Mammothite

a new mineral from Tiger, Arizona and Laurium, Greece

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ABSTRACT

Mammothite, $AlCu_4Pb_6Sb(SO_4)_2Cl_4(OH)_{18}$, is a new mineral species from Tiger, Arizona, where it is associated with anglesite and phosgenite, and from Laurium, Attika, Greece, where it is associated with cerussite and phosgenite. Microprobe analysis yielded $Al_2O_3 = 2.3$, $CuO = 14.9$, $PbO = 57.6$, $Sb_2O_3 = 6.1$, $SO_3 = 7.7$, $Cl = 5.7$, H_2O (by difference) = 7.0, less $O = Cl = 1.3$, sum = 100.0 %. Mammothite is monoclinic, space group *C2*, *Cm*, or *C2/m*, with lattice parameters $a = 18.89(3)$, $b = 7.22(1)$, $c = 11.31(2)$ Å, $\beta = 112.43(18)°$, $Z = 2$. Mammothite is blue; hardness (Mohs) = 3; cleavage is {010}, luster is vitreous, density (calc.) is 5.25 g/cm^3. Optically, mammothite is biaxial, positive, 2V = 80°; with indices of refraction $\alpha = 1.868$, $\beta = 1.892$, and $\gamma = 1.928$. Pleochroism is moderate with varying hues of light blue; absorption is $Z < Y \leq X$. The strongest lines in the X-ray powder diffraction pattern are: (*d*, I/Io, *hkl*) 10.4(60)(001), 6.67(90)(110), 6.08(60)(11$\bar{1}$). 4.72(80)(40$\bar{1}$, 31$\bar{1}$), 3.05(90)(221), and 2.896(100)(600,203). Mammothite is named for the Mammoth vein, Tiger, Arizona, and the town of Mammoth, Arizona.

INTRODUCTION

The new mineral described herein has been known for at least 15 years. It was originally noted by one of the authors (RAB) who found it in 1968 during an investigation of the mineralogy of the mines at Tiger, Arizona. Preliminary microprobe investigation by Richard W. Thomssen revealed that it is a lead-copper-antimony chloride-sulfate, and it was reported as an unknown by Bideaux (1980). This species was also known to many European collectors as a light blue unknown from Laurium, Attika, Greece. However, at Laurium, the minerals occur in crystals much too small to permit characterization of the species. During the course of examination of some Cl-bearing phases from Tiger in the Smithsonian collection, another habit of the same mineral was encountered and the common identity of specimens from all these occurrences was established.

We take pleasure in naming this species *mammothite* after the Mammoth vein (one of the two principal ore veins at Tiger) and the town of Mammoth, Arizona, which was named for the mine. The species and the name were approved by the Commission on New Minerals and Mineral Names, I.M.A., prior to publication. Type material is preserved in the Smithsonian Institution under catalog numbers NMNH #141368 and #161200, and in the Mineralogical Museum of the University of Goettingen under catalog #M5632.

X-RAY CRYSTALLOGRAPHY

Crystals from Tiger, Arizona, are sufficiently large and perfect to provide single-crystal X-ray diffraction data. Weissenberg and precession photographs show that mammothite is monoclinic, space group *C2/m*, *C2*, or *Cm*. Lattice parameters were refined by least-squares, utilizing powder diffraction data, yielding the values $a = 18.89(3)$, $b = 7.22(1)$, $c = 11.31(2)$ Å, $\beta = 112.43(18)°$, V = 1426(5) Å^3, Z = 2. The powder diffraction data are listed in Table 1. They were obtained utilizing a 114.6-mm diameter Gandolfi camera, Cu$K\alpha$ X-radiation, polycrystalline sample, and Si as an internal standard.

PHYSICAL DESCRIPTION

The holotype mammothite from Tiger, Arizona (#161200), is bright blue; it was described as having a cerulean-blue color by Bideaux (1980). The hue is similar to that of linarite or azurite. The crystals are complexly developed and appear similar to triclinic

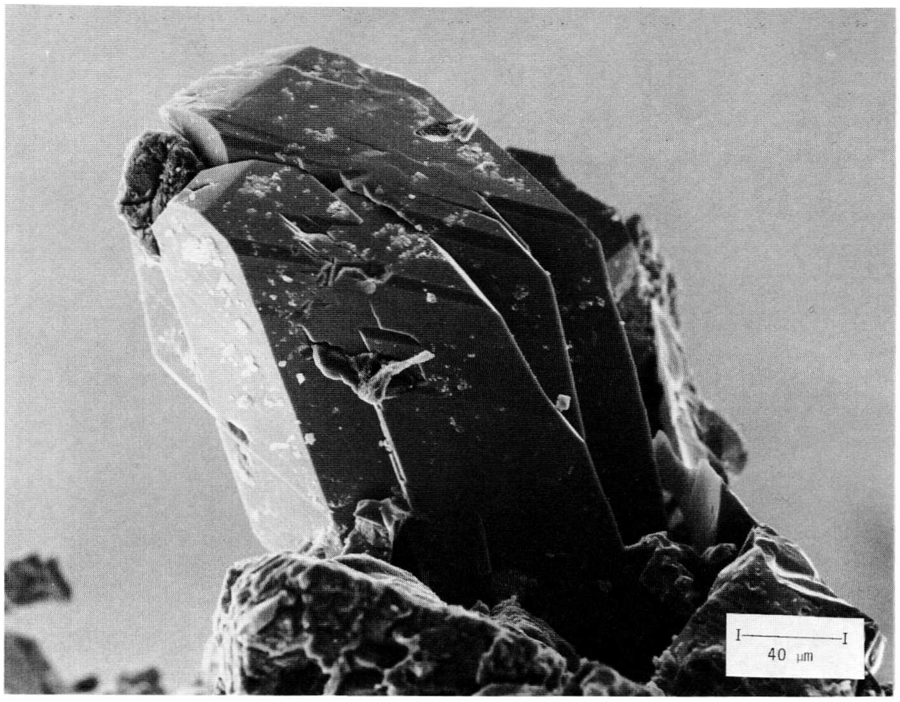

***Figure 1.* Mammothite crystals in parallel growth; scale bar is 40 μm. NMNH #161200, Tiger, Arizona.**

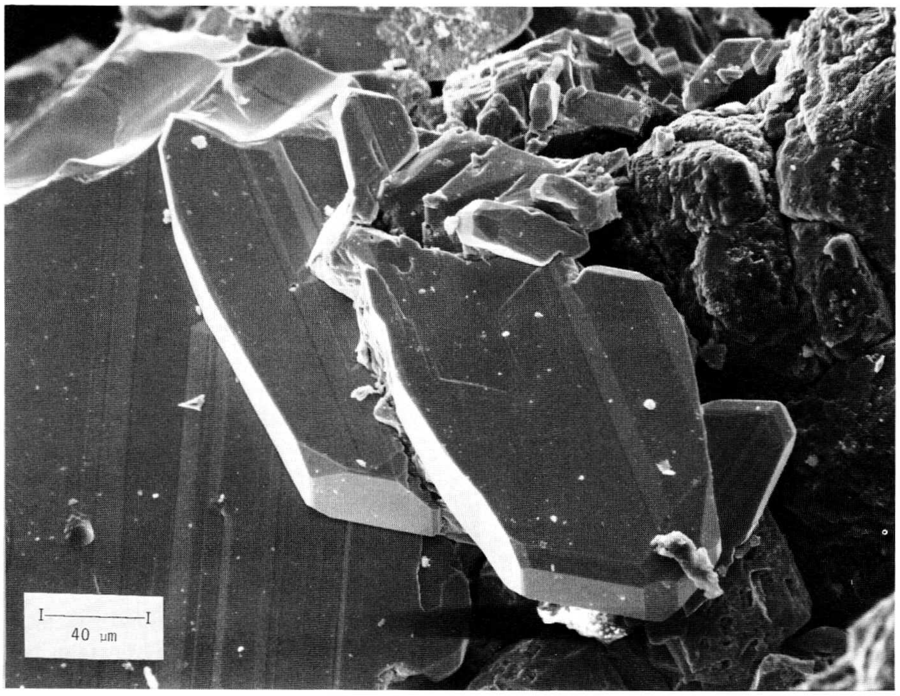

***Figure 2.* Severely flattened mammothite crystals. Scale bar is 40 μm. NMNH #161200, Tiger, Arizona.**

chalcanthite crystals in habit, albeit with more complex morphology. Optical goniometer data were obtained for one crystal. The dominant forms are {001}, {110}, and a possible {010}, which is not directly determinable due to low quality reflections on the optical goniometer. Although most crystals are tabular, several are elongate; the axis of elongation is [001]. Crystals which exhibit this morphology are shown in Figure 1, an SEM photomicrograph of three mammothite crystals in parallel growth. Another mammothite crystal from the holotype occurrence is shown in Figure 2. The cotype mammothite (#141368), not depicted here, is markedly different in color and crystal habit; the color is a distinct green-blue with equal intensity of blue and green color components. The habit is strongly prismatic and the crystals have a pseudotetragonal aspect. Crystals are less than 1.0 mm in size.

Mammothite from Laurium, Attika, Greece, is quite different in physical appearance. The material varies in color from pale blue to very pale blue to nearly white. Crystals are extremely small and the morphology is not easily determined by visual examination. There are two habits: one prismatic and bladed; the other extremely prismatic, elongate on [001]. Figure 3 shows a cluster of the prismatic bladed crystals; Figures 4 and 5 show the extremely acicular habit.

Physical properties were determined on the holotype material from Tiger. These include bright blue color; pale blue streak; hardness (Mohs) approximately 3; vitreous luster on both cleavage and fracture surfaces; cleavage distinct on {010}; even fracture; and very brittle. The density could not be precisely measured due to small crystal size and abundant attachments of associated species. It is greater than 4.2 g/cm^3, measured using heavy liquid techniques. The calculated value for the idealized end-member is 5.25 g/cm^3.

Optically, mammothite is biaxial, positive, with $2V = 80°$ (meas.). Indices of refraction are $\alpha = 1.868$, $\beta = 1.892$, and $\gamma = 1.928$. Pleochroism is moderate with varying shades of pale blue; absorption is $Z < Y \leq Z$. Mammothite is transparent, with no discernible response to ultraviolet radiation. Calculation of

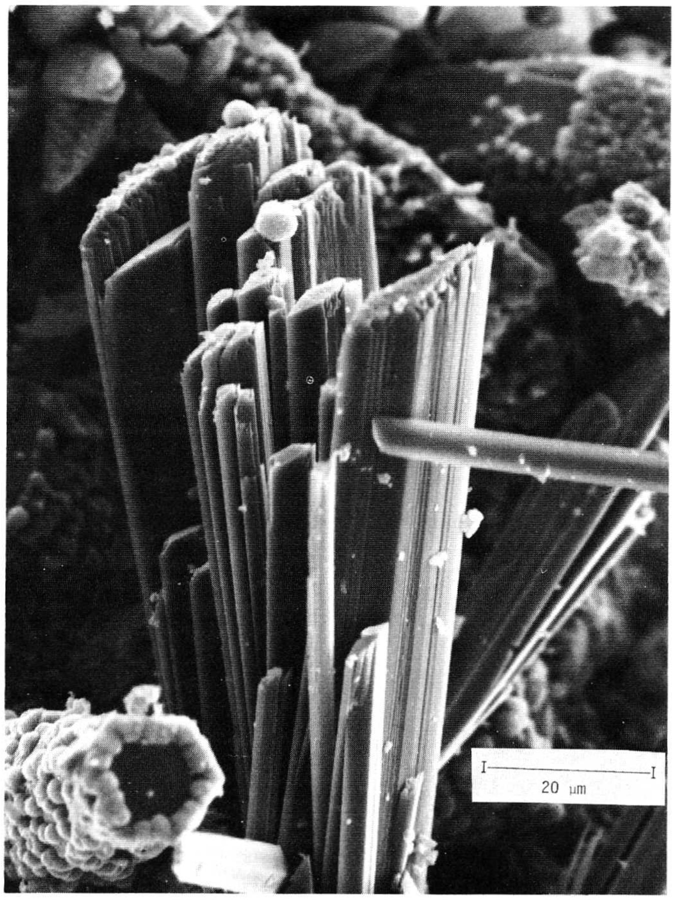

Figure 3. **Prismatic, bladed mammothite crystals in parallel growth. Scale bar is 20 μm. Laurium, Greece.**

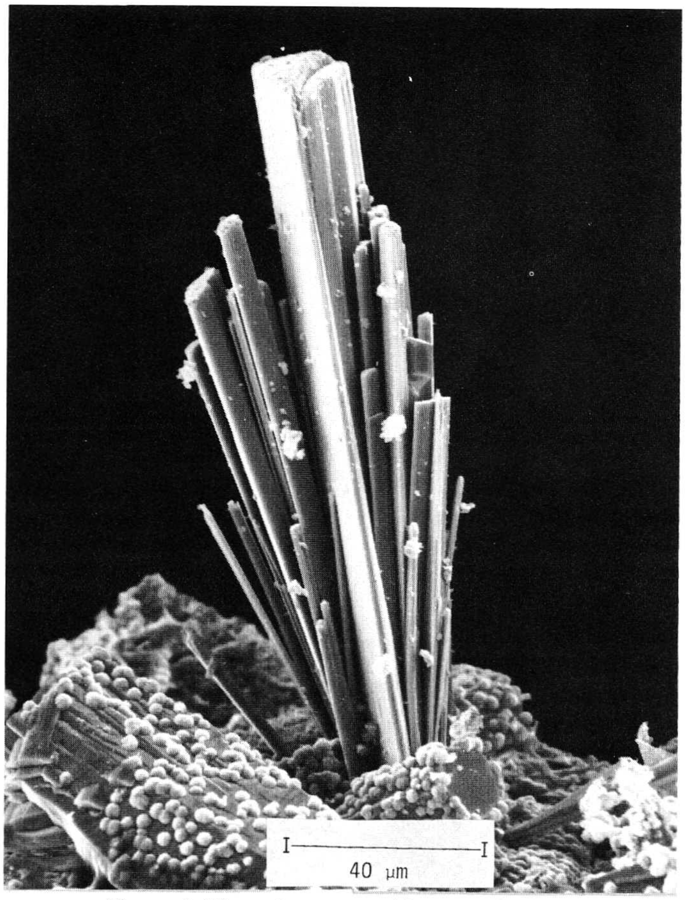

Figure 4. **Elongate mammothite crystals showing prismatic habit. Scale bar is 40 μm. Laurium, Greece.**

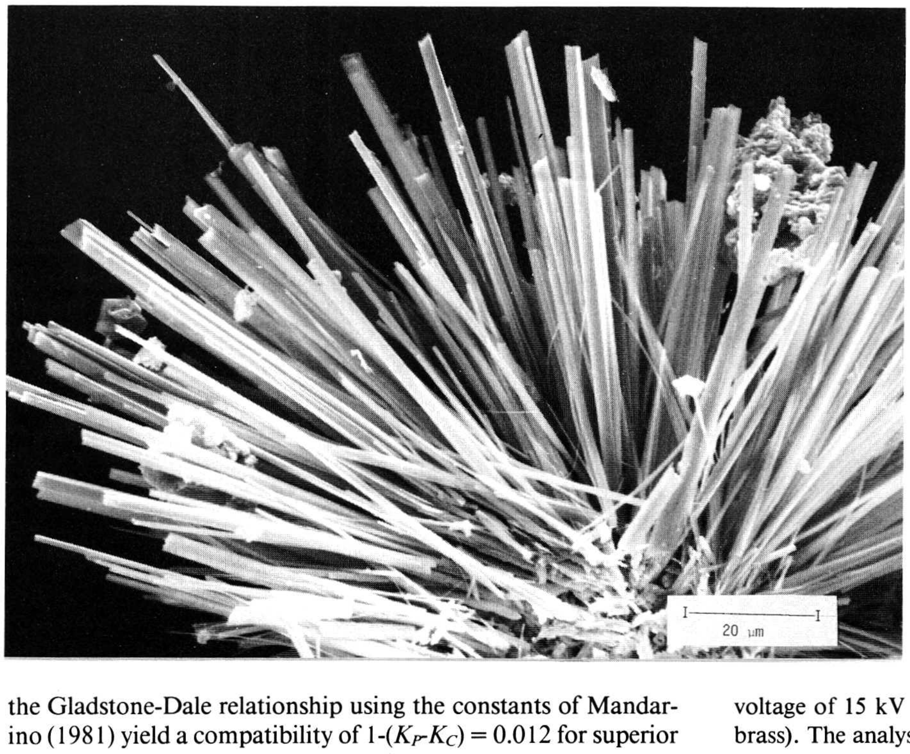

Figure 5. **Spray of radial, acicular mammothite crystals. Scale bar is 20 μm. Laurium, Greece.**

the Gladstone-Dale relationship using the constants of Mandarino (1981) yield a compatibility of $1\text{-}(K_P\text{-}K_C) = 0.012$ for superior agreement of the chemical and physical data.

CHEMICAL COMPOSITION

Crystals of mammothite from Tiger, Arizona, are of adequate size to permit analysis by microprobe. These crystals were analyzed using an ARL-SEMQ electron microprobe utilizing an operating voltage of 15 kV and a sample current of 0.025 μA (measured on brass). The analysis was performed with a large (40 μm) beam spot after first ascertaining homogeneity with a small beam spot. A wavelength-dispersive microprobe scan indicated the absence of elements with atomic number greater than 8, except those reported herein. The standards used were synthetic Sb_2O_3 (Sb), cuprite (Cu), PbO (Pb), halite (Cl), barite (S), and hornblende (Al). The data were corrected using a modified version of the *MAGIC-4* program.

Water was calculated by difference. The resultant analyses are given in Table 2. Calculation of unit cell contents was not possible due to the difficulty in obtaining a precise density measurement. The formula for the holotype mammothite, calculated on the basis of $\Sigma(O+Cl)=30$, is: $Al_{1.02}Cu_{4.22}Pb_{5.81}Sb_{0.94}S_{2.14}Cl_{3.62}H_{17.49}O_{26.38}$ for the holotype sample ($Z=2$). We interpret this as $AlCu_4Pb_6Sb(SO_4)_2Cl_4(OH)_{18}$ with the presumption that all hydrogen is present as hydroxyl, inasmuch as there are no associated hydrated minerals; those associated with mammothite do have hydroxyl, however.

Mammothite from Laurium occurs in crystals too small and sparse to permit a highly accurate microprobe analysis. However, qualitative microprobe analysis of this mammothite by Alfred Schneider of Goettingen found the same elements in roughly the same proportions. This identification of Laurium mammothite was confirmed by X-ray diffraction methods.

Mammothite whitens in dilute 1:1 HCl, but because diaboleite and linarite (both found at Tiger) react similarly, this is not a diagnostic test.

Table 2. **Microprobe analyses of mammothite from Tiger, Arizona**

	NMNH #161200 (holotype)	NMNH #141368 (cotype)
Al_2O_3	2.3	2.3
CuO	14.9	15.1
PbO	57.6	56.9
Sb_2O_3	6.1	6.2
SO_3	7.7	7.4
Cl	5.7	5.8
H_2O	7.0*	7.6*
O = Cl	1.3	1.3
Total	100.0%	100.0%

* Water determined by difference.

Table 1. **X-ray powder diffraction data for mammothite.**

I/Io	*d*(obs)	*d*(calc)	*hkl*	*I/Io*	*d*(obs)
60	10.43*	10.46	001	30	2.377
10	8.46*	8.48	$20\bar{1}$	20	2.331
90	6.67*	6.67	110	40	2.274
60	6.08*	6.04	$11\bar{1}$	30	2.244
20	5.72*	5.72	201	5	2.135
20	5.51*	5.51	$20\bar{2}$	10	2.095
30	5.24*	5.23	002	5	2.050
80	4.72	4.72	$40\bar{1}$	5	2.032
		4.70	$31\bar{1}$	2	1.994
10	3.78	3.77	$20\bar{3}$	2	1.966
		3.77	311	10	1.882
30	3.59	3.61	401	30	1.835
		3.57	020	20	1.753
20	3.49*	3.49	003	10	1.707
30	3.37	3.41	021	10	1.679
		3.34	$51\bar{1}$	5	1.623
20	3.29*	3.29	$11\bar{3}$	2	1.603
90	3.05*	3.05	221	10	1.576
100	2.896	2.911	600	5	1.542
		2.884	203	10	1.526
20	2.824	2.827	$60\bar{3}$	5	1.513
		2.817	$20\bar{4}$	30	1.448
20	2.761*	2.761	511	5	1.419
10	2.640*	2.642	222	10	1.383
20	2.518	2.516	$71\bar{2}$	10	1.317
				5	1.301
				2	1.288
				20	1.193

Intensities estimated visually.

* Refers to lines used in the least-squares refinement of lattice parameters.

OCCURRENCE

Mammothite is known from the Mammoth mine, Tiger, Arizona, and from Laurium, Attika, Greece.

Mammothite from Tiger, Arizona, occurs as euhedral crystals imbedded in microgranular white anglesite which has a saccharoidal texture. The associated species are phosgenite, wulfenite, leadhillite and caledonite. The anglesite crystals exhibit various color and crystal habits, and are likely of several generations, as is commonly seen in other Tiger specimens. Of the nearly 100 species known to occur at Tiger, about 25 are considered by Bideaux (1980) to belong to an anomalous oxidized sequence. These anomalous minerals, which occur in close association, are anomalous with respect to the much more commonly occurring Pb, Cu, Fe and Zn normal oxidation minerals which also occur at Tiger and at numerous other deeply oxidized base-metal deposits worldwide. The minerals of this anomalous sequence are characterized by the presence of Pb and Cu, often in the same species, and SO_4 and CO_3 similarly. Chlorine is especially a characteristic element in the anomalous assemblage. Because mammothite from Tiger shows these chemical associations, it is clearly also a member of the anomalous sequence. Aluminum is noted from Tiger in beaverite, $Pb(Cu,Fe,Al)_3(SO_4)_2(OH)_6$. Antimony is a very rare element in the Tiger suite; the only other Sb-bearing mineral is tetrahedrite, $(Cu,Fe)_{12}Sb_4S_{13}$, which is rarely observed as tiny crystals implanted on primary pyrite crystals.

At Laurium, mammothite occurs in very small euhedral crystals and as microscopic druses in the slags. The associated minerals are cerussite, phosgenite and matlockite.

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