copper found in the ore. Analyses of the shale show few alkalies, which is normal for a slightly calcareous clay-shale.

The Newark shales and sandstones stretch broadly beneath the low erosion surface (Somerville peneplain) that extends around Somerville, and their inferior resistance to weathering and erosion has permitted the basaltic flows to stand above them in the several Watchung ridges. (See figure 7.)

A small fault is reported to occur in trap rock at the American mine. Its trend is northeast, at right angles to the strike of the shales, and its throw is between four and six feet; there is no indication that it offsets the main basaltic sheet.[1] A "great fissure" was reported cutting the sheet near the lower portion of the main mine drift.

The following table shows analyses of the various bedrock types at the American mine.

[1]Kümmel, H. B., The Newark System of New Jersey; Ann. Rept. State Geologist of New Jersey for 1897, pp. 79, 124, 1898.

ANALYSES OF BEDROCK TYPES, AMERICAN MINE[1]

| | Basalt | | Altered shale | Triassic shales | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| $SiO_2$ | 51.09 | 44.34 | 57.24 | 57.45 | 71.40 |
| $Al_2O_3$ | 14.23 | 17.68 | 24.31 | 21.19 | 17.10 |
| $Fe_2O_3$ | 2.56 | 6.81 | 6.21 | 9.61 | 2.75 |
| FeO | 7.74 | 4.3 | .... | 1.54 | .... |
| MgO | 7.56 | 3.90 | 3.20 | 0.83 | 2.30 |
| CaO | 10.35 | 10.70 | 5.80 | 4.00 | .... |
| $Na_2O$ | 1.92 | 1.80 | .... | 0.26 | .... |
| $K_2O$ | 0.42 | 1.36 | .... | 0.63 | .... |
| $H_2O$ | 1.67 | 8.20 | 3.08 | 4.12 | .... |
| Cu | .... | 8.17 | tr. | tr. | 0.22 |
| Ag | .... | .... | .... | .... | .... |
| Total | 97.54 | .... | 99.84 | 99.53 | .... |

1. Basalt, Hartshorn quarry, Springfield, N. J.
2. Basalt above orebed, American mine.
3. Altered purplish shale or hornstone, American mine.
4. Shale below orebed, American mine.
5. Shale below mineralized zone, American mine.

### *Ore Minerals and Occurrence*

The ore minerals at the American mine consist essentially of native copper, largely altered above a depth of 100 feet (600 feet on the mine slope) to cuprite, chrysocolla[2] and malachite. There are some small grains and crystals of chalcocite and chalcopyrite, and very

[1] Analysis 1, Lewis, J. V., Petrography of the Newark igneous rocks of New Jersey; Ann. Rept. State Geologist of New Jersey for 1907, p. 159, 1908.
Analyses 2-4, Weed, W. H., Copper deposits of the Appalachian States; U. S. Geol. Survey Bull. 455, p. 48, 1911.
Analysis 5, Bond, Josiah, Copper leaching at the American Copper mine; Ann. Rept. State Geologist of New Jersey for 1901, p. 154, 1902.

[2] Bowen, G. T., Analysis of a siliceous hydrate of copper from New Jersey; Am. Jour. Sci., 1st ser., vol. 8, p. 118, 1824.

small amounts of hydrocuprite and bornite. Some of the copper is argentiferous, and there are a few tiny threads or wires of native silver.[1] Calcite, quartz, manganocalcite, prehnite and zeolites form common gangue minerals in addition to the three types of bedrock—basalt, altered shale and normal red shale.

Native copper encrusts and sheaths numerous amygdules at the bottom of the main flow, or surrounds tiny masses of calcite in white splotches in the purple orebed ; some is pseudormorphic after calcite. There is little or no native copper in unbleached portions of the ore-bed, a fact which attests a genetic relation between the metal and the bleaching. The sheet copper of deeper workings occurs in joints that are near the trap contact, where are also found layers of black calcite shot through with minute spicules of chalcocite. Some metallic copper occurs in fairly large bodies, one mass weighing 128 pounds being found during the discovery period. Most bodies, however, are small, and the total volume is insignificant in comparison with the bulk of the containing rock. There is little or no native copper in the basalt above the amygdaloidal layer, but the metal is found some distance below the orebed in broken but unaltered shale.

Chalcocite occurs mainly in fractures and is not present in large volume. Below the zone of oxidized ores it lies in and with calcite along joint fractures which may also contain sheets of native copper. It occurs in bleached zones in lower mine drifts, where it is found as solid nodules surrounded by sooty chalcocite of supergene origin. The latter also impregnates some adjacent porous rock. Weed[2] reports native copper around and upon this supergene chalcocite, occurring in finely divided state and apparently being reduced from the chalcocite. This native copper is surrounded by a bleached zone, about one-half the width of the copper particle, the halo possibly indicating an alteration due to reactions involved in the reduction to native copper. Chalcocite also occurs in drusy masses and along fractures and joints in crystalline calcite that encloses a mesh of very minute mossy hairs, the minerals being synchronously deposited.

At a depth of 800 feet below the surface, measured on the dip, the orebed carries native copper and minute specks of chalcocite in nodules of the bleached rock. Some masses of this material are several feet in diameter, and carry 20 to 25 per cent copper. At a little higher position, the copper is altered to orange-colored oxide

[1] Nelson, N. H., An occurrence of native silver in New Jersey; Am. Jou Sci., 4th ser., vol. 30, p. 80, 1885.
[2] Weed, W. H., op. cit., pp. 49-50.

in small tufts of hair-like crystals that occupy small cavities. Above these levels the oxide is mainly a coloration disseminated through the rock ; while closer to the surface, it occurs as small concretions that are larger at shallower levels and form nodules or "kidneys" of red cuprite. Still nearer the surface, these are crusted with malachite and/or chrysocolla, and there is a little bornite just below the soil. The nodules and "kidneys" may be traced for several miles along the mountain flanks, but extend below the ground only 100 to 150 feet. Crystals of prehnite and chalcopyrite also occur in minute cavities near the basalt margin.

An attempt was made by Weed[1] to determine if there was any increase in sulphide ore at depth, but no important change was detected.

There is considerable variation in percentage of copper within short distances in the orebed, but the averages do not vary greatly if wider areas are considered. The composite of 273 carefully measured sections across the orebed on the main slope and in its side drifts and chambers is said to show 2.101 per cent copper. The findings were as follows :

| Percentage of copper | Number of samples |
|---|---|
| Less than 1% | 52 |
| 1-2% | 94 |
| 2-3% | 64 |
| 3-4% | 43 |
| 6-7% | 5 |
| 7-8% | 7 |
| | 273 |

The mine tailings were analyzed for gold and silver, and though no gold was detected, 6.94 oz. of silver per ton were found in a sample collected for testing by Weed.[2]

Tests were also made upon ore that had been ground to various screen sizes, to determine the amount of copper present in each size.

The following table shows the reported results of these tests :

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[1] Weed, W. H., op. cit., pp. 52-53.
[2] Idem.

RESULTS OF COPPER SCREENING TESTS[1]

| | Percentage of size | Percentage of copper |
|---|---|---|
| Between 16-20 mesh | 36.00 | 49.9 |
| 20-40 | 17.50 | 21.6 |
| 40-60 | 16.25 | 7.6 |
| 60-80 | 18.50 | 5.5 |
| 80-100 | 3.00 | 3.3 |
| Less than 100 | 8.75 | 12.9 |

Various reported analyses of ore are as follows:

ANALYSES OF COPPER ORES[2] AND TAILINGS

AMERICAN MINE

| | Ore | | | | Tailings | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $SiO_2$ | 59.68 | 55.28 | 56.82 | 51.32 | 69.70 | 65.25 | 70.10 | 53.10 |
| $Al_2O_3$ | 26.35 | 15.84 | 14.95 | 16.79 | 16.90 | 14.35 | 13.21 | 16.20 |
| $Fe_2O_3$ | 6.29 | 5.71 | 4.53 | 6.87 | 3.25 | 5.20 | 4.06 | 5.70 |
| FeO | .... | .... | .... | .... | .... | .... | .... | .... |
| MgO | 1.71 | 2.75 | 2.90 | 2.91 | 3.10 | 1.50 | 4.50 | 15.30 |
| $K_2O$ | .... | .... | .... | .... | .... | .... | .... | .... |
| $CaCO_3$ | 4.18[a] | 9.73 | 9.40 | 2.75 | .... | .... | .... | .... |
| $Na_2O$ | .... | .... | .... | .... | .... | .... | .... | .... |
| Loss | 1.75 | .... | .... | .... | .... | .... | .... | .... |
| Cu | .... | 2.83 | 2.66 | 0.47 | 0.50 | 0.44 | 0.30 | 0.15 |
| Ag [b] | .... | 0.84[c] | 0.50 | 0.11 | .... | tr. | .... | .... |

[a] CaO. [b] Oz. per ton. [c] Plus 0.01 Au.

1. Ore, American mine.
2. Do.
3. Do.
4. Ore and shale, mixed.
5. Tailings, American mine.
6. Do.
7. Do.
8. Tailings from processed slime.

[1] Bond, Josiah, op. cit., pp. 154-5.

[2] Analysis 1, Weed, W. H., op. cit., p. 48.
Analyses 2-8, Bond, Josiah, op. cit., p. 154.

*Origin of the Ores*

Weed[1] postulated that these ores were produced by descending meteoric waters that leached copper from the overlying basalt and deposited it in beds directly beneath the flow. As elsewhere indicated, this theory is not currently accepted, and the writer with most other authors, follows Lewis[2] in believing that the ores are the product of ascending magmatic solutions that relinquished copper upon oxidation and cooling. The relatively impermeable trap rock served as an overhead blanket to hinder further ascent and the solutions deposited their mineral content at the base of this impervious barrier. (See figure 7.)

It is believed that the ores were produced during or following invasion of the Palisade-Rocky Hill intrusive sill which must lie beneath the surface rocks of this area. The intrusion of this diabase occurred some time after the outpouring of the Watchung basalts, and the ascent of mineral-laden solutions probably began during the igneous invasion. These solutions of copper and other salts ascended along fractures and fissures where some of their mineral content was left behind as precipitates. The latter are now sulphide accumulations in the more open channels through Newark rocks. When the solutions became trapped by the impermeable basalt flow, they spread laterally into the orebed or altered shale, where ferric iron caused their oxidation and the attendant precipitation of native copper. During this process, the reducing agent was itself destroyed, red ferric iron changing to ferrous iron in a reaction which effected the bleaching of areas around zones of copper precipitation. Possibly some sulphides were formed here, presumably chalcopyrite, bornite and, perhaps, chalcocite, although none of the latter has been established as of hypogene origin.

Later supergene alteration by circulating meteoric waters transformed some metal from native copper and primary sulphides to other sulphides, the carbonates and oxides. The variety of minerals was thus increased, although the volume of copper was not correspondingly augmented.

In terms of this hypothesis, the copper is younger than the zeolitic minerals formed at the base of the trap. It is possible that some native copper was formed during the period of zeolitization immediately

[1] Weed, W. H., Copper deposits of the Appalachian States ; U. S. Geol. Survey Bull. 455, pp. 50-54, 1911.

[2] Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, pp. 156-164, 1907.

following extrusion of the surface lava, but most of it was introduced into the orebed long after the contact-metamorphic minerals had been produced. This is attested by the position of copper minerals that surround the contact minerals; by the presence of native copper in cavities produced by solution of older exomorphic minerals ; and by the fact that some copper is pseudomorphic after such minerals.

It should be noted that there is no reason to expect greater concentration of copper minerals at depth than occurs immediately below the basalt contact. In fact, it is more likely that the richest ore accumulations were produced where the ascending solutions were dammed and spread laterally along the base of the flow.

This is the deepest copper mine in New Jersey, yet its workings penetrated no zone of secondary sulphide enrichment, although a level 600 feet below the ground was reached. As the mine is sufficiently deep to encounter such a zone were it present, one must conclude that such enriched levels do not exist in New Jersey copper deposits of this type.

*Present and Future Possibilities*

Although it is now impossible to enter the American mine, previous descriptions of the workings indicate that physical conditions of mining were good. The overlying basalt formed a solid and substantial hanging wall that required little or no timbering. The ore was easily mined and crushed, and its character did not materially change with depth. Transportation facilities were good, and accessibility to eastern markets was assured. None of these factors has changed since the days when the mine was active, and if the conditions were suitable for operation then, they would similarly be so now. The potentialities of the mine depend solely upon the amount of copper present in the orebed, and the economic factor of its profitable extraction. The data available as to the amount of copper present have been recounted above where it is reported that an average of more than 2 per cent copper was indicated by repeated samplings. If this copper is found in such form that it can be economically reclaimed from the ore, and if there is, a sizable body of such ore, then the way should be open for the profitable operation of the deposit.

These conditions, however, are still unproven. Modern unprejudiced sampling of the ore is still needed before a reliable statement of the quality of the ore can be established ; and more geologic information than is now available must be obtained before the volume of ore present can be reliably estimated. Finally, tests must be satisfactorily conducted on extraction of metal from the ore before the metallurgical side of operation can be profitably assured. Unfortunately, with his present information, the writer is not able to recommend the further expense needed to determine these unknown factors. It would be necessary to open the mine, to undertake considerable cleaning of the old workings, and to erect a hoist and pump before even the most recently worked drifts would be available for restudy. It would be necessary further to carry on detailed geologic investigation of ore possibilities, and to prepare a modern metallurgical analysis of the ore minerals, all of which would take time and cost money. The past history of mining at this locality does not justify these expenses, however much one might wish for an unprejudiced modern inventory of the locality.

## *Other Watchung Mountain Mines*

### *Location*

Of the many copper workings located along the Watchung ridges of Somerset County, the American or Bridgewater mine has been the most famous and best known. Others, however, are equally old, and some have been as hopefully prospected.

Most of the mines are located along the outer rim of the crescent-shaped First Watchung Mountain, their shafts and tunnels piercing the mountain-side near—commonly below—the basaltic flow which forms the ridge. A few prospects are located on the inner side of the ridge, above the flow, along the narrow subsequent valley which separates First and Second Mountains. (See figure 6.)

All workings were on a small scale save those on the previously described Bridgewater-American property. Most of them were first prospected in colonial times, then abandoned, and later reopened between 1825 and 1868. Weed[1] about 1901 counted 21 workings, mostly tunnels and open cuts, in a distance of 4 1/2 miles going west from Chimney Rock ; and he also noted the ruins of 3 smelting furnaces. Probably the relics of these old prospects conceal a poignant story of financial loss and discouragement, for there is no indication that any return for the time, labor and money invested in them was ever obtained by their owners, and the likelihood that any of them can ever be made profitable is equally remote. Nonetheless, if future exploration should establish the presence of workable ore

[1]Op. cit., pp. 38-39.

at any point along the basalt flows, there would be every reason to encourage the careful investigation of some of these older prospects.

The mines near Chimney Rock, others along Stony Brook, the Hoffman mine, and copper ore noted 2,000 feet north of Great Notch, near Paterson, are located at the under contact of the basalt of First Mountain. Prospects at Feltville (Glenside Park), near Martinsville, Warrenville and Pluckemin occur in beds above this basaltic sheet.

*Chimney Rock Mines*

After draining the valley between First and Second Mountains, West Branch and East Branch of Middle Brook unite to flow south through First Mountain in a deep narrow gorge about one mile northwest of Bound Brook, Somerset County. (See figure 6.) A large trap-rock quarry is now in operation at this locality, and in former times copper was actively mined on both sides of the gorge below the basalt contact. Camman's original smelter (see page 78) was erected at the mouth of this gorge, and the latter has been the site of some mineral industry for nearly 200 years.

The workings on the east side of the gorge, beneath Chimney Rock, include an old tunnel more than 300 feet long. This drift follows the contact of basalt (above) and altered shale, the latter being the orebed as at the American mine. This bed is 2 feet thick, is slightly indurated, and has a purplish color. The base of the igneous flow is partly amygdaloidal, and the main copper minerals are native copper and chalcocite, with some chrysocolla. There are two 100-foot side drifts at the end of the main tunnel ; these also follow the basalt contact. This property was on lands belonging to Thomas Smith during the Civil War, and was leased for $100 per year to a New York company which worked it for a few months in 1866. It is reported that 25 to 50 tons of ore were taken out and sent to Bergen Point and to Boston before the company abandoned work.[1]

On the west side of the gorge one tunnel is reported to have extended 700 feet into the mountain. A drift of this mine, revealed in the course of subsequent quarrying, showed conditions very similar to those at the American mine, although the rock is somewhat less bleached about the disseminated ores than at Somerville. The orebed is about two feet thick, and the exposed minerals are chiefly

[1] Cook, G. H., Geology of New Jersey; p. 677, Newark, N. J., 1868

copper carbonates.[1] There is some native copper which contains rare particles of native silver. Some of the drifts penetrated the basalt flow, and nodules and small sheets of copper have been found in the basalt forty to fifty feet above its base. There is evidence of columnar jointing in the trap-rock quarry, as well as minor flowplanes within the sheet.

*Stony Brook Mines*[2]

Stony Brook cuts through First Mountain in a deep narrow gorge 1 mile northwest of Plainfield and about 7 miles northeast of Chimney Rock, Somerset County. The topographic and geologic relations are practically identical with those in the Middle Brook gorge at Chimney Rock. (See figure 6.) Extensive early explorations were made on both sides of Stony Brook gorge in the early 1800's, and a mine was in operation in 1866 at which time ore was being sent to Bergen Point. Work was then going on under the auspices of two companies whose drifts and tunnels penetrated both sides of the gorge for several hundred feet. The longest tunnels on each side were reported to be 400 feet. Workings on the east side were those of the Green Valley Copper Company, and the New Jersey Copper Mining Company operated mines on the west side of the gap.

The ores are mainly copper carbonates and the "gray oxide", little or no cuprite being present. Several fine specimens of copper minerals have been discovered, and the average of sorted ore taken from the mines is reported to have run 3.9 per cent copper. The orebed, as mined, was 8 inches to 2.5 feet thick, and several small faults with throws of 3 or 4 feet were reported. The general dip of the shales and orebed is 12°, N. 15° W. The workings are in contact-metamorphosed shale as at Chimney Rock and in the upper workings at the American mine. Practically all of the copper minerals occur in this orebed. Little or no copper was found in the basalt save where it is thoroughly disintegrated.

*Hoffman Mine*[3]

The Hoffman mine in Somerset County is on the west flank of First Watchung Mountain about two miles northwest of the American mine. It is approximately three-quarters of a mile southeast of Pluckemin. (See figure 6.) The locality was prospected early in the

[1] Lewis, J. V., op. cit., pp. 147-150.
[2] Lewis, J. V., op. cit., p. 150; also Cook, G. H., op. cit., pp. 676-7.
[3] Lewis, J. V., op. cit., p. 150; also Cook, G. H., op. cit., pp. 676-8.

nineteenth century, and a mine was mentioned at this place in a report written in 1812. The main shaft, which penetrates shale, sandstone and basalt, is said to be 136 feet deep. The ore was reported to be four feet thick and to contain some native copper. The old mine dump when examined in 1905, showed chalcocite in sandstone and brecciated basalt, with smaller quantities of chrysocolla and malachite. The broken basalt may indicate a local zone of faulting.

This mine was operated by the True Vein Copper Company of Philadelphia, yielding several tons of ore that was sent to Bergen Point. The main period of its activity occurred during the Civil War and for three subsequent years. It has not been worked since 1868.

*Bolmer Prospect*[1]

The Bolmer prospect was discovered on lands belonging to Robert Bolmer near Martinsville, Somerset County. The small workings, which consisted of a few shallow pits and trenches along the southwest bank of West Branch of Middle Brook, were wholly in red shales and gray copper-stained Newark sandstones above the trap flow of First Mountain. The first prospecting was attempted in the early 1800's, and the locality had been long abandoned as a possible source of copper by 1868. (See figure 6.)

*Feltville Mine*

In 1733 a deed for a tract of land near Feltville recorded "414 acres, at the foot of Second Mountain, by the side of an old mine, and on the east side of Green River between the mountains." This record[2] appears to indicate a copper working at this locality in colonial time, but there are few other data to confirm such a mine.

A mine hole was visible in 1923 near Silver Lake in the vicinity of Glenside Park, and this appears to be the opening referred to in the deed above. The locality was prospected during the period of the Civil War when copper minerals were found in a ravine on the east side of the old lake bed on lands then belonging to Samuel Badgley. The locality was worked only one season and then abandoned. The ore is said to have been chalcocite associated with chalcopyrite in a thin rock seam between the top of the trap rock and overlying shales.[3] Little or no copper bloom was present at the surface. The mine was never of economic importance.

[1] Cook, G H., op. cit., p. 677.
[2] Honeyman, A. V. D., History of Union County, New Jersey; vol. 2, p. 530, New York, 1923.
[3] Cook, G. H., op. cit., p. 677.

Other copper minerals were discovered during the same general period in the vicinity of Warrenville and Washingtonville, Somerset County. The Field copper mine[1] near Warrenville shows an old shaft sunk through Newark shales on top of the trap flow. On the dump pile are fragments of green, gray and black carbonaceous shale, while scoriaceous and amygdaloidal basalt indicates that the top of the flow was reached. According to Cook[2] the best ore occurred chiefly as chalcocite disseminated in gray sandstone 30 feet below the surface of the ground.

*Other Prospects*

Mention may also be made of old workings[3] along First Watchung Mountain in and near Paterson, Passaic County, some 10 miles northwest of the Schuyler mine, and about 30 miles northeast of the American mine above Somerville. In the grading of Marion Street, Totowa, between Totowa and Union Avenues, several old mine workings were uncovered and destroyed. One of these was a large shaft from which two drifts extended toward the hill, one beneath Union Avenue, the other running nearly at right angles to the first beneath and beyond Marion Street. William Nelson explored the latter drift in 1870, and penetrated more than 70 feet of chambers. The rock is brecciated basalt cemented with siliceous material through which some chalcocite and encrusting masses of copper carbonates are scattered. Probably the workings trace back to the colonial period, but little is known of their history. No serious mining seems to have utilized the small excavations.

Copper minerals in sandstone along a fault were reported at Great Notch,[4] about 3 miles southwest of Paterson, in excavations for the nearby East Jersey Reservoir. All trace of the vein was buried during construction of the dam.

Shows of copper minerals,[5] but no workable ore, have also been found along Second Mountain near Union Village; at Jeliff's Mill, one mile southeast of Liberty Corner ; and on the west slope of Second Mountain near Lesser Cross-roads. These attest the rather

[1] Lewis, J. V., op. cit., p. 151.
[2] Cook, Geo. H., N. J. Geol. Survey Ann. Rept. for 1874, pp. 32-33, 1874.
[3] Nelson, William, Josiah Hornblower and the first steam-engine in North America; New Jersey Hist. Soc. Proc., 2nd ser., vol. 7, 184, 1883.
[4] Kümmel, H. B., Notes on copper mines; Ann. Rept. State Geologist of New Jersey for 1889, p. 175, 1900.
[5] Cook, G. H., op. cit., pp. 678-9.

broad distribution of cupriferous minerals along the Watchung ranges.

Although it does not qualify as a copper occurrence of the Watchung Mountains, an early prospect along the Hudson River at Fort Lee, Bergen County, may be mentioned here. This locality is approximately opposite 125th Street, New York City, and the workings were situated near the present site of the Fort Lee ferry. Small amounts of chalcopyrite and some chrysocolla were discovered in sandstone underneath the base of the Palisade diabase. The minerals were sparsely disseminated, and the locality was prospected before the Revolution under the delusion that a gold mine was indicated by the mineral association.[1] Chalcopyrite was also noted by Meredith E. Johnson in 1931 in pegmatite veins cutting through the Palisade diabase in the cut made for the approach to the George Washington bridge. The vein material consists chiefly of calcite with scattered grains of chalcopyrite and occasional crystals of feldspar. Ferromagnesian minerals and platy hematite occur sparingly.

## *Menlo Park (Edison) Mine*

### *Location*

The Menlo Park mine is one-half mile north of Menlo Park, now Edison, in Raritan Township, about 7 miles northeast of New Brunswick, Middlesex County, and approximately 11 miles due east of Bound Brook. The mine openings occur on the north bank of the South Branch of Rahway River, almost exactly across from Union Street, Menlo Park, at a surface elevation of about 70 feet above sealevel. (See figures 1 and 6.)

### *History*

Copper minerals were discovered in the vicinity of Menlo Park as early as 1784, and were worked for a short time thereafter. The first workings were mainly exploratory, and numerous trenches were cut in the surface exposures while a few short tunnels were sunk into the hillside. As the poor showing of metal soon discouraged early miners, the prospects were abandoned without any ore being shipped from the locality.

The workings were reexplored during the war of 1812, and again in 1827, but lay abandoned during the intervening years, when a report of 1820 noted that "no vestiges of copper remain upon the surface".

[1] Cook, G. H., op. cit., p. 223 ; also Lewis, J. V., op. cit., p. 155.

In the early 1880's, Thomas Edison became interested in the possibility of obtaining low-grade copper ore at this locality, which he thoroughly prospected and sampled.[1] He located a thin seam of workable ore, but shortly abandoned its mining as the ore averaged less than one per cent of copper. Spasmodic operations were continued for the next 25 years, and a stock company, organized early in the 1900's installed a hoist, pump and mill, and carried on explorations through 1903.[2] The deepest shaft is said to be 120 feet, and it is reported that several drifts and galleries were excavated. As in the case of most other New Jersey copper mines, the vigor of the company was exerted mainly in selling stock with mining a secondary objective. The openings have long since been abandoned, and the workings are now in disrepair and dangerous to explore. The old dump piles, however, are still combed for minerals by local mineralogists.

*General Geology*

The copper mines near Menlo Park (Edison) occur in a broad outcrop of Brunswick shales, not far northwest of the Cretaceous overlap. No igneous rock is exposed in the vicinity, but a dike or other extension of the Palisade diabase sheet may not be far below ground at this locality. The Brunswick shales show their usual bright-red to brown-red colors, and dip 12 degrees northwest. There is a fault at the main mine striking roughly north-south. Movement has occurred parallel to the bedding, resulting from a nearly horizontal heave or shove.[3] This is indicated both by the slickensided walls and fault breccia, and by an abrupt upward termination of the fault beneath undisturbed conformable shale.

A narrow zone of breccia, ranging from 6 inches to 2 feet wide, follows the plane of displacement, and for a distance of about 3 feet on each side, the bedrock is altered to soft dark-gray shale. The latter grades into normal Brunswick shales through an intermediate zone of mottled gray and red rock. The gradation is not abrupt, and there is considerable variation in the distance through which the change takes place. The dark shale is traceable in a nearly horizontal position westward from the top of the fissure, a fact that has been interpreted as attesting that the displacement probably

[1] Clayton, W. W., History of Union and Middlesex counties, New Jersey; p. 579, Philadelphia, 1882.
[2] Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, pp. 153-5, 1907.
[3] Lewis, J. V., op. cit., p. 153.

followed a bedding plane. Locally the dark-gray altered shale is spotted or otherwise mottled by white, bleached patches. These are similar to those observed in orebeds at Somerville and New Brunswick. Probably they represent areas where ferric iron has been reduced to ferrous iron by copper-charged solutions.

### *Nature and Occurrence of the Ore*[1]

Ore minerals at Menlo Park are native copper, chalcopyrite and chrysocolla. The native copper occurs as thin sheets and films in joint cracks of the darkened shale; it also covers slickensided surfaces on the breccia and wall rocks. Minute grains and strings of copper likewise occur in bleached zones of the altered shale, but are most abundant in and along the fault plane. Chrysocolla, which is a super-gene alteration product, is mainly developed along joints and fissures, although it has permeated some of the more porous or sandy sediments. Minute crystals or grains of chalcopyrite are sparsely scattered through the shales.

The ore minerals are chiefly confined to the vicinity of the fault and the fault-breccia, which served as channels for ascending copper-bearing solutions. As the fault is believed to be abruptly terminated above, probably these solutions were partially dammed and spread laterally into the red rock. It is believed that the native copper was deposited where these upward-moving solutions were oxidized by ferric iron, as in the red Newark shales ; secondary alteration to chrysocolla is regarded as a supergene effect of descending meteoric waters.

It may be noted at this mine as at Arlington and Glen Ridge, that small bits of bituminous coal or other carbonaceous material are found more or less infused with copper-bearing minerals. No doubt this organic matter aided in copper precipitation, but many parts of the adjacent bedrock that are practically barren of organic material also contain similar mineral associations.

Thomas Edison, who thoroughly examined the mine and surrounding property about 1882, stated that he found the ores were too lean to pay the costs of mining. He attempted to work one streak about four feet thick, but the copper content was scarcely 0.5 per cent, and he soon abandoned the venture.

Lewis[2] concluded in 1906: "There seems little probability that there is a great body of ore at this place, such as a deposit of low

[1] Lewis, J. V., op. cit., pp. 152-4.
[2] Idem.

grade would require for profitable exploitation, and there is, therefore, no encouragement for further expenditures in exploration." This conclusion is equally applicable in 1943.

## *New Brunswick Mines*
## (Including the French Mine)

### *Location and Nearby Prospects*

Several copper mines have been opened in and near New Brunswick, Middlesex County, of which the French mine, located on the former farm of Phillip French, is most famous. This mine is on property now included in Neilson Campus of Rutgers University. There is also evidence of another mine, or a tunnel of the French mine, along Livingston Avenue, New Brunswick, and it is probable that many other prospects were explored in the vicinity during the period of colonial discovery. (See figures 1 and 6.)

Mention may also be made of the Raritan mine, located 3 miles southwest of New Brunswick, and worked prior to 1840. This mine was purchased about 1847 at a "high price", and large expenditures were made on advice of Dr. C. T. Jackson, geologist, and J. H. Blake, Esq.[1] A main shaft was sunk 160 feet with a short tunnel that ran north-northeast, but the ubiquitous water and low grade of ore made mining unprofitable. The mine was inactive in 1868 when it was in the hands of the Raritan Copper Company and it has not since been worked. The dump piles near the old shafts show mostly red and purple Triassic shale in which small amounts of chalcocite and some secondary carbonate ores may be seen. Not far from the mine are small trap dikes that intrude the Brunswick shales, and may have been responsible for the concentration of the ore. There is a little trap rock on the mine dumps, indicating that one of the workings may have encountered a dike. It is barely possible that the mine was active in colonial time.

Specimens of gray sandstone stained with chrysocolla and possibly containing native silver, have been reported on the farm formerly belonging to George Drake, near Newtown, Middlesex County, four miles north of New Brunswick.[2] The silver is reported to occur in small specks, and only surface prospecting has been attempted. There are no nearby outcrops of igneous rock. Copper minerals have

[1] Whitney, J D., The metallic wealth of the United States ; p. 328. Philadelphia, 1854.
[2] Lewis, J. V., op. cit., p. 155.

also been noted[1] on the Randolph and Politica farms in the same neighborhood where they occur on barren ground where even weeds won't grow. It seems possible, indeed, that the copper minerals may even be resopnsible for this condition. Only chrysocolla has been reported from the Randolph farm, but the oxides, cuprite and tenorite, were also identified in specimens from Politica's farm, and in addition, small scales or flakes of native silver were noted.

The descriptions and historical data which follow, refer primarily to the main New Brunswick working, formerly known as the French Mine.

*History*

About 1748 several lumps of native copper were plowed up on the farm of Phillip French, then about a quarter of a mile from New Brunswick.[2] These nuggets totalled more than 200 pounds in weight, and were the source of considerable interest. Elias Boudinot, later president of the Continental Congress, leased mineral rights on the French farm for a term of 99 years, and organized a local company to prospect for and mine copper. The first shaft was sunk in 1751 about 300 yards from the river, at a place where a traveller reported a "body of flame rising from the ground about three o'clock in the morning."[3] The miners encountered a sandstone bed whose surface was irregularly plated with thin sheets of native copper having the consistency of gold leaf. Even the rock itself contained scattered grains of copper, and occasional larger nuggets were also found.

Encouraged by these findings, the operators followed the "vein" 30 feet underground and several tons of ore were extracted. A small stamping mill was erected in the hollow between the college and the seminary, and was supplied with water from Mine Run. The ore was pulverized and washed, and it is reported that several tons of pure copper thus obtained were shipped to England.[4] Sheets of copper as thick as "2 pennies" and 3 feet square were taken from rocks within four feet of the surface, while at 50 to 60 feet a "fine body of solid ore" was reported. Operations were soon expanded, the shaft was deepened, and numerous entries were driven in several directions ; some, it is said, extended beneath the river.

[1] Wm. Lee Phyfe's unpublished manuscript.

[2] Winterbotham, William, View of the American United States; vol. 2, p. 368, London, 1795.

[3] Weld, Isaac, Jr., Travels through the States of North America; p. 151, London, 1799.

[4] Whitney, J. D., op. cit., p. 327.

Water problems, however, soon put an end to underground mining and the company withdrew, concluding the costly but unsuccessful attempt to operate the property. Some carbonate ore may also have been worked during this period along the banks of the Delaware and Raritan Canal, one mile northwest of New Brunswick.

The initial company abandoned work before the Revolution, and although several later efforts were made at various periods to find workable ore at New Brunswick, none was successful, and there has been no mining activity there for more than a century. Probably there is nothing to encourage any further prospecting and little enough to have repaid the original miners save the scattered nuggets of native copper that first attracted attention to the locality. Fortunately for speculators in mining stock, less money seems to have been fruitlessly sunk in this mine than in other, equally unpromising, copper prospects of the State.

*Geology*[1]

The exposed bedrock in the vicinity of New Brunswick is mostly sedimentary, consisting of New Brunswick shale and sandstone north and west of Lawrence Brook, and Cretaceous rock to the south and east. The Newark beds have a general northwestward dip, and save for a few small dikes, no rocks of igneous origin are exposed.

There is evidence, however, that intrusive igneous rock occurs at depth, for the buried extension of the Palisade diabase sheet may be projected to connect with the Rocky Hill intrusive along a line that would pass not far from New Brunswick, and the presence of trap rock at no very great depth is probable. Indeed, several deep wells in New Brunswick, although drilled mainly in red shale, have en-countered near the bottom zones of purplish rock resembling shale altered by contact metamorphism along an intrusive contact. There are some sandy beds, but shales dominate the Newark series at this locality.

The copper ores of New Brunswick are native copper, cuprite, malachite, and a little chrysocolla and azurite. There is evidence of a minor fault that has a general east-west strike, the plane of the fault being nearly vertical. The copper minerals occur in a zone of bleached grayish shale and in gray and grayish-white splotches that are scattered through the normal red shales bounding the fissure. Cuprite, malachite, chrysocolla and azurite are found incrusting thin

[1]See particularly Lewis, J. V., op cit. pp. 151-2; and Cook, G. H., Geology of New Jersey; pp. 678-9, Newark, N. J., 1868.

sheets of metallic copper, or entirely replacing them in joint cracks of the rock. Grains, strings and leaves of copper occur in the shale and joint planes. Chalcocite, if present, is inconspicuous. Only one of the New Brunswick workings is known to have encountered igneous rock, although the presence of altered shales in the deep wells testifies to its presence. Cook reports that a sample of altered purplish shale found near the mine on the property of James Bishop showed 3.2 per cent of copper. Beck's early report of an occurrence of native copper at this locality may be quoted.[1]

> "The occurrence of native copper above noticed, however, is not so interesting as the vein or sheet of this metal which is found in the city of New Brunswick. About 50 rods nearly east of Rutgers' College, a thin vein of this kind crosses the red shale, which is here the prevailing rock. It sometimes adheres so closely to the rock as to be with difficulty separated from it. The thickness of the vein is from one-sixteenth to one-eighth of an inch; in regard to its extent, no certain information can be obtained: It has, however, been traced for several rods. . .Specimens . . . are all malleable; but some are much more so than others. Sometimes a thin plate of the metal passes through the center, which is encrusted on. both sides with the oxide and carbonate and a little adhering silica; while at others, the metallic plate is on the outside."

There is no indication that the New Brunswick mine was ever profitably operated, and the original masses of native copper seem to have been its most valuable products. Probably the underlying Palisades-Rocky Hill intrusive extended finger-like apophyses and dikes into the red overlying shales, and the diabase that reaches the surface east, south and southwest of New Brunswick gives evidence of widespread fissuring. Copper-bearing solutions and vapors from the intrusive are believed to have originated during the general period of igneous activity when the dikes and fissures served as channels for their upward passage. Native copper was released by action of ferric iron in the red shales, being precipitated along joint planes and fissures; the secondary ores were produced in later epochs when the copper was redistributed by surface meteoric waters.

### *Flemington Mines*

(Including the Neshanic mine)

*Locations*

Several old copper mines have been operated within a few miles of Flemington, Raritan Township, Hunterdon County, and the term "Flemington copper mine" has been variously applied to each of

[1] Beck, L. C., Notices of native copper. . . .; Am. Jour. Sci., 1st ser., vol. 36, pp. 107-114, 1839.

these. (See figure 1.) Most of the excavations were made on property formerly belonging to Hugh Capner, situated a quarter of a mile west of the Flemington town boundary ; and on the old Dvoor farm in the south part of town along Mine Brook, about half a mile southwest of the courthouse. This locality is not far from the present intersection of State Highways 12 and 29. The Capner prospect is located along State Highway 12, near its intersection with the Flemington-Sergeantsville road.

The Neshanic mine, also one of the Flemington group, was located on the old Jacob Rockafellow farm about one and one-half miles south of Flemington in Delaware Township of Hunterdon County.

Because of the confusion in the old reports regarding the several mines, it is not always clear which particular locality is being described.

Mention may also be made of an old copper prospect showing traces of carbonate minerals on the property of Mr. Hartpence, three-fourths of a mile southeast of Mount Pleasant, Hunterdon County, about 17 miles northwest of Flemington. Several excavations have been made along a lane and in adjoining fields. The copper occurs as thin films along a fine black shale which is overlain by red shale and rests upon coarse sandstone. No trap rock is known to occur nearby. These traces of copper ore have no commercial importance. The same is true in respect to the copper occurrences[1] on the slopes of the steep hill two miles north-northwest of Pennington, where the source of the copper minerals can unhesitatingly be ascribed to the diabase of which the hill is composed.

Copper Hill, situated two and one-half miles south of Flemington, owes its name to copper stains that early directed attention to this general area as a possible copper-producing locality. It is known that one or more small workings were attempted in and around Copper Hill, but the history of these operations, and indeed, their very locations, are now quite obscure.

*Historical Development*[2]

The Flemington copper mines were first operated in pre-Revolutionary days, probably by English miners, but there is no available record or present evidence of these early workings. It seems likely

[1] Phyfe, Wm. Lee, unpublished Ms.
[2] Snell, J. P., History of Hunterdon and Somerset Counties, New Jersey: p. 307; Philadelphia, 1881.

that the operations were neither extensive nor remunerative. Indeed, it is probable that they were small and unorganized, as a report of 1834 describes the mine as "abandoned", and notes with surprise that about 60 tons of ore had been taken out "despite the limited excavations." [1]

Early in 1825, the New Jersey State Legislature was petitioned from Flemington for the formation of a mining company, but there seems to have been little further mining activity at this locality until about 1835 when prospecting was in progress on the Hugh Capner farm near the town limits, the Jacob Rockafellow farm about 1.5 miles south of Flemington, and the Dvoor farm along Mine Brook.

The Neshanic Mining Company was incorporated February 29, 1836, with a capitalization of $100,000, and its incorporators included William H. Sloan, Hugh Capner, Samuel Hill, John H. Capner, and Joseph Case. This company was originally organized to operate the Neshanic mine, located on the Rockafellow farm south of Flemington. In 1840 the State legislature gave this company permission to construct a railroad from its lands in Raritan Township to South Branch and Delaware Rivers respectively, with the provision that the railroad was to be used only for mining purposes. There is no indication that this road was ever built, and the only work the company seems to have attempted was the development on the Capner farm nearer town.

About 1840, Albert Cammon and Peter I. Stryker, who had recently concluded their unsuccessful management of the Bridgewater mine (see page 78) near Somerville, bought the Flemington property from Hugh Capner, and operated it for the next few years. Their venture was a failure and the mine reverted to Capner, who continued operations until 1844, when workings were suspended "because of the pecuniary pressure of the times."

In 1847 Charles Bartles bought the Van Sinderlin farm located about one-half mile from the Flemington mine, with rights to all mines and minerals. He sold immediately to the Central Mining Company of Flemington, organized February 17, 1848, by John G. Reading and William Sloan of Flemington, and Jonathon Ogden and Edward Remington of Philadelphia. This company sank three large shafts and prospected about the property, reporting good copper ore but not in paying quantities. The company and its holdings were sold March 7, 1861, to the Acorn Copper Company.

[1]Clemson, T. G., Flemington copper ore. .. ; Geol. Soc. Pennsylvania Trans., vol. 1, p. 167, 1834.

The Flemington Copper Company, incorporated February 24, 1847, and capitalized at $200,000 was another of the companies organized to exploit the Flemington mines, and it was soon reorganized as the Raritan Consolidated Mining Company. The South Flemington Mining Company and the Readington Company were also in existence in 1847-48, the latter company offering about 15,000 shares of assessable stock.

The Hunterdon Copper Company was incorporated March 20, 1857, and held mineral rights to 400 acres in fee, together with surface rights to 17 more acres and permission to appropriate any part of the 400-acre tract necessary to reach or work the ore. Somewhat desultory activity continued at the locality until 1861, when a riot occurred among the miners and work was shut down, not again to be resumed.

Apparently the most extensive workings near Flemington were those on the Capner, Van Sinderlin and Dvoor farms. At the former locality, a gang of miners under the direction of Captain Staley uncovered evidence of pre-Revolutionary mining, including picks, shovels, wedges and an old bucket bound with stout iron. They also discovered a chamber about 30 feet square from which ore had been removed.

The best ore is reported to have been discovered beneath Mine Brook on the Dvoor farm, where several galleries are said to have extended laterally from surface shafts. The last remaining shaft was recently being used by the Flemington Water Company as one source of local water supply. The last of the old mine buildings, formerly used as a storehouse, was torn down a few years ago.

The history of these Flemington mines portrays the fruitless copper fever that spread across New Jersey before the Civil War, and prompted the creation in 1847 of six different copper-mining companies with nearly 70,000 shares of stock having a purported market value of $1,000,000. Practically all of the companies were speculative endeavors and not business operations, for the energies of the operators were directed mainly to stock-selling. Thousands of dollars were sunk in these ventures, and scarcely a pound of copper metal was produced. Even the token mining of the companies rarely progressed beyond repairing the workings of preceding companies, and the sum of all operations added little to the body of geologic knowledge regarding the ores, and nothing at all to the pockets of the hopeful but misguided investors.

*General Geology*

Flemington is situated on an outcrop of Brunswick shale and some sandstone about one mile east of the curving trace of the great Brookville-Flemington fault, which brings these rocks against Lockatong argillite west of the fault. The eastern side of the block is downdropped ; the upthrown side is at the west. The amount of displacement is not definitely known, but must be considerable, possibly amounting to several thousand feet.

A series of trap dikes extends northward from the large Sourland intrusive sill, striking through Copper Hill to Flemington. The dikes are narrow and form a low ridge that barely mars the level surface of the surrounding country. There is a small round stock-like exposure of diabase near the fault just west of Flemington, and the dikes roughly connect this intrusive with the larger Sourland Mountain sill. Probably the latter is analogous in age and formation with the Rocky Hill-Palisade sill. The dikes and small stock west of Flemington suggest an association between the Sourland and Cushetunk Mountain intrusives, the latter being located several miles north of Flemington.

Adjacent to the small stock and belt of dikes, occur zones of indurated shales that show metamorphic effects as a result of proximity to heated igneous materials. The shales are "baked" and are changed in color, being turned from red shades to the brown and purplish hues of altered Newark shales found at other contact localities. The zone of alteration grades imperceptibly into unaltered shales a short distance away from the dikes, and there is no sharp boundary to provide distinct lateral zonation. The dikes consist of dark-gray dense medium to fine-grained diabase.

*Ore Minerals and Occurrence*[1]

The ore mined at Flemington consisted of chalcocite, cuprite, chrysocolla and malachite, associated with calcite. Chalcopyrite is disseminated in small grains through the larger masses of chalcocite. Cook reported that a sample of "dressed ore" ran 6.7 per cent of copper, and that a green-stained sandstone contained 0.5 per cent copper.[2]

[1] Dickeson, M. W., Report on the geological survey and condition of the Hunterdon Copper Company property, Hunterdon County, New Jersey, with geological report by B. and C. H. Hitchcock; pp. 1-23, Philadelphia, 1859.

[2] Cook, G. H., Geology of New Jersey; pp. 679-680, Newark, N. J., 1868.

The ore belt, as described by Henry D. Rogers in 1840 from a series of east-west cross-cuttings that were being made at the time of his visit, is a zone of metalliferous rock of variable width in the partly altered shale close to the dikes. In places it was 20 to 30 feet wide. It strikes north-south for a distance of several hundred feet, and may continue to, or have a separate extension near Copper Hill, two miles to the south. Rogers[1] reported the ore as being intimately blended with partially altered sandstone and shale, the whole mass having the appearance of a breccia of recemented fragments, in which metalliferous minerals formed part of the cement. Most of the ore is finely disseminated in small bodies, although a few larger masses were found of "considerable size and great purity." The main values were found in brecciated sandstone along a northward trending fault against which red shale is downthrown on the west.

One may now examine old mine dumps in the vicinity, but there is no additional information as to the character and occurrence of the orebody below ground. As the main mine is located along Mine Brook, the workings are now water filled and drainage must have been a problem from the very beginning of operations.

Considerable prospecting was also done at Copper Hill south of the Flemington mine, but not enough ore was found to meet expenses of the search. Lewis[2] reported in 1906 that the conditions at Flemington resembled those at the Schuyler mine at Arlington, but that little was known about the value and extent of the ore bodies encountered. He found nothing to offset the "discouraging experience of those who have attempted at various times to operate the mine," a conclusion that may be renewed at the present time.

The formation of the ore minerals seems to be definitely associated with the diabase intrusion, from which it is believed ascending solutions or vapors transported copper to the zone of altered shales, where it has been subsequently redeposited and disseminated in other form by percolating waters of surface origin.

[1]Rogers, H. D., Final report on the geology of New Jersey; pp. 162-3, Philadelphia, 1840.

[2]Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, pp. 144-5, 1907.

## *Griggstown Mine*
(Also known as the Franklin mine)

### *Location and Nearby Prospects*

The Griggstown mine is located at the edge of a hilly tract about 8 miles north of Princeton and 3 miles north of Rocky Hill, Franklin Township, Somerset County. (See figures 1 and 8.) The mine is about one mile south of Griggstown and one-half mile east of Mill-stone River and the old Delaware and Raritan Canal. The property lies in open, smooth fields east of the river and west of the crest of Tenmile Run Hill. The elevation at the mine is about 200 feet above sealevel or 150 feet above the river. The location is midway between State Highways 31 and 27, which are about 4 miles apart at the latitude of the mine.

In this same region, copper minerals have been reported near Hopewell, Mercer County, about eight miles west-southwest of Griggstown, and at another locality on the south slope of Mount Rose, two miles southeast of Hopewell.[1] These localities, as in the case of another prospect reported near Marshall Corners, are chiefly occurrences of cupriferous minerals, and no mining or prospecting of consequence has been attempted or is warranted.

Mention may also be made of small-scale prospecting along the south and southwest slopes of Pennington Mountain,[2] about one mile southwest of Pennington, Mercer County, possibly 8 miles north of Trenton. Traces of copper minerals occur in altered shales adjacent to the intrusive trap sheet which forms the backbone of the mountain. There has been considerable discoloration of shales and sandstones by copper carbonate and silicate minerals, but no body of workable ore has been found. The general conditions are much the same as at Griggstown.

### *History and Workings*

The exact date of discovery of the Griggstown mine is not now known. The Pennsylvania Gazette of January 16, 1753 reported the presence near Griggstown of a valuable "Copper Vein of Six Foot Square", mining shares in which were offered for sale about 1765. Ore is said to have been raised before the American Revolution according to a grandson of Captain Rule, the original mine manager, who stated that his grandfather employed 160 Welsh miners ; that

[1]Cook, G. H., op. cit., p. 679.
[2]Kümmel, H. B., Mining industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1900; p. 213, 1901; also Lewis, J. V., op. cit., p. 155.

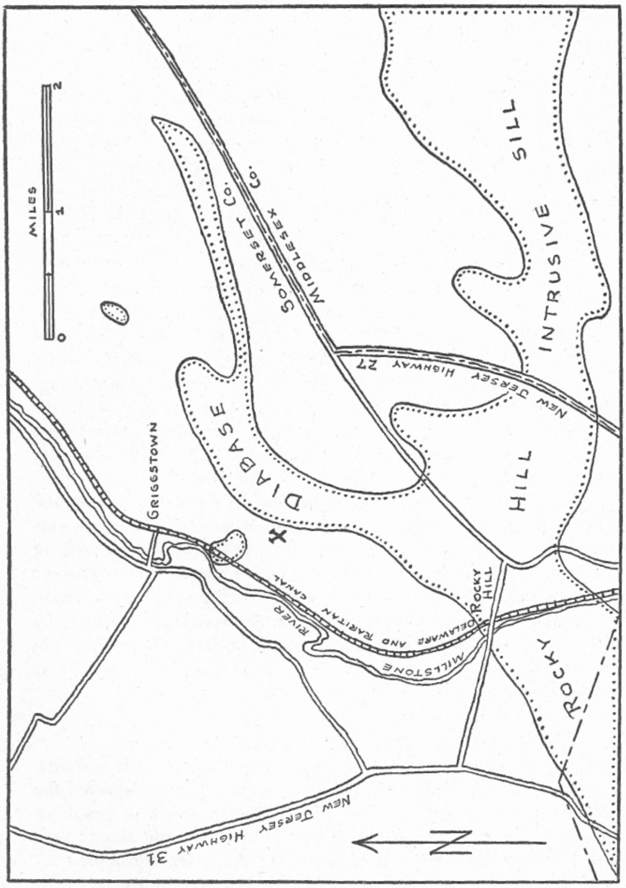


FIG. 8. Generalized sketch map of the Griggstown area showing location of the old Griggstown copper mine and the outcrop of the nearby Rocky Hill intrusive diabase sill.

considerable ore was shipped to England for smelting; that mining ceased when the Revolution began ; and that the property was idle for the next 40 years.[1]

Apparently the mine was reopened early in the 19th century when it was worked for a short time at a reported considerable financial loss. The mine was mentioned in a report of 1812, but the property was described as being "dilapidated" in 1840 and 1844, when the workings were no longer accessible below ground. In the latter year, the mine was referred to as the Franklin copper mine, "formerly extensively worked".[2] Its deepest shaft was said to have reached 190 feet.

There were several small attempts to work the mine between the Revolution and the Civil War, but none was successful and the property was sold in 1865 or 1866 as a "salt mine".[3] It was inactive in 1868 and there seems to have been no mining later in the century.

Late in 1901 the main shaft was reopened and partially cleaned, sampling of the ore being undertaken at this time. The mine was then owned by Isaac D. Gabel of Bordentown and Robert Dixon of New York, who continued cleaning the old passages down to the 100-foot level. They reported the presence of copper, gold and silver, but took out no ore. In 1905 the mine was being pumped and further exploratory work was reported to be in progress.[4] By 1906 the deepest shaft was open and renovated to its bottom, probably for the first time in a century. The property then included 152 acres between the hill and the river, and the mine workings consisted of several shafts partly caved and a drain tunnel 1,600 feet long. A new inclined shaft had been started and there were several additional stoped-out chambers (See figure 9.) This flurry of activity, however, was short-lived.

During the first World War when the price of copper rose to 26 cents a pound, there was much speculation in copper stocks, and a company was formed to operate the Griggstown Mine with a Mr. Labaw of Hopewell as Superintendent.[5] During the spring and summer of 1916 the workings were pumped out and the mine was opened to inspection. Several prominent men visited the mine and gave

[1] Hamilton, S. H., The mineral industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1903, pp. 109-111, 1904.

[2] Barber. J. W., and Howe, H., Historical collections of New Jersey, p. 454, New York, 1844.

[3] Cook, G. W., Geology of New Jersey; p. 679, Newark, N. J., 1868.

[4] Kümmel, H. B., Mining industry of New Jersey ; Ann. Rept., State Geologist of New Jersey for 1905, pp. 321-2, 1906.

[5] Phyfe, Wm. Lee, unpublished Ms.

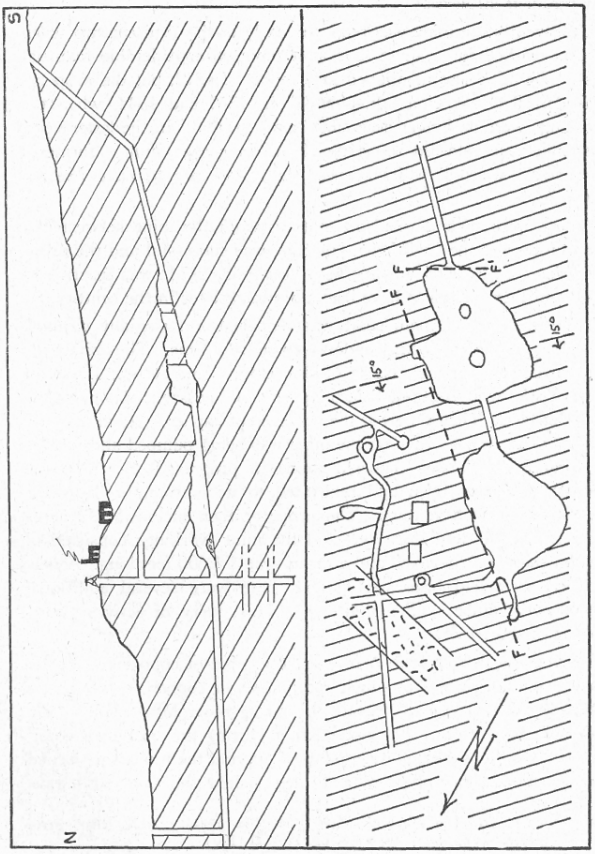


FIG. 9. Section at the Griggstown copper mine. The upper figure shows the extent of the workings, the lower figure a plan of the chambers at the 100-foot level. A dike of diabase is reported along the drain tunnel north of the main shaft. (After J. D. Gabel.)

favorable reports. Professor Phillips of Princeton University also visited the property but when asked to give his opinion, stated only that the owners would not like to hear what he thought. In spite of this, many shares of stock were sold in the vicinity of New Brunswick and Princeton. A few sacks of ore (probably collected from the old mine dump) were sent to Perth Amboy but after several months operations ceased and the unfortunate investors were left "holding the bag". Later, Isaac Gabel of Bordentown acquired the mineral rights and he still owned these in 1933.

Save during the pre-Revolution period, it is likely that this mine was never a profitable venture. Stock-selling rather than mining seems to have been the chief interest of its operators, who have always been "cleaning the property preparatory to operation" but have never been actually mining the ore. At present, the excavations are water filled, the openings caved, and access underground is practically impossible.

*General Geology*[1]

The Griggstown mine is near the northwest margin of a narrow diabase sheet or sill that extends northeastward from the main Rocky Hill sill. (See figure 8.) There is no mineral outcrop at the mine, and the workings and dumps lie in a smooth cultivated hill-slope that descends to Millstone River from the crest of Tenmile Hill. The summit of this ridge, which lies east of the mine, is formed by the diabase outcrop. The latter strikes southwestward to join the main sill which forms Rocky Hill. Brunswick shale crops out at the mine and in the area to the west and north ; Cretaceous sediments overlap parts of the diabase in several patches two to three miles southwest of the mine.

The Rocky Hill sill, of which the extension near Griggstown is part, is a southwest continuation of the Palisade diabase intrusive, whose surface trace between Carteret and Deans is buried beneath the Cretaceous overlap. There are numerous upshoots of the diabase into overlying shales near the mine, and one of these, some 60 feet thick, was cut by a drift extending west of the main shaft. There are several other oval or irregular diabase exposures in fields west and north of the mine.

[1]Weed, W. H., The Griggstown, New Jersey copper deposit; U. S. Geol. Survey Bull. 225, pp. 187-9, 1904:
Lewis, J. V., The Newark (Triassic) copper ores of New Jersey; Ann. Rept. State Geologist of New Jersey for 1906, pp. 136-9, 1907:
Weed, W. H., Copper deposits of the Appalachian States ; U. S. Geol. Survey Bull. 455, pp. 42-44, 1911.

The trap rock adjacent to the mine workings has been intruded into red Brunswick shale in which it conformably lies as a gently inclined sheet or thin sill. The dip of both shale and diabase at the mine is 10° to 20°, N. 45° W. Inasmuch as the diabase crops out at the ridgecrest only a short distance east of the mine, its exposed dip, if continued westward, would scarcely carry it far beneath the deepest mine workings (190 feet).

There is little or no evidence of faulting, although joints are common to both igneous rocks and shale.

The diabase is a coarse-grained, bluish-gray, dense igneous rock of fairly uniform character ; it is similar to that exposed at Rocky Hill, and closely resembles the Palisade diabase. The unaltered red Brunswick shale is well exposed in the ravine north of the mine. Near the contact with the diabase, however, it is materially altered, the change in character being marked at the mine. The most obvious alteration is one of color, shale exposed on the lower ridge slopes and along Millstone River having the normal red color, whereas farther up the slope nearer the igneous rock, the color gradually changes to purple, becoming brown and almost black at the mine and near the diabase. Probably the visible alteration of the shale extends as much as 100 feet vertically above the intrusive sheet.

In the mine workings, where the most highly altered shale occurs, there is a brown to dark altered shale or "hornfels" that is well exposed in the inclined shaft of the mine. This material is thickly spotted with rounded and rectangular masses of chlorite, possibly altered from green hornblende or cordierite, ranging in size from minute pellets to bodies an inch or more in diameter. These are invariably surrounded by bleached halos about 1 millimeter wide. The altered shale is dense and hard at most points, but where mineralized, it has been partially decomposed or changed to a pale pink or whitish kaolin wherein dark-green spherules of chlorite are highly conspicuous.

One of the bedding planes of the hornfels carries 3 to 12 inches of clay-like material charged with ore. This seam bears evidence of slipping or possibly thrust-faulting, and apparently developed along a zone of minor movement. It furnished most of the ore in the early workings, and was known as the orebed. Although it fails to crop out at the surface, it seems to be wholly conformable with the altered shales, having a dip to the northwest of about 10 degrees. Presumably the hornfels, produced by contact metamorphism during intrusion of the sill, serves as the wall rocks for the ore seam. The latter may have been later enriched by supergene alteration, or it may merely have been the main pathway of mineralizing solutions attendant upon the igneous invasion. Data are not at hand to indicate which alternative is the proper explanation.

*Ores and Occurrences*

The chief ore mineral is chalcocite ; there is a little chalcopyrite and chrysocolla, and smaller amounts of malachite, cuprite and, rarely azurite (reported by Meredith E. Johnson) and native copper. Weed[1] reports finding bornite[2] and tenorite, but Lewis[3] believes that masses of chalcocite and hematite may have been mistaken for the former, and associations of magnetite and tourmaline for the latter. Nonmetallic minerals include tourmaline, epidote, chlorite and feldspar crystals. Magnetite and micaceous hematite are also present.

The chalcocite occurs as a constituent of some of the chlorite nodules with which the rock is thickly studded. It also penetrates minute cracks in the hornfels, or altered shale, and occurs in fissures and broken zones in the flinty bedrock which is locally bleached to a light-gray or white color. This bleaching is notable near the patches of ore minerals where calcite may occur as well. The ore follows fractures in the orebed, and is not uniformly distributed through it. Chalcocite is absent in the diabase and in the main mass of the hornfels, being a constituent only of the chloritic nodules. Fractures run down from some of these spherules into rock below the orebed, but the ore rarely follows these far into the lower bedrock. Some chlorite bodies coalesce to form layers several inches thick but there is little copper in the chlorite itself, as revealed by analyses that show only 0.69 per cent copper.

The secondary ores—chiefly chrysocolla, less abundantly malachite and cuprite—were formed by supergene alteration of chalcocite or chalcopyrite, probably by percolating surface waters. These minerals occur with the chalcocite in fissures and brecciated zones. Some of them also penetrate adjoining strata along joints and bedding planes, so that large masses of frock are impregnated with thin films of light-green chrysocolla. Cuprite and malachite have similar, but less extensive occurrences.

The orebed which contains the chalcocite and oxidized ores has been worked beneath a relatively small area in rude elliptical bodies possibly 200 feet in width. There is said to be a vertical ore vein in the shaft as well as a lower sheet of ore at the 150-foot level, but

[1] Weed, W. H., op. cit., p. 44.
[2] Also reported by Phyfe.
[3] Lewis, J. V., op. cit., pp. 138-9.

these reports cannot now be verified. Several vertical fractures intersect the main seam near the incline, and these are filled with crushed and altered rock and carbonates. As the seam of workable ore is relatively small, much adjoining rock has been handled to reach and extract it.

It is believed that the Rocky Hill intrusive, which lies but a few hundred feet beneath the mineralized zone, sent up small dikes and apophyses into the overlying shales. Some of these now appear as small rounded outcrops of diabase that are scattered over the nearby area. (See figure 8.) Possibly there was some fracturing or fissuring of the shales, but this was undoubtedly confined to the close proximity of the intrusive. Contact metamorphism materially altered the rock adjacent to the heated diabase, turning the red Newark shale into purplish-brown or dark hornfels at the igneous contact. Probably the alteration above the intrusive at Griggstown was relatively similar to that at Arlington, New Brunswick and Menlo Park and analogous (although less intense) with that beneath the Watchung basalt at Somerville.

It is thought that the Griggstown copper came directly from the diabase, probably dissolved in heated solutions or vapors. These are believed to have arisen from the intrusive and to have penetrated into fractures and fissures within the area of contact metamorphism. The original magmatic solutions precipitated their copper as hypogene sulphide minerals that were later altered to chrysocolla and malachite. The impregnation of the thin ore seam at Griggstown seems to be somewhat different from the primary mineralization at some of the other New Jersey copper mines, and it is possible that this ore concentration, as well as the bleaching of spots in the altered shale, took place during supergene mineralization rather than during the earlier stage of hydrothermal alteration. On the other hand, the ore seam may have been hypogenically enriched as in other mines. There is no doubt, however, that the present carbonates and other secondary ore minerals were produced by circulating meteoric waters, moving long after the period of igneous invasion.

The owners of the property in the period from 1900 to 1905 were insistent that gold and silver occurred in workable quantities in this mine, and were in the possession of numerous assays to bear out this contention. One of these reported $212 of gold per ton of ore; another, $26 of silver per ton. An independent assay of reportedly rich ore of this type was requested by the New Jersey Geological Survey, and this test showed .01 oz. of gold and 0.03 oz. of silver per ton. The locality is mineralogically interesting, however, and has supplied showy specimens of various minerals, some of which were exhibited at the St. Louis Exposition.

*Economic Possibilities*

Although this mine was once extensively worked, it has not been active in more than a generation and the likelihood that it will again be operated seems remote.

Lewis[1] reported in 1907 that the conditions under which the ores were found could well be expected to extend beyond the area mined both laterally and at depth. It was his recommendation, as the mine had recently been cleaned to its lowest levels, to ascertain if there were similar orebodies elsewhere in the nearby area. If such could be found, he suggested extending drifts from the present workings to prospect for other bodies of workable ore.

It would seem, in view of the fairly shallow depth of this deposit, that core-drilling might be used satisfactorily to test the bedrock adjacent to the old workings, or to prospect for analogous deposits elsewhere along the intrusive sheet. Whether there is any likelihood that such prospecting would be successful, or whether any ore, if found, could be mined profitably, are questions for which there is no sure answer. The writer doubts the wisdom of spending much effort or money in further prospecting. The old workings and dump reveal no trace of high-grade ore, and the known geologic structure of the deposit does not indicate a large volume of ore of any kind. It is believed that the main bodies encountered in the stopes have already been pretty thoroughly exhausted.

## TRIASSIC COPPER LOCALITIES OF OTHER EASTERN AREAS

### *Nova Scotia*[2]

Small but abundant masses of native copper, ranging from bodies several pounds in weight to tiny grains, are found in amygdaloidal trap rocks, mainly basalt, of the Triassic System in Nova Scotia, particularly near Margaretsville on the east coast of the Bay of Fundy, and at Cape d'Or (which derives its name from the metal[3]), north of Minas Channel. The copper occurs with quartz, calcite and various zeolites in veins and fissures that cut a thick

[1] Lewis, J. V., op. cit., p. 139.
[2] Ells, R. W., Bulletin on the ores of copper in the provinces of Nova Scotia, New Brunswick and Quebec; Canada Geol. Survey, Min. Resources, 1904, 58 pp.
[3] Dawson, J. W., Acadian geology; pp. 107-08, London, 1878.

Extrusive basaltic flow w hich forms the northwestern shore of Nova Scotia. The occurrences are of no economic importance.

*Massachusetts*

Although copper stains occur at Turners Falls in Greenfield, Massachusetts, where Triassic diabase and sandstone are discolored with copper carbonates, there are no true copper ores nor prospects in this State.

*Connecticut*

Several Triassic occurrences of copper minerals have been mined or prospected in Connecticut, of which the most important is the Simsbury,[1] or Newgate Mine, located in the east part of Granby Township, Hartford County, along the extreme north-central margin of the State near the Massachusetts line. This mine was opened early in the 18th century, and was worked for about 40 years; it was reopened after the Revolution and used as a prison when it acquired the name "Newgate" after the notorious British prison. The chief ore mineral is chalcocite accompanied by bornite, native copper, malachite, azurite and chalcopyrite. The bornite and chalcocite occur in nodules and veins in a fine-grained yellowish sandstone, the main orebed being two feet thick, and dipping eastward at an angle of 25 degrees. The mineralized zone extends over two or three square miles in the vicinity of intrusive diabase that crops out in ridges south of the mine. Native copper occurs in the trap. The ores are too lean to warrant modern operation.

At the Higby mine, 1.5 miles south of the Simsbury opening, cuprite, chalcocite, malachite, azurite and bornite also occur in sandstone, but are in smaller quantities than at Simsbury.

The Tallman mine is located just north of New Haven, in Hamden Township, New Haven County. Here occur bornite, chalcocite and malachite, with sphalerite, galena, barite, quartz and calcite. The minerals are found along the contact of intrusive diabase and Triassic sandstone, and were once mined from one or more vertical shafts, an incline and a 100-foot cross-cut. The deposit is of negligible importance.

The Copper Valley mine,[2] two miles east of Cheshire, just north of the road leading from Cheshire to Wallingford, Wallingford

[1]Weed, W. H., Copper deposits of the Appalachian States ; U. S. Geol. Survey Bull. 455, pp. 35-36, 1911.

[2]Schairer, J. F., Minerals of Connecticut ; Connecticut Geol. and Nat. Hist. Survey Bull. 51, pp. 104-5, 1931.

Township, New Haven County, was in operation in 1812 and 1836. The old dumps now show large masses of bornite and chalcocite covered with malachite. There is a three-foot dike which cuts Triassic sandstone, and the ore minerals impregnate fractured sediments adjacent to the dike. Calcite and talc are also present. Similar ores occur one mile to the west, and at a locality two miles from Walcottsville.

In a slightly different category and of considerable geologic interest, is the famous Bristol mine,[1] situated along the west wall of the Connecticut Triassic Lowland, 4 miles north of Bristol and 1.5 miles north of Polkville, Bristol Township, Hartford County. This mine was opened in 1839 and was worked intensively between 1847 and 1854, reportedly producing copper ore with a value of nearly $200,000. It was reopened between 1888-1895, but has been inactive since. The ore minerals occur at the fault contact of Triassic sandstone and the crystalline Hartland schist. The fault strikes N. 35° F., and the plane of dislocation dips 70° east. Probably the displacement along this border fault is in excess of 1,000 feet.[2]

Ore minerals at the Bristol mine include chalcocite, bornite, chalcopyrite, native copper, malachite, azurite, cuprite and a little covellite. These occur with other metallic minerals including sphalerite, galena, molybdenite, siderite, pyrite and barite. Allophane, talc, quartz, feldspars, muscovite, biotite, garnet, tourmaline and calcite are also present. There is a little native silver with the copper. The chief ore mineral is bornite, which occurs in vugs and veinlets one to five inches wide, together with impregnations of chalcopyrite and chalcocite. Films of native copper are common, some extending for several feet. The ore occurs in a mineralized zone of brecciated rock along the fault plane. This breccia is visible at the surface, and has been considerably decomposed during weathering and attendant kaolinization. It has been followed underground by shafts to the ore, which is disseminated- where the breccia has been mineralized by copper-bearing solutions. There are several horsts of pegmatite in the breccia, and the richest ore has been reported from the walls of these bodies.

The locality is famous for the excellence of its specimens of crystalline chalcocite, some masses of which have been determined by Bateman[3] to be hypogene or primary in origin. It is his belief that chalcocite was directly deposited by solutions associated with the

[1] Weed, W. H., op. cit., pp. 36-37.
[2] Wheeler, Girard, West wall of the New England Triassic Lowland; Connecticut Geol. and Nat. Hist. Survey, Bull. 58, pp. 26, 61-62, 1937.
[3] Bateman, A. M., Primary chalcocite; Bristol copper mine, Connecticut; Econ. Geology, vol. 18, pp. 122-166, 1923.

Triassic igneous intrusions, and that the epoch of mineralization occurred and ceased long before the end of Triassic sedimentation. The fault plane served as a channel for these ascending solutions, and according to this hypothesis the faulting was in progress during Triassic deposition.

Without entering into a discussion of particulars at this locality, one may conclude that while the exact time of mineralization is not clearly defined, probably the mineral solutions followed the west border and interior fault systems at a time late in Triassic deformation, whenever that event took place, whether after or during Triassic sedimentation.

Near Meriden, Connecticut, a specimen has been reported showing a core of native copper surrounded by a shell of chalcocite. This occurrence clearly indicates the chalcocite to be the younger mineral.[1]

### *Pennsylvania*[2]

None of the few Pennsylvania Triassic copper deposits has proved to be of importance or lasting value. The old Perkiomen and Ecton mines are located about 5 miles northwest of Norristown, 1 mile east of Oaks, and near Audubon in Lower Providence Township, Montgomery County, and there are a few extensions across Schuylkill River in Chester County. The ore minerals of these abandoned workings are chalcopyrite and malachite occurring in light red-gray coarse sandstone and dark-red sandy shale of Triassic age cropping out a short distance north of the point where the Triassic overlaps crystalline terranes of the Piedmont.

About eight miles due north of the above locality are several old copper prospects[3] near Woxall (Mechanicsville), Upper Salford Township, Montgomery County, about one-half mile southeast of Sumneytown. Another prospect occurs one-half mile west of Schwencksville. These prospects lie in a belt of highly altered purplish baked shale that is similar to the "hornfels" of certain New Jersey localities. The zone of alteration follows the contact of a thick intrusive diabase sill whose thermal effects extended some distance into the adjoining Triassic shale and sandstone. A zone of shattering is located along a small faulted area that served as a channel for

[1] Butler, B. S., and Burbank, W. S., Copper deposits of Michigan; U. S. Geol. Survey Prof. Paper 144, p. 143, 1929.

[2] Wherry, B. T., Newark copper deposits of southeastern Pennsylvania; Econ. Geology, vol. 3, pp. 726-738, 1908.

[3] Bascom, Florence, et al., Geology and mineral resources of the Quakerstown-Doylestown district, Pennsylvania and New Jersey; U. S. Geol. Survey Bull. 828, pp. 52-3, 1931.

copper-bearing solutions. The ore minerals are chalcopyrite, bornite, malachite and calcite in veins and fissures that extend more or less vertically through the altered shale.

A little native copper is also present, as well as zeolites, pyroxene, epidote and calcite.

In York County,[1] malachite and chrysocolla are found coating and impregnating carbonized fossil wood in Triassic rocks at the LeCron prospect, 1.25 miles south of Zion View. There are two or more prospects near Hunterstown, Adams County.[2] About one-half mile north of this town, copper minerals occur in a contact zone between diabase and shale. The latter is brecciated, contains epidote veining and shows a pink discoloration ; copper carbonates are visible in the old mine dumps. Another prospect occurs about 3 miles northeast of Hunterstown in altered shales and sandstones near diabase. Copper carbonate stains occur here also. A small pit has been dug one mile east of Fairfield, Adams County, in shale at a diabase contact where a few traces of cupriferous minerals may be seen. Copper carbonate stains also occur at several places near Gettysburg.

### *Maryland*

A few localities in the Maryland Triassic belt are reported to show copper minerals, but none is found in sufficient abundance to deserve special mention.

### *Virginia*[3]

Sparsely disseminated copper deposits occur in red Triassic sandstones and shales in northeastern Virginia. There are no veins nor workable prospects, and the minerals occur mostly as films or thin coatings on joint surfaces, or as small disseminated grains in porous rock.

The Goose Creek[4] prospect occurs on the west side of Goose Creek, one mile north of the Leesburg-Washington pike, Loudoun County. The ore minerals are chalcopyrite and pyrite, altered to azurite and spectacular hematite ; calcite, quartz and epidote are also present. The minerals are found in red sandstone and shale near their faulted

[1] Stose, G. W., Geology and mineral resources of Adams County, Pennsylvania ; Pennsylvania Topog. and Geol. Survey Bull. Cl, pp. 138-9, 1932.

[2] Stose, G. W., and Jonas, A. I., Geology and mineral resources of York County, Pennsylvania Topog. and Geol. Survey Bull. C67, p. 186, 1939.

[3] Watson, T. L., and Weed, W. H., The Virginia copper deposits ; Econ. Geology, vol. 1, pp. 309-330, 1906.

[4] Shannon, E. V., Mineralogy and petrology of intrusive diabase at Goose Creek, Loudoun Co., Virginia; U. S. Nat. Mus. Proc., vol. 66, art. 2, 86 pp., 1924.

contact with a massive Triassic border of conglomerate and also near a dike or stock of diabase. All minerals are too scarce to warrant mining, although there have been several attempts to work them.

Five miles east of Leesburg, near Sugar Run, greenish sandstones are interbedded with red Triassic shales. The light-colored beds contain films or coatings of malachite, and carry a little chalcocite associated with carbonized plant remains.

The Brentsville prospect,[1] is situated a few hundred feet southeast of the old Court House at Brentsville, Prince William County. Here malachite and azurite are associated with red shale near the east border of the Triassic basin ; no nearby diabase is reported. The copper minerals occur in small fissures and on rock surfaces which they stain bright blue and green. The same minerals are reported in a nearby sandstone quarry.

Two and one-quarter miles southeast of Bealeton, Fauquier County, and 100 yards north of the public road, is an old copper prospect that shows crystalline pyrite, amorphous chalcopyrite and calcite in a very hard blue calcareous altered shale. The minerals occur either in small fissures, or are disseminated through the shale. The locality is about 5 miles west of the eastern Triassic border, and occurs between two diabase dikes of considerable size.

The Stevensburg prospect[2] is 4.5 miles east of Stevensburg, near Batna, Culpeper County. The chief minerals, chalcopyrite, pyrite and azurite, are found in small fissures or are disseminated through red Triassic shale and sandstone. Rich specimens may be obtained, but the brilliant color of the carbonate gives a misleading impression of the volume of the ore, which is too small to warrant mining.

Another prospect occurs west of the Southern Railway tracks, 2.5 miles south of Culpeper, Culpeper County. A small pit has been dug in a mineralized zone in a Triassic fault breccia a short distance west of the Mt. Pony diabase intrusion. The minerals are chalcocite, azurite, malachite and specular hematite, which occur in the matrix of the conglomerate or breccia, here composed of diabase fragments in a siliceous cement.

A little chalcopyrite is disseminated through red shale and sand-stone near Somerset, Orange County ; no igneous rock is reported in the vicinity. Some carbonate stains are visible and were responsible for excavations at the old Taylor mine, once operated here.

[1] Roberts, J. K., Geology of the Virginia Triassic; Virginia Geol. Survey Bull. 29, pp. 134-136, 1928.
[2] Weed, W. H., op. cit., pp. 92-93.

### *Summary*

With the possible exception of the Simsbury and Bristol mines in Connecticut, which may be compared in output and commercial value with the Schuyler mine of New Jersey, practically all Triassic copper localities of other eastern States besides New Jersey are of insignificant economic importance and cannot justify any attempts to develop them as copper mines. The brilliant and fairly common colors of copper-carbonate minerals first attracted attention to these localities, and unfortunately kept alive the hope of discovering rich veins of ore. No profitable return has ever resulted from the unhappy attempts to exploit these minerals, and there is nothing known to encourage further investigation.

These brief comments on the Triassic copper ores of other States serve to document the conclusion that the New Jersey ores are essentially like the analogous deposits of the eastern seaboard states and Nova Scotia. Indeed, the whole picture of Triassic copper occurrences of this area offers little of economic promise despite a long and diversified history of investigation and exploitation, most of which was fruitless.

## COPPER DEPOSITS OF NEW JERSEY NOT IN TRIASSIC ROCKS

The copper deposits described previously occur in Triassic rocks and include practically all economic occurrences of this ore in New Jersey. The main New Jersey deposit in rocks other than Triassic is the Pahaquarry ore of Warren County, which is contained in Silurian sandstone. (See figure 1.) A few unimportant occurrences of copper minerals are reported in crystalline rocks of probable pre-Cambrian age.

### PAHAQUARRY MINE

*Location*

The old Pahaquarry (Pahaquarri or Pahaquarra) copper diggings are situated near the former site of Dimmick's Ferry across Delaware River, 8 miles above the town of Watergap and 20 miles southwest of (below) Minisink Island. (See figures 10 and 11.) The locality is about 6 miles southwest of Flatbrookville and is approximately two miles due north of Mt. Vernon. It is situated in Pahaquarry Township of Warren County, about half a mile from the southeast bank of the river. The mine property and old buildings now belong to the George Washington Council, Boy Scouts of America.

It is difficult to reach the mine by automobile, the only route being the partly improved road which follows the southeast bank of the Delaware between Dunnfield and Millbrook. An old wagon road formerly crossed Kittatinny Mountain from the ferry to Mt. Vernon, but this route is now impassable for automobile traffic.

The mine openings lie on the northwest flank of Kittatinny Mountain at an elevation of about 650 feet above sealevel. The mountain slope is rocky and mostly wooded ; for except along the river, the region is poor farm land and is thinly populated. Long ago, however, the road past the mine was an important colonial highway, then widely known as the Old Mine Road. In December, 1776, General Gates marched down this road with seven regiments to reinforce Washington's depleted army only three days before the famous crossing of the Delaware.

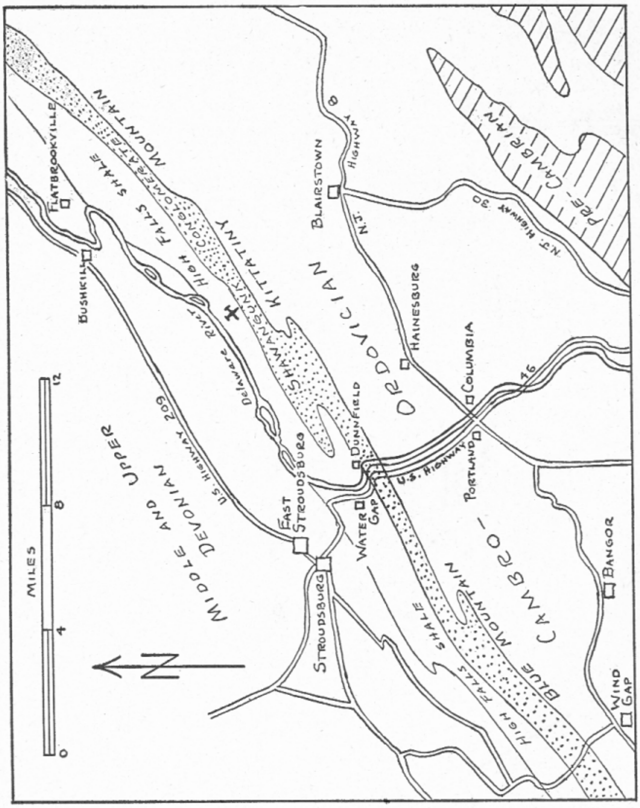


Fig. 10. Generalized sketch map of the Pahaquarry area, showing location of the old mine workings, the surface outcrop of the Shawangunk conglomerate and High Falls shale. The old Mine Road followed the Delaware River down to Water Gap.

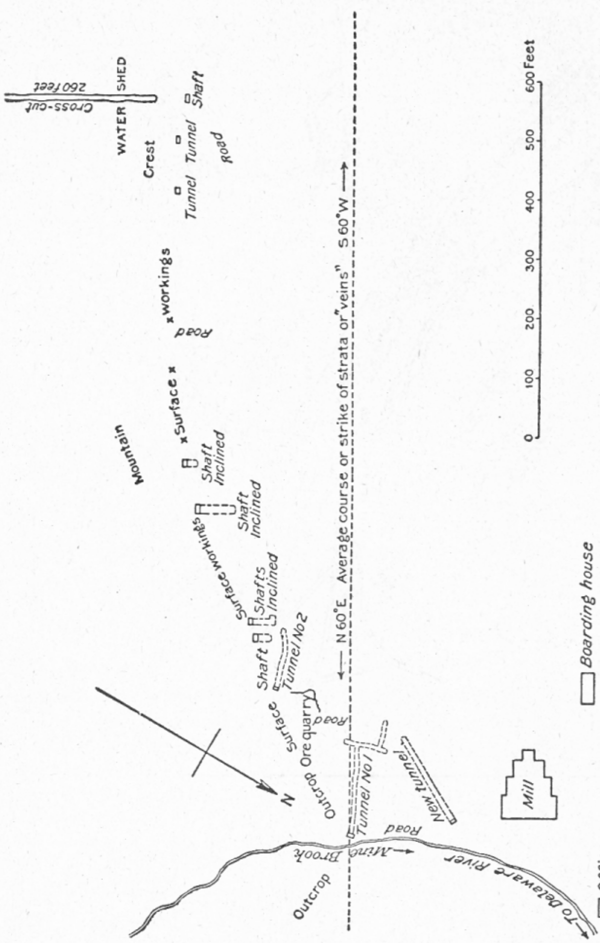


FIG. 11. Sketch map of the Pahaquarry area made during period of last mining activity. (Source: Wm. Lee Phyfe's unpublished Ms.)

*History*[1]

There is considerable legendary lore and a little direct evidence to indicate that the "Mine Holes of Pahaquarry" are the oldest copper mines in New Jersey if not in the United States, and that they are among the oldest mines of any kind to be worked by Europeans on this continent. The diggings seems to have been first excavated by the Dutch during the middle of the 17th century.

A report of one Hendrick van der Capellen, written from New Netherlands in October 1644 to deputies of the Dutch West India Company at Amsterdam, Holland, includes the following statement:[2]

> "Mines of copper and lead have been discovered in these countries, particulars of which have been given to this Director. A private individual has brought here copper ore that is very rich, and hath also some silver in it. Orders have been given to test it further."

So many other rumors of copper discoveries reached Holland that, under date of April 22, 1659 the home Commissioners of the "Colonie on the Delaware River" wrote vigorously to Vice-Director Alrichs from Amsterdam, Holland, as follows :[3]

> "We have heard indirectly that there is a great probability of mineral being discovered in New Netherlands, and even some copper ore which has come thence has been shown to us. In order to inquire further about it, we have examined Claes de Ruyter, an old and experienced inhabitant of that country, from whom we have learned this much, that the reported copper mine does not lie on the South River, but that a crystal mountain (Kittatiny Mountain?) was situate between that colonie and the Manhattans, whereof he himself had brought divers pieces and specimens ; furthermore that the acknowledged gold mine was apparently there . . . and the Indians (said that) quick silver was to be found there also. You are hereby recommended to look further into this matter."

Piecing together the fragmentary records of this early period, one may deduce that the old Dutch settlement of Esopus (now Kingston, New York, founded on Hudson's River about 1615) sent energetic traders and pioneer prospectors southwestward along the Esopus, Wallkill, Rondout and Neversink Rivers. These adventurers established a permanent settlement, then called Minisink, in the vicinity

[1] See particularly Snell, J. P., History of Sussex and Warren counties, New Jersey, p. 697, Philadelphia, 1881; Cummins, G. W. History of Warren County, New Jersey, pp. 3, 221-2, New York, 1911; Shampanore, Frank, History and directory of Warren County, New Jersey, pp. 29G-30G, Washington, N. J., 1926; and Honeyman, A. V. D., Northwestern New Jersey: A history of Somerset, Morris, Hunterdon, Warren and Sussex counties ; vol. 2, p. 734, New York, 1927.

[2] O'Callaghan, E. B., Documents relating to the Colonial History of New York; vol. 1, p. 148, 1856.

[3] Idem, pp. 60-64, vol. 2.

of the present town of Port Jervis. As this settlement flourished, a good road was soon constructed through the "howling wilderness" from Esopus to Minisink, a distance of about 100 miles. Because it was used for the hauling of ore, the road was known as the "Old Mine Road", and it became a popular route in early colonial times. It was substantially built without government aid at a time when there were few highways on the continent, and for more than a century it was the longest stretch of good road in the colonies. It was well travelled as late as 1800, and played an important part in Washington's victory at Trenton in 1777. An Indian trail, built into a road about 1650, led from Minisink through Culver's Gap southeastward across New Jersey to Ambo Point, now Perth Amboy. This was primarily a trading route and was known as the Minisink Trail. For a short time Arent Schuyler occupied and maintained a trading post along this road. (See page 40.)

It is believed that adventurous Hollanders exploring southwestward from Esopus, found a small lead mine near Ellenville, New York, about 50 miles from the Hudson, and first constructed their road to this mine. Encouraged by their findings, they pushed farther to the southwest, and discovered the Pahaquarry copper deposits below Minisink on Delaware River some time before 1659.

Little is known about these ancient mining activities, but it is likely that they were small and unorganized. The ore is thought to have been hauled down the Mine Road to Esopus, and thence shipped to Holland. The mining epoch lasted for only a few years, probably less than ten, for the English took over the colony in 1664, and all independent Dutch enterprises were speedily brought to a close. The conquest of New Netherlands dampened the ardor of the adventuresome miners, many of whom are believed to have returned to Holland. In 1697 when the Schuyler and Swarthout land patents in the Minisink country were purchased from the Indians, the mines had been long abandoned, the tunnels had slumped, and their openings were grown over with vegetation.

When the first English settlers of Warren County came down the Old Mine Road in 1727, all trace of the miners had vanished, and the new colonists could not find out who had dug the holes, when they had been excavated, or even what ore had been sought. Probably mining ceased in 1664, for the strict British regulations on export made it unprofitable for the Dutch to continue operations of this type. Robert Erskine, Surveyor General for Washington, mapped the Old Mine Road in 1777, and it is mainly from his survey that its former route is now known although Nicholas Scull apparently made an earlier survey in 1739.

Although crude and small-scale, the early Dutch operations nonetheless were ambitious for that period. Most of the excavations were exploratory only, and it is possible that they were interrupted before any intensive work could commence. One of the openings was a tunnel about 7 feet high and 6 feet wide that ran into the hill for nearly 100 feet ; it then turned to the right for about 50 feet, and again to the left for a similar distance. It can now be entered for only the outer 50 feet. There were several other openings of this kind, while two inclined shafts 40 and 60 feet long were sunk on the dip.

If Peter Kalm's account of 1748 was correct, the copper deposits were known to the Indians even before the period of Dutch discovery, for he wrote as follows :[1]

> "Some Dutchmen who live in Philadelphia preserve the account among them that on digging in this mine, the people met with holes worked in the mountain out of which some copper had already been taken; and they found even tools which the Indians probably made use of, when they endeavored to get metal for their pipes."

It should be noted that Kahn erroneously assigned the above account to Schuyler's mine at Arlington ("Hanover"), which obviously does not fit the description, there being no "mountain" at Arlington. (See also page 44.)

From the early epoch of Dutch operation, through the next 200 years, no activity is recorded at the Pahaquarry locality, and the mines lay neglected during this long period.

About 1860 the property was investigated again, apparently by Philadelphia interests, and some of the long-abandoned workings were cleaned out. Samples of ore were assayed, and active mining was contemplated. The ore, however, was found to be too poor to work, and nothing resulted from the venture. The mines again lay idle until 1868, at which time they were owned by Mr. Keyser of Hainesburg, who explored the old tunnels and reported that there was then one adit, 150 feet long, and an inclined shaft.[2] An unsuccessful attempt was made to open the mines about 1900, but nothing came of it save to redirect attention to the former mining history, begun 250 years before.

In 1901, the Montgomery Gold Leaf Mining Company bought 1,028 acres of land from Philip Godley of Philadelphia, including the old

[1] Kalm, Peter, Travels into North America ; vol. 1, p. 300, London, 1772.
[2] Cook, G. H., Geology of New Jersey; p. 680, Newark, 1868.

copper workings. The company prospected widely over the area, and dug some new cross-cuts at several points. H. D. Deshler of Belvidere was secretary and O. R. Deshler was president of the company, which sold mining stock mostly to residents of the near vicinity. Some token mining was done, and one of the new tunnels is reported to have penetrated the mountain for 240 feet. By 1905, however, there had been little or no genuine mining, although 100 tons of ore was reported to have been removed. A 200-ton mill was erected to use the Keith process,[1] patented by Dr. N. S. Keith, metallurgist for the Montgomery Company.

In 1906 the Pahaquarry Copper Company (successors of the Montgomery Company) reported that operations were "at a stage where the ore and methods of treatment can now be tested", but in 1908 the company officials admitted that the character of treatment and equipment at hand needed to be "materially altered". In 1910, they wrote that they had been compelled to close down the previous year so as to install a pumping station, and that they had electrified the plant, adding a flotation system as well as a large ore-drier. The mine was operated for three months in 1911, and the 200-ton concentrating mill was active for two months, but no concentrates were shipped. It was reported that the ore mineral broke too finely for profitable extraction by the process used, and that losses in tailings were considerable. Also, that experiments were being made to improve the recovery.

Unfortunately the whole venture proved fruitless, the hope of successful exploitation apparently being no better grounded than in the painfully parallel history of operations at the Schuyler mine, 10 years before. The Pahaquarry Copper Company went into the hands of a receiver, and the property was ultimately taken over by the Delaware Valley Exploration Company, of which Philip Godley of Philadelphia, an earlier owner, was president. It was rumored in 1917 that this company was negotiating with an English group that represented the Lockwood process for extraction of copper, but the years passed with no further activity at the locality. Ultimately the mine buildings were dismantled and the workings abandoned.

Some years later the mines were included in the purchase of a tract of 1,500 acres by the George Washington Council, Boy Scouts of America, for use as a permanent summer camp. The little-used machinery was broken up, hauled away and sold as junk. One of the

[1]It may be noted that Dr. Keith had previously held a similar post in the unfortunate Arlington Copper Company, lately active at the Schuyler mine. (See footnote, page 56.)

old mine buildings has served as a mess hall and handicraft shop for the scouts-its only profitable use since construction.

The Pahaquarry mine was never profitable, and its history fails to suggest any prospects of future economic importance. The extreme antiquity of the workings lends them historical interest, and the ore occurrence in Silurian rocks gives the copper minerals geologic significance. As a workable mine, however, the locality is unpromising.

*General Geology*

The Pahaquarry mine occurs on the northwest slope of Kittatinny Mountain, from 150 to 450 feet above Delaware River. (See figure 10.) The geologic sequence near the mine is as follows :

| | | |
|---|---|---|
| | Decker formation | 60 feet |
| | Bossardville limestone | 75 |
| Silurian | Poxino Island shale | 200 |
| | High Falls formation | 1800-2000 ± |
| | Shawangunk conglomerate | 1900 ± |
| Ordovician | Martinsburg shale | 3000 ± |

The ore-bearing beds occur in red and gray sandstones of the High Falls formation, which is a thick assemblage of red and green-gray nonmarine rocks of middle and late Silurian age. This formation overlies the Shawangunk conglomerate and is apparently overlain by the Poxino Island shale, but the exact relations of its upper and lower contacts are far from clear. The main body of the formation consists of fairly massive sandstone and intercalated shale. The sandy zones show no cleavage, but exhibit numerous joint planes; the red shales contain marked cleavage that dips southeastward at steep angles. Most of the shales are thin bedded, with smooth or dimpled surfaces and somewhat splotchy colors. High Falls sandstones are gray-green to green in color and vary in texture from fine to coarse ; many are rough-bedded and most are pebbly. The exact thickness of this formation is difficult to determine, both because of minor folds that complicate the local structure and because of the uncertain location of the precise top and bottom of the unit. An estimate by Kümmel gives 2,300 feet for the thickness of the High Falls near the Pahaquarry mine, but the average is probably somewhat less, possibly 1,800-2,000 feet.

Because no fossils have been found in it, the age of the High Falls formation can be approximated only by its stratigraphic position, a method that is not sufficiently accurate to establish its exact correlates. Data derived from studies in eastern Pennsylvania, however, suggest that the underlying Shawangunk conglomerate is partly the northern equivalent of the Tuscarora sandstone (lower Silurian) of Pennsylvania, and that it also ranges higher than the Tuscarora to include some, possibly a considerable part, of the Rose Hill (Clinton) horizon as well. From observations in Maryland and Pennsylvania, it is known that a red-shale facies gradually replaces marine late Silurian rocks in an easterly direction, forming the Bloomsburg redbed facies of the upper Silurian of Maryland and Pennsylvania. It is believed that this facies passes directly eastward into the High Falls formation, where it replaces not only the late Silurian, but also extends downward to supplant the equivalent Niagara beds, and probably the upper part of the Clinton horizon also. The suggestion is therefore made that the High Falls formation is the nonmarine redbed equivalent of the upper Clinton (Rose Hill), Niagara (McKenzie) and, possibly, lower Cayugan (Wills Creek) formations of central Pennsylvania. The formation thins northward into New York State, losing its sandy beds, and becoming a thin red shale at High Falls, New York, where it is possibly 200 feet thick. It is there overlain by the Binnewater sandstone and Wilbur limestone, both of probable Tonoloway age (late Cayugan) ; and it is underlain by a thinned Shawangunk conglomerate.

The Shawangunk conglomerate, which underlies the High Falls formation at the Pahaquarry mine, maintains the crest of Kittatinny Mountain with bold rocky bluffs that supply much coarse talus to the mountain flanks. It is an indurated sandstone and conglomerate, many beds carrying pebbles up to one inch in diameter. There are several small lenses of dark shale, and some green and reddish shale, especially in the upper portion. As the High Falls formation is sandy near its base, the mutual boundary between the two formations is difficult to establish.

The sandy layers of the Shawangunk are even-grained, and the entire formation shows evidence of good sorting ; for even the pebbles of conglomeratic zones show a small range of size in any one bed. A few strata are cross-bedded, while others show ripple marks. Much of the rock is gray or dark-gray on weathered surfaces, and many beds approach the lithologic character of quartzite. Probably the term "subquartzite" is appropriate for much of the formation. The thickness of the Shawangunk formation varies but must be close to 2,000 feet near the mine. It does not contain fossils in this vicinity, although small collections obtained elsewhere indicate an early Silurian age. Its upper portion probably includes representatives of the early Clinton. It is unconformably underlain by the Martinsburg shale of Ordovician age.

The basal beds of the Shawangunk formation contain considerable pyrite, and it is reported that the lower few inches of the rock carry native gold, in places to an alleged value as high as $11 per ton.[1] "Anywhere along the outcrop of the contact between the conglomerate and the Ordovician slate, one can obtain pyrite ore that is rich in gold."[2]

The red shales of the upper part of the High Falls formation are concealed along Delaware River, where the next higher formation is a buff or greenish calcareous shale cropping out on Poxino Island about one mile north of the Pahaquarry mine. This shale is irregularly bedded and contains no fossils ; its lower contact with the High Falls shale is concealed. The rock has been called Poxino Island shale, and it has an estimated thickness of 150-200 feet, being overlain by the Bossardville limestone of Tonoloway age (latest Cayugan). Probably the Poxino Island shale is Cayugan, possibly early Tonoloway or late Wills Creek in age. The Bossardville limestone, 50-100 feet thick, is overlain by the Decker formation above which are rocks definitely of Devonian age.

The geologic structure of the Pahaquarry area is that of a gently dipping homocline wherein the rugged Shawangunk conglomerate, which forms the summit of Kittatinny Mountain, dips about 45°, N. 30° W. The upper side of the mountain is a dip-slope developed on the conglomerate, but the High Falls formation flanks the mountain in increasing volume on the lower, more gentle slopes where the conglomerate passes into the ground. Differential erosion of High Falls sandstone and shale has produced minor terraces and swales along the flank of the hill, while Delaware River has entrenched its channel on the soft upper red shales of this formation.

There are slight local disturbances in the structure of the upper part of the High Falls formation, minor synclinal and anticlinal folds being revealed by slight changes in dip. These are visible in the excellent exposed section across the truncated end of the mountain at Delaware Water Gap. In general, however, the rocks at the mine have a uniform strike, and any variations from the dip of 40-45° are small. There is no indication of faulting near the mine.

[1] Cook, G. H., op. cit., p. 147.
[2] Weed, W. H., Copper deposits of the Appalachian States; U. S. Geol. Survey Bull. 455, pp. 54-57, 1911.

*Nature and Occurrence of the Ore*[1]

The chief ore mineral of this locality is chalcocite which impregnates sandstone of the middle part of the High Falls formation in a zone that may be traced for several thousand feet along the strike, and may range through a vertical thickness of 200 feet. The portion of the formation containing the copper minerals consists of gray sandstone in beds 2 to 6 feet thick separated by bands of red shale six inches to 2 feet thick. The ore-bearing sandstones are dense and not especially permeable, although they are traversed by numerous vertical joints that strike N. 20 E. The intervening shales have a splintery fracture, possibly due to a rudely developed cleavage that corresponds with the direction of the sandstone joints. One sandstone ledge, known as the "watershed", is conspicuously exposed above the main workings, and has been stripped for a lateral distance of nearly 2,000 feet along the strike. Several crosscuts and old workings reveal sections across the ore-bearing zones and indicate the character of the beds worked.

The grayish mineral chalcocite is finely impregnated through the Silurian sandstone, which because of its similar gray color, generally conceals the copper ore. Probably attention was first directed to the mineral by the green carbonate stains which develop from incrustations of malachite and chrysocolla that coat some bedrock surfaces. These stains occur on joint planes, but do not penetrate far below ground. Chalcocite also occurs in thin seams along certain bedding or joint planes, in places extending some distance into the bedrock. Less commonly the fractured surfaces of the sandstone reveal patches several inches or even a foot across wherein chalcocite has partially replaced the body of the rock. These patches, or nodules, have irregular shapes and occur in groups that are unevenly distributed through the rock. In these richer orebodies, the copper mineral is readily visible to the naked eye. Throughout most of the leaner rocks, however, it is completely invisible until it is specially concentrated, as by panning the pulverized sandstone.

The ore beds crop out near the mine in a ravine known as Mine Run, their lowest exposures being about 150 feet above the Delaware or 450 feet above sealevel. From this point to an elevation of 750 feet along the ridge, the rocks appear to be more or less continuously cupriferous. Thus there is a considerable width as well as length of

[1]See particularly Weed, W. H., op. cit., pp. 54-57; Kummel, H. B., Mineral industry of New Jersey; Ann. Rept. State Geologist of New Jersey for 1901, pp. 160-61, 1902; do., Ann. Rept. State Geologist of New Jersey for 1908, pp. 133-34, 1909.

exposed copper-bearing beds. The thickness of the copper-impregnated zone has not been accurately determined but may be 200 feet or more. If these estimates of extent and thickness are reliable, the volume of low-grade ore present is noteworthy. It has been reported that 100 samples of the ordinary gray sandstone averaged 3.25 per cent copper in the form of chalcocite.

### *Genesis of the Ore*

The origin of the Pahaquarry copper deposits is far from clear, for the extensive occurrence of chalcocite in a Silurian sandstone is unique in the eastern United States. Copper ores of this general type are known in late Paleozoic rocks of many regions, and are common in western Triassic sandstones ; but there is no close eastern analogue in rocks of this age with which the New Jersey deposit may be genetically compared.

Perhaps the most important difference between the Pahaquarry deposit and other New Jersey copper localities lies less in the age of the containing rocks than in an apparent independence of igneous rocks. Whereas all Triassic occurrences reveal at least a probable genetic association of the copper minerals with some igneous body, the Pahaquarry deposit has no such detectable relation. It is true that on the opposite side of Kittatinny Mountain some 30 miles northeast of the Pahaquarry mine there is an intrusion of nepheline syenite near Beemerville, New Jersey, and that this intrusive may be an apophysis of a larger igneous body which might extend beneath or near the Warren County copper locality. On the other hand there is no cogent reason to link the copper minerals with this intrusive, and it cannot anywhere be seen cutting the adjacent Shawangunk conglomerate. The intrusive is therefore, probably older than the Shawangunk (and the overlying High Falls formation) and it seems most probable that the cupriferous occurrence is independent of any igneous material.

Thus it appears that the Pahaquarry copper is definitely epigenetic in character and contains no material of hypogenic origin. On the basis of evidence at hand, one may surmise that the original copper minerals were disseminated in the sediments at the time of deposition, possibly as finely divided copper ores, in part precipitated from solutions derived from the land area of the time, in part carried as rare cupriferous detritus.

The High Falls shale at High Falls, New York, contains a conspicuous quantity of cubic pyrite. The mineral occurs in red shales from which perfect cubic crystals may be obtained, some being as much as one-half inch wide. This pyrite is sparsely accompanied by chalcopyrite, attesting the presence of copper metal there also.

It is reasoned that the High Falls formation is of shallow-water or even subaerial origin ; that it accumulated rapidly ; and that deposition occurred under conditions of partial, or at least seasonal aridity. The sediments represent alluvial or coastal-plain detritus in which small amounts of both iron and copper were carried in finely divided state. Probably the metals were assembled during erosion of the same rocks that produced the sedimentary debris. The iron may have been transported as grains of magnetite, the copper as tiny particles of chalcopyrite embedded in heavy-mineral grains in the sedimentary debris. Concomitant conditions of aridity or partial aridity led to local impregnations of salt and gypsum in allied red shales.

When atmospheric waters charged with salt and gypsum reached beds containing the cupriferous detritus, they are believed to have taken the copper into solution, leaching it from the zones in which it had been contained. The waters which concentrated the copper are thought to have been mainly sodium-chloride or calcium-sulphate solutions capable of carrying copper sulphate or, possibly, copper chloride. These concentrating solutions transported the metal, de-positing it in certain horizons probably not far removed from the original source of the copper. The geologic features suggest deposition at relatively low temperatures, presumably below the point (91° C.) above which octahedral chalcocite is produced.

In other deposits of this general type, as in redbeds of the south-west, deposition of copper has taken place where the solutions en-countered carbonaceous material or plant remains in the rocks. As the latter are conspicuously lacking in the High Falls formation, it seems probable that here the copper-bearing waters relinquished their metal for some other reason, possibly in zones where they encountered other, more acidic, meteoric circulation.

Inasmuch as the chalcocite of the High Falls formation has been partially altered to carbonate and silicate minerals, it is clear that a later generation of meteoric waters in the zone of oxidization must have induced production of younger alteration minerals, whose genesis is a function of fairly recent exposure of the copper-bearing beds to surface circulation.

In summary, it is believed that the disseminated copper of the Pahaquarry deposit is assuredly epigenetic in origin, being concen-trated by meteoric solutions that leached the metal from minute grains of chalcopyrite previously scattered through the sandstone in detrital form. As the copper minerals are all supergene, there is no reason to anticipate richer deposits or for that matter any copper minerals at greater depth.

*Economic Importance*

All ore deposits of the general Pahaquarry type are of low tenor, and can be utilized only in exceptional cases. The importance of any locality is a function of the ease with which its copper can be recovered from lean ore, and of transportation and other costs. It has been indicated that a considerable volume of copper-impregnated sandstone occurs at the Pahaquarry mine. Data are not now available, however, to guarantee that the ore minerals can be separated from the rock in workable quantities, or that a concentrated ore can be satisfactorily smelted in a profitable enterprise. It must be strongly suspected that this is not a deposit of commercial value or potential economic significance ; yet such a suspicion has not been proven beyond shadow of doubt, and the status of the deposit must still be described as uncertain. Nonetheless, the writer cannot now recommend the expenditure of time and money needed to remove the uncertainty ; the risk of failure is too great.

## PROSPECTS IN NEW JERSEY CRYSTALLINE ROCKS

The north-central or "Highlands" portion of New Jersey is an extension of the New England Upland, a physiographic province which continues from West Point on the Hudson southwestward to the Reading Hills of eastern Pennsylvania. As it ends abruptly near Reading, Pennsylvania, it has been called the "Reading Prong" of the New England Upland. The oldest rocks of this belt are highly metamorphosed graphitic gneisses with intercalated quartzites and marbles, of which the best-known member probably is the Franklin limestone (usually a marble). Analogous gneisses in eastern Pennsylvania (Honeybrook uplift) may be represented in the Pickering gneiss. These ancient rocks were intruded by a younger igneous complex that included the following types : Pochuck gabbro-gneiss, Losee diorite-gneiss, Byram granite-gneiss, and dikes of pegmatite and diabase. The Pochuck is an injection gneiss which includes a dioritic phase, several types of hornblendic gneiss, highly complex schists, and serpentinized limestones; commonly it is heavily granitized. According to Knopf and Jonas,[1] it contains an older amphibolite and a younger metagabbro. As mapped in New Jersey and as described by Berkey,[2] the Pochuck includes some sedimentary gneisses that may be of the same age as those of the Pickering gneiss. As the Losee diorite-gneiss, which is apparently younger than the Pochuck, has intimately invaded the older rock, lit-par-lit injection phases of the two are very common. It is possible that there is a relation between the Losee gneiss of New Jersey and the Canada Hill gneiss of the Hudson Highlands.

The Byram granite-gneiss, apparently the youngest of the larger intrusives, includes a variety of igneous types that intergrade with both Pochuck and Losee gneisses. It may be analogous with the Storm King granite of the West Point region. Still younger pegmatite and diabase dikes also occur in this complicated basement.

A great deal of detailed work still remains to be done on the crystalline rocks of New Jersey, and the exact correlation of these with those of the Piedmont and Blue Ridge regions is as yet uncertain. Problems both of structure and age await solution ; but until more precise determinations are at hand, it may be assumed that they are mostly of pre-Cambrian age—an assumption, however, which may later be partly revised with some of the younger intrusives being assigned to the early Paleozoic.

Widely scattered mineral deposits occur in the New Jersey "Highlands" or local section of the Reading Prong. Best known of these are the zinc deposits of Franklin Furnace, Sussex County, and the numerous magnetite deposits of Passaic, Sussex, Warren, Hunterdon and Morris Counties. In some of these, as at the Sulphur Hill mine, near Andover, Sussex County, associations of copper-bearing minerals are reported, mainly occurring as accessory minerals of no economic value. Three deposits may be noted as typical. They are the Banghart prospect of Hunterdon County, and the Davis and Howell prospects of Warren County. The information available about these prospects is very meager, and there is no economic stimulus to a more detailed study of the deposits. Probably the copper comes entirely from hypogenic chalcopyrite produced during some stage of igneous invasion. The deposits cannot be called copper mines ; rather they are undistinctive mineral localities.

[1] Knopf, F. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pennsylvania; U. S. Geol. Survey Bull. 799, chart opp. p. 68, 1929.
[2] Berkey, C. P., and others, New York and vicinity; 16th Internat. Geol. Congr. Guidebook 9, p. 25, 1933.

*Banghart Prospect*[1]

The Banghart mine, or prospect, is about 1.25 miles northeast of Glen Gardner, in Lebanon Township, Hunterdon County. It is named from the original farm-owner, Abraham Banghart, upon whose property copper minerals were discovered shortly before 1868. Discovery was followed by desultory prospecting during two seasons, about 1867 and 1879. Workings at this locality originally consisted of three small openings that uncovered a streak of very lean ore. In 1879 a shallow shaft was sunk to a depth of 35 feet without revealing more favorable deposits and no further work has been done.

The ore minerals at this locality consist of pyrite and chalcopyrite in a narrow vein possibly 3 feet wide. The deposit occurs in Byram gneiss.

*Davis Prospect*[2]

This now-abandoned prospect occurs on top of Jenny Jump Mountain in Independence Township, Warren County. It was first opened in 1873 by a 25-foot shaft, at the bottom of which was a layer of ore about one foot thick. The ore consisted of pyrite and chalcopyrite, with calcite and some azurite. The latter was observed principally as a coating on joint-planes of the rock. Work was continued in 1880, 1881 and in 1883, and a small quantity of ore was raised. The material proved not to be of economic importance and no additional prospecting has since taken place.

*Aaron Howell Prospect*

Chalcopyrite was also found[3] in association with malachite and azurite "about one-quarter of a mile from Aaron Howell's" near the northeast end of Jenny Jump Mountain where a shaft was sunk to a depth of 50 feet in light-colored gneiss. Some ore is said to have been sent to New York, but recent investigation has shown that the ore was lean and favorable indications pointing towards the possible occurrence of richer ore are lacking.

[1]See particularly Cook, G. H., Geology of New Jersey ; pp. 66, 617, 680, Newark, N. J., 1868; and Bayley, W. S. Iron Mines and Mining in New Jersey; Final Report VII, N. J. Geol. Survey, p. 347, 1910.

[2]Bayley, W. S., op. cit., p. 216.

[3]Cook, Geo. H., Geology of New Jersey, p. 680.

## RESUME OF NEW JERSEY COPPER MINING

With so large an assortment of copper-bearing minerals and so broad an area of distribution, it was only natural that New Jersey should have been one of the first areas investigated in the search for mineral treasures upon which discovery and settlement of the New World had been partly predicated. A brief resume of the copper phase of this mining activity follows.

### DISCOVERY AND EARLY DEVELOPMENT

Almost as soon as the first European settlers established themselves in the new hemisphere, their attention was hopefully turned to the search for its mineral wealth. The pioneer farmer kept a watchful eye on all rocks plowed up in his fields, while the trader eagerly assembled reports of valuable minerals that were prospected near his post. French, Dutch and English colonists all hoped—if not expected—that the new lands would vindicate their discovery by yielding rich metal and ore. Pioneer prospecting, however unskilled and haphazard, soon became the close auxiliary of exploration and settlement.

Thus it happened that the hardy Dutch settlers of the central Hudson Valley explored southwestward up the Wallkill and Neversink rivers, and found deposits of lead in Ulster County, New York, in the early 1600's, and copper a few years later at Pahaquarry in Warren County, New Jersey. The Pahaquarry mines, scarcely more than holes in the mountainside, were ancient and long abandoned at the beginning of the 18th century and little is known about the Hollanders who worked them. Probably they were deserted as early as 1664. Only the El Cobre mine at Santiago, Cuba, is an older copper working to be mined by Europeans in North America.

Another Hollander, one Arent Schuyler, perhaps already acquainted with New Jersey copper, settled near what is now North Arlington, Bergen County, New Jersey, and unearthed copper on his estate about 1712 or 1713. The copper mine which he opened became the most famous in the State, and was worked intermittently for nearly 200 years. The Dod mine in East Orange was discovered in 1720, and other prospects were encountered during the next few years. Indeed such a copper-mining fever spread through the State at that time, that Governor Burnet, reporting to Lord Carteret on February 12, 1722, wrote :[1]

> "There must be a great allowance made for the humour that now prevails to run a-mine-hunting."

Probably the copper minerals near Feltville were found during this period of prospecting, and it is possible that mines opened at Totowa, Flemington, Neshanic and along First Mountain date back to these early days. Colonel John Schuyler worked the Schuyler mine to good advantage during the 1730's and 1740's, while John Dod, then Dod and Roe, and later Frind Lucas kept the East Orange mine active until 1755 or 1760. Not all prospecting was successful, however, for some Bristol merchants who had come from England to open a mine near Arlington, quit their lease in 1745 and gave up mining as an unprofitable venture. In 1746 the Glen Ridge mine was opened, while three years later copper metal was found on French's farm near New Brunswick where Elias Boudinot leased its mineral rights in 1751. By 1753 the Griggstown deposit had been discovered, and the mining of copper had become an extensive, if small and local, colonial industry in New Jersey.

The Schuyler mine, operating under better management than others and perhaps showing better ore values, was so deep in 1748 that a "fire-engine" was ordered from England to pump it dry. Josiah Hornblower brought the engine to Belleville in 1753, where two years later it became a greater attraction to visitors than the mine itself. About the same time somewhat more careful prospecting along First Watchung Mountain near Bound Brook and Somerville located copper minerals at Chimney Rock and nearby sites, a discovery that led to the first serious excavation at what was later to be called the Bridgewater, or American, mine, 3 miles above Somerville.

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[1] A valuable source of incidental contemporary information regarding colonial copper mining is found in the numerous public documents of the period. Specific mention may be made of the following collections of such documents :

a. Documents relating to the colonial history of New Jersey; New Jersey Archives, First Series, vol. 1, pp. 77, 94, 222, 450, 1882.
b. Do.; New Jersey Archives, First Series, vol. 5, pp. 7, 9, 267, 377, 1882.
c. Barber, J. W., and Howe, H., Historical collections of New Jersey; pp. 155, 230, 252, 317, 451, 454, New York City, 1844.
d. Nelson, William, New York colonial documents ; vol. 5, pp. 462, 556, 603.
e. Nelson, William, Calendar of New York historical manuscripts: Dutch ; edited by F. B. O'Callaghan; pp. 286-7, Albany, N. Y., 1865.
f. O'Callaghan, F. B., Documents relating to the colonial history of New York; vol. 1, p. 148, 1856; vol. 2, pp. 60-4.

By 1760 difficulties were being encountered at the Dod mine and the nearby Glen Ridge mine, while the Schuyler property was suffering from repeated changes in managers. The Griggstown mine, nonetheless, kept so actively at work that 160 Welsh miners were digging in its chambers during 1765. The onset of the Revolution, however, slowed most operations, and soon all copper mining was suspended while the heavy hand of the British was being lifted from the newly united colonies. The Dod and New Brunswick mines closed first, and neither was reopened after the war. Next the Griggstown mine shut down. Finally a fire at Arlington so damaged Hornblower's engine that the mine was closed and the Revolution began with no copper mine active in the State.

It is reported that men from Washington's army, encamped near Bound Brook in 1777, salvaged enough metallic copper from the nearby Bridgewater and Chimney Rock mines to forge a small brass cannon. If fact and not legend, this cannon is the sole product of New Jersey copper taken from the ground during the Revolution.

In 1784 a new copper locality at Menlo Park was prospected, and by 1793 the New Jersey Copper Mining Association had organized to reopen the Schuyler mine. Although they spent most of their energy building steam-engines and experimenting with Livingston's steamboat, this new company found time to run the Arlington mine for several years and to reopen the abandoned Glen Ridge mine for a short period. Mining was renewed at Griggstown near the turn of the century, and copper minerals were worked near Stony Brook and at the Hoffman and Balmer prospects. All of these efforts were short-lived, however, and the Schuyler mine was again closed in 1807. Practically all New Jersey copper workings lay idle for the first quarter of the new century, only the Menlo Park mine being active during the War of 1812.

## COPPER BOOM OF THE NINETEENTH CENTURY

For the 50 years following 1820, a second copper fever passed through New Jersey. This began modestly with the development of the Bridgewater Copper Company in 1821, but soon flamed into a speculative wave that was probably stimulated by discovery of the vast copper mines of Michigan in 1841-1848. It flared through the Civil War, and probably would have lasted longer save for the financial depression of the early 1870's. Although stock in New Jersey copper mining ventures worth millions of dollars was sold during these 50 years, neither the State nor the investors seems to have benefited thereby.

The Bridgewater Copper Company operated the Bridgewater Mine from 1821 to 1830, and brought no one including its owner, Augustus Camman, any returns. The Schuyler mine was leased again in 1825 but the machinery failed on the day of opening and the company soon followed suit. The Menlo Park mine was worked in 1827, but seems to have shortly closed, probably being found unprofitable to work. An English company that leased the Schuyler mine in 1833 became discouraged at the low grade of ore and moved away in 1839. At Flemington, where more than $400,000 was spent from 1834-1846, the local company went out of activity without profitably mining any copper. The Washington Mining Company opened the Washington mine near Somerville in 1835, and soon sold out to a Boston company that shortly quit work because of water. The Neshanic Mining Company opened the Neshanic mine near Flemington at considerable expense, but did no serious mining. The main Flemington mine was reopened about 1840, but this project also ended in failure.

In the year 1847 the Raritan Copper Company was exploiting the Raritan mine near New Brunswick ; the Passaic Mining Company held the Schuyler mine; and the Central Mining Company was engaged at Flemington. None of these companies lasted beyond the refurbishing of their properties preliminary to active mining. In 1857 the Hunterdon Mining Company owned the Flemington mine; the Brisk Mining Company was operating the Schuyler mine in 1859, and shortly gave way to the Consolidated Mining Company. The old "mine holes of Pahaquarry", abandoned for 200 years, were being prospected in 1860, and there was talk of organizing a company to mine them, while the Feltville mine, idle since before the Revolution, was temporarily reopened. The True Vein Copper Company prospected the old Hoffman mine and the New York and New Jersey Mining Company leased the Schuyler mine in the period from 1863 to 1865, and two concerns—the New Jersey Mining Company and the Green Valley Copper Company—were active at the Stony Brook locality. The Pahaquarry mines were unsuccessfully opened for a year about 1867.

Again, however, as about a century before, the mining fever suddenly abated. One by one the companies disbanded, closing their operations, and leaving the mining scene. Probably no more than a few new tons of raw ore were taken out of the ground during these hectic 50 years, and it is difficult to find evidence that any metallic copper was derived from this ore. G. H. Cook,[1] State Geologist of New Jersey, wrote pertinently in 1868:

> "Some of these copper mines were opened before the Revolution, and have been worked repeatedly at intervals up to a recent date. Nearly all of these copper mining enterprises are of a speculative character, companies being organized and large amounts of stock sold, and but little mining done. The workings of our copper mines, with few exceptions, have not been regular business operations."

For the 30 years between 1870 and 1900, there was little activity in New Jersey copper. The American Copper Company was organized in 1880, and for 10 years conducted sporadic exploration and a little mining at the old Bridgewater mine, now renamed the American mine. About the same time, Thomas Edison briefly operated the Menlo Park mine. In 1892, the Schuyler mine was reopened by the New York and New Jersey Copper Mining Company ; but the resources of the company were so precarious that miners robbed out the supporting mine pillars, and brought down upon their heads the mine roof and the company's collapse.

Two sandstone quarries enjoyed a brief notoriety in the early 1880's because of copper ore. A rich pocket of chalcocite was discovered in Westlake's quarry near the Schuyler mine, but the ore was quickly exhausted and no more was encountered. Surface workings of the Glen Ridge Quarry and Mining Company cut into a drift of the old Glen Ridge mine, and a few tons of copper ore were shipped to Bergen Point in a short-lived epoch of fruitless excitement.

At the close of the century, most of the mines had been shut down for nearly 30 years, the earlier boom had been forgotten, and the time was ripe for further exploitation of the prospects.

## FINAL EPOCH OF INTENSIVE DEVELOPMENT

About 1900, the third and latest wave of activity visited New Jersey copper mines. Probably this enthusiasm was aroused by the recently discovered electrolytic method of refining copper ore, and by the new hope that the copper-lean minerals of New Jersey might be as profitably handled as the low-grade ores of western mines. Part of the fervor of the time may have been a genuine belief in the economic possibilities of the ores ; in part, however, it reflected a purely speculative and possibly fraudulent excitement. Whatever its basis, it was mainly fruitless, and the chief emphasis was on patented

[1]Cook, G. H., Geology of New Jersey; p. 675. Newark, N. J., 1868.

processes, stock manipulation and the construction of elaborate but useless equipment and machinery.

A revived American Copper Company undertook in 1899 to develop the old Bridgewater-American mine, and carried an incline below the zone of oxidation until it became the deepest copper shaft in the State. An experimental mill and smelter were built, but by 1905 the company had failed, and the Alpha Copper Company which took over the property lasted only until 1910. The elaborate equipment and reconditioned mine were abandoned and the assets written off in red ink. The mine has not since been opened.

The Menlo Park mine was taken over by another stock company whose operations got no further than the partial cleaning of the former excavations. In similar fashion, the Griggstown mine was cleaned and pumped out at the beginning of the century ; the ore was sampled and some exploratory work was started, but nothing came of it.

The most elaborate enterprise was that of the Arlington Copper Company which leased the Schuyler mine, and spent three years in preparing the property for operation. A refinery was built at great expense to exploit a patented process with a mill, roasting ovens, and great lixiviation tanks. The company started work in 1900 and was ready to run ore through the refinery within two years ; but the process failed to work and after two more years of futile reorganization, the company collapsed and the Schuyler mine was finally closed after nearly 200 years of sporadic mining history.

During the same period the Pahaquarry mine claimed the attention of the Montgomery Gold Leaf Mining Company, which cleaned the property, outfitted a mill and other buildings, dug a few surface trenches, and engaged in other activity between 1901 and 1911. Like all of its Triassic associates, this Silurian mine produced nothing to justify the new equipment, and the latter was soon dismantled and sold for junk without having contributed any copper to the State's mineral output.

Probably many million dollars—the Arlington company alone was incorporated for $2,500,000—were expended on copper-mining stock in New Jersey between 1900 and 1910; but like the wave of speculation between 1820 and 1870 nothing productive resulted. Enough money was spent to provide accurate and complete knowledge of the entire mineral resources of the State; but not enough new data were actually assembled about the geology of the copper mines materially to augment the small store of information available before their ill-fated reopening.

Since 1910 New Jersey copper mining has been left in the past tense. At least 30 years have elapsed since any serious prospecting has been undertaken, and a generation of citizens have grown to maturity without any recollection of copper mining or local copper-stock selling within the State's borders. Interest is again turning to mineral deposits during the present international emergency, when all ore deposits of crucial metals are being examined in the brighter and more favorable light of forced demand and imperative need. On these grounds alone, the present resume of New Jersey copper mining should be accompanied by a statement of the present and possible future potentialities of these copper deposits.

Such a consideration of economic possibilities follows the list of historical citations noted immediately below.

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## ECONOMIC IMPORTANCE OF NEW JERSEY COPPER ORES

The sum of all copper-mining activities in the State from the earliest time to the present has been disappointingly unproductive, and exceedingly few mines, if indeed any, can he said to have paid for themselves during any extended period. The fault, however, should not be laid wholly at the door of the mines, for poor management, fraudulent objectives and financial manipulations have also been heavily responsible for the lack of copper production. It takes experienced direction, sound metallurgical engineering and cautious economy to make lean ore of any type pay profits ; and there is little to indicate that New Jersey copper mines have ever been permitted to produce under all of these conditions. One is led to the conclusion that hitherto the copper deposits have been forced to appear in their most unfavorable light.

The value of a mineral deposit, like the value of any other commercial material, consists of two elements that may not readily be differentiated, and neither of which exists without the other. One element includes the intrinsic qualities of the material itself, the nature of the ore, its metallic content and its volume. The other, external, element is the availability of the deposit, its ease of operation and accessibility, the practicability of refining the ore and the nature of the demands for it.

It is also necessary to assay what is meant by the "value" of a particular mine. Is the value of a mine the profit that can be brought to a particular operator, or is it an assessment of balance between the total return from the mine and the total investments of all operators, whether successful or unsuccessful? If the value of New Jersey copper mines is to be interpreted in terms of surplus of receipts over total expenditures, it is somewhat doubtful if even the most favorable circumstances will ever permit individual mines to move over from the red to the black side of the cost sheet. On the other hand, if their value is to be interpreted in terms of new investment weighed against future financial return, the picture might be revealed in different perspective.

Only five New Jersey copper mines seem to exhibit the dimensions of possible profitable operation, either in the past or in the future. These are the mines at Somerville, Pahaquarry, Griggstown, Arlington and Flemington. Three of these briefly produced copper ore :

Arlington, Griggstown and Flemington ; the other two have never been essentially productive.

Except for local unpredictable pockets no ore at any of these five mines is of high grade, and all mines show low values of copper in a miscellaneous assortment of minerals—a situation that does not make metallurgical refinement of the metal a simple process. On the other hand, save possibly at Flemington and Griggstown, the volume of ore as interpreted by previous sampling, is not discouraging; and except for the Pahaquarry locality, conditions of accessibility and transportation are wholly favorable. Nevertheless, the Arlington locality has now developed into a residential community wherein future underground mining will be increasingly difficult ; operations at Somerville will probably be very costly to resume ; and mining at Griggstown may already have exhausted the best ore at the locality.

It is apparent, therefore, that one can anticipate fairly definite hazards to the probable success of operation at any of these localities ; while on the favorable side of the balance lie only features of uncertainty—value, quantity and character of ore, for none of which adequate data are available.

Cutting briskly to the core of this tangle, the author is forced to report that he cannot justly recommend the initiation of further mining activity at any New Jersey copper locality on the basis of the information at hand. At the same time, however, he must admit his desire for more complete and unbiased information about some of the mines, particularly the Schuyler mine at Arlington, where occur the most favorable conditions for future mining operations—if any New Jersey copper locality may be said to hold promise of economic exploitation. Possession of reliable and extensive data about these mines might well relieve the general pessimism with which the prospects must generally be regarded ; but the available information fails to place any of these mines clearly in the category of potentially important economic localities.

It is hazardous on the part of the geologist to recommend expenditure of time and money in the further exploitation of these hitherto unsuccessful copper mines. This opinion is certainly not intended to smother a possible economic study of these ores, or to deter an optimistic and resourceful operator from attempting their development. Rather, it is designed to forestall disappointment if, as now seems likely, such an endeavor should fall short of success ; and it is particularly directed to dissuade the potential speculator from investing capital in any project relative to these copper mines that does not have actual mining as a primary goal under the direction of a capable and experienced operator.

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