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TURNEAUREITE, A NEW MEMBER OF THE APATITE GROUP FROM FRANKLIN, NEW JERSEY, BALMAT, NEW YORK AND LÅNGBAN, SWEDEN

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ABSTRACT

Turneaureite, ideally $Ca_5[(As,P)O_4]_3Cl$, is hexagonal, space group $P6_3/m$, a 9.810(4), c 6.868(4) Å, V 572.4 Å^3, $Z = 2$. It occurs at Franklin, New Jersey, Långban, Sweden (holotype), and Balmat, New York. Microprobe analysis gave CaO 43.8, PbO 0.7, MnO 1.9, As_2O_5 44.9, P_2O_5 6.1, Cl 3.2, F 1.2, less O ≡ Cl,F 1.2, sum 100.6 weight %, corresponding to $(Ca_{9.70}Mn_{0.33}Pb_{0.04})_{\Sigma 10.07}[(AsO_4)_{4.85}(PO_4)_{1.07}]_{\Sigma 5.92}(Cl_{1.12}F_{0.78})_{\Sigma 1.90}$. Turneaureite is colorless with a vitreous to slightly greasy lustre; hardness (Mohs) 5; density 3.60(5) (meas.), 3.63 g/cm^3 (calc.). Optically turneaureite is uniaxial negative, with ω 1.708 and ϵ 1.700 (both ± 0.003). Turneaureite has a bright orange fluorescence in short-wavelength ultraviolet radiation. At Långban, turneaureite is associated with andradite and calcite on andradite–magnetite ore. At Franklin, it is associated with andradite, magnetite and calcite, and at Balmat, it is associated with donpeacorite, tirodite, braunite and tourmaline. The name honors Dr. Frederick Stewart Turneaure, Professor Emeritus at the University of Michigan, in recognition of his contributions to the geology and mineralogy of ore deposits. Type material is preserved at the Smithsonian Institution.

Keywords: turneaureite, new mineral species, arsenate apatite, Franklin, Långban, Balmat.

SOMMAIRE

La turneaureïte, de composition idéale $Ca_5[(As,P)]O_4]_3Cl$, est hexagonale et a les propriétés suivantes: groupe spatial $P6_3/m$, a 9.810(4), c 6.868(4) Å, V 572.4 Å^3, $Z = 2$. Ce minéral se trouve à Franklin, New Jersey, Långban, Suède (holotype), et Balmat, New York. L'analyse à la microsonde donne 43.8% CaO, 0.7 PbO, 1.9 MnO, 44.9 As_2O_5, 6.1 P_2O_5, 3.2 Cl, 1.2 F, moins 1.2 pour O ≡ Cl,F, pour une somme de 100.6% (en poids), correspondant à la formule: $(Ca_{9.70}\ Mn_{0.33}\ Pb_{0.04})_{\Sigma 10.07}[(AsO_4)_{4.85}(PO_4)_{1.07}]_{\Sigma 5.92}(Cl_{1.12}F_{0.78})_{\Sigma 1.90}$. La turneaureïte est incolore, à éclat vitreux légèrement gras, dureté 5, densité mesurée 3.60(5) et calculée 3.63. La turneaureïte est uniaxe négative, ω 1.708 ± 0.003, ω 1.700 ± 0.003. Elle montre une fluorescence orange claire aux radiations ultraviolettes de courte longueur d'onde. A Långban, la turneaureïte s'associe à l'andradite et la calcite sur le minerai d'andradite-magnétite. A Franklin, elle s'associe à l'andradite, la magnétite et la calcite, et à Balmat, aux minéraux donpeacorite, tirodite, braunite et tourmaline. Le nom de *turneaureïte* honore Frederick Stewart Turneaure, Professeur Emérite à l'Université de Michigan, pour ses contributions à la géologie et la minéralogie des minerais. Le matériau type est conservé au Smithsonian Institution.

(Traduit par la Rédaction)

Mots-clés: turneaureïte, nouvelle espèce minérale, apatite à arsenate, Franklin, Långban, Balmat.

INTRODUCTION

A systematic study of the arsenate apatites has resulted in the discovery of several new species, including morelandite (Dunn & Rouse 1978) and johnbaumite (Dunn *et al.* 1980); a recent part of this investigation resulted in the characterization of hedyphane as an ordered phase, $Ca_4Pb_6(AsO_4)_6Cl_2$ (Rouse *et al.* 1984). Hedyphane had formerly, and erroneously, been considered as the member of the apatite group with the general formula $(Ca,Pb)_5(AsO_4)_3Cl$ and was usually assigned the niche in the arsenate apatite group with Ca as the dominant divalent cation. This assignment was found to be in error by Rouse *et al.* (1984) because all known samples of hedyphane have essential Pb and have Pb in excess of Ca. Thus the redefinition of hedyphane created a vacancy in the apatite-group series, such that there was no known phase with Ca > Pb, As > P, and Cl > F or (OH). We have found such a mineral at three localities: Franklin, New Jersey, Långban, Sweden, and Balmat, New York.

We take pleasure in naming this new mineral *turneaureite* in honor of Dr. Frederick Stewart Turneaure, Professor Emeritus at the University of Michigan, in recognition of his contributions to the mineralogy and geology of economic mineral deposits. It is particularly fitting that turneaureite comes from three deposits, all of economic significance. Both the species and the name have been approved by the Commission on New Minerals and Mineral Names, IMA. Type material is preserved at

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the Smithsonian Institution under catalogue numbers C6270–1 and C6270–2 (Franklin), 134981 (Långban), and 159862 (Balmat). Turneaureite, ideally $Ca_5(AsO_4)_3Cl$, is the Cl analogue of svabite $Ca_5(AsO_4)_3F$ and johnbaumite $Ca_5(AsO_4)_3(OH)$, the arsenic analogue of chlorapatite $Ca_5(PO_4)_3Cl$, and the Ca analogue of morelandite $Ba_5(AsO_4)_3Cl$ and mimetite $Pb_5(AsO_4)_3Cl$.

X-Ray Crystallography

Single crystals of turneaureite were studied using the precession and Weissenberg methods. In addition, results were obtained for another Långban crystal that has F:Cl:OH = 2:2:1 but is otherwise compositionally similar to turneaureite. Although most apatites have space group $P6_3/m$, several have been reported to be monoclinic with a superstructure, especially those with a significant Cl content. The photographs of holotype turneaureite and the additional crystal mentioned above were therefore studied especially carefully in order to determine the occurrence, if any, of deviations from hexagonal symmetry. None were observed. Photographs included sets of three related by 60° rotations about c^* so that direct comparisons of six-fold-related patterns could be made. All observations are consistent with space groups $P6_3/m$ and $P6_3$. We assume that the former is the correct one by analogy with other members of the apatite group.

Cell parameters for turneaureite [a 9.810(4), c 6.868(4) Å] were obtained from least-squares refinement of data (Table 1) from a 114.6-mm-diameter Gandolfi camera photograph. This photograph was obtained using Cu$K\alpha$ radiation, a polycrystalline sample, and Si as an internal standard.

TABLE 1. X-RAY POWDER-DIFFRACTION DATA FOR TURNEAUREITE

I/I_o	d(obs)	d(calc)	hkl	I/I_o	d(obs)
20	8.46	8.50	100	30	1.692
15	5.32	5.34	101	5	1.563
15	4.91	4.91	110	20	1.523
50	3.98	3.99	111	10	1.490
10	3.61	3.61	201	20	1.468
60	3.43	3.43	002	2	1.394
15	3.22	3.21	210	5	1.366
100	2.907	2.909	211	5	1.315
90	2.826	2.832	300	5	1.294
		2.813	112	10	1.265
50	2.670	2.671	202	1	1.209
5	2.617	2.618	301	2	1.189
10	2.358	2.356	310	2	1.173
2	2.309	2.310	221	5	1.144
20	2.232	2.229	311	2	1.038
30	1.995	1.996	222	2	1.021
10	1.951	1.949	320	2	0.9874
40	1.864	1.864	213	1	0.9507
2	1.807	1.806	402	5	0.9385
30	1.718	1.717	004		

Intensities estimated visually.

TABLE 2. CHEMICAL DATA FOR TURNEAUREITE

	Weight Percent			Number of atoms*		
	Långban 134981	Franklin C6270-1	Balmat 159862	Långban 134981	Franklin C6270-1	Balmat 159862
CaO	43.8	45.4	42.7	4.88	4.99	4.64
PbO	0.7	1.4	0.0	0.02	0.04	0.00
MnO	1.9	0.6	3.9	0.17	0.05	0.33
MgO	0.0	0.0	0.3	0.00	0.00	0.05
As_2O_5	44.9	42.5	32.2	2.44	2.28	1.71
P_2O_5	6.1	8.5	15.2	0.54	0.74	1.30
Cl	3.2	2.1	4.4	0.56	0.36	0.76
F	1.2	0.8	0.5	0.39	0.26	0.16
H_2O	n.d.	0.2	n.d.	n.d.	0.14	n.d.
O=Cl,F	1.2	0.8	1.2			
Total	100.6	100.7	98.0			

Ba and Sr absent or only present as traces in all samples.
* Calculated on the basis of 13 (O,Cl,F).
Standards for analysis of 134981 and C6270-1: Fluorapatite (Ca,P,F), olivenite (As), Barite (Ba), manganite (Mn), scapolite (Cl), PbO (Pb). Operating conditions: 15 kV, 0.025 μA sample current.
Standards for analysis of 159862: Olivine (Si,Mg), Ba-Cl apatite (Ba,Cl), An48 (Na), rhodonite (Mn), fluorapatite (Ca,P,F), olivenite (As). Operating conditions: 15 kV, 0.015 μA sample current.
Ba and Sr absent or present only as traces in all samples.

Physical and Optical Properties

Turneaureite was found at three localities, but only the sample from Långban, Varmland, Sweden, provided single crystals of a size and quality adequate for the characterization of the species. Accordingly, the Långban sample was chosen as holotype, and the principal features of the description are based on this sample. Comparative examination of samples of turneaureite from Franklin and Balmat confirm that these samples have very similar optical and diffraction properties.

Turneaureite occurs at Långban as colorless, slightly turbid, prismatic crystals up to 1.5 mm long; they are prismatic in habit, and only the forms $\{10\bar{1}0\}$ and $\{0001\}$ are present. Turneaureite has a white streak and a vitreous to slightly greasy lustre. The hardness (Mohs) is 5. The fracture is uneven; cleavage was not observed. The density, measured using heavy-liquid techniques, is 3.60(5) compared with the calculated value of 3.63 g/cm^3. Turneaureite fluoresces a bright orange color in short-wavelength ultraviolet radiation, but is not discernibly fluorescent in long-wavelength ultraviolet radiation. Phosphorescence is weakly discernible in massive material from Franklin, but was not observed on crystals from the other localities. Optically, turneaureite is uniaxial negative, with indices of refraction ω 1.708(3), ϵ 1.700(3), measured in sodium light. Calculation of the Gladstone–Dale relationship yields K_C 0.188, and K_P 0.196, indicating good compatibility of the physical and chemical data (Mandarino 1981).

Chemical Composition

Turneaureite was chemically analyzed by electron microprobe in two laboratories: the Smithsonian Institution for samples from Franklin and Långban, and the University of Michigan for that from Balmat. The operating conditions and standards are given, together with the resultant compositions, in Table 2. The unit-cell contents for the holotype sample, calculated with the determined unit-cell parameters and observed density, are: $(Ca_{9.70}Pb_{0.04}Mn_{0.33})_{\Sigma 10.07}[(AsO_4)_{4.85}(PO_4)_{1.07}]_{\Sigma 5.92}(Cl_{1.12}F_{0.78})_{\Sigma 1.90}$ or, ideally, $Ca_5[(As,P)O_4]_3Cl$, with $Z = 2$.

Occurrence

Turneaureite occurs at the Långban mine, Varmland, Sweden, as euhedral crystals associated with calcite and several generations of secondary andradite, on massive andradite–magnetite ore. Several specimens are known, but it must be considered rare at this locality.

At Franklin, turneaureite occurs in large, massive samples up to 5 × 3 × 2 cm in size. It is greyish white, does not occur in euhedral crystals, and has a duller lustre than the Swedish material. It is associated with magnetite, andradite and manganoan calcite, all of which occur in centimetre-size crystals or aggregates. It was probably locally abundant. Similar specimens, none of which were analyzed, exist in local systematic collections.

Turneaureite also occurs in the manganese-rich siliceous marbles exposed on the 2500 level of the Balmat #4 mine, New York. Manganese-rich pods are scattered within several of the siliceous marble units (Brown *et al.* 1980). At Balmat, turneaureite forms subhedral, isolated crystals intimately associated with donpeacorite (Petersen *et al.* 1984), tirodite, minor ferrian braunite, dravite ($dravite_{54}uvite_{46}$), anhydrite and manganoan dolomite. All these phases were identified in thin section, and by qualitative energy-dispersion and quantitative wavelength-dispersion analyses on an electron microprobe.

It is of interest to note that all three occurrences of turneaureite are in high-grade marble terranes. At Långban, manganiferous ores were metamorphosed to the amphibolite grade of regional metamorphism (Ohlsson 1979) during the 1.9 Ga Svecokarelian Orogeny (Frietsch *et al.* 1979). The Franklin ores and the enclosing Franklin Marble were metamorphosed to the amphibolite-to-granulite facies (Baker & Buddington 1970, Frondel & Klein 1965). Peak metamorphic conditions in the Balmat area were 6.5 ± 1.0 kbar (Brown *et al.* 1978) and 650 ± 30° C (Bohlen *et al.* 1980). Both the Franklin and Balmat localities were metamorphosed during the 1.0 Ga Grenville Orogeny (Baker & Buddington 1970, Engel & Engel 1953, respectively). Although there are few thermodynamic data on As- and Cl-bearing apatites, it seems that turneaureite may be a metamorphic mineral typically confined to the amphibolite and granulite facies.

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