

Foggite, $\text{CaAl}(\text{OH})_2(\text{H}_2\text{O})[\text{PO}_4]$; Goedkenite, $(\text{Sr},\text{Ca})_2\text{Al}(\text{OH})[\text{PO}_4]_2$; and Samuelsonite, $(\text{Ca},\text{Ba})\text{Fe}_2^{2+}\text{Mn}_2^{2+}\text{Ca}_8\text{Al}_2(\text{OH})_2[\text{PO}_4]_{10}$: Three New Species from the Palermo No. 1 Pegmatite, North Groton, New Hampshire

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Abstract

Three new phosphate species have been found from the Palermo No. 1 pegmatite, North Groton, New Hampshire. They occur in the whitlockite-carbonate apatite paragenesis which derived from the replacement of triphylite crystals. The complex mineral chemistry obtains from the partial solution of the triphylite and the composition of the aqueous-rich fraction formed during core consolidation. Local stagnant conditions probably led to concentrations of unusual cations in the late stage such as Ba^{2+} and Sr^{2+} . Associated minerals include quartz, siderite, scorzalite, goyazite, palermoite, bjarebyite, childrenite, arrojadite, and many very late products.

Foggite, $\text{Ca}(\text{H}_2\text{O})\text{Al}(\text{OH})_2[\text{PO}_4]$, a 9.270(2)Å, b 21.324(7)Å, c 5.190(2)Å, $A_2, 22$, $Z = 8$, specific gravity 2.78, hardness 4, cleavages {010} perfect and {100} good, occurs as colorless-to-white foliated plates upon quartz, childrenite, and siderite. Biaxial (+), $2V$ 40–45°, α 1.610(2), β 1.610(2), γ 1.611(2), $X||c$, $Y||b$, $Z||a$.

Goedkenite, $(\text{Sr},\text{Ca})_2\text{Al}(\text{OH})[\text{PO}_4]_2$, a 8.45(2)Å, b 5.74(2)Å, c 7.26(2)Å, β 113.7(1)°, $P2_1/m$, $Z = 2$, computed density 3.83 g cm⁻³, hardness 5, cleavage {100} fair, occurs as colorless to pale yellow lozenge-shaped tabular crystals on palermoite and replacing goyazite. Forms observed are $c\{001\}$, $l\{011\}$, $e\{012\}$, $d\{\bar{1}01\}$ and $g\{111\}$. Biaxial (+), α 1.669(2), β 1.673(2), γ 1.692(2), $2V$ 45–50°, $X||b$. It is probably isostructural with brackebuschite.

Samuelsonite, $(\text{Ca},\text{Ba})\text{Fe}_2^{2+}\text{Mn}_2^{2+}\text{Ca}_8\text{Al}_2(\text{OH})_2[\text{PO}_4]_{10}$, a 18.495(5)Å, b 6.805(2)Å, c 14.000(5)Å, β 112.75(6)°, $C2/m$, $Z = 2$, specific gravity 3.353 and 3.267, hardness 5+, cleavage {001} fair, occurs as subadamantine, colorless striated flattened prismatic crystals parallel to [010] associated with whitlockite, apatite, childrenite, and arrojadite. It also occurs abundantly as large lamellar plates as the sole mineral bordering decomposed phosphate nodules. Forms observed are $c\{001\}$, $a\{100\}$, $d\{101\}$, $f\{\bar{1}01\}$, $j\{\bar{2}01\}$, $e\{012\}$, $t\{211\}$, and $r\{\bar{1}12\}$. Biaxial (+), α 1.645(2), β 1.650(2), γ 1.655(2), $2V$ large, O.A. $\perp\{100\}$.

Introduction

The Palermo No. 1 pegmatite is located on the boundary between the Rumney and Cardigan quadrangles, 1-1/8 miles southwest of North Groton, Grafton County, New Hampshire. A well-known source of unusual minerals for over seventy years, it is probably the world's most diverse pegmatite with respect to species. We have positively identified fifty-four discrete phosphate species from this single location, these comprising over half the known phosphates recorded from pegmatites over the world. In addition, a wide variety of sulfides and carbonates,

presently incompletely investigated, occur in moderate abundance in association with the phosphates.

We report three species new to scientific intelligence from this pegmatite and shall defer the general description and synoptic mineralogy of the body to a future communication.

Foggite



Descriptive Mineralogy

Several specimens of dense whitlockite-carbonate apatite-quartz rock show open cavities into which are projected colorless quartz crystals, stubby white carbonate apatite, and pale greenish-brown childrenite

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as fan-like aggregates of thin prismatic crystals. In addition, dense masses of quartz and montebasite showing sporadic granular scorzalite often contain cavities lined with quartz crystals and childrenite. Upon these earlier minerals in the cavities are often snow-white balls and radial aggregates of platy foggite, much resembling stilbite in its appearance.

A distinctly different paragenesis provided single crystals suitable for detailed study. The colorless crystals occur as bunched platy aggregates hinged on a common axis like the pages of a partly opened book. These are perched upon siderite rhombohedra in open cavities. Forms observed are $c\{001\}$, $b\{010\}$, and $a\{100\}$. The crystals are thin tabular parallel to $b\{010\}$, slightly elongated parallel to $[001]$, and are ten to twenty times as broad as they are thick. Rarely do the crystals exceed 0.2 mm in maximum dimension. The hardness is about 4, cleavage perfect parallel to $\{010\}$ and good parallel to $\{100\}$. The specific gravity is 2.78(1), determined by sink-float in methylene iodide-toluene solutions at 22.0°C.

Both paragenetic settings suggest that the mineral crystallized at relatively low temperature (<300°C).

X-Ray Data

A partly indexed powder pattern is offered in Table 1. The calculated interplanar spacings directly obtain from a least-squares fit of twelve reflections taken from a PICKER automated diffractometer, affording a 9.270(2)Å, b 21.324(7)Å, c 5.190(2)Å, space group $A2_122$. The space group, unusual for a mineral structure, is supported from observation on long-exposure Weissenberg and precession photographs and a thorough three-dimensional crystal structure analysis, the results of which are reported in the following paper. Accepting the formula $\text{Ca}(\text{H}_2\text{O})$

$\text{Al}(\text{OH})_2[\text{PO}_4]$, $Z = 8$, the density calculates to 2.771 g cm⁻³.

Chemical Composition

Refined electron microprobe analysis afforded CaO 25.1, Al₂O₃ 22.9, P₂O₅ 32.3 percent utilizing anorthite, diopside, and wylieite standards. Crystals were homogeneous throughout. The proposed formula $\text{Ca}(\text{H}_2\text{O})\text{Al}(\text{OH})_2[\text{PO}_4]$ yields calculated CaO 26.2, Al₂O₃ 23.8, P₂O₅ 33.2, and H₂O 16.8. All non-hydrogen atoms were located in the crystal structure analysis.

Optical Properties

Foggite is optically orthorhombic, biaxial (+), observed $2V$ 40–45°, α 1.610(2), β 1.610(2), γ 1.611(2), $X||c$, $Y||b$, $Z||a$. The computed mean index of refraction from the relationship of Gladstone and Dale employing the tables of Larsen and Berman (1934) for the specific refractive energies is $\langle n \rangle = 1.625$.

Discussion

The simple composition of the new species suggested that it may correspond to some incompletely studied and poorly defined species. Possible candidates include lehiite, ca $(\text{Na},\text{K})_2\text{Ca}_5\text{Al}_6(\text{PO}_4)_8(\text{OH})_{12} \cdot 6\text{H}_2\text{O}$; davisonite, ca $\text{Ca}_3\text{Al}(\text{PO}_4)_2(\text{OH})_3 \cdot \text{H}_2\text{O}$; isoclasite $\text{Ca}_2(\text{PO}_4)(\text{OH}) \cdot 2\text{H}_2\text{O}$; harbortite, ca $\text{Al}_3(\text{PO}_4)_2(\text{OH})_3 \cdot 3\text{H}_2\text{O}$; englishite, ca $\text{K}_2\text{Ca}_4\text{Al}_6(\text{PO}_4)_8(\text{OH})_{10} \cdot 9\text{H}_2\text{O}$; cirrolite, $\text{Ca}_3\text{Al}_2(\text{OH})_3(\text{PO}_4)_3$; coeruleolactite, $\text{CaAl}_6(\text{OH})_8(\text{PO}_4)_4 \cdot 4\text{H}_2\text{O}$.

Of these, davisonite is isostructural with apatite according to Frondel (private communication (1954) in Strunz, 1970); coeruleolactite has a powder pattern suggesting isotypy with turquoise according to Fischer (1958). Cirrolite, whose only known locality is a high pressure skarn assemblage at Westanå, Sweden, has a specific gravity (3.08) and hardness (5–6) too high to suggest a possible relationship with foggite. These data are cited from Dana (1892). Harbortite is evidently a mixture of millisite and crandalite according to Capdecombe (private communication (1954) in Strunz, 1970). The physical properties of isoclasite (Sandberger, 1870) exclude this uncertain compound from consideration.

We have examined englishite by powder and single crystal X-ray photography. The very complex cell and powder pattern do not even remotely resemble foggite. Lehiite, which owing to its composition and optical properties is the most likely candidate for a relationship with foggite, poses several problems. We

TABLE 1. Foggite. Powder Data*

I/To	d(obs)	d(calc)	hkl	I/To	d(obs)	d(calc)	hkl
4	10.67	10.66	020	2	2.102	2.099	191
5	6.96	6.99	120	1	2.060	2.044	162
10	4.24	4.25	220	3	1.964	1.954	291
5	4.20	4.19	031	2	1.943	1.937	2,10.0
3	3.82	3.82	131	3	1.831	1.827	520
2	3.50	3.50	240	4	1.744	1.749	480
2	3.44	3.41	211	1	1.663	1.654	133
3	3.325	3.318	160	1	1.631	1.622	1,10.2
7	3.109	3.105	151	1	1.586	1.593	382
3	2.961	2.968	320	2	1.568	1.564	0,13.1
8	2.693	2.666	080	2	1.548	1.590	3,12.0
2	2.584	2.595	002	2	1.521	1.515	571
1	2.559	2.562	180	1	1.268		
5	2.505	2.499	102	1	1.233		
1	2.334	2.333	042	1	1.152		
4	2.292	2.286	271	1	1.132		
4	2.259	2.254	351				

* 114.6mm Gandolfi camera diameter. Results on single crystal. Fe/Mn radiation. Film corrected for shrinkage.

obtained a vial labelled "lehiite 94 percent, deltaite 6 percent" from the type material of Larsen and Shannon (1930), U.S. National Museum No. 119987 TYPE. Two powder photographs on separate batches clearly show that the material is a member of the crandallite structure type. Both englishite and lehiite will require further detailed study. At present, it is impossible to rationalize their chemistry without new analyses.

Owing to the lack of distinctive physical properties, foggite is a mineral which will pose problems in sight identification. Much of the so-called "crandallite" from the Palermo pegmatite appears to be this mineral. The snow-white radial aggregates closely resemble "neomesselite" (= anapaite + messelite), although the latter intracrystalline mixture is usually confined to a late siderite-ludlamite-vivianite paragenesis. Perhaps the best easily accessible tool is optical study since, to our knowledge, foggite is the only platy colorless phosphate whose optical properties clearly adhere to orthorhombic symmetry.

Name

It is a pleasure to name this new mineral after Mr. Forrest F. Fogg of Penacook, New Hampshire, a collector of micromounts who has greatly advanced our knowledge of the practically unique Palermo paragenesis. His collection provided the first specimens (including the type) which constituted the basis of our study.

The species and name were approved by the International Commission on New Minerals and New Mineral Names (IMA); the type specimen is preserved in the collection of the U.S. National Museum, The Smithsonian Institution.

Goedkenite



Descriptive Mineralogy

During the summer of 1973, Mr. Peter B. Samuelson exposed a large corroded mass of triphylite near the top of the main opening and at the south wall of the Palermo No. 1 pegmatite. Typical for most triphylites at this locality, the great mass (estimated to be about two cubic meters in dimension) was emplaced at the interface between the quartz core and the intermediate zone of quartz, perthite, and wedge mica. The upper part of the mass consisted almost entirely of ferric and manganic oxides and remnant outlines of siderite crystals in vuggy cavities. The lower part was extensively replaced by

dense whitlockite-carbonate apatite-siderite rock in which open cavities up to 2 cm across occur. Adjacent to the mass on the west side were large blebs and stringers of scorzalite which was locally intergrown with the wedge mica.

Over 100 kg of whitlockite-carbonate apatite-siderite rock were collected. The earlier-formed siderite was extensively altered and dark brown and displayed cross sections of primitive rhombohedral crystals embedded in the compact dull white whitlockite and carbonate apatite. One spectacular specimen measuring $10 \times 11 \times 6$ cm gives an outline of the very complex paragenesis. The ground mass consists of deep brown siderite cleavage surfaces about 1–5 mm in dimension and a greater amount of dense compact greasy white whitlockite and carbonate apatite. Abundant pores up to 1 mm across and irregular cavities up to 1 cm across show stubby white simple hexagonal prisms of the carbonate apatite upon which are implanted quartz crystals and a second generation of brown siderite scalenohedra and colorless badly etched whitlockite. One large cavity measuring 4 cm across has at its center a colorless etched whitlockite rhombohedron 2 cm on an edge. Grouped around it are colorless prismatic quartz crystals; siderite scalenohedra; pseudocubic crystals of goyazite, $\text{SrAl}_3(\text{OH})_6[\text{PO}_3(\text{O},\text{OH})]_2$; emerald green aggregates of etched bjarebyite, $\text{Ba}(\text{Mn,Fe})_2\text{Al}_2(\text{OH})_3[\text{PO}_4]_3$ crystals; lustrous well-terminated greenish-brown childrenite, $(\text{Fe,Mn})\text{Al}(\text{OH})_2(\text{H}_2\text{O})[\text{PO}_4]$; striated prisms of colorless palermoite, $\text{SrLi}_2\text{Al}_4(\text{OH})_4[\text{PO}_4]_4$ in parallel growth; and finally goedkenite which is perched individually or as bunched aggregates upon the palermoite. In addition, one goyazite crystal, 3 mm on an edge, is almost completely replaced by goedkenite crystals. About twenty hand specimens showing goedkenite were collected. It invariably occurs in close association with palermoite (less so with quartz) and crystallized later than that mineral. Single prisms of palermoite frequently "spear" single crystals of goedkenite.

Since the whitlockite-carbonate apatite-siderite rock abuts against the quartz core, we interpret the paragenesis as a carbonate and calcium replacement of earlier triphylite at the stage where the aqueous-rich fluid separated from the rest liquid during consolidation of the core. In the process, Li^{1+} and metals of the first transition series entered into solution. The triphylite provided Li^{1+} , Fe^{2+} , Mn^{2+} , and $[\text{PO}_4]^{3-}$ and the aqueous-rich fluid provided Ca^{2+} , Al^{3+} , CO_2 and subordinate amounts of Ba^{2+} and Sr^{2+} . Oxida-

tion of some of the Fe^{2+} to form hydroxides along with the formation of siderite led to local enrichment of Mn^{2+} relative to Fe^{2+} at some later stage. If the conditions were sufficiently stagnant, minor cations such as Ba^{2+} and Sr^{2+} would become concentrated whereas Ca^{2+} would be preferentially sequestered in whitlockite and apatite. At the final stage, the local fluid was sufficiently concentrated in Sr^{2+} to allow a goedkenite replacement of goyazite and palermoite. The excess transition metals were probably transported outside the local system and precipitated as oxyhydroxides along joints and fractures in the enclosing quartz. The Li^{1+} , typical for most examples of badly corroded triphylites in pegmatites, was transported completely out of the system and reappeared at the final pocket stage as lepidolite and gem minerals, or as replacement in the wall rocks.

Goedkenite occurs as lozenge-shaped to spear-

shaped crystals, tabular parallel to $\{001\}$ and slightly elongated parallel to $[100]$. It is colorless to pale yellow, luster subadamantine, hardness 5, cleavage $\{100\}$ fair. Owing to relatively high density and the difficulty of obtaining sufficient single crystals, a specific gravity determination was not possible.

Crystal Morphology

Goedkenite always occurs as warped crystals, the $c\{001\}$ face becoming increasingly bent toward the terminus, imparting "feathery" tips to the crystals. This feature is sufficiently constant that it is an aid for visual identification of the mineral. It also hindered the morphological analysis of the crystal surfaces. Reflections toward the center of the crystals were sufficiently sharp, however, to provide adequate interpretable goniometric data. The crystals are up to 1 mm in dimension and, when they replace an earlier phase, occur with their c axes in parallel growth. Crystals perched on palermoite reveal a monoclinic holosymmetric development. The observed forms are $c\{001\}$ (large); $l\{011\}$ (medium); $e\{012\}$ (medium); $d\{\bar{1}01\}$ (small); and $g\{111\}$ (large). A typical development is shown in Figure 1.

X-Ray Data

Goedkenite is monoclinic, space group $P2_1/m$ (centrosymmetry inferred from morphological evidence); a 8.45(2) \AA , b 5.74(2) \AA , c 7.26(2) \AA , β 113.7(1) $^\circ$. Partly indexed powder data, used to refine the cell parameters, appear in Table 2. Accepting the formula $(\text{Sr}_{0.61}\text{Ca}_{0.39})_2\text{Al}(\text{OH})[\text{PO}_4]_2$, $Z = 2$, the computed density is 3.83 g cm^{-3} .

Chemical Composition

Refined electron microprobe analysis afforded SrO 32.7, CaO 11.4, Al_2O_3 13.7, P_2O_5 34.9 percent. Minor MgO 0.17 percent was detected, as well as FeO, MnO, and Na_2O , each less than 0.05 percent. Standards included celestite, anorthite, diopside, and wylieite. The crystals were homogeneous throughout. The proposed formula is $(\text{Sr}_{0.61}\text{Ca}_{0.39})_2\text{Al}(\text{OH})[\text{PO}_4]_2$, which yields SrO 34.0, CaO 11.8, Al_2O_3 13.7, P_2O_5 38.1, and H_2O 2.4 percent.

Optical Properties

Goedkenite is biaxial (+), α 1.669(2), β 1.673(2), γ 1.692(2), $2V$ 45–50 $^\circ$, $X||b$.

Discussion

Goedkenite is probably isostructural with brackebuschite, $\text{Pb}_2\text{Mn}(\text{H}_2\text{O})[\text{VO}_4]_2$ since a 8.94 \AA , b

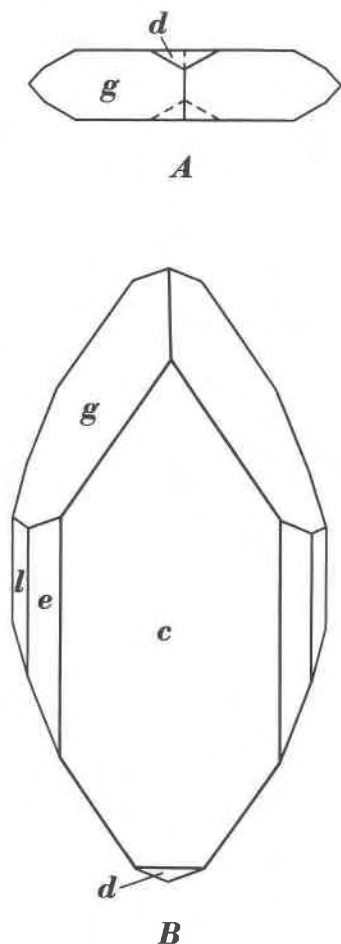


FIG. 1. Crystal of goedkenite showing the forms $c\{001\}$, $l\{011\}$, $e\{012\}$, $d\{\bar{1}01\}$ and $g\{111\}$. Palermo Mine. A. Plan B. Clinographic projection.

6.17Å, *c* 7.71Å, β 111°47', space group $P2_1/m$, $Z = 2$, for the latter mineral. According to the partial structure analysis by Donaldson and Barnes (1955), the Mn–O octahedra form linear edge-sharing chains where one water molecule and one vanadate oxygen constitute the links between octahedra. A similar arrangement was discovered in our laboratory for palermoite, where Al–O octahedral edge-linked and corner-linked chains possess hydroxyl and phosphate oxygen links. We further note that the isomorphic replacement of Mn(H₂O) by Al(OH) conserves the electrostatic valence bond sums of cations coordinating to the anions in both brackebuschite and goedkenite.

Name

Type goedkenite is properly a calcian variant since the pure Sr²⁺ end-member was not found. We propose the name for all compositions in which Sr > Ca. The species and name received approval from the International Commission on New Minerals and New Mineral Names (IMA) and the type specimen is preserved in the U.S. National Museum of Natural History, The Smithsonian Institution.

We honor Dr. Virgil L. Goedken of the Department of Chemistry, The University of Chicago, who maintains a continued and sympathetic interest in our studies of new mineral species and who assisted in collection of the original specimens.

Samuelsonite



Descriptive Mineralogy

Large masses of dense whitlockite-carbonate apatite rock occasionally contain pockets in which lustrous colorless phases occur. Owing to the very complex Palermo paragenesis, we have found it often necessary to prepare a suite of single crystals for Gandolfi camera powder patterns in order to properly identify the phases.

Two specimens show open cavities in which a peculiar lustrous colorless phase appears. Striations parallel to the prism suggested palermoite, but the crystals were invariably flattened, unlike the more equant cross-sections of most palermoites. A powder pattern followed by single crystal study led us to conclude that the phase was probably new to scientific intelligence.

The cavities contain four phases in variable amounts. In one cavity, the new species is the sole mineral and afforded nearly all the material used in

this study. It appears to have crystallized toward the end of the formation of the whitlockite-apatite masses and occurs directly attached to the cavity walls. One crystal was partly embedded in the massive phosphates. Another cavity exhibited lustrous laths of the new mineral which possessed good facets for morphological study. In the same cavity and crystallized at a later stage were thin brown laths of childrenite, two large pale pink hexagonal bipyramids up to 2 mm across of hydroxyl (?) apatite, and deeply etched lustrous pale yellow-green arrojadite. These species were identified by single crystal X-ray study.

Samuelsonite has been identified as a rare constituent of the whitlockite-apatite paragenesis. It occurs as colorless flattened striated prisms up to 1 mm in length, occasionally with terminations although these tend to be badly etched. The luster is subadamantine, hardness 5+, specific gravity 3.353(5) by Berman torsion balance at 22.5°C (toluene as displaced fluid), cleavage {001} fair.

During construction of this manuscript, several kilograms of an unknown lustrous bladed mineral, subsequently shown to be samuelsonite, were brought to our attention by Mr. Robert W. Whitmore. Mr. Whitmore informed us that the specimens were collected along the side of a disintegrated

TABLE 2. Goedkenite. Powder Data*

I/Io	d(obs)	d(calc)	hkl	I/Io	d(obs)
5	7.76	7.74	100	3	2.074
3	6.46	6.50	$\bar{1}01$	4	2.008
1	4.60	4.61	110	2	1.977
4	4.33	4.30	$\bar{1}11$	2	1.950
1	3.61	3.63	$\bar{1}02$	2	1.928
4	3.423	3.424	111	2	1.844
3	3.316	3.324	002	2	1.820
2	3.208	3.208	210	3	1.785
10	3.061	3.067	$\bar{1}12$	1	1.760
6	2.841	2.827	$\bar{2}12$	2	1.685
4	2.813	2.816	$\bar{3}01$	1	1.658
2	2.696	2.691	120	5	1.609
3	2.675	2.687	102	3	1.592
1	2.626	2.625	$\bar{1}21$	2	1.534
7	2.585	2.573	211	1	1.444
3	2.428	2.434	112	3	1.428
2	2.374	2.374	$\bar{3}12$	1	1.338
2	2.351	2.360	$\bar{2}21$	3	1.295
1	2.223	2.215	$\bar{1}13$	2	1.206
4	2.167	2.165	$\bar{3}03$	2	1.186
3	2.149	2.151	222		

* 114.6 mm camera diameter; Fe/Mn radiation; film corrected for shrinkage.

phosphate pod in a paragenesis distinct from the earlier find ("Find 1"). To distinguish this more recent material from the original, we shall call it "Find 2".

Specimens donated by Mr. Whitmore show broad lamellar plates and blades of the mineral up to 4 cm in length and up to 1 cm in width embedded in black ferric and manganic oxides. It is colorless to palest pink, stained yellow and brown by the oxides and is locally replaced by laueite crystals, which occur abundantly in local pockets throughout the masses. The specific gravity, determined on Berman balance, is 3.267(5) (toluene, 21.0°C).

In this study, the original material is accepted as type and the determinative results were performed on the Find 1 specimens. Chemical analyses were ob-

tained on both Find 1 and Find 2 materials. Except for differences in the chemical analyses and specific gravities, we could not recognize any obvious differences in X-ray and optical data between the two.

Crystal Morphology

Samuelsonite crystals are elongated and striated parallel to [010]. Forms observed are $c\{001\}$, $a\{100\}$, $d\{101\}$, $f\{\bar{1}01\}$, $j\{\bar{2}01\}$, $e\{012\}$, $t\{\bar{2}11\}$ and $r\{\bar{1}12\}$. Although the 2-fold rotor could be established on goniometric observations, it was not possible to search for a reflection plane owing to the lack of suitable doubly terminated crystals. Two developments are shown in Figure 2.

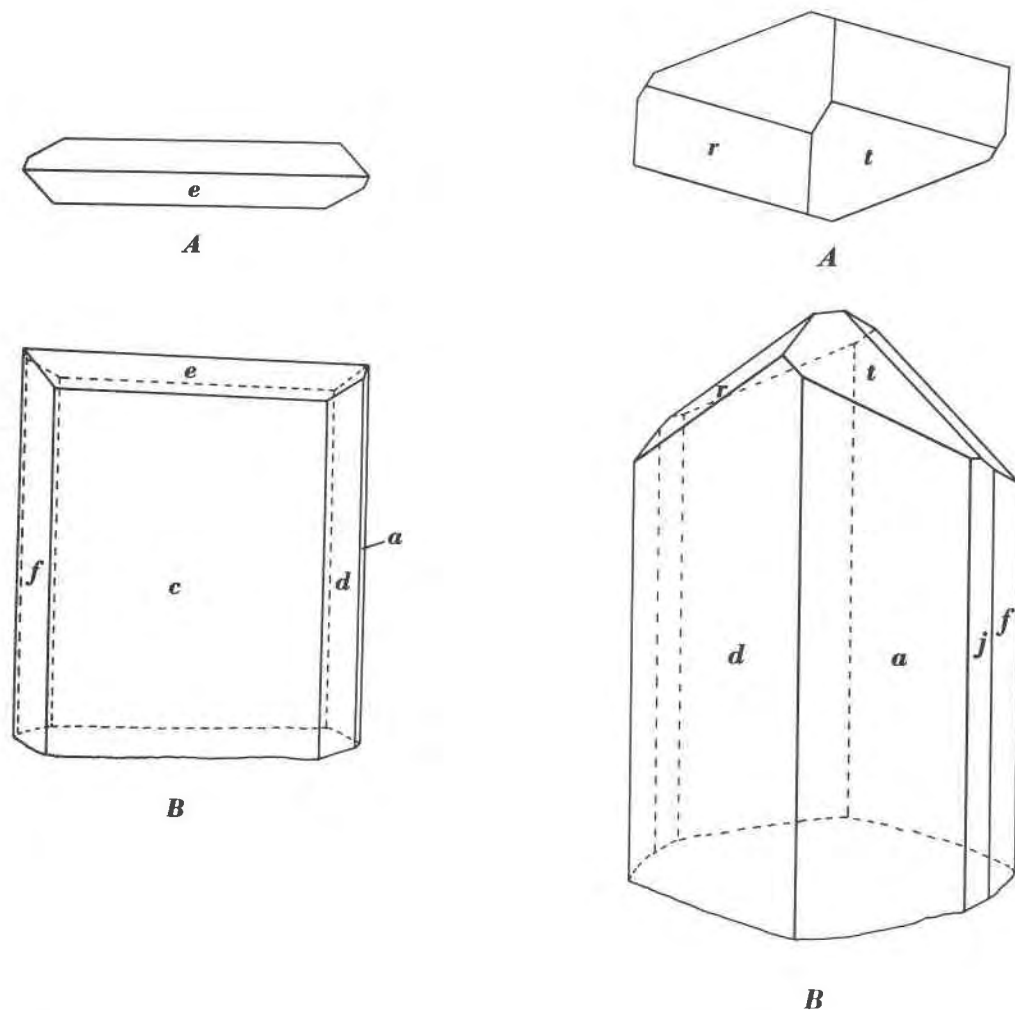


FIG. 2. Crystals of samuelsonite showing the forms $c\{001\}$, $a\{100\}$, $d\{101\}$, $f\{\bar{1}01\}$, $j\{\bar{2}01\}$, $e\{012\}$, $t\{\bar{2}11\}$, and $r\{\bar{1}12\}$. Palermo Mine. A. Plan. B. Clinographic projection.

TABLE 3. Samuelsonite. Powder Data*

I/Io	d(obs)	d(calc)	hkl	I/Io	d(obs)
1	12.61	12.91	001	2	2.096
2	6.48	6.50	202	2	2.051
1	6.03	6.03	111	2	2.042
2	5.33	5.38	111	4	1.984
2	4.60	4.61	401	1	1.968
3	4.39	4.36	310	1	1.934
2	3.771	3.805	311	4	1.893
5	3.389	3.356	203	4	1.871
2	3.316	3.341	113	2	1.843
4	3.245	3.248	404	3 brd	1.813
3	3.146	3.160	220	1 brd	1.761
10	3.058	3.066	314	1	1.728
6	3.032	3.033	601	6	1.706
1	2.951	2.973	221	2	1.671
3	2.785	2.788	205	1	1.605
5	2.734	2.739	514	2	1.581
7 brd	2.657	2.669	023	1	1.563
		2.660	420	2 brd	1.515
4	2.556	2.572	403	2	1.491
2	2.483	2.489	421	1	1.459
2	2.431	2.437	605	2	1.423
3	2.316	2.314	406	3	1.270
2	2.276	2.273	422	2	1.212
1	2.190	2.197	404	2	1.172
3	2.126	2.123	624	2	1.102

* Fe/Mn radiation: 114.6 mm camera diameter; film corrected for shrinkage.

X-Ray Data

Rotation and Weissenberg photographs on Find 1 material and calibrated precession photographs (MoK α radiation) provide a 18.495(5) \AA , b 6.805(2) \AA , c 14.000(5) \AA , β 112.75(6) $^\circ$, space group $C2/m$, based on the success of a structure analysis. Miller indices for the complex powder data (Table 3) were assigned through examination of the strong reflections on the single crystal photographs and from the structure factors.

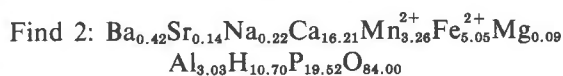
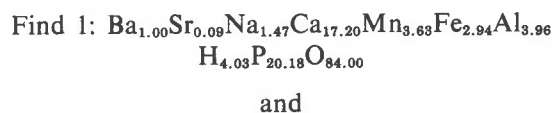
Chemical Composition

The material from Find 1 occurred in limited amount and a few crystals were sacrificed for an electron probe analysis. These refined results were based on a wyllieite standard (Na, Fe, P), barite (Ba), celestite (Sr), synthetic diopside (Ca), rhodonite (Mn), and synthetic anorthite (Al). Find 2 material, which occurred in abundance, was analyzed in detail by Dr. Jun Ito, who employed chemical techniques. Dr. Ito informs us that emission spectrographic analysis revealed trace quantities of Cu, Ti, and Ga in addition to the elements reported herein. Both analyses are presented in Table 4.

Since the compound is rather complex, it was necessary to assign an unambiguous formula from a complete structure analysis for Find 1 material. The

structure analysis, which shall be discussed in a future paper, proceeded with site occupancy refinements and the use of multiple scattering curves whose fractional occupancies could be varied pairwise at each site. Combined with bond distance considerations, the proposed assignments are Al = 1.00 Al; $X(1) = 0.42 \text{ Ba} + 0.58 \text{ Hole}$; $X(2) = 0.46 \text{ Ca} + 0.54 \text{ Hole}$; $M(1) = 0.59 \text{ Fe}^{2+} + 0.41 \text{ Na}^{1+}$; $M(2) = 0.90 \text{ Mn}^{2+} + 0.10 \text{ Na}^{1+}$; $\text{Ca}(1) = \text{Ca}(2) = \text{Ca}(3) = 1.00 \text{ Ca}$. Accounting for the equipoint rank numbers, the cell contents are $X(1)_2X(2)_4M(1)_4M(2)_4\text{Ca}_{16}\text{Al}_4(\text{OH})_4[\text{PO}_4]_{20}$, which affords the cell composition $\text{Ba}_{0.84}\text{Na}_{2.04}\text{Mn}_{3.60}^{2+}\text{Fe}_{2.36}^{2+}\text{Ca}_{17.84}\text{Al}_4(\text{OH})_4[\text{PO}_4]_{20}$. This yields a charge imbalance of $\Delta e = -0.68$.

From the analyses in Table 4, we compute the cell contents based on $\Sigma \text{O} = 84$ for the two samuelsonites:



These contents differ only slightly from those calculated from the cell volume and densities in Table

TABLE 4. Samuelsonite. Chemical Analyses

	Find 1		Find 2	
	1	2	3	4
K ₂ O	-	-	0.02	-
Na ₂ O	1.4	1.46	0.21	0.22
BaO	4.8	0.99	2.04	0.42
SrO	0.3	0.09	0.44	0.14
CaO	29.6	17.07	28.30	16.05
MnO	7.9	3.60	7.20	3.23
MgO	-	-	0.12	0.09
FeO	6.5	2.92	11.30	5.00
Fe ₂ O ₃	-	-	nil	-
Al ₂ O ₃	6.2	3.93	4.80	3.00
P ₂ O ₅	44.0	20.03	43.10	19.32
H ₂ O ⁺	n.d.		3.00	10.60
			100.53	

¹A.R.L. electron probe. A. J. Irving analyst.

²Cations in the unit cell using $\rho = 3.353 \text{ gm cm}^{-3}$.

³Jun Ito, analyst.

⁴Cations in the unit cell using $\rho = 3.267 \text{ gm cm}^{-3}$.

4. The Find 1 contents are in fair agreement with the assignments from structure analysis. The Find 2 sample is interpreted as a variant of Find 1 material, containing more Fe^{2+} and less Ba, Na and Ca than the type. In addition, limited replacement of $[\text{PO}_4]$ tetrahedra by $[\text{H}_4\text{O}_4]$ is suggested. A possible ordering scheme for Find 2 material is $\text{Al} = 0.76 \text{ Al} + 0.22 \text{ Fe}^{2+} + 0.02 \text{ Mg}$; $X(1) = 0.21 \text{ Ba} + 0.07 \text{ Sr} + 0.72 \text{ Hole}$; $X(2) = \text{Hole}$; $M(1) = 0.97 \text{ Fe}^{2+} + 0.03 \text{ Hole}$; $M(2) = 0.82 \text{ Mn}^{2+} + 0.07 \text{ Fe}^{2+} + 0.06 \text{ Na} + 0.05 \text{ Ca}$; $\text{Ca}(1) = \text{Ca}(2) = \text{Ca}(3) = 1.00 \text{ Ca}$. This scheme takes in account the structure analysis on Find 1 material and the proposed distributions of alkali and alkaline earth cations for the compositionally related wyllieite (see Moore and Molin-Case, 1974).

These results force us to conclude that a general formula can be written for samuelsonite which allows the flexibility so necessary for a structure possessing partly occupied sites. We recommend $X(1)X(2)_2M(1)_2M(2)_2\text{Ca}_8\text{Al}_2(\text{OH})_2[\text{PO}_4]_{10}$ ($Z = 2$), where $X(1) = \text{Ba, Sr, Hole}$; $X(2) = \text{Ca, Hole}$; $M(1) = \text{Fe}^{2+}, \text{Na}^{1+}$; $M(2) = \text{Mn}^{2+}, \text{Fe}^{2+}, \text{Ca}^{2+}, \text{Na}^{1+}$. A more specific composition which embraces both Find 1 and Find 2 material and which counts only the predominant cations at each site is $(\text{Ca, Ba})\text{Fe}_2^+\text{Mn}_2^+\text{Ca}_8\text{Al}_2(\text{OH})_2[\text{PO}_4]_{10}$. A yet simpler formula is not suggested since the presence of partial site occupancies in the structure does not admit a precise end-member composition. In addition, the minimal equipoint rank number found in the structure is 2 which, divided into the cell contents, we adopt as the formula unit.

Optical Properties

Biaxial (+), α 1.645(2), β 1.650(2), γ 1.655(2), observed $2V$ large (70–80°), inclined extinction, ca 22°. An optic axis is nearly normal to the {001} cleavage plane. By the relationship of Gladstone and Dale, $\langle n \rangle$ calc = 1.67, the specific refractive energies for the component oxides obtained from the tables of Larsen and Berman (1934).

Comments on the Structure

Samuelsonite is structurally related to apatite and childrenite-eosphorite. It consists of double columns of composition $[\text{Ca}_4(\text{PO}_4)_{10}]^{12-}$ which run parallel to the b axis and which are isomorphic to a section of the apatite structure. $\text{Al}(\text{OH})(\text{Op})_4$ octahedral corner-sharing chains also run in this direction and establish a relationship between regions of the samuelsonite and childrenite structures. Details of the samuelsonite structure shall appear in a future paper.

Name

The species and name received approval from the International Commission on New Minerals and New Mineral Names (IMA) and the type specimen has been donated to the U.S. National Museum of Natural History, The Smithsonian Institution.

We christen the species after Mr. Peter B. ("Topaz") Samuelson of Rumney, New Hampshire, a young, intrepid prospector whose first love evidently is pegmatites and who has brought many new localities and old classic sources and their specimens to light.

Acknowledgments

Messrs. Forrest Fogg, Robert Whitmore and Curt Segeler have generously provided many specimens and detailed descriptions of occurrences. These dedicated amateurs have contributed freely of their time and energy in order to advance our knowledge of the peculiar Palermo paragenesis. Mr. Peter B. Samuelson halted operations during our visits so that we could document the paragenetic relationships *in situ* and permitted removal of many fine research specimens. The graphic artistry of Mr. Dennis H. Lund, who drew the crystals, is appreciated. Mr. John S. White, Jr. (U.S. National Museum), arranged for the portion of the type lehiite.

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