MANSFIELDITE, A NEW ARSENATE, THE ALUMINUM ANALOGUE OF SCORODITE, AND THE MANSFIELDITE-SCORODITE SERIES*

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Abstract

The name mansfieldite is given to a new mineral having the formula $Al_2O_3 \cdot As_2O_5 \cdot 4H_2O$, the aluminum analogue of scorodite. It occurs at Hobart Butte, Lane County, Oregon, and together with intermediate members near the iron end of the mansfieldite-scorodite series, was formed by hydrothermal solutions. Mansfieldite occurs as white to pale gray, porous, cellular masses of spherulitic fibers. Chemical, optical, and *x*-ray data are recorded for mansfieldite, scorodite, and an aluminian scorodite. The specific gravity of mansfieldite is 3.03 and of scorodite 3.278. The indices of refraction of mansfieldite are: $\alpha = 1.622$, $\beta = 1.624$, and $\gamma = 1.642$; of the aluminian scorodite: $\alpha = 1.741$, $\beta = 1.744$, and $\gamma = 1.768$; and of scorodite: $\alpha = 1.784$, $\beta = 1.795$, and $\gamma = 1.814$. Both 2V and the birefringence increase with increasing iron content.

Introduction

A hydrous aluminum arsenate recently discovered at Hobart Butte, about fourteen miles south of Cottage Grove, Lane County, Oregon, has proved to be a new mineral, the aluminum analogue of scorodite. This new mineral, $Al_2O_3 \cdot As_2O_5 \cdot 4H_2O$, is named mansfieldite in honor of the late Dr. George R. Mansfield, former Chief of the Section of Areal and Non-metalliferous Geology, U. S. Geological Survey. This discovery not only adds a new member to the small and rare group of natural aluminum arsenates[1] but also has enabled us to establish the variations in physical properties of intermediate members of the mansfieldite-scorodite series. The occurrence of mansfieldite also contributes to an understanding of the geologic history of an important high-alumina clay deposit, for the conditions of the origin of mansfieldite at Hobart Butte are clearly indicated.

The first specimen of this new hydrous aluminum arsenate was collected by the senior author on July 29, 1942, in the company of Robert L. Nichols, who was mapping the clay deposit as part of a joint program of the U. S. Geological Survey and the U. S. Federal Bureau of Mines on high-alumina clay. In January 1943, R. M. Denning[2] published a note on

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* Published by permission of the Director, U. S. Geological Survey.

[1] Clarke, F. W., An aluminum arsenate from Utah: *Jour. Wash. Acad. Sci.*, **2**, 516–518 (1912).

[2] Denning, R. M., Aluminum-bearing scorodite from Hobart Butte, Oregon: *Am. Mineral.*, **28**, 55–57 (1943).

an aluminum-bearing scorodite from Hobart Butte, Oregon. In November 1943, excellent specimens of mansfieldite and of an intermediate member of the series labeled "representative specimens of rock types from Hobart Butte, Oregon," collected by R. L. Nichols, were received for petrographic study. Dr. Nichols has graciously placed these specimens at the disposal of the writers during this investigation.

The discovery of mansfieldite was first announced at a joint meeting of the Society of Economic Geologists and the American Institute of Mining and Metallurgical Engineers in February 1944[3] in one of six papers presented by members of the U. S. Geological Survey[4] to honor Dr. Mansfield on the occasion of his retirement from the Survey.

GEOLOGIC OCCURRENCE

Hobart Butte, Lane County, Oregon, consists of altered pyroclastic rocks, chiefly of andesitic composition and water-laid sediments belonging to the Calapooya formation of probable Eocene age.[5] Among the sediments are conglomerates[6] containing white kaolinite pellets surrounded by a gray, brown, or reddish matrix of clay, organic matter, charcoal fragments, silicified wood, diatoms, and minor amounts of quartz and silicified volcanic fragments. In places conspicuous stratification is developed by the alignment of the long axes of the pellets in one direction and by streaks of organic material curving around them. The structure and composition of these sediments together with the somewhat plastic condition of the pellets which permitted them to be molded against grains of quartz, rock fragments, and other pellets, at the time of deposition, indicate that the kaolinitic pellet clay at Hobart Butte had the composition of kaolinite when it was deposited. The presence of kaolinite books in a leaf-bearing shale on the southwest side of Hobart Butte, about 200 feet below the summit is further evidence of a supply of kaolinitic clay in the area at the time of deposition of the Calapooya formation. Many features of the sediments at Hobart Butte suggest their derivation from an Eocene profile of weathering, which furnished not only white kaolinitic clay for pellets and books, but also reddish clay high in iron for the matrix surrounding the white pellets and the pumice fragments altered to kaolinite. The alteration of pumice fragments to

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[3] Allen, V. T., Sedimentary and volcanic processes in the formation of high-alumina clays: *Econ. Geol.*, **39**, 80, 85, 250 (1944); **41**, 124–138 (1946).

[4] Smith, H. I., Report of Industrial Minerals Division, *Min. and Met.*, **25**, 217 (1944).

[5] Wells, F. C., and Waters, A. C., Quicksilver deposits of southwestern Oregon: *U. S. Geol. Survey, Bull.* **850**, 26–35 (1934).

[6] Allen, V. T., and Nichols, R. L., Clay-pellet conglomerates at Hobart Butte, Lane County, Oregon: *Jour. Sedimentary Petrology*, **15**, 25–33 (1945).

white kaolinite after they were surrounded by reddish or purplish clay could not have taken place without accompanying bleaching of the ferric iron of the matrix to reach the enclosed fragments or pellets. It therefore seems likely that some volcanic glass and breccia fragments were altered to kaolinite before they were embedded in the strongly colored clay matrix by stream deposition during the Eocene.

The rocks of Hobart Butte were invaded by hydrothermal solutions, probably in late Miocene time[7] and realgar, stibnite, pyrite, arsenates, quartz, dickite, and other minerals were deposited. The hydrothermal solutions altered volcanic glass and lithic fragments to kaolinite which appears practically isotropic. Some of the pumice retained its original texture so well during the alteration that one receives the impression that the cloudy, nearly isotropic material is the original glass, but all the specimens isolated and examined have the indices of refraction and the *x*-ray pattern of kaolinite. In many specimens the development of kaolinite from glass and lithic fragments was accompanied by the crystallization of quartz so fine-grained that it escapes detection except in *x*-ray patterns. However, in a few specimens, quartz of microscopic size occurs as prismatic crystals having well-developed terminations. At the summit of Hobart Butte, the glass of welded tuffs is altered to an isotropic-appearing material giving the *x*-ray patterns of kaolinite and of quartz. Parts of the tuff showing relict pumice texture were hand-picked and analyzed for "available alumina," which is the alumina that can be extracted with 20 per cent sulfuric acid from a clay that has been calcined at a temperature of 700° C. The available alumina of the altered glass at Hobart Butte, determined by Margaret D. Foster in the Chemical Laboratory of the U. S. Geological Survey and based upon the weight of the sample dried at 130° C., is 27.4 per cent. This contrasts with the less than one per cent of available alumina in an unaltered vitric tuff from Camanche, California.

A white kaolin mineral accompanied by finely divided quartz fills cracks ranging from 1 to 8 mm. in width that cut across rock fragments in the lower part of the deposit at Hobart Butte. In thin sections, this mineral shows the mosaic intergrowth characteristic of the massive dickite from Chihuahua, Mexico, and Neurode, Silesia. However, all the specimens from Hobart Butte, including one in which small areas had an extinction angle of about 16°, gave the *x*-ray pattern of kaolinite. This suggests that the amount of dickite present is too small to be recorded

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[7] Wells, F. C., and Waters, A. C., *loc. cit.*, p. 25.

Callaghan, Eugene, and Buddington, A. F., Metalliferous mineral deposits of the Cascade Range in Oregon: *U. S. Geol. Survey, Bull.* **893,** 21 (1938).

in the *x*-ray pattern of a mixture mainly kaolinite, and that the temperature of the hydrothermal solutions may have been sufficiently high at first to allow some dickite to crystallize but soon was lowered to a stage where kaolinite crystallized.[8] The available alumina of a typical veinlet giving the *x*-ray patterns of kaolinite and of quartz was determined by Margaret D. Foster to be 26.7 per cent.

Siderite scales cover the surface of some kaolinite having a mosaic intergrowth and containing admixed quartz and also fill cracks in the clay. Siderite nodules, with or without a radial structure, fill openings in the pellet clay and the altered andesitic breccias. Some of the siderite nodules appear to be cut by stringers of realgar, and this arrangement suggests that some siderite was deposited by hydrothermal solutions after kaolinite and before realgar. Siderite and iron oxides are responsible for the high iron content of some of the Hobart Butte clays. Wells and Waters[9] consider that the oxidation of siderite caused pronounced iron oxide ribs at Hobart Butte and at Black Butte about two miles away. Pyrite crystals of pyritohedral habit occur in the siderite and kaolinite veinlets. Marcasite has been reported[10] in the Black Butte area, but definite proof is lacking that any of the iron sulfide at Hobart Butte is marcasite.

Tiny acicular crystals of stibnite occur in small amounts in some of the clay and locally comprise radiating groups of crystals 3 mm. in diameter. The greatest concentration of stibnite is along slickensides, where needles of microscopic size form aggregates a millimeter or so in thickness. The time relations of stibnite to the other sulfides and to the arsenates are unknown.

Realgar is the most conspicuous sulfide at Hobart Butte, where it is distributed along slickensides, in cracks, and in the matrix of the pellet clay. Some of the realgar conforms to the striated grooves of the slickensides and some of the realgar is itself slickensided. This suggests that the pellet clay was slickensided before the hydrothermal solutions brought in realgar, that the slickensides served as one type of opening for the invading solutions and that movement along slickensides was renewed during or after the deposition of realgar.

The arsenates of iron and aluminum occur as colloform crusts along open cavities in the clay. The time relations of the arsenates to the sulfides are unknown because at no place were they observed in contact.

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[8] Ewell, R. H., and Insley, H., Hydrothermal synthesis of kaolinite, dickite, beidellite, and nontronite: *Jour. Nat. Bur. Stand.*, **15,** Research paper R.P. 819, 173–186 (1935).

[9] *Loc. cit.*, p. 34.

[10] Wells, F. C., and Waters, A. C., *loc. cit.*, p. 25.

However, it is believed that they were deposited by hydrothermal solutions similar to those which have deposited scorodite at other localities.[11] The presence of realgar and stibnite in the same deposit is also suggestive of deposition by hot ascending waters related to volcanic processes.[12]

Some re-arrangement of kaolinite by hydrothermal solutions is indicated by (1) the occurrence of kaolinite in veinlets, and (2) the cavities formed by the removal of kaolinite and now partially filled with scorodite, mansfieldite, realgar, and siderite. Where hydrothermal solutions moved along the slickensides in the sedimentary clay now exposed in the Hobart Butte quarry, little new kaolinite was formed to increase the alumina content of the clay. Bleached zones from one to several centimeters wide were produced by the removal of some organic matter and iron. The alumina content of the bleached zone was increased only by an amount equal to that resulting from the removal of iron and organic matter and this amounted to less than one per cent in the specimens analyzed.

MANSFIELDITE AND ALUMINIAN SCORODITE AT HOBART BUTTE

Mansfieldite is white to pale gray, has a vitreous luster, a hardness of about 3.5, a spherulitic or axiolitic structure, and occurs as porous, cellular masses ranging in length from a few centimeters to about 20 centimeters. Optically, mansfieldite is positive, has indices of refraction: $\alpha = 1.622$, $\beta = 1.624$, $\gamma = 1.642$, 2V (measured) very close to 30°, and dispersion $r > v$. In thin section, mansfieldite appears as clear bands with an aggregate structure or intergrown with kaolinite. Care was taken, in determining the optical properties listed in Table 2, to select only clear grains, because those intergrown with kaolinite gave low values for both refringence and birefringence. The presence of kaolinite and quartz with the mansfieldite complicated the interpretation of the analysis, which was made on the mixture of the three minerals.

In occurrence and appearance, the aluminian scorodite differs from mansfieldite in one respect only—the color is light green. At the Hobart Butte quarry, lumps of both minerals, large enough to be seen easily, are removed by hand during the mining of the clay and discarded. In hand specimen, the aluminian scorodite resembles some varieties of opal or

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[11] Hague, J. D., Notes on the deposition of scorodite from arsenical waters in Yellowstone National Park: *Am. Jour. Sci.* (3), **34**, 171–175 (1887).

[12] Weed, W. H., and Pirsson, L. V., Occurrence of sulfur, orpiment and realgar in the Yellowstone National Park: *Am. Jour. Sci.* (3), **42**, 401–405 (1891).

Becker, G. F., Geology of the quicksilver deposits of the Pacific Slope: *U. S. Geol. Survey, Mon.* **13**, 349 (1888).

chalcedony. No individual or terminated crystals were observed. Optically, the mineral is positive, has indices of refraction: $\alpha=1.741$, $\beta=1.744$, $\gamma=1.768$, a measured 2V of approximately 40°, and dispersion $r>v$. In thin section, most of the aluminian scorodite appears as colloform crusts, with variable indices of refraction. In crushed samples examined in immersion oils with a petrographic microscope, some grains showed two or more zones of different indices. Such material was discarded as unsatisfactory for chemical analysis. The aluminian scorodite in Table 2 was composed mainly of one member and the optical properties recorded are believed to be those of the dominant member present.

At Hobart Butte no scorodite has been found thus far which represents the pure iron end member. In order to record additional chemical and optical data for the scorodite end of the series, a specimen that had been collected by W. F. Foshag at Durango, Mexico, was obtained from the U. S. National Museum. The indices of refraction are: $\alpha=1.784$, $\beta=1.795$, $\gamma=1.814$, 2V (measured) approximately 75°, and dispersion $r>v$. These data (Table 2) agree closely with those obtained by Foshag for analyzed scorodite from Gold Hill, Utah,[13] and from Mapimi, Mexico.[14]

The lack of scorodite free from alumina, as well as the textural relations of the aluminian scorodites and mansfieldite to kaolinite, suggests that the hydrothermal solutions depositing the arsenates at Hobart Butte had assimilated alumina from the clay. Colloform crusts composed of various proportions of aluminum and iron arsenate as well as the nearly iron free mansfieldite were deposited locally by these solutions in an intimate intergrowth with kaolinite. The only uncontaminated mansfieldite forms thin bands adjoining zones of intergrown mansfieldite and kaolinite.

CHEMICAL COMPOSITION OF MANSFIELDITE

Petrographic and *x*-ray examinations showed that the mansfieldite was intimately associated and intergrown with quartz and kaolinite. This necessitated the application of a procedure that would correctly allocate the SiO_2 between the quartz and the kaolinite, and the Al_2O_3 and H_2O between the kaolinite and the mansfieldite. The complete analysis of the sample was made as follows:

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[13] Foshag, W. F., Berman, H., and Doggett, R. A., Scorodite from Gold Hill, Toole County, Utah: *Am. Mineral.*, **15,** 390–391 (1930).

[14] Foshag, W. F., Carminite and associated minerals from Mapimi, Mexico: *Am. Mineral.*, **22,** 482 (1937).

TABLE 1. ANALYSIS OF MANSFIELDITE

Chemical Analysis of Sample Containing Mansfieldite, Kaolinite and Quartz		Calculated Mineral Composition			
	Per cent		Per cent		Per cent
SiO_2	14.58	Quartz	3.25	SiO_2	3.25
Al_2O_3	25.78	Kaolinite	24.37	SiO_2	11.33
Fe_2O_3	.66			Al_2O_3	9.63
TiO_2	2.20			H_2O	3.41
As_2O_5	39.12	Mansfieldite (Recalculated to 100 per cent in Table 2)	69.32	Al_2O_3	16.15
Sb_2O_5	.08			Fe_2O_3	.61
P_2O_5	.41			TiO_2	.63
$H_2O-110°$ C.	.35			As_2O_5	39.12
$H_2O+110°$ C.	15.73			Sb_2O_5	.08
CuO	.16			P_2O_5	.41
CaO	.02			H_2O	12.32
MgO	.02	Insoluble in H_2SO_4	1.62	TiO_2	1.57
Na_2O	.28			Fe_2O_3	.05
K_2O	.03	Soluble in H_2SO_4	.51	Na_2O	.28
Organic Matter	.38			K_2O	.03
Total	99.80			CuO	.16
Sp. Gr.	2.903			CaO	.02
				MgO	.02
		Organic Matter	.38		.38
		$H_2O-110°$ C.	.35		.35
		Total	99.80		99.80

A half gram sample was treated in a small platinum dish with 15 ml. of H_2SO_4 (1:2) and heated on the steam bath overnight. The mansfieldite dissolved completely, the quartz and most of the kaolinite remained insoluble. The contents of the dish were washed into a 400 ml. Erlenmeyer flask, the dish was washed with 20 ml. of water, the washings and 200 ml. of concentrated HCl being added to the flask. Arsenic was precipitated by H_2S from the cold solution, the filtered precipitate was dissolved in NaOH and H_2O_2, reduced with SO_2 by the method of Kurtenacker and Furstenau,[15] and finally titrated with standard iodine solution. Antimony was precipitated as the sulfide in the filtrate from the

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[15] Kurtenacker, A., and Furstenau, E., *Zeits. Anorg. Allgem. Chem.*, **212**, 289 (1933).

arsenic sulfide precipitation, after diluting with water to 900 ml. and allowing to stand over night before filtering. It was determined gravimetrically as Sb_2S_5. No tin was present. In the filtrate Fe_2O_3, P_2O_5, TiO_2, CaO, and MgO were determined and their percentages recorded in Table 1. Alumina was not determined on this sample because a small amount of the clay had been decomposed by the H_2SO_4. Total SiO_2, Fe_2O_3, Al_2O_3, P_2O_5, and TiO_2 were determined on a separate sample. The difference between the total Fe_2O_3 and the Fe_2O_3 soluble in H_2SO_4 gave 0.05 per cent Fe_2O_3 insoluble in H_2SO_4. Likewise 1.57 per cent TiO_2 was found to be insoluble in H_2SO_4. All of the P_2O_5, CaO, MgO, and the alkalies present in the sample were soluble in H_2SO_4. Water was determined by the Penfield glass tube method and 0.16 per cent CuO soluble in H_2SO_4 was found in a separate sample.

It was evident that if the percentage of quartz could be measured and deducted from the percentage of total SiO_2, the remaining percentage of SiO_2 could be allotted to kaolinite and from that figure the percentage of the kaolinite in the sample could be computed. The Al_2O_3 of the kaolinite could then be deducted from the total Al_2O_3, leaving the percentage of Al_2O_3 present in the sample as aluminum arsenate. Similarly, the total H_2O would be divided between the kaolinite and the mansfieldite.

In order to make these computations, the percentage of quartz present was determined by treating a gram sample in a small platinum dish with 30 ml. H_2SO_4 (1:2), heating on the steam bath overnight, then diluting with water and carefully decanting after the insoluble portion had settled. Five ml. HF (1:4) were then added to the residue and stirred at room temperature for one minute, diluted with water, and after allowing to settle, carefully decanted. The residue was transferred to a larger platinum dish, 50 ml. of a 10 per cent Na_2CO_3 solution were added, and heated to boiling for ten minutes. It was then diluted with water, allowed to settle, and carefully decanted. After treating the residue with 15 ml. HCl (1:2) and heating on the steam bath for 15 minutes, the quartz was filtered, ignited, and weighed. Examination with the petrographic microscope showed the quartz to have only a negligible amount of impurities. With this figure for quartz and the complete analysis of the sample, the percentages of quartz, kaolinite, and mansfieldite were readily computed and are recorded in Table 1. The mansfieldite analysis is recalculated to 100 per cent in Table 2.

The specific gravity of mansfieldite was computed at 3.03 by determining the specific gravity of the analyzed sample (Table 1) and applying the proper corrections for the percentages of kaolinite and quartz present.

The analyses of the sample of scorodite and of the intermediate member of the series, Table 2, differ from that of the sample of mansfieldite in that the samples are almost free from any extraneous insoluble matter.

THE MANSFIELDITE-SCORODITE SERIES

It is well established that scorodite crystallizes in the orthorhombic system, and on the basis of similar optical and *x*-ray properties, mansfieldite is also probably orthorhombic. The molecular ratio of the intermediate member, Table 2, agrees very closely with the 1:1:4 ratio required by the formula of scorodite and its aluminum analogue, mansfieldite. Two straight-line curves are drawn (Fig. 1), representing the variation in the alpha and gamma indices of the members of the mansfieldite-scorodite series. The lines terminate on the left with the alpha and gamma indices of mansfieldite and on the right with those of scorodite. The lower abscissa is divided to represent the percentages of ferric oxide in the series, ranging from 0 in pure mansfieldite to 34.6 in pure scorodite. The upper abscissa is divided to represent the percentages of alumina, ranging from 0 in pure scorodite to 25.2 in pure mansfieldite. The gamma index of 1.768 for the aluminian scorodite listed in Table 2, plotted on the curve, gives percentages of 25.7 and 6.2, respectively, of Fe_2O_3 and Al_2O_3. These figures closely approximate the values found in the chemical analysis.

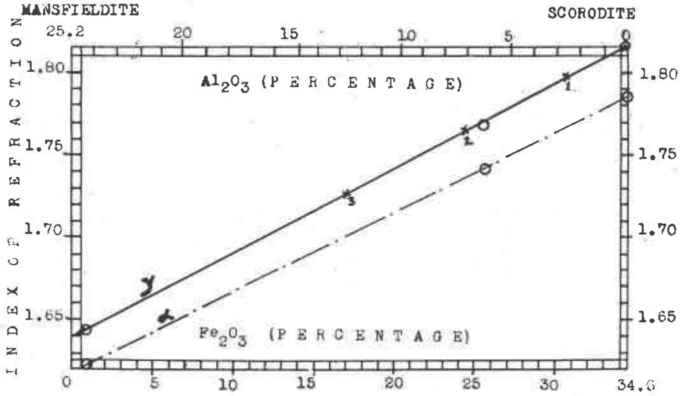

FIG. 1. Curve showing relation of indices of refraction of mansfieldite-scorodite series to percentage of alumina and ferric oxide present. Points 1 and 2 are after Larsen, 3 is after Denning, and 0 is aluminian scorodite recorded in Table 2.

Two specimens,[16] listed by Larsen as scorodite (1 and 2 of Fig. 1) appear to be intermediate members of this series: (1) an unanalyzed sam-

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[16] Larsen, E. S., Microscopic determination of nonopaque minerals, *U. S. Geol. Surv., Bull.* **679,** 132 (1921).

ple from Nassau, Germany, with $\gamma=1.797$ would have, according to the curve (Fig. 1), 30.7 per cent Fe_2O_3 and 2.8 per cent Al_2O_3; (2), with $\gamma=1.765$ would have 24.5 per cent Fe_2O_3 and 7.2 per cent Al_2O_3. (2) an analyzed sample from Black Pine, Idaho, contains, according to the analysis, 4.80 per cent P_2O_5 and no Al_2O_3. Hence it seems that iron aluminum arsenates in which As_2O_5 is in large part replaced by P_2O_5 are not amendable to measurement by this chart (Fig. 1). The specimen of aluminian scorodite from Hobart Butte (3 on Fig. 1) which was measured by Denning[17] with $\gamma=1.728$ would contain, according to this curve, 17.0 per cent Fe_2O_3 and 12.7 per cent Al_2O_3. Measurements

TABLE 2. MANSFIELDITE-SCORODITE SERIES

	Mansfieldite (Recalculated) Hobart Butte $Al_2O_3 \cdot As_2O_5 \cdot 4H_2O$		Aluminian Scorodite Hobart Butte $(Fe, Al)_2O_3 \cdot As_2O_5 \cdot 4H_2O$		Scorodite Durango, Mexico $Fe_2O_3 \cdot As_2O_5 \cdot 4H_2O$	
	Per cent	Molecular Ratio	Per cent	Molecular Ratio	Per cent	Molecular Ratio
Al_2O_3	23.30	.99	5.76	1.00	None	1.01
TiO_2	.91		.06		.02	
Fe_2O_3	.88		25.72		34.79	
As_2O_5	56.43	1.01	48.88	1.03	49.52	1.00
Sb_2O_5	.12		.74		.06	
P_2O_5	.59		1.72		None	
H_2O+	17.77	3.99	15.86	3.98	15.44	3.98
H_2O-	—		1.18		None	
SiO_2	—		.20		.30	
Total	100.00		100.12		100.13	
Sp. Gr.	3.031		3.135		3.278	
Alpha	1.622		1.741		1.784	
Beta	1.624		1.744		1.795	
Gamma	1.642		1.768		1.814	
B.	.020		.027		.030	
2V	30° ±		40° ±		75° ±	
Disp.	$r>v$		$r>v$		$r>v$	

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[17] *Loc. cit.*, p. 55 (1943).

TABLE 3. POWDER DIFFRACTION PATTERNS—UNFILTERED IRON RADIATIONS

Mansfieldite		Aluminian Scorodite		Scorodite	
d	*I*	*d*	*I*	*d*	*I*
6.00	mw	6.10	m	6.16	m
5.45	vvs	5.52	vs	5.56	vvs
4.84	m	4.89b	ms	4.95	ms
4.36	vvs	4.41	vvs	4.44	vvs
3.97	ms	4.02	m	4.06	m
3.71	mw	3.75	m	3.78	m
3.41	mw	3.47	mw	3.50	m
3.32*Q*	mw	3.35	mw	3.36	m
3.29	mw	3.28	w		
3.09	vs	3.14	s	3.16	vvs
2.98	s	3.03	ms	3.05	s
2.92	m	2.97	m	2.98	ms
2.77	w	2.83	w	2.84	mw
2.68	m	2.74	mw	2.75	mw
2.62	m	2.67	mw	2.67	m
2.52	s	2.57	ms	2.58	vs
2.44	m	2.48	m	2.50	ms
2.25	w	2.30	w	2.31	mw
2.18	mw	2.22	vw		
2.08	w	2.17	w	2.18	mw
		2.12	vw	2.13	mw
		2.09	vw	2.11	mw
2.00	w	2.03	w	2.04	mw
1.959	mw	1.991	mw	2.00	m
1.779	mw	1.824	w	1.836	mw
1.753	mw	1.784	w	1.797	mw
1.709	mw	1.748	w	1.753	mw
1.627	ms	1.653	m	1.664	ms
		1.626	w	1.645	mw
1.543	mw			1.583	mw
1.480	m	1.505	w	1.513	mw
1.401	mw	1.468	w	1.473	m
		1.434	w		
1.361	mw	1.397	w	1.401	mw
1.276	mw				
1.263	mw	1.295	w	1.280	mw
1.215	m	1.226	vw	1.230	mw
1.178	mw			1.207	mw
1.169	mw	1.193	w	1.197	mw
1.084	mw	1.106	w	1.110	mw
				1.054	mw
				1.018	mw
.996	m			1.006	m
				.998b	mw

b = broad.

on several specimens indicate that some colloform crusts from Hobart Butte have indices of refraction intermediate between the values reported by Denning and those of mansfieldite, but the material is so interbanded that it is unsatisfactory for chemical analysis.

X-RAY ANALYSIS

X-ray photographs were made of the three samples analyzed, namely mansfieldite, aluminian scorodite, and scorodite. Debye-Scherrer cameras of 57.3 mm. radius and unfiltered iron radiation were used; intensities of the lines were estimated visually. Because the scorodite sample was better crystallized than the two aluminous minerals, it gave a sharper diffraction pattern, but the patterns are all strikingly similar and undoubtedly represent isostructural minerals. The similarity is significant also, in that the progressively smaller increases in interplanar spacings with increasing iron content may be used, in the absence of other composition variations, to estimate the scorodite content to a precision of about ten per cent.

The measurements on the stronger lines of each pattern are given in Table 3. The mansfieldite contains kaolinite and quartz, and one line partly due to quartz is marked with a *Q*. The unit cell and space group of scorodite have been published by Kokkoros[18] and McConnell.[19]

ISOMORPHISM AMONG PHOSPHATES AND ARSENATES

It has been shown in this paper that mansfieldite and scorodite are end members of an isomorphic series. The literature contains many analyses of samples intermediate between variscite and strengite, the phosphate analogues of mansfieldite and scorodite. These four orthorhombic minerals may be placed at the four corners of a tetrahedron. In view of the fact that isomorphism has been found only between end members having the same acid radical, the question as to whether or not isomorphism can exist between end members with different anions presents itself. Is isomorphism possible between mansfieldite, and variscite or strengite, or between scorodite, and variscite or strengite? The aluminian scorodite, Table 2, containing 1.72 per cent P_2O_5 and the scorodite from Black Pine, Idaho (number 2, Fig. 1) containing 4.80 per cent P_2O_5 seem to indicate that such isomorphism may exist.

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[18] Kokkoros, Peter, Vergleichende Röntgenographische Untersuchung von Arsenaten und Selenaten: *Praktika Acad. Athens,* **13,** 337–344 (1938); *Min. Abs.,* **8,** 140 (1941).

[19] McConnell, Duncan, Clinobarrandite and the isodimorphous series, variscite-metavariscite: *Am. Mineral.,* **25,** 719–725 (1940).

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