Zinc-Lead Deposit at Shawangunk Mine Sullivan County New York

GEOLOGICAL SURVEY BULLETIN 978-D

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By PAUL K. SIMS *and* PRESTON E. HOTZ

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1951

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A geologic description of the mine and of the new ore shoot

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1951

UNITED STATES DEPARTMENT OF THE INTERIOR

Oscar L. Chapman, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 60 cents (paper cover)

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By Paul K. Sims and Preston E. Holtz

ABSTRACT

The Shawangunk mine on the west flank of Shawangunk Mountains, Sullivan County, N. Y. is one of the oldest zinc-lead mines in the country, but it has not been worked for many years. Drilling by the United States Bureau of Mines has partly delineated a new ore shoot 500 feet below the former mine workings and only 100 feet from the face of the exploratory adit near the base of Shawangunk Mountains.

The deposit in a reverse fault zone in the Shawangunk conglomerate has a proven length of about 1,900 feet, a vertical depth of over 700 feet, and an average thickness of nearly 5 feet. It occupies a sheeted zone along which recurrent movements occurred during vein filling. The deposit ranges from a simple tabular quartz vein to a more complex, branching lode of subparallel veins separated by barren rock. Fragments of wall rock occur throughout the vein.

The ore is of several types: massive lenses and layers, situated commonly along the footwall of the vein; ring or cockade ore; and fillings and replacements along small fractures and in vugs. There has been practically no replacement or alteration of the wall rock.

The ore minerals are concentrated mainly in irregular, poorly defined shoots. The coincidence of a flattening in dip with a deflection in strike is particularly favorable for the development of ore shoots. Appreciable quantities of metals are generally absent in the steeper portions of the lode.

The mineralogy of the ore is simple. Sphalerite is the chief ore mineral, and galena is next in abundance. Chalcopyrite and pyrite are present in small amounts. Minor covellite, malachite, and limonite constitute the minerals of secondary origin.

The paragenesis is similar to that in other base metal veins, and began with quartz, followed by pyrite, sphalerite, galena, and chalcopyrite in that order.

INTRODUCTION

The Shawangunk mine is one of several small zinc-lead mines on the Shawangunk Mountains that has been abandoned for many years. It was worked extensively from 1830 to 1840 and some high-grade lead ore was removed, but since then the mine has been idle except for a brief time during World War I. Because of the strategic importance of lead and zinc the mine was examined in 1948 and later was explored by the United States Bureau of Mines, in cooperation with the United

States Geological Survey. This report presents some of the geologic data obtained during the investigation. The results of the work by the Bureau of Mines are given by Eilertsen (1950).

PREVIOUS INVESTIGATIONS

Mather first described the zinc-lead deposits on Shawangunk Mountains and an account of the early operations at Shawangunk mine is contained in his report on the First District of New York (Mather 1843, pp. 359–362). In 1919, Newland (1919, pp. 296, 300–305) reviewed the geology of the district and described the small-scale mining operations during 1917. Later, Ingham (1940) described the general character and mineralogy of the deposits on Shawangung Mountains, particularly the Shawangunk mine, and in addition gave a brief review of the regional geology. The first detailed stratigraphic study of the Shawangunk mine area was made by Gray,[1] but the results of his work have not yet been published.

FIELD WORK

The present investigation began in September 1948 and continued through April 1949. The Bureau of Mines cored 24 diamond drill holes, totaling 6,526 feet in length; surveyed the mine workings; and assayed samples from the mine and drill cores. The Geological Survey made geologic maps of the mine workings and geologic logs of the drill core. The writers visited the mine at intervals during the winter and spent a total of 2 weeks in the field. Polished-surface and thin-section studies were made in the laboratories of the geology department at Princeton University.

ACKNOWLEDGMENTS

Nils A. Eilertsen, project engineer for the Bureau of Mines, prepared all the base maps. The writers are indebted to A. F. Buddington, A. F. Shride, J. K. Grunig, and R. M. Hernon of the Geological Survey and to Prof. E. Sampson of Princeton University for their critical review of the manuscript. Many of the regional stratigraphic and structural problems were discussed with Prof. Franklin B. Van Houten of Princeton University.

LOCATION AND ACCESSIBILITY

The Shawangunk mine is 2½ miles northeast of the village of Wurtsboro in Sullivan County, N. Y. (fig. 36). The principal mine workings are on the west slope of Shawangunk Mountains approxi-

[1] Gray, Carlyle, 1947, The geology of the Shawangunk mine and environs: Unpublished M. A. thesis, Columbia University, New York, N. Y.

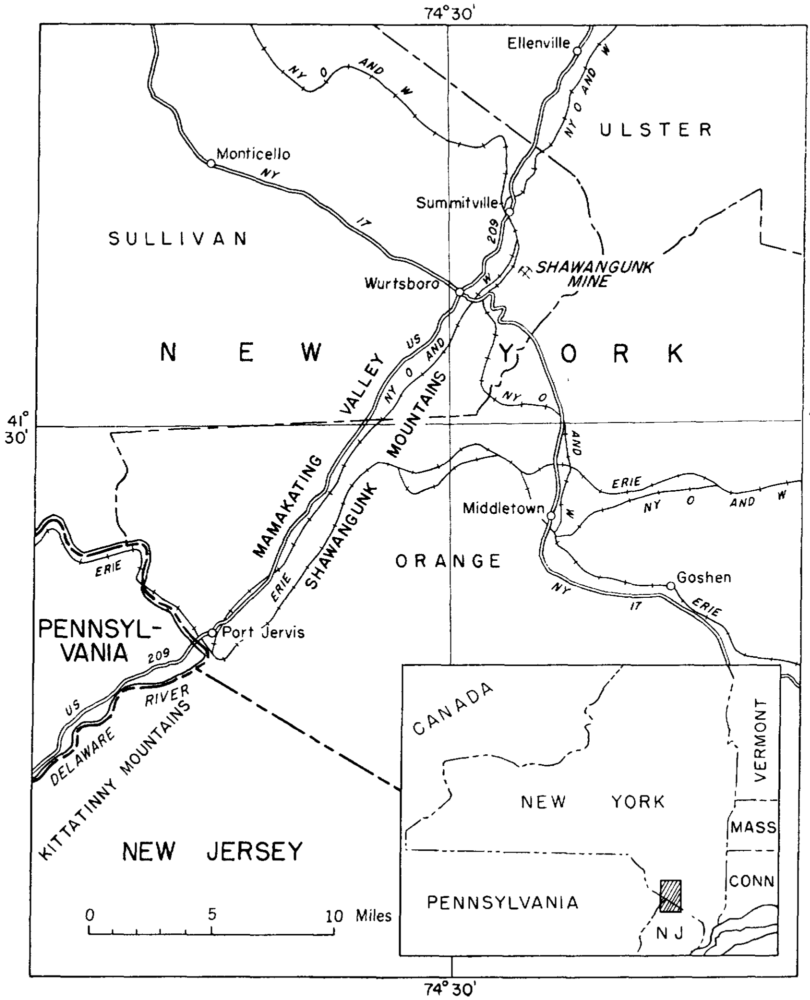

FIGURE 36.—Index map showing the location of Shawangunk mine, Sullivan County, N. Y.

mately 600 feet above the floor of the valley locally known as Mamakating Valley, which separates the mountains from the Catskill Mountains on the west. At the base of the Shawangunk Mountains is the portal of a 1,100 foot exploratory adit. Two main roads, United States Highway No. 209 and State Route 17, intersect at Wurtsboro and a good secondary road, which joins the United States Highway 1¼ miles north of Wurtsboro, extends to the base of the mountain. An access road, now impassible to motor traffic, extends to the upper mine workings. The main line of the New York, Ontario and Western Railway and a branch line of this railway between Port Jervis and Kingston pass along the base of Shawangunk Mountains, a third of a mile west of the mine.

STRATIGRAPHY

The generalized section of formations in the northern part of Shawangunk Mountains modified after Berkey, (1911, p. 55) is as follows:

Generalized section in northern part of Shawangunk Mountains

	Feet
Devonian: Helderberg formation	250
Silurian:	
Manlius limestone	70
Cobleskill limestone	30
Binnewater sandstone	50
High Falls shale	75–80
Shawangunk conglomerate [1]	250–300
Unconformity.	
Ordovician: Slates, shales, and sandstone	2,000+

[1] The Shawangunk conglomerate thickens southward.

The Shawangunk conglomerate contains the ore deposit at Shawangunk mine, and it was the only formation studied during this survey. It is composed predominantly of sandstone, conglomerate, subgraywacke (as used by Pettijohn, 1949, p. 255), and siltstone. The dominant color in outcrops is white, gray, red, or brown. The formation, which is estimated to be 1,280 to 1,470 feet thick in the vicinity of Shawangunk mine,[2] crops out along the crest and on the west flank of Shawangunk Mountains. It rests unconformably on the slates, shales, and sandstones of Ordovician age and is overlain by the High Falls shale (Berkey, 1911, p. 55).

A composite section totaling approximately 900 feet was measured on the west slope of Shawangunk Mountains and is given below:

Composite section of part of the Shawangunk conglomerate, west slope of Shawangunk Mountains, Shawangunk Mine, Sullivan County, N. Y.[1]

	Feet
Quartz sandstone, gray, thin-bedded, including some green shale beds. The quartz grains are well-sorted and rounded	89+
Siltstone, red, and shale interbedded with brown to gray quartz sandstone	75
Quartz sandstone, gray, locally brown	92
Quartz sandstone, gray, and thin green shale beds	14
Quartz sandstone, gray	158
Quartz sandstone, greenish gray to gray, pebbly; contains some thin green shale beds	92
Siltstone, red or green, shale, and subordinate interbedded gray to red quartz sandstone	[2] 84–150

[1] Section does not include approximately 475 feet of the lower part of the Shawangunk conglomerate.

[2] The beds above this member were measured in the exploratory adit.

[2] Gray. op. cit.

Composite section of part of the Shawangunk conglomerate, west slope of Shawangunk Mountains, Shawangunk mine, Sullivan County, N. Y.—Continued

	Feet
Subgraywacke, gray, heterogeneous, cross-bedded, in part conglomerate; consists of quartz grains with varying amounts of black shale (as much as 30 percent) and some feldspar fragments. The matrix is clay for the most part. Authigenic pyrite as large euhedral crystals is scattered throughout the unit	57–190
Quartz sandstone, white (quartzite)	14–45
Quartz sandstone, greenish gray, and conglomerate. Subgraywacke beds are prominent near top. Some thin green shale beds. Pyrite locally present	170–240
Quartz sandstone, gray, and black shale. Individual beds are as much as 2 feet thick	35
Quartz sandstone, gray, with a clay matrix	18+

Conglomerate constitutes a large part of the Shawangunk formation. It is composed of white, generally subangular, quartz grains in a quartz or clay matrix. The grains in the lower part of the formation are as much as half an inch in diameter but are smaller in the upper part. The conglomerate is interbedded with sandstone, and the relative proportion of conglomerate decreases upward in the formation.

The sandstone is composed for the most part of the same minerals as the conglomerate. A few beds contain a little carbonaceous material, however. A layer, 14 to 45 feet thick, of white quartz sandstone (quartzite), continuous throughout the drilled area, lies about 600 feet above the base of the formation.

The sandstone and conglomerate are hard, generally resistant to weathering and form ledges or, more rarely, cliffs.

The subgraywacke, which is in part conglomeratic, consists predominantly of quartz grains, but contains as much as 30 percent black shale fragments. Feldspar fragments are present locally, and euhedral crystals of pyrite, believed to be authigenic, are scattered throughout. Pyrite seems to be particularly abundant in some of the conglomeratic layers. The subgraywacke is thin-bedded and locally slabby in outcrops. Crossbedding is common, and the individual beds only a few inches thick.

Red and green variegated siltstone and shale are present in the upper part of the formation (section and pl. 12) where they are interbedded with red and gray sandstone. The siltstone and shale crumble rapidly upon weathering and the sandstone forms benches along the outcrops.

Abbreviated geologic logs of the Bureau of Mines drill holes are contained in the Bureau of Mines Report of Investigations 4675 (Eilertsen, 1950).

The Shawangunk conglomerate is considered to be of Tuscarora and Clinton age (Spencer, 1908, p. 13; Swartz and Swartz, 1930, p. 474).

Krynine[3] described the Shawangunk conglomerate as a second-cycle quartzite that was formed by the reworking of preexisting quartzose sediments. Possibly all the strata above the base of the lower red bed should be classified as the High Falls shale.

STRUCTURE

Shawangunk Mountains, a northwest-dipping homocline that is probably the northwest limb of a broad anticline, have been breached by erosion (Ingham, 1940, p. 754). In the Shawangunk mine area the strata dip near 20° along the crest of the mountain but steepen to about 45° along the lower slopes. Longitudal folds such as those described from Ulster County (Darton, 1894, p. 542) are not present in this area.

Many faults and small fractures transect the strata. Most of the faults are bedding slips, or reverse faults of small displacement, that strike northeast nearly paralled to the bedding in the Shawangunk conglomerate and dip from 30° to 60° westward. Minor cross faults are present locally. Many, but not all the faults, contain quartz veins.

The Shawangunk fault is a reverse fault zone filled with 1 to 10 feet of vein material. The fault strikes about N. 35° E. where it has been exposed by mining (pl. 13), but it is deflected at its northern and southern extremities (pl. 14). It dips from 30° to 50° NW. (pls. 12 and 16). The deflection in strike to the west in the vicinity of the lower exploratory adit is accompanied by a flattening in dip, and this irregularity in the structure is the locus of an ore shoot.

The fault is a sheeted zone consisting of several subparallel fractures, many of which display prominent slickensided surfaces and mullions that rake from 40° to 70° NNW. (pl. 13). Mullions on the fault surfaces and drag folds locally present along the hanging wall of the fault indicate reverse movement along the fault. The displacement on the fault apparently is small as stratigraphic marker beds on opposite sides of the fault are not greatly offset.

The steeply dipping cross faults are minor fractures of no economic importance. Gray[4] mapped an eastward-trending fault of this type that displaces the contact of the Shawangunk conglomerate and the underlying slates, shales, and sandstones of Ordovician age about 100 feet. The faults of this type within the mine appear to be later than, or perhaps essentially contemporaneous with, the reverse faults, and have no apparent displacement.

From the relationship of the fractures to the homoclinal structure of Shawangunk Mountains, the reverse faults are interpreted as shear

[3] Krynine, P. D., 1943, Diastrophism and the evolution of sedimentary rocks. Lecture presented under the sponsorship of the distinguished lecture committee, Am. Assoc. Petroleum Geologists, April–June.

[4] Gray, op. cit.

fractures developed by the same (horizontal?) compressive forces that produced the folding, and which must have acted in a northwest-southeast direction. The shearing force in part produced movements along the bedding surfaces but also caused breaks across the bedding at a small angle.

The eastward-trending faults could be, with this interpretation, tear faults, or they may be normal faults formed after the relaxation of the compressive forces.

The folding and reverse faulting must have taken place after Middle Devonian time, for in the area near Rondout 30 miles to the northeast, within the same belt of deformation, the entire Silurian and Devonian sequence is much folded and thrust faulted (Schuchert and Longwell, 1932, p. 308). The deformation may have been due either to Acadian or Appalachian movements, but available evidence does not permit a more exact dating. Schuchert and Longwell (1932, p. 325) favor a late Paleozoic age for the folding.

ORE DEPOSIT

HISTORY OF DEVELOPMENT

Shawangunk mine, now owned by Mr. Leo D. McDonald of Wurtsboro, N. Y., is said to have been discovered by a hunter. The first workings were only some 40 to 50 feet from shaft 2. The mine was developed between 1830 and 1840, and during this time (Mather, 1843, p. 360) the ore was hauled from the main level to the portal of the lower adit where it was picked, washed, and then sent to a smelter at the base of the mountains.

After this early period of development the mine apparently was not worked until 1917 when it was reopened by the St. Nicholas Zinc Co. (Newland, 1919, p. 296). According to Newland, a mill was installed near the base of the mountain and work was carried on for part of the year. The drifts were extended a short distance, and ore which had been left in the old stopes was mined and brought down the hill to the mill by an aerial tramway 1,600 feet long. At the mill it was broken in a jaw crusher, sent through a ball mill in closed circuit with a classifier, and then passed over Wilfley tables on which the sphalerite and galena were recovered. Since its abandonment in 1917, the mine has not been worked.

The principal mine workings consist of three shafts, two adits, and nearly 1,100 feet of drifts (pl. 13). The upper adit (elevation 1,162 feet) connects with the upper level. The main adit, 75 feet below the upper one, is 250 feet long and connects with the main level which is 370 feet in length. Two sublevels between the main levels are separated from them by open stopes. Shaft 5, an inclined shaft now largely filled with debris, is 650 feet northeast of shaft 4. Like shaft 1, it does not connect with the main mine workings. The exploratory adit (elevation 562 feet at portal) is 1,113 feet in length and is not connected with the principal mine workings (pl. 14). The date of completion of this adit is not known as no mention of it is made in the literature, but the presence of wooden ventilation pipe in the adit indicates that it was driven at an early date, perhaps during the earliest period of development prior to 1840.

PRODUCTION AND GRADE OF ORE

The production of the Shawangunk mine is not accurately known as records were not kept or were destroyed. During the early operations large quantities of both zinc and lead ore were removed (Mather, 1843, p. 361). Three masses of galena weighing 800, 1,000, and 1,400 pounds respectively were taken out during Mather's visit. The Bureau of Mines (Eilertsen, 1950, p. 6) estimates that approximately 4,700 cubic yards of vein material and wall rock have been extracted from the stopes.

Assays indicating the zinc, lead, and copper content of the ore have been published by the Bureau of Mines (Eilertsen, 1950, pp. 12–22) and will not be given here in detail. Plate 15 presents in graphic form the results of assays for zinc and lead in samples cut in the mine. A summary of the drill hole assay data is given in table 1.

GENERAL CHARACTER OF THE DEPOSIT

The Shawangunk lode is a sheeted zone having more than 1,900 feet of length and a proven vertical depth of over 700 feet. It commonly ranges from 1 to 5 feet in thickness, but thicknesses as much as 10 feet were intersected in some of the drill holes. In places the form of the deposit is very simple and consists of a tabular body of quartz with well-defined walls, but elsewhere the deposit is a lode consisting of subparallel stringers or veins of varying thicknesses separated by barren rock. Splits of the lode are common (pl. 13). The contacts with the wall rock are usually well-defined, but the hanging wall commonly contains a reticulated network of small quartz veins that are in part gash veins (fig. 37). At many places fragments of wall rock that have been torn from the adjacent walls are enclosed within the vein where they are cemented by vein material. These fragments are angular to subangular and range from 1 inch to about 10 inches in diameter.

The ore minerals occur principally as: massive layers, lenticular or pod-shaped, from a few inches to a little over 2 feet in width, that are essentially parallel to the vein walls (fig. 37); ring or cockade ore

TABLE 1.—*Assay data of cores from vein intersections.*

[U. S. Bureau of Mines diamond drill holes, Shawangunk mine, Sullivan Co. N. Y.]

Hole No.	Depth	Uncorrected penetration [1]	Zinc (percent)	Lead (percent)
1	185. 4–190. 6	5. 2	0. 38	0. 13
2	172–176. 5	4. 5	3. 26	7. 84
3	89. 4– 89. 6	. 2	24. 1	. 17
	195. 0–202. 7	7. 7	3. 11	. 75
4	187. 2–192. 2	5. 0	9. 20	. 61
5	167. 8–177. 0	9. 2	3. 82	1. 21
6	150. 1–152. 8	2. 7	8. 09	6. 65
7	142–142. 6	. 6	2. 61	. 07
	147. 1–147. 9	. 8	. 87	. 07
8	104. 9–111. 2	6. 3	8. 05	. 16
9	329. 7–332. 2	2. 5	. 20	Tr.
10	113. 3–118. 3	5. 0	5. 32	. 06
11	218. 2–223. 7	5. 5	. 36	. 14
12	266. 2–266. 8	. 6	8. 57	Tr.
	380. 2–383. 7	3. 5	2. 32	Tr.
13	297. 2–303. 0	5. 8	. 37	Tr.
14	284. 9–292. 0	7. 1	Tr.	Tr.
15	332. 7–333. 3	. 6	4. 61	. 3
16, 16a	244. 7–254. 6	9. 9	. 10	. 04
17	400. 0–401. 2	1. 2	3. 77	. 64
18	143. 6–143. 9	. 3	8. 48	28. 73
	150. 4–150. 6	. 2	32. 4	13. 26
UG–1	112. 2–121. 5	9. 3	6. 93	. 58
3	115. 4–120. 7	5. 3	11. 34	. 66
4	83. 3– 87. 8	4. 5	6. 87	3. 70
5	146. 6–158	11. 4	7. 12	. 57
6	254. 1–263. 5	9. 4	1. 01	. 03

[1] Holes were drilled nearly normal to dip of Shawangunk vein.

FIGURE 37.—Photograph of Shawangunk vein, "A" level, south of inclined shaft 4, Shawangunk mine. Note gash veins in the hanging wall. The camera case is 6 inches long. Photo by N. A. Eilertsen, U. S. Bureau of Mines.

consisting of thin coatings of vein material around breccia fragments (fig. 38); and fillings and replacements along small fractures and in vugs (figs. 39 and 42). The wall rock is unaltered and almost unreplaced. The ore is not distributed uniformly throughout the lode;

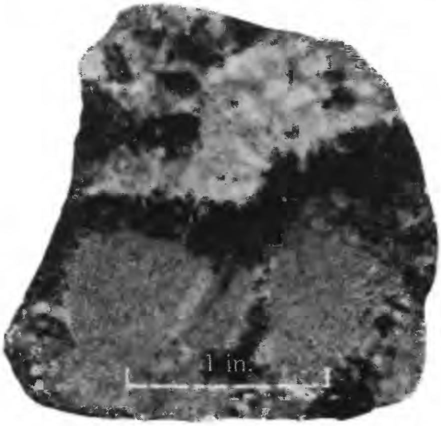

FIGURE 38.—Typical specimen of sphalerite vein material (black) in cockade structure around fragments of country rock (gray) in vein quartz (white). Polished surface.

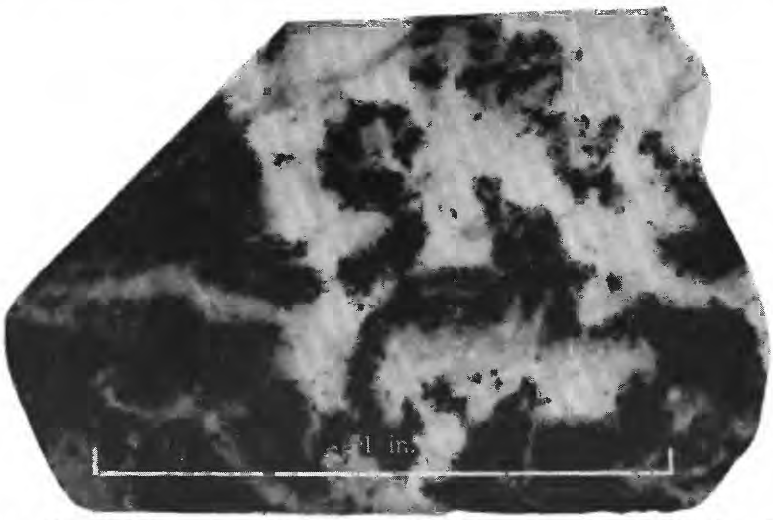

FIGURE 39.—Typical specimen of sphalerite (black) in vein quartz. Polished surface.

instead it occurs as streaks and layers that tend to follow the footwall or, less commonly, the hanging wall.

Small veins that may be branches off the Shawangunk lode but that are not known to contain appreciable quantities of sphalerite or galena lie in the hanging wall of the lode. Two veins, 430 and 1,093 feet respectively from the portal, were intersected in the exploratory adit.

The 430-foot vein dips 65° west, and consists of 6 inches to 2 feet of massive vein quartz, barren of sulfides. The other vein dips 52° west and consists of 6 inches or less of vein quartz containing thin seams of massive sulfides. Fracture surfaces are coated by malachite. Mullions produced by movements along the vein after the deposition of the ore rake 50° N. 30° W. A thin branching barren vein occurs in the adit to the main level 60 feet west of the Shawangunk lode.

Small quartz veins in the hanging wall of the Shawangunk lode were intersected in some of the drill holes (see pl. 16), but only four veins contained visible ore minerals. (See table 1.)

OUTCROP OF THE LODE

The Shawangunk lode is exposed on the hill directly above the principal mine workings in a poorly defined zone consisting of an intricate network of generally small discontinuous quartz veins from a fraction of an inch to 6 inches in width that occupy fractures in the country rock. Conspicuous massive continuous quartz veins can be seen only at the collar of shaft 3. The quartz is milky white and contrasts sharply with the buff color of the wall rock. All ore minerals have been leached from the outcrop.

ORE SHOOTS

The Shawangunk lode does not everywhere contain sufficient quantities of metals to constitute ore. The ore occurs in small lenticular bodies or shoots that seem to be localized by a flattening in dip and generally occur where the vein dips 35° or less. The steeper parts of the vein are nearly barren. A deflection in strike of the lode also is favorable for the formation of ore shoots.

Contours drawn on the footwall of the lode demonstrate the major irregularities of the Shawangunk fault (pl. 14). In general, the upper part of the lode, near the outcrop, dips about 40° west. A short distance below the mine workings the dip steepens slightly (pl. 12), and then flattens again, at least in part, below the vein intersection in holes drilled from the lower base line.

In the mine the ore minerals are sparsely distributed through the lode or, more rarely, concentrated into pods or bunches large enough to constitute ore. Most of the ore is on the main level and at the north end of the upper level, where the lode dips 35° or less. Near the adit in the upper level, a lenticular body of massive sulfide ore may be noted along the footwall (pl. 13). The vein dips 33° at this place. Laterally the vein steepens within a short distance with a concomitant decrease in content of ore minerals. Nearly everywhere in the sublevels the lode dips 40° or more and the deposit is narrow and contains only thin mineralized zones.

Drilling by the Bureau of Mines has demonstrated the existence of a new ore shoot below the mine workings. The ore shoot is 500 feet vertically below the main adit level, and was penetrated by drill holes UG 1, 3, 4, 5, and 6 (pl. 17). It is about 10 feet wide and has an average tenor of 5.9 percent zinc and 0.4 percent lead, and contains traces of copper, silver and gold. The dimensions of the shoot were in part determined by drilling. The shoot has a stope length of at least 320 feet at the altitude of the exploratory adit (pl. 17). Its breadth was not determined, but drill hole UG 4 indicates that the shoot extends more than 50 feet below the altitude of the adit. The vertical limits of the new shoot could be determined by further drilling from the exploratory adit.

The scant data suggest that the ore shoots do not have a well-defined rake. The ore shoots in the mine are irregular in size and shape and their boundaries are poorly defined. Pods and bunches of ore commonly pinch out entirely or give way to thin sulfide stringers in short distances. Plate 13 shows that most stope walls trend east-southeast and this may well indicate that the ore rakes in this direction. Possibly, however, the shoots follow the direction of the slickensides and mullion structure, and thus rake 40° to 70° N. 20° W.

MINERALOGY

The ore is composed of minerals of simple chemical composition. The chief ore mineral is sphalerite. Galena ranks second in abundance but its distribution is spotty. Pyrite and chalcopyrite, which are present in small amounts, complete the list of primary metallic minerals. Limonite, covellite and malachite are secondary minerals. Small amounts of gold and silver occur with the ore minerals, but the nature of their occurrence is not known. According to Mather (1843, p. 361), the silver is contained in the galena. Quartz is the only nonmetallic gangue mineral.

QUARTZ

Two kinds of quartz, a gray granulated early variety, and a late white massive to vuggy or comb variety (fig. 40), can be recognized in thin sections and in hand specimens. In some specimens the gray quartz has a distinctly granular appearance and is easily mistaken for fine-grained gray quartzite. In most specimens, however, the gray quartz appears only as faint gray areas in the white quartz. Thin sections show the gray variety to be thoroughly crushed whereas the white quartz is generally uncrushed and the crystals show little or no strain. The white quartz cuts and encloses the gray variety and apparently replaces it.

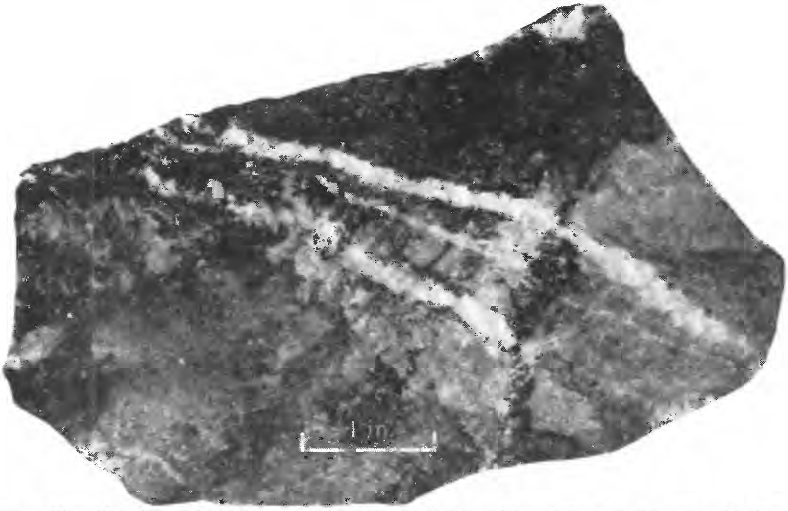

FIGURE 40.—Massive sphalerite (dark areas) cut by white vein quartz. Speckled gray country rock is subgraywacke.

The quartz of the Shawangunk lode and of the minor veins is characteristically massive to vuggy but may have a fairly well developed comb structure (fig. 41). Crystals of quartz ranging from a few hun-

FIGURE 41. Sphalerite (black) and quartz (white) in comb structure. Speckled gray country rock is subgraywacke. Polished surface.

947309—52——2

dredths of an inch to about half an inch in length line the vugs, only a few of which exceed half an inch in maximum dimension. Many of these crystals are fairly clear but most are cloudy to milky white.

SPHALERITE

The most abundant ore mineral is sphalerite (ZnS). The sphalerite in most specimens is dark reddish brown, but some is nearly black. The generally dark color may indicate a substantial content of iron.

In much of the ore sphalerite obviously occupies primary openings in the quartz such as vugs and the spaces between crystals, and replaces the quartz only slightly (fig. 42). Characteristically frag-

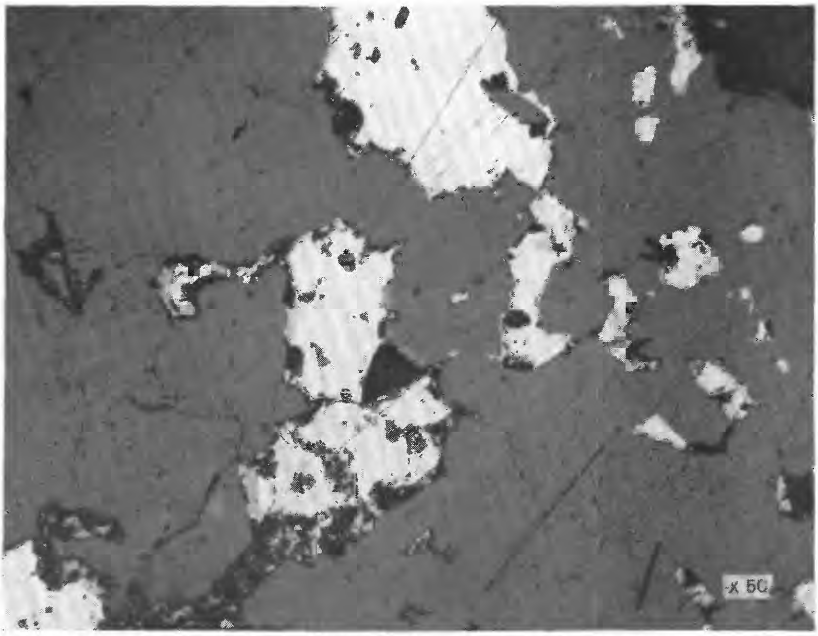

FIGURE 42.—Photomicrograph of polished sections of ore showing sphalerite (white) filling vugs in vein quartz (gray).

ments of country rock in the vein have a cockade structure; comb quartz forms rims around the fragments, and the spaces between the quartz crystals are filled with sphalerite. In many specimens of ore the sphalerite appears to replace previously fractured quartz.

Polished specimens of ore show, on examination under the microscope, that the sphalerite contains different but generally small amounts of chalcopyrite as microscopic grains and tiny laths in parallel arrangement. Similar globules and minute grains of galena can also be seen in the sphalerite. Because the chalcopyrite blebs and grains in the sphalerite are not generally in an ordered arrangement and because chalcopyrite occurs in the ore as replacement bodies in galena as well as in veinlets crossing galena and sphalerite, its presence in sphalerite is considered to be due principally to replacement.

Sphalerite is veined or replaced by all the primary ore minerals. On polished surfaces it shows the same age relation to quartz as that visible megascopically. Etching with potassium permanganate solution [5] reveals the grain structure and twinning lines in the sphalerite. The grain size differs in most specimens and some of the twining striae are slightly bent. Some specimens show pronounced brecciation of the sphalerite.

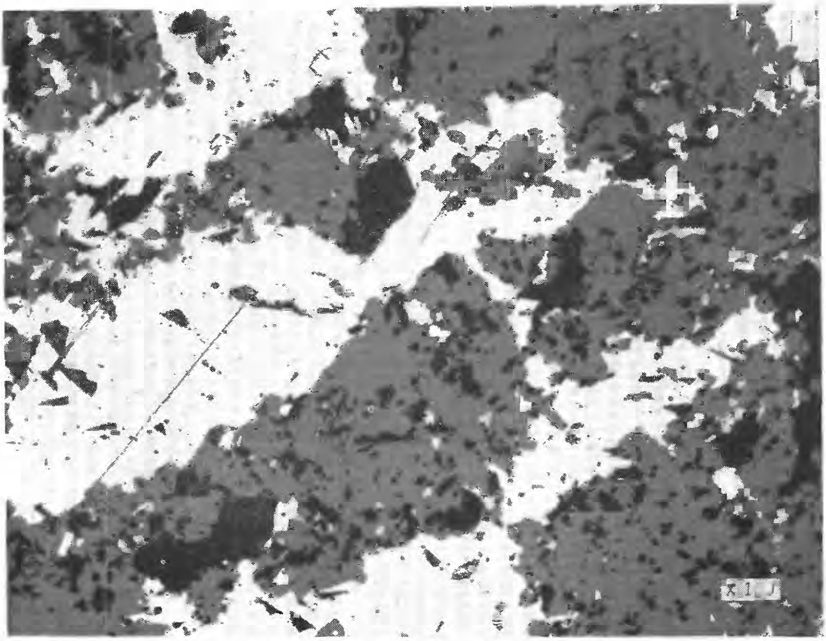

FIGURE 43.—Photomicrograph of polished section of ore showing typical replacement of sphalerite (gray) by galena (white).

GALENA

Galena (PbS) is about one-third less abundant than sphalerite and is somewhat erratic in its distribution. In a few places on the upper levels of the mine it predominates over sphalerite. It replaces sphalerite (fig. 43), but some of the galena and sphalerite appear to have mutual boundaries suggesting simultaneous crystallization. A few dots and globules of galena occur with the sphalerite. Etching shows that most of these small bodies are situated along grain boundaries of the sphalerite. Galena itself shows no inclusions except for some

[5] 1 cc. saturated solution of potassium permanganate and 1 drop of concentrated sulfuric acid.

quartz fragments and unreplaced remnants of sphalerite. Some galena fills small cavities in the quartz where it may be an original filling or a replacement of sphalerite.

The galena appears streaked or schistose in some hand specimens. Under the microscope these specimens are seen to consist of very fine-grained galena, sphalerite, and small fragments of quartz intergrown in an irregular manner. Etching indicates that sphalerite was crushed to a very fine grain size, whereas galena [6] shows no apparent granulation. The galena appears to have replaced sphalerite along crushed zones.

CHALCOPYRITE

Chalcopyrite ($CuFeS_2$) seldom amounts to more than 1 percent of any specimen, but locally it is more abundant, as in the ore shoot intersected by drill hole UG 6. Chalcopyrite occurs as minute bodies in sphalerite, larger irregular bodies in galena and sphalerite, and replacement veinlets cutting quartz, sphalerite, and galena.

Microscopic chalcopyrite bodies in sphalerite are believed to result principally from replacement, though the possibility of their having been formed in part by exsolution is recognized. Most of the larger irregular replacement bodies are along boundaries between galena and sphalerite. Replacement veinlets of chalcopyrite that cut quartz and earlier ore minerals are the least common mode of occurrence.

PYRITE

Pyrite (FeS_2) is the least abundant primary mineral, and it is irregularly scattered. In most specimens it is aligned in trains of minute grains having crystal outlines, but some veinlets and irregular bodies have also been seen in polished surfaces. A few coarse-grained masses and exceedingly fine grained coatings on fracture surfaces have been observed. Pyrite cuts and replaces quartz, sphalerite, and galena, and is in turn cut and replaced by quartz and galena.

Pyrite, believed to be authigenic in origin, occurs as euhedral crystals scattered throughout subgraywacke in the Shawangunk conglomerate.

COVELLITE

Soft masses of dark blue covellite (CuS) are associated with chalcopyrite in very small quantities. Polished surfaces of most specimens of ore, when viewed under the microscope, are seen to contain a little covellite. Covellite replaces chalcopyrite and is undoubtedly a secondary mineral.

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[6] Galena was etched with Fackert's solution (Schneiderhöhn and Ramdohr, 1931, p. 249) to reveal the grain boundaries.

MALACHITE

Another secondary mineral, malachite ($CuCO_3.Cu(OH_2)$), stains fracture surfaces in some of the ore. Its relationship to covellite is not clear but the malachite is believed to be of later origin. The secondary carbonate is common in the upper part of the vein and also occurs in the small vein intersected in the exploratory adit 1,093 feet from the portal.

PARAGENESIS

The succession of events bringing about the formation of the lode is shown in figure 44. The order of introduction of the different

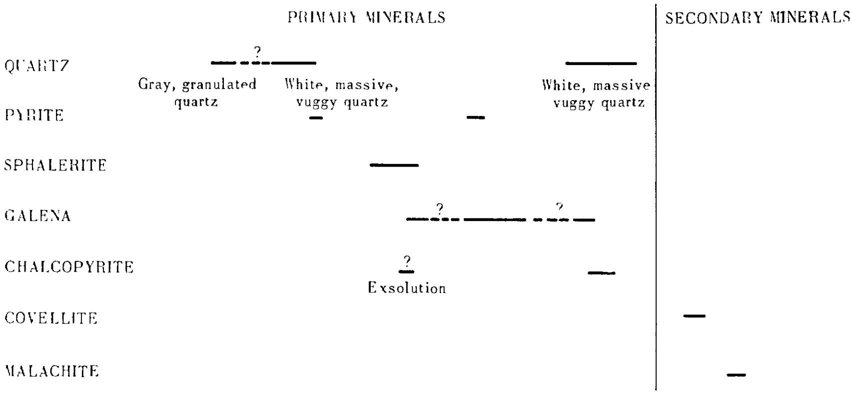

FIGURE 44.—Paragenesis of the vein minerals.

minerals follows rather closely the usual stages in base metal veins, commencing with the deposition of quartz followed in order by pyrite, sphalerite, galena, and chalcopyrite. Throughout the period of mineralization there were repeated movements in the vein.

Mineralization began with the deposition of gray quartz. The quartz filled the fissure and was subsequently strongly granulated. Following this the bulk of the quartz was deposited, and in this stage vugs and comb structures were developed. Toward the end of this period of crystallization of quartz a little pyrite was introduced. Apparently no additional quartz was deposited after this until the final stages of vein filling.

Sphalerite was the first metallic mineral to be deposited, except for very small amounts of early pyrite. Sphalerite occupies a distinct stage in the succession and most of it antedates the galena. Some sphalerite, however, was still being deposited when galena started to crystallize. Sphalerite occupied primary openings in the quartz, which were formed by fracturing. A little chalcopyrite may have been exsolved from sphalerite at an early stage. Following the deposition of sphalerite, movement in the vein was renewed and sphalerite as well as quartz was fractured. In places the sphalerite was brecciated and fissures were opened in it in which galena veinlets formed. Some of the galena filled fissures but most of it made room for itself by replacing sphalerite. As copper entered the solutions toward the close of the period of primary mineralization chalcopyrite crystallized simultaneously with the last of the galena and filled minor fractures in all the older minerals. This terminated the period of deposition of primary sulfides. Primary mineralization ended with a renewed influx of silica. White quartz filled small fractures and coated the earlier-formed minerals.

The final event in the history of the vein was the replacement of small amounts of the chalcopyrite by covellite, and the formation of malachite. These secondary minerals were precipitated from cupriferous supergene solutions.

ZONING

Observations within the mine and assay data indicate that the zinc-lead ratio increases in depth and that copper is more abundant in depth. In the UG series of holes drilled from the exploratory adit the zinc-lead ratio is about 12 to 1, whereas it is approximately 2½ to 1 in the holes drilled from the surface (table 1). Assays from the mine also indicate a small zinc-lead ratio (Eilertsen, N. A., 1950, tables 1, 2, 3, and 4). The copper in the ore from the mine is negligible, but it occurs in somewhat greater amounts in the ore shoot intersected by drill hole UG 6 (pl. 17).

Evidence of zoning was noted also in the Ellenville deposit (Ihlseng, 1903, p. 630) where lead decreases as depth increases.

ORIGIN

The lode was formed by minerals deposited from hydrothermal solutions. Repeated movements along the Shawangunk fault zone throughout the period of ore deposition kept open a channel through which the vein-forming solutions could migrate. Deposition of minerals by fracture filling and by replacement of earlier deposited minerals was closely restricted to the zone of fracturing. The wall rocks are not replaced and show practically no alteration.

It is rather difficult to assign the Shawangunk deposit to one of the usual pressure-temperature classifications. Ingham (1940, p. 759) classified it as telethermal, possibly because it is apparently far removed from its igneous source. The writers prefer to place the deposit in the leptothermal zone (Graton, 1913, pp. 536–540). The lode does not show the development of complex branchings usually characteristic of shallow deposits. The quartz is unlike the finely crystal-line quartz in many epithermal and most telethermal ore bodies; yet its plentiful vugs and the development of comb structure in places indicates that the conditions of formation were somewhat shallower than most mesothermal types. Cockade structure is common in the vein but the layering and crustification characteristic of epithermal deposits are absent. The simple mineralogy could be indicative of either mesothermal or telethermal conditions. The lack of wall rock alteration might result from low temperatures and the weakness of solutions far from their source, or it might be that the rocks resisted alteration because of their high silica content.

AGE

The available evidence suggests that the Shawangunk zinc-lead deposit is of late Paleozoic age. The lode occupies a fracture in rocks of Silurian age. The faulting is dated on the basis of indirect evidence as post-Middle Devonian, probably late Paleozoic (p. 107) and inasmuch as the mineralization is contemporaneous with the faulting it may also be considered to be late Paleozoic in age.

There are no nearby intrusive igneous bodies to which the deposit can be directly related, but lamprophyric dikes and small plutons of nepheline syenite of Paleozoic age are known about 20 miles to the south, near Beemerville, N. J. These bodies cut Ordovician rocks and Spencer (1908, p. 13) considers them to be post-Devonian and probably much later.

FUTURE OF THE MINE

The discovery of a new ore shoot by the Bureau of Mines has stimulated new interest in the Shawangunk deposit. The ore shoot is only 100 feet from the face of the exploratory adit and is, therefore, favorably situated in relation to existing mine workings. (See pl. 17.) The shoot is known to have a stope length of more than 300 feet, and a breadth of more than 50 feet. Further development drilling should be done before any attempt is made to mine the shoot.

Small pockets of ore remain in the upper mine workings (pls. 13 and 15), but for the most part these are too small to warrant extraction.

A large part of the Shawangunk deposit has not been tested. The most favorable areas for exploration are along strike from the new shoot discovered by holes drilled from the exploratory adit. This part of the lode could be tested for the most part by surface holes drilled from the lower slopes of the Shawangunk Mountains.

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