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Sabelliite, a new copper-zinc arsenate-antimonate mineral from Sardinia, Italy

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Abstract: Sabelliite, ideally $(Cu,Zn)_2Zn[(As,Sb)O_4](OH)_3$, is a new mineral from Is Murvonis Mine, Domusnovas, Sardinia. It occurs as intergrown aggregates or isolated crystals in a compact quartzitic matrix, in an outcrop close to worked fluorite veins of an old mine. The platy {001} disk-shaped emerald-green crystals are transparent with adamantine lustre. Associated minerals are theisite, malachite, azurite, and tetrahedrite. Electron microprobe analyses give: Cu 34.80, Zn 15.65, Si 0.33, As 15.04, Sb 4.96, O 28.00, H 0.67 (calculated), total 99.45 wt%. Optically, sabelliite is nonpleochroic, uniaxial negative, with $\omega = 1.802(2)$ and $\varepsilon = 1.797(2)$. VHN_{15} microhardness = 386. Density (calc.) = 4.65 g/cm^3. The unit cell is trigonal with $a = 8.201(1)$, $c = 7.315(1)$ Å, $V = 426.07(9)$ Å^3, space group $P\bar{3}$, and $Z = 3$. The strongest lines in the Gandolfi X-ray pattern are ($d_{obs.}$,I,hkl) 2.522(100)(121), 2.166(88)(122), 1.805(92)(123), 1.550(100)(410), 1.513(85)(124). The IR spectrum is also given. The mineral is named after Dr. Cesare Sabelli, researcher of the C.N.R.. Sabelliite belongs to a proposed mineral family that includes spangolite, schulenbergite, namuwite, and theisite.

Key-words: sabelliite, new mineral, copper-zinc arsenate-antimonate, Is Murvonis Mine (Sardinia, Italy).

Introduction

In 1990, during field work in Southern Sardinia for an ongoing study of copper alteration minerals, a few specimens were found of an unknown mineral. A preliminary investigation of the material, which was collected in the abandoned Is Murvonis Mine (Domusnovas, Iglesias district), suggested the mineral might be a new species (Brizzi *et al.*, 1993). Shortly thereafter, a mineral showing similar morphological and chemical characteristics was found at mine dumps near Schwaz, Austria (Dillen, 1993, pers. comm.).

A full mineralogical study confirms that the Is Murvonis mineral really is a new species. We are pleased to name the new mineral sabelliite in honour of Dr. Cesare Sabelli, of the Consiglio Nazionale delle Ricerche (C.N.R.), in recognition of his important work with the copper alteration minerals of Sardinia. The new mineral and name have been approved by the I.M.A. Commission on New Minerals and Mineral Names. A type specimen is kept at the Museum of Natural History of the University of Florence, under catalogue number 2053/RI.

The crystal structure of sabelliite was determined by Olmi *et al.* (1995).

Occurrence

Geologically, the Iglesiente region (S-W Sardinia) consists of a Cambrian-Silurian succession (Carmignani *et al.*, 1986). The Domusnovas area offers a good example of the geology of the region; the main formations comprise a limestone known as the "Calcare Ceroide" as well as poly-

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genic Ordovician conglomerates and coarse sandstones with interbedded shales. During Hercynian deformation, the area underwent low-grade metamorphism with the formation of a complex system of faults. Karst phenomena later developed, and hydrothermal fluids subsequently deposited fluorite vein-like bodies along the faults and karst rims occurring in the dark-gray limestone. Only one body of economic interest has been mined in this century. The green or blue fluorite always contains traces of copper (Uras, 1958).

The fluorite is frequently accompanied by sulphides and sulphosalts (galena, sphalerite, chalcopyrite, tetrahedrite-tennantite), and by copper-zinc alteration minerals (aurichalcite, malachite, azurite, brochantite, rosasite, hemimorphite). Sabelliite occurs in a quartzitic outcrop as rare minute crystals often overgrown on foliated aggregates of theisite, to which it is closely related from a chemical and physical standpoint. Both minerals are believed to be weathering products of sulphides and sulphosalts. Sabelliite is probably the last-formed mineral of the oxidation process.

Physical properties

Sabelliite has a highly characteristic appearance: its crystals are tabular {001} and cylindrical, thus resembling small coins (no crystal form other than the basal pinacoid has been recognized) (Fig. 1 and 2). The diameter of intergrown disk-shaped crystals rarely exceeds 400 μm, while isolated single crystals can be up to 200 μm in diameter and 15 μm in thickness. They are transparent and emerald-green, having an adamantine lustre and a light-green streak. The crystals are brittle, with no cleavage, and have a micro-hardness of VHN = 386 (average of 20 determinations with 15 g indentor: range 322-469), which corresponds to a calculated Mohs' hardness of about 4.5.

The mineral's density is too high to be measured using floatation techniques, and not enough material was available for the pycnometer (density bottle) method. The calculated density is 4.65 g/cm^3, on the basis of the experimental chemical composition and assuming three formula units in the unit-cell. The mineral does not fluoresce under long- or short-wave ultraviolet radiation.

Sabelliite is optically nonpleochroic, uniaxial negative, with $\omega = 1.802(2)$ and $\varepsilon = 1.797(2)$. Refractive indices were measured in Na gel-filtered light by immersion in mixtures of Cargille oils and sulphur saturated methylene iodide. Since the high values of the indices prevented the use of an Abbé refractometer, the indices of the mixtures were determined on an Eickhorst Modul 1 gemmological refractometer (Hurlbut, 1984).

Calculation of the Gladstone-Dale relationship gives Kp = 0.1720 and Kc = 0.1753, which indicate a "superior" compatibility index 1-(Kp/Kc) of 0.019 (Mandarino, 1981).

Chemistry and infrared study

Sabelliite was analysed with a Jeol JXA-8600 electron microprobe (15 kV accelerating voltage, 10 nA beam current- Faraday cup, 5 μm defo-

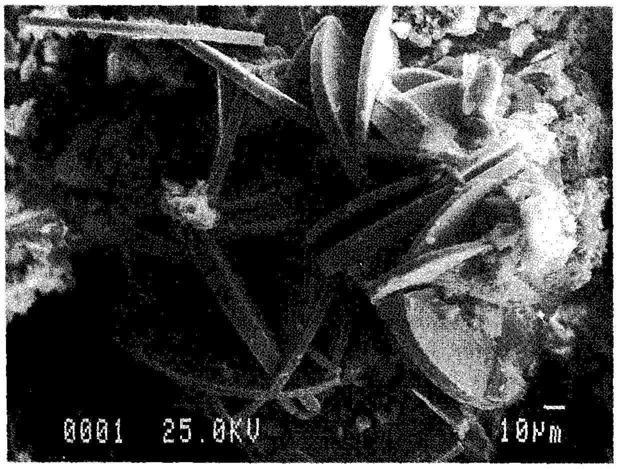

Fig. 1. Electron micrograph of some disk-shaped sabelliite crystals.

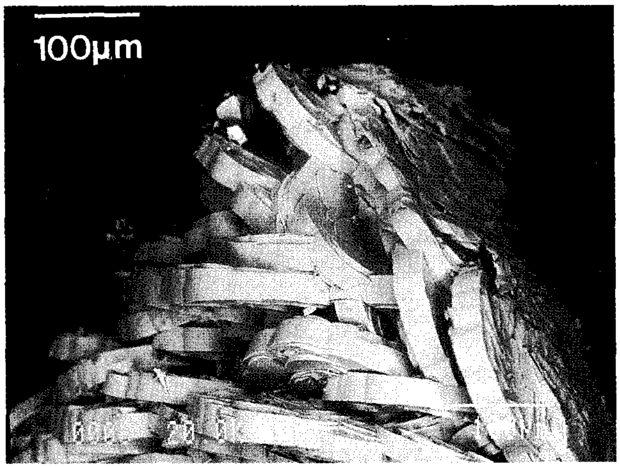

Fig. 2. Electron micrograph of an aggregate of strongly intergrown sabelliite crystals.

cused beam) equipped with a Tracor-Northern Series II system. No elements (with $Z > 9$) other than those reported here were detected by a preliminary 300s-energy-dispersive scan. The standards used were: cuprite (Cu*K*α), willemite (Zn*K*α,Si*K*α), arsenolite (As*L*α) and senarmontite (Sb*L*α). The dearth of pure material prevented the quantitative determination of the H_2O content. For this reason, the oxygen content was also measured by electron microprobe with a LDE1 crystal, which is a layered synthetic dispersion lattice (Nash, 1992) manufactured by the Jeol Company, using quartz as standard (McGuire *et al.*, 1992). The raw data were reduced using a $\varphi(\rho z)$ correction routine (Bastin *et al.*, 1987). The results of the analyses (twenty different spots on four crystals) are given in Table 1. The empirical formula, calculated on

Table 1. Electron microprobe analytical results.

	1			2	3
Cu	34.80	(32.44-37.26)	CuO	43.56	40.61
Zn	15.65	(13.91-17.34)	ZnO	19.48	20.77
Si	0.33	(0.19- 0.49)	SiO_2	0.71	-
As	15.04	(13.42-16.32)	As_2O_5	23.07	23.46
Sb	4.96	(4.10- 6.15)	Sb_2O_5	6.59	8.26
O	28.00	(26.94-29.20)	H_2O	6.05	6.90
	98.78			99.46	100.00
H	0.67				
	99.45				

1 - Atomic wt.% (ranges in parenthesis), including the O content, experimentally determined.
The 0.67 wt% H amount was calculated to compensate the excess of negative charge.
2 - Converted oxide percentages.
3 - Calculated oxide percentages for the idealized formula, with Cu/Zn=2 and As/Sb=4.

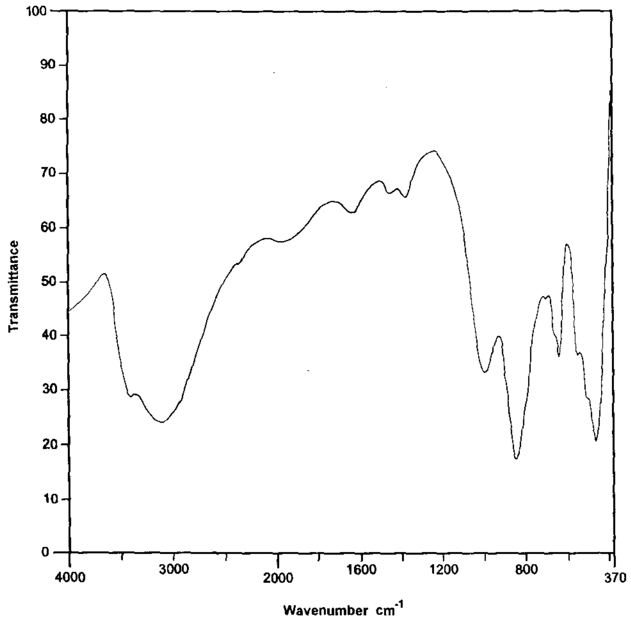

Fig. 3. Infrared absorption spectrum of sabelliite.

the basis of O = 7, is $Cu_{2.19}Zn_{0.96}(As_{0.80}Sb_{0.16}Si_{0.05})_{\Sigma 1.01}O_{4.31}(OH)_{2.69}$. The crystal structure refinement (Olmi *et al.*, 1995) shows that the Zn atoms are coordinated both octahedrally (as are the Cu atoms) and tetrahedrally. Further occurrences of sabelliite may display some variation in cationic content. Owing to this possibility, the simplified formula $(Cu,Zn)_2Zn[(As,Sb)O_4](OH)_3$ was adopted.

For the IR study, a very small amount of material was examined with a FTIR Perkin-Elmer SYS 2000 spectrophotometer. Several IR spectra (which were reproducible to ± 4 cm^{-1} in the 4000-2000 cm^{-1} region, and to ± 2 cm^{-1} in the 2000-370 cm^{-1} region) were recorded in the 4000-370 cm^{-1} range, using a KBr micropellet. The spectrum (Fig. 3) confirms the absence of structural H_2O (Olmi *et al.*, 1995), as there is simply a broad intense band in the 3500-3000 cm^{-1} region. The weak peak at 1636 cm^{-1} may be attributed to water adsorbed by the KBr micropellet (Braithwaite, 1983), or to a harmonic of lower-frequency fundamentals (Sumin de Portilla, 1974; Hill, 1976). As discussed in the structural study, the presence of one ascertained OH group and of an additional disordered hydroxyl appears confirmed by the two bands at 3420 and 3126 cm^{-1}, which are within the region of the stretching vibrations of the hydroxyl groups (Braithwaite & Ryback, 1988). The spectrum is more complex in the region with frequencies lower than 1000 cm^{-1}. The strong absorption bands at 844 and 457 cm^{-1}, with shoulders at 795 and 504 cm^{-1}, are due to the stretching and bending vibrations of the AsO_4^{3-} group (Farmer, 1974). The absorption at 993 cm^{-1} is probably due to the deformation of OH groups bonded to Cu atoms (Braithwaite, 1983; Sumin de Portilla, 1974), while the absorption at 545 cm^{-1} can be related to stretching vibrations of Zn-O and Cu-O bonds (Tarte & Preudhomme, 1970; Sumin de Portilla, 1974; Sumin de Portilla *et al.*, 1981; Braithwaite, 1983 and 1987).

X-ray crystallography and related species

Single-crystal X-ray studies (Weissenberg camera and single-crystal diffractometer) show that sabelliite is trigonal. The space group, from the crystal stucture analysis, is $P\bar{3}$.

The X-ray powder diffraction data given in

Table 2. X-ray powder diffraction pattern for sabelliite (114.6 mm Gandolfi camera, Ni-filtered Cu$K\alpha$ radiation, photometrically measured intensities).

hkl	$d_{calc.}$ (Å)	$d_{obs.}$ (Å)	I/I_0	*hkl*	$d_{calc.}$ (Å)	$d_{obs.}$ (Å)	I/I_0
001	7.314	7.33	42	412	1.427	1.427	54
100	7.102	7.15	7	224	1.365	1.364	12
101	5.096	5.11	18	025	1.353	1.352	8
110	4.101	4.11	55	240	1.342	1.341	23
002	3.657	3.66	52	241	1.320	1.320	55
111	3.577	3.58	49	413	1.308	1.308	13
102	3.252	3.25	31	125	1.285	1.284	25
201	3.195	3.20	46	242	1.260	1.260	16
112	2.729	2.726	29	512	1.204	1.204	9
120	2.684	2.688	29	414	1.182	1.183	22
022	2.548	2.548	15	243	1.176	1.175	31
121	2.520	2.522	100	315	1.175		
030	2.367	2.369	26	405	1.129	1.129	8
031	2.252	2.253	28	216	1.110	1.109	23
122	2.164	2.166	88	244	1.082	1.082	26
113	2.096	2.096	25	415	1.064	1.064	24
220	2.050	2.054	12	440	1.025	1.025	7
221	1.974	1.974	18	530	1.015	1.014	17
311	1.902	1.901	18	070	1.015		
004	1.829	1.828	7	531	1.005	1.005	31
123	1.805	1.805	92	701	1.005		
132	1.734	1.733	23	245	0.989	0.989	12
041	1.725	1.725	23	532	0.978	0.978	18
114	1.670	1.670	26	702	0.978		
204	1.626	1.626	18	703	0.937	0.937	23
321	1.590	1.591	22	533	0.937		
223	1.569	1.569	9	360	0.895	0.895	15
410	1.550	1.550	100	361	0.888	0.888	27
313	1.532	1.532	8	704	0.887		
124	1.511	1.513	85	534	0.887		
322	1.488	1.489	17	705	0.834	0.834	15
005	1.463	1.462	11	535	0.834		
034	1.447	1.448	16				

Table 2 were obtained using a Gandolfi camera (114.6 mm diameter) with Ni-filtered Cu$K\alpha$ radiation. Indexing was performed on the basis of single-crystal data, taking account of the intensities of the reflections collected for the structural study. The unit-cell parameters, refined by means of a least-squares calculation from the powder data, are: a = 8.201(1), c = 7.315(1) Å, V = 426.07(9) Å^3.

The chemical composition, unit-cell parameters and symmetry of sabelliite are fairly similar to those of several other copper minerals, which are listed in Table 3. The powder patterns of all these species also show significant similarities. The lattice parameters of sabelliite are practically identical to those of schulenbergite (Hodenberg *et al.*, 1984). The chemical variability assumed for sabelliite is actually observed in schulenbergite: its Zn-analogue, indeed, has a highly variable Cu/Zn ratio, whose lowest value is 0.34 (Livingstone *et al.*, 1992), compared with the value of 1.33 found in schulenbergite. Spangolite

Table 3. Formulae and lattice parameters of related minerals.

Mineral	Chemical formula	Cell parameters (Å)		Symmetry
Spangolite	$Cu_6Al(SO_4)(OH)_{12}Cl.3H_2O$	a=8.274	c=14.371	$P31c$
Namuwite	$(Zn,Cu)_4(SO_4)(OH)_6.4H_2O$	a=8.29	c=10.50	hexagonal
Schulenbergite	$(Cu,Zn)_7(SO_4,CO_3)_2(OH)_{10}.3H_2O$	a=8.249	c= 7.183	$P3$ or $P\overline{3}$
Theisite	$Cu_5Zn_5[(As,Sb)O_4]_2(OH)_{14}$	a=8.223	c=15.019	trigonal
Sabelliite	$(Cu,Zn)_2Zn[(As,Sb)O_4](OH)_3$	a=8.201	c= 7.315	$P\overline{3}$

(Merlino *et al.*, 1992), whose *a* parameter is the same and *c* parameter is twice that of sabelliite or schulenbergite, exhibits dense octahedral sheets, as does sabelliite (Olmi *et al.*, 1995). Namuwite (Bevins *et al.*, 1982) and theisite (Bonazzi & Olmi, 1989), whose structures are still unknown, show the same *a* parameter and a closely similar symmetry.

From the above considerations, and from the structural analogies discussed by Olmi *et al.* (1995), the grouping of these species in the same mineral family appears quite reasonable, following also the suggestion by Hodenberg *et al.* (1984) who have pointed out that schulenbergite is closely related to spangolite and namuwite.

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