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THE MANGANESE MINERALS OF THE SUNNYSIDE VEINS, EUREKA GULCH, COLORADO

W. S. BURBANK,¹ *U. S. Geological Survey.*

INTRODUCTION

Since 1926 the cooperative geologic survey carried on jointly by the State of Colorado and the United States Geological Survey has undertaken the remapping of a number of the San Juan mining districts. Much attention has been given to the mineralogy of the veins since only a few of the San Juan ores have been studied in the light of modern methods and advances in the science of mineralogy. The ores of this region are chiefly of late Tertiary age and occur principally in fissure veins in the Tertiary volcanic rocks. Among the most interesting of the veins are those that contain a large proportion of hypogene manganese minerals. The writer's interest in the apparently erratic distribution of the highly manganeseiferous gangues and the paragenetic relations of the different manganese minerals has been encouraged by Mr. D. F. Hewett of the Geological Survey. Certain characteristic paragenetic relations between the manganese minerals of the Bonanza district² in the northeastern San Juan and of the manganeseiferous base-metal ores of the Camp Bird and nearby areas in the western San Juan indicated similar conditions of formation in widely separated areas of this volcanic province. Hewett and Rove³ have called attention to certain seemingly constant relations between alabandite and rhodochrosite and rhodochrosite in many districts of the United States and other parts of the world. It seems possible that the manganese minerals may provide a useful guide in classifying and defining con-

¹ Published by permission of the Director of the United States Geological Survey and that of the Chairman of the State Geological Survey Board of Colorado.

² Burbank, W. S., and Henderson, C. W., *Geology and ore deposits of the Bonanza mining district, Colorado: U. S. Geol. Survey, Prof. Paper 169*, pp. 70, 86, 126, 127, and Pl. 13-B, 1932.

³ Hewett, D. F., and Rove, O. N., *Occurrence and relations of alabandite: Econ. Geol.*, 25, pp. 36-56, 1930.

ditions of vein formation and that a preliminary study of the manganese minerals of the Sunnyside mine at Eureka may give further information on this problem, since the veins are noted for the large bodies of rhodonite associated with base-metal ores.

In 1931 Mr. E. N. Goddard and the writer visited Eureka, but as the mine was not operating at the time of the visit it became impracticable to make underground studies in the short time available. However, numerous specimens of the manganese minerals were collected from the waste pile near the mill at Eureka. These

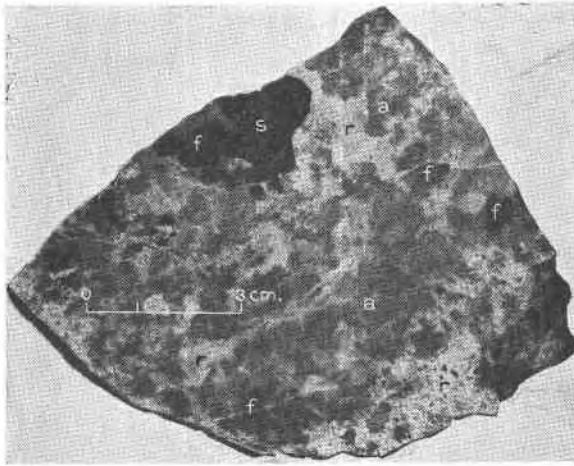


FIG. 1. Alleghanyite (a), tephroite (locally with alleghanyite), and friedelite (f), partly replaced by rhodonite (r). S, fragment of sphalerite of an earlier stage. Specimen illustrates influence of minute fractures on replacement phenomena.

were selected at random from a very large pile although some care was taken in selecting representative specimens of as many different types and textures of manganiferous gangue as was practicable. A study of these specimens with the advantage of advice and assistance from Messrs. Hewett, C. S. Ross and W. T. Shaller of the Geological Survey revealed at least five or six manganese minerals unreported from this particular deposit and several of which have been reported from only one or two localities in the United States. Since the original plan of studying the vein cannot be carried to completion in the immediate future, it has been decided to report these occurrences.

GEOLOGY AND LOCATION OF THE SUNNYSIDE VEIN SYSTEM

The principal workings of the Sunnyside mine are located about 7 miles north-northeast of Silverton and about 3 miles northwest of Eureka in the Silverton quadrangle, at elevations ranging between 11,000 feet (3,353 meters) and a little over 13,000 feet (3,960 meters). The mine has been one of the largest producers of base-metal ore in the San Juan region, and the mill at Eureka, which was the first plant in North America to practice selective flotation on the complex ores of the Rocky Mountain region, yielded both zinc and lead concentrates carrying valuable amounts of silver and gold.⁴ The outcrop of the vein was located in 1873 and the first work on it exposed rich gold ore, but this was soon exhausted. The large scale mining and milling operations of the United States

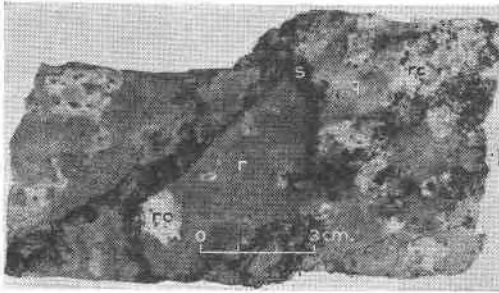


FIG. 2. Massive rhodonite (r), brecciated and partly replaced by late sulphides (s), rhodochrosite (rc), and quartz (q).

Smelting, Refining & Mining Company were started in 1912 after a series of intermittent operations and attempts to treat the lower grade and complex ores.

The country rock of the area about the Sunnyside consists of lava flows, chiefly latitic, which form the middle part of the Silverton volcanic series of Miocene age.⁵ The volcanic rocks, including the Potosi volcanic series which is now eroded in this particular area, originally attained a thickness probably of 6,000 to 8,000 feet (1829 to 2438 meters). At some time following the eruption of

⁴ Robie, E. H., Lead-zinc flotation at Sunnyside: *Eng. and Min. Jour.-Press*, **121**, pp. 757-762, 1926.

⁵ Cross, W., and Larsen, E. S., San Juan region of southwestern Colorado: *U. S. Geol. Survey Bull.* (In preparation.)

the Potosi series large bodies of magma invaded the crust and caused regional fracturing and faulting, which resulted in the sinking of a large block of crust in the central part of the Silverton quadrangle below the level of the surrounding areas.⁶ The great faults that form part of the Sunnyside vein system belong to the fault systems that define the margins of this downfaulted block. This structure is important in considering the nature of the mineralization at the Sunnyside mine, since these major faults and their immediately attendant systems of fracturing largely furnished the most direct channels through which the mineralizing solutions ascended. The mineralogic evidence conforms with the structural evidence in that the veins occupy channels which carried great volumes of hot solutions, and that the ores and gangues represent certain relatively high temperature facies of the San Juan mineralization. This mineralization probably occurred in late Miocene or earliest Pliocene time, and under a cover of approximately 4,000 to 5,000 feet (1,219 to 1,524 meters).

The Sunnyside vein system consists of a number of different veins, which range from 20 to 80 feet (6 to 24 meters) in width, and have been stoped to a width of over 50 feet (15 meters). The principal zone of faulting and fissuring strikes northeast and along it there has been a displacement of approximately 1,000 feet (305 meters), but northwest and east-west fault fissures are also mineralized. Hulin⁷ presents evidence to show that the vein growth proceeded by successive reopening of the Sunnyside fissures caused by faulting movements along them. He stated⁸ that “. . . two of the most important ore shoots which have been developed are controlled by variation in strike of the vein fissure. . . . Minor pre-mineral cross-faults modify these ore shoots to some extent.”

Hulin⁹ furthermore recognized three principal mineralogic stages in the formation of the Sunnyside veins, an early stage of barren pyritic quartz veins, a second stage of base metal ores, and a third stage of rhodonite veins and ribs. He considered these stages as

⁶ Burbank, W. S., Vein systems of the Arrastra Basin, and regional geologic structure in the Silverton and Telluride quadrangles, Colorado: *Colo. Sci. Soc. Proc.* (In preparation.)

⁷ Hulin, C. D., Structural control of ore deposition: *Econ. Geol.*, **24**, pp. 22-30, 32, and 39-42, 1929.

⁸ *Op. cit.*, pp. 38, 39, and Fig. 8, B.

⁹ *Op. cit.*, p. 32, and Fig. 5.

part of a continuous period of mineralization, and in pointing out the importance of the time of reopening of the fissures in relation to the stages of mineralization stated,¹⁰ "Here again it is manifest that ore shoots must be restricted to those portions of the veins receiving the mineralization of the second stage. Portions of veins receiving mineralization only during the first stage will consist of barren quartz, whereas those portions of the veins formed during the third stage consist essentially of barren rhodonite." Thus it seems clear from Hulin's descriptions of the veins that both the

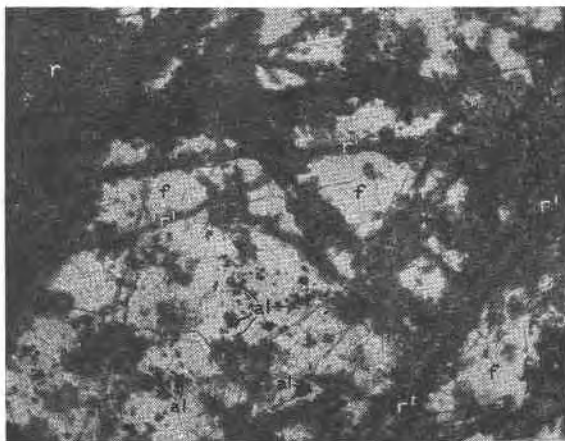


FIG. 3. Friedelite (f), partly replaced by early rhodonite (r), and all cut by later veinlets of rhodonite (r'). al, alabandite. Photomicrograph of thin section in ordinary light. (37 diameters.)

base metal ores and the bodies of manganese silicates were formed by the filling of open fissures and not to any great extent by replacement of wall rock.

The principal minerals of the veins consist of quartz and pyrite of the early stage, of sphalerite, galena, and chalcopyrite that followed in overlapping deposition, and of a little tetrahedrite. According to Weinig and Palmer,¹¹ a part of the sphalerite of the Sunnyside ore is the marmatite variety. The third stage, with which most or all of the manganese minerals described in this paper

¹⁰ *Op. cit.*, p. 32.

¹¹ Weinig, A. J., and Palmer, I. A., The trend of flotation: *Colo. School of Mines Quart.*, 24, No. 4, p. 52, 1929.

are presumably associated, consisted chiefly of rhodonite with the other manganese minerals and minor amounts of still later sulphides. Free gold in quartz is found with the ore bodies and has been observed cutting both the base metal ores and the later rhodonite. Calcite, fluorite, rhodochrosite, and huebnerite have also been recognized in the veins.

The manganiferous gangues with which the remainder of this paper will deal contain in addition to rhodonite different quantities of the following minerals: alabandite, alleghanyite, friedelite, helvite, rhodochrosite, and tephroite, with small quantities of other perhaps supergene minerals such as neotocite. The hypogene manganese minerals will be described briefly and following these descriptions a review of the paragenetic relations as observed in the specimens will be given. For the mineralogic work ten representative specimens were sawed, five of which were polished; numerous thin sections were also prepared.

THE MANGANESE MINERALS

ALABANDITE (MnS). The sulphide of manganese, alabandite, forms minute grains and veinlets mostly of microscopic size, which are irregularly distributed through the manganese silicates friedelite, alleghanyite, and rhodonite (Fig. 3). The largest grains of alabandite seen were about 0.75 millimeter in diameter. No large masses or crystals of this mineral were found. The alabandite is recognizable by its bright green color as seen by strong transmitted light in thin section, and by the odor of hydrogen sulphide given off when small quantities of it are treated with hot acid or heated in the closed tube with friedelite. The alabandite is associated with a little pyrite, sphalerite, galena, and probably chalcopyrite.

ALLEGHANYITE ($5\text{MnO} \cdot 2\text{SiO}_2$). The silicate of manganese, alleghanyite,¹² occurs in five of the specimens studied, usually in association with tephroite. It is more abundant than tephroite but less abundant than rhodonite in these particular specimens. The largest grains seen in thin sections range from 0.8 to 1.6 millimeters in length and 0.1 to 0.3 millimeter in width. The color of the mineral on polished faces of the specimens is of a darker grayish-pink as contrasted with the lighter pink of the rhodonite and the greenish-gray color of the tephroite. The fine twinning lamellae which are a

¹² Ross, C. S., and Kerr, P. F., The manganese minerals of a vein near Bald Knob, North Carolina: *Am. Mineralogist*, 17, pp. 7-13, 1932.

characteristic feature of this mineral lie at right angles to the elongation of the grains of the above dimensions, but grains oriented so as to show no twinning lamellae are generally more nearly equidimensional in cross section. The lamellae are generally narrow and, like those in the Bald Knob mineral, show symmetrical extinction in sections perpendicular to the axial plane. A few individuals show combined double twins that present a herringbone pattern with symmetrical and essentially equal extinction in each

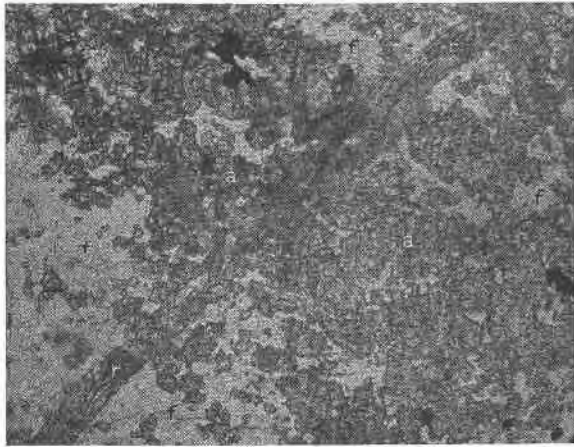


FIG. 4. Alleghanyite (a), and friedelite (f), cut by veinlet of rhodonite (r). Photomicrograph of thin section in ordinary light. (68 diameters.)

twin when the section is at right angles to the long twinning plane. A photomicrograph showing the general shape and size of the alleghanyite grains is shown in Figure 4.

The determined optical properties of this alleghanyite are given in the following table together with those of alleghanyite from the type locality.

No chemical tests, other than the determination of manganese, have been made to confirm the identification of the mineral, but the optical and general physical properties appear sufficiently conclusive.

Alleghanyite was first discovered by C. S. Ross in association with spessartite, rhodonite, tephroite, galaxite (a new manganese spinel), manganiferous calcite, and other minerals near Bald Knob, North Carolina, and described by Ross and Kerr in the paper re-

TABLE 1. OPTICAL PROPERTIES OF ALLEGHANYITE

	Sunnyside mine, Colo.	Bald Knob, N. C. ¹
Indices of refraction	$\alpha=1.756$ $\beta=1.776$ $\gamma=1.790$	$\alpha=1.756$ $\beta=1.780$ $\gamma=1.792$
Birefringence034	.036
2 V	75°-80°	72°
Dispersion of the axes	$r > v$	$r > v$
Optical character	Negative	Negative

¹ Ross and Kerr, *Op. cit.*, pp. 7-10

ferred to above. This occurrence at the Sunnyside Mine is the second verified occurrence although Ross and Kerr¹³ call attention to a mineral described by Rogers from an erratic boulder near San Jose, California, which has similar physical properties.

FRIEDELITE. A chlorine-bearing hydrous silicate of manganese, for which the general formula given in Dana's Mineralogy¹⁴ is $6\text{MnO} \cdot 2\text{Mn}(\text{OH}, \text{Cl})_2 \cdot 6\text{SiO}_2 \cdot 3\text{H}_2\text{O}$, occurs in association with alleghanyite, tephroite, and rhodonite. The mineral forms fine-grained, translucent masses of a rose-red or brownish-red color. In thin sections, the masses are seen to be made up of fine cleavable scales which mostly range from 0.01 to 0.02 millimeter in diameter grown compactly together. Coarser scales are also present and are evidently due to the stage of formation and amount of recrystallization the mineral has undergone. Where the mineral crystallized late it forms distinctly tabular crystals 0.06 to 0.13 millimeter in diameter, which are similar to the common rhombohedral form of friedelite.

When the mineral is heated in a closed tube it yields a considerable volume of water which reacts for chlorine. An odor of hydrogen sulphide, sometimes detectable on heating, is probably due to small grains of alabandite which can be seen in the friedelite under the microscope. Some arsenic, as well as chlorine, was found to be present in the mineral by qualitative wet tests kindly made by Dr. Schaller. In the absence of definite quantitative determinations of these constituents the distinction between friedelite and schal-

¹³ *Op. cit.*, p. 13.

¹⁴ Ford, W. E., Dana's Textbook of Mineralogy, 4th edition, p. 590, John Wiley and Sons, Inc., N. Y., 1932.

lerite,¹⁵ the analogous arsenic-bearing manganese silicate, rests upon comparison of optical properties. The optical properties of the Sunnyside mineral correspond more closely to those of friedelite than to the type specimens of schallerite from Franklin, N. J., as shown in the following table:

TABLE 2. OPTICAL PROPERTIES OF FRIEDELITE AND SCHALLERITE

	Friedelite Sunnyside mine, Colo.	Friedelite Franklin, N. J. ¹	Friedelite Sweden ²	Schallerite Franklin, N. J. ³
Indices of refraction	$\left\{ \begin{array}{l} \omega = 1.657 \\ \epsilon = 1.625 \end{array} \right.$	1.656	1.664	1.704
Birefringence	0.032	1.62	1.629	1.679
Optical character	Negative	0.03	0.035	0.025
2 V	Negative	Negative	Negative	Negative
	0°, or a few degrees	0°	Small	0°

¹ Bauer, L. H., and Berman, H., Friedelite, schallerite, and related minerals: *Am. Mineralogist*, 13, pp. 342, 343, Table 1, No. 4, and Table IIa, No. 2, 1928.

² Larsen, E. S., Microscopic determination of the non-opaque minerals: *U. S. Geological Survey, Bull.* 825, p. 77, 1921.

³ Bauer and Berman, *Op. cit.*, p. 343.

The friedelite from Franklin, N. J., the optical properties of which are given in the table above, contained 2.32 percent of chlorine, and 1.15 percent of As₂O₃, but the members of this group of minerals are probably not sufficiently well known for the optical and chemical properties to be correlated closely. The Sunnyside Mine seems to be the only locality in the United States other than Franklin, N. J., from which this mineral has been recorded.

HELVITE, 3(Mn, Fe)BeSiO₄·MnS. The comparatively rare species, helvite, was found in three specimens of the mixed silicates of manganese. It forms small grains not over a few millimeters in diameter that are usually near small grains of pyrite or other common sulphides. The brilliant honey-yellow color, however, makes it conspicuous. The mineral was identified by its isotropic character, refractive index near 1.74, presence of beryllium, and absence of zinc, as determined by spectrographic tests kindly made by Mr. George Steiger of the U. S. Geological Survey.

Under the microscope some grains of the mineral are seen to be

¹⁵ Gage, R. B., Larsen, E. S., and Vassar, H. E., Schallerite, a new arseno-silicate mineral from Franklin Furnace, New Jersey: *Am. Mineralogist*, 10, pp. 9-11, 1925.

partly altered to a yellowish birefracting product, and the clear grains show small tetrahedral-shaped cavities containing minute spherical bodies. The small particles of sulphide nearest to the mineral appeared in several instances to be pyrite, rather than either alabandite or sphalerite.

This is the second record of the occurrence of helvite in the United States. The only locality is the area near Amelia Court House, Va., where the mineral occurs in cracks in orthoclase and spessartite at the mica mines,¹⁶ in association with monazite, micro-lite, allanite, and other pegmatitic minerals. The most common foreign occurrences of helvite also appear to be pegmatitic or contact zone associations, but Dana records it from Kapnik, Hungary, on quartz and rhodochrosite.

RHODOCHROSITE ($\text{MnO} \cdot \text{CO}_2$). The carbonate of manganese is found in small amounts at least in practically all of the specimens, and in some of them it is abundant. It is usually less common than rhodonite. The carbonate has replaced many of the silicates and locally some of the sulphides, so that it occurs in veinlets and irregular replacement masses. The indices of refraction indicate that all of the carbonate tested is high in manganese and is rhodochrosite rather than manganocalcite. In one specimen the lowest value of the index, ω , was about 1.79, but other specimens showed still higher values so that according to the data given by Krieger¹⁷ the carbonate contains 80 to 85 percent or more of MnCO_3 .

RHODONITE ($\text{MnO} \cdot \text{SiO}_2$). The material from the dump at Eureka and the specimens studied, contain much more rhodonite than the other manganese silicates. The grains of rhodonite range from about 0.1 to 1.0 millimeter in diameter and well formed crystals, about one millimeter in maximum diameter, were found in small vugs in the massive rhodonite gangue. The color of the rhodonite masses appears to vary chiefly according to their texture. Some specimens are very pale pink but others are deep pink. Little variation could be detected in the indices of refraction.

Some rhodonite crystals show twinning but in general the min-

¹⁶ Lewis, H. C., An American locality for helvite: *Proc. Acad. Nat. Sci. Phila.*, **34**, pp. 100-102, 1882.

Dana, E. S., System of mineralogy, 6th Ed., p. 435, 1909. John Wiley and Sons, N. Y.

¹⁷ Krieger, P., Notes on an x-ray diffraction study of the series calcite-rhodochrosite: *Am. Mineralogist*, **15**, pp. 23-29, 1930.

eral is distinguished by the sparseness of twinning whereas grains of alleghanyite uniformly show it. The optical properties of the rhodonite in several massive specimens were determined, and of some small transparent rose-pink crystals in a cavity as well.

TABLE 3. OPTICAL PROPERTIES OF RHODONITE

	Sunnyside mine, Colo.	Vittinge, Finland ¹
Indices of refraction	$\left\{ \begin{array}{l} \alpha=1.733 \\ \beta=1.736 \\ \gamma=1.747 \end{array} \right.$	$\left\{ \begin{array}{l} \alpha=1.733 \\ \beta=1.737 \\ \gamma=1.747 \end{array} \right.$
Birefringence	0.014	0.014
Dispersion	$r < v$	—
2 V	55°-60°	61°
Optical character	Positive	Positive

¹ Sundius, N., On the triclinic manganiferous pyroxenes: *Am. Mineralogist*, 16, pp. 488-489, and pp. 517, 518, 1931.

The chemical analysis of the rhodonite from Vittinge shows 94.69 percent of MnSiO₃, and only 3.05 percent CaSiO₃, and the close correspondence of its optical properties with those of the Sunnyside rhodonite suggests that this rhodonite also has a high manganese content.

TEPHROITE (2MnO·SiO₂). The manganese olivine, tephroite, was identified in four of the specimens as small anhedral grains nearly always associated with larger masses of alleghanyite. The grain size ranges from 0.1 to 0.35 millimeter in diameter. The color of the mineral is gray and a mottled appearance is noticeable in polished specimens containing much of the mineral. On the surfaces of pieces that have been exposed on the dump tephroite assumes a darker color than the other minerals and it probably weathers more quickly. The relative susceptibility to weathering of the other silicates is not clearly shown.

At first the tephroite in thin section was not distinguished from anhedral grains of alleghanyite that were so oriented as not to show the twinning lamellae. The presence of tephroite was first determined by a study of the powdered material by the immersion method, and it could then be rather readily identified in thin sections. Tephroite commonly shows a brownish amorphous alteration product around the edges and in cracks; it also has a smaller optic axial angle than alleghanyite.

Table 4 presents the optical properties of tephroite from the

Sunnyside mine and for comparison those of tephroite from Franklin, N. J., and Bald Knob, N. C.

TABLE 4. OPTICAL PROPERTIES OF TEPHROITE

	Sunnyside mine, Colo.	Franklin, N. J. ¹	Bald Knob, N. C. ²
Indices of refraction	$\left\{ \begin{array}{l} \alpha=1.771 \\ \beta=1.800 \\ \gamma=1.815 \end{array} \right.$	$\left\{ \begin{array}{l} \alpha=1.770 \\ \beta=1.792 \\ \gamma=1.804 \end{array} \right.$	$\left\{ \begin{array}{l} \alpha=1.785 \\ \beta=1.803 \\ \gamma=1.820 \end{array} \right.$
Birefringence	0.044	0.034	0.035
Dispersion	$r > v$	$r > v$	$r > v$
2 V	$70^\circ \pm$	large	72°
Optical character	Negative	Negative	Negative

¹ Larsen, E. S., The microscopic determination of the nonopaque minerals: *U. S. Geol. Survey, Bull.* 679, p. 143, 1921.

² Ross and Kerr, *Op. cit.*, p. 5.

Tephroite is not an uncommon mineral of the deep vein zones of manganese deposits that lie largely in the crystalline rocks of the Appalachian belt. This occurrence seems to be the first in the United States in the younger deposits that have thus far been considered to be epithermal.

PARAGENETIC RELATIONS

Since the interrelations of the different minerals in veins were not studied in place, it would not be wise to correlate confidently the relations observed in the specimens with the general paragenetic relations in the mine recorded by Hulin and mentioned in the introduction. This might result in misleading if not wholly erroneous conclusions. However, the relations observed between the different silicate minerals are probably worth recording briefly as these seem to be fairly constant in all of those specimens studied.

Several specimens showed distinct veins of the manganese silicates cutting through earlier masses of sulphides and quartz, or showed fragments of sulphides included within the silicates so that it seems clear that a part of the massive sulphides was earlier than any of the minerals herein described. Practically all of the specimens, however, showed small amounts of galena, sphalerite, pyrite, and chalcopyrite, as well as alabandite, which are interlayered in the silicates of manganese or were deposited somewhat later than the silicates. Some of the more evident relations are illustrated in Figures 2 and 3. In what follows the relations between sulphide

and gangue minerals concern only those sulphides contemporaneous with or later than the manganese minerals.

What at first appears to be a somewhat anomalous feature of the paragenesis is that the hydrous silicate, friedelite, wherever found in appreciable amounts in association with the other silicates, is one of the earliest of the manganese minerals. The largest masses found in the specimens ranged from 2 to 10 millimeters in diameter, but these were veined and partly replaced by tephroite, alleghanyite, rhodonite, and rhodochrosite. The alleghanyite tends to form sheaf-like or irregular clusters of crystals that appear to have grown at the expense of friedelite. These clusters are clearly related to fissures or cracks from which the crystals advanced into the unreplaced friedelite. Rhodonite crystals exhibit exactly the same type of replacement forms along the borders of later veinlets of rhodonite cutting friedelite. The peculiar manner in which the alleghanyite crystals have grown suggests that the friedelite is possibly replacing the anhydrous silicates, which have the appearance around their edges of much corroded and frayed crystals; but that this appearance is deceiving is shown by comparison with similar crystals growths about the distinct and later veinlets of rhodonite. Growths of alleghanyite in friedelite are illustrated by the photomicrograph shown in Fig. 4. Nuclear masses of tephroite grains within the larger alleghanyite masses show that this mineral was also one of the first to form at the expense of friedelite, and from its spacial relations was presumably formed before the bulk of the alleghanyite. On the other hand one specimen shows that some of the friedelite is later than tephroite and perhaps indicates local repetition of the early stages of paragenesis.

Rhodonite was later than alleghanyite, and free crystals were deposited in vugs after the bulk of the anhedral granular mass of rhodonite had formed. The formation of rhodonite appears to have been interrupted at least once by renewed fracturing, with the result that the earlier manganese silicates as well as the bulk of the rhodonite is cut by interlacing veinlets of later rhodonite. The process of replacement of most of the earlier silicates by rhodonite is shown both by the thin sections and the polished faces of the specimens. (Figures 1, 3, 4.)

Whether or not most of the rhodonite formed at the expense of earlier friedelite or of other manganese silicates cannot be determined conclusively from the study of small hand specimens. In

several of the thin sections small nests of comparatively large sized friedelite crystals occur interstitially in the midst of masses of rhodonite crystals. It is not clear whether these represent remnants of recrystallized friedelite remaining from the earlier finer grained mass, or whether they represent a later generation of friedelite, transported and redeposited. It is perhaps significant however that friedelite crystals could not be found in any of the small vugs in the gangue, although rhodonite, rhodochrosite, and several different sulphides were found in them.

Rhodonite is the only manganese silicate found associated directly with or intergrown with quartz. No quartz was found in any vugs in the mixed silicate gangue, nor were quartz veinlets cutting these silicates noted. Most of the quartz in the Sunnyside ores evidently belongs to stages of vein formation preceding these manganese minerals. However, there is evidently some later quartz or quartz and free gold that was deposited with or later than rhodonite, but which does not happen to be represented in the particular specimens of friedelite, alleghanyite, and tephroite examined. As set forth below, the silica content of the solutions evidently increased following deposition of the earlier silicates until finally rhodonite and quartz crystallized together. As tephroite and alleghanyite are orthosilicates and the ratio of manganese to silica in them is less than 1 to 1, the ratio in the metasilicate rhodonite, it is possible that a hiatus in the deposition of quartz exists at their particular stage of formation in the Sunnyside veins.

The sulphide, alabandite, appears to have formed during the crystallization of the silicates, chiefly with friedelite and alleghanyite, but also with the rhodonite. Its distribution is unrelated to the later lines of fracturing along which the latest rhodonite and along which the rhodochrosite were formed. The helvite cannot be exactly placed in the sequence but may have formed late in the crystallization of rhodonite, and is definitely earlier than rhodochrosite. Helvite was seen in only one thin section where it was interstitial among crystals of rhodonite. Sphalerite, galena, chalcopyrite, and small amounts of pyrite and possibly tetrahedrite filled in along cracks and replaced brecciated rhodonite as shown in Fig. 2. The formation of some of these sulphides possibly in part overlapped that of helvite.

Rhodochrosite was the last of the manganese minerals to form and it has partly replaced all of the earlier ones and some of the

common sulphides. This sequence is the same as observed by Hewett and Rove.¹⁸

The general picture obtained from these paragenetic relations is that the solutions which brought in the manganese were at first low in silica, high in manganese, and contained sufficient chlorine to permit the deposition of massive friedelite. Later solutions which were presumably less acid but still low in silica caused the dehydration of the friedelite and the formation of tephroite and alleghanyite. This dehydration may have been caused by an increase in temperature of the emanations. As the silica content of these solutions increased, rhodonite began to form and continued until locally rhodonite and quartz were formed together. Probably the later rhodonite was formed in part by direct precipitation in openings rather than entirely by replacement of the earlier silicates. The late rhodochrosite and any other carbonates that are present may be attributed to the attack of carbonated water as they do not necessarily indicate further introduction of manganese from the original source.

Conclusions as to the classification of the different manganese minerals in the common temperature schemes cannot be made safely with the data at present available on their occurrence and paragenesis. However, from the general mineralogy of the Sunnyside veins as compared with the more distant and characteristic epithermal facies of the San Juan veins, the Sunnyside mineralization may be tentatively assigned to facies commonly defined as mesothermal.

The not uncommon occurrence of tephroite in the deep vein zones of the Appalachian region indicates that this mineral is formed more typically at great depths under hypothermal or pyrometamorphic conditions. Its presence in small quantities in the Sunnyside veins indicates however that it may form likewise at comparatively shallow depths (5,000 feet or less) when other factors in its formation are favorable, and lends support to the possibility that many of the San Juan veins were formed at temperatures higher than those generally accepted for the veins of this region.

¹⁸ Hewett, D. F., and Rove, O. N., Occurrence and relations of alabandite: *Econ. Geol.*, 25, pp. 55-56, 1930.