

# Tooeleite, a new mineral from the U.S. Mine, Tooele County, Utah

FABIEN P. CESBRON AND SIDNEY A. WILLIAMS

Globo De Plomo Enterprises, P.O. Box 872, Douglas AZ 85608, U.S.A.

## Abstract

The new mineral tooeleite occurs with pyrite, arsenopyrite, scorodite, and jarosite at the U.S. Mine, Tooele County, Utah. Analysis by electron microprobe gave Fe<sub>2</sub>O<sub>3</sub> 43.56%, As<sub>2</sub>O<sub>5</sub> 38.61%, SO<sub>3</sub> 7.24%, and H<sub>2</sub>O by the Penfield method 9.80%. For this analysis, the suggested formula is Fe<sub>8-2x</sub><sup>3+</sup>[(AS<sub>1-x</sub>S<sub>x</sub>)O<sub>4</sub>]<sub>6</sub>(OH)<sub>6</sub>·5H<sub>2</sub>O; *x* is about 0.2.

Crystals are orthorhombic, perhaps *Pbcm* or *Pbc2<sub>1</sub>*, with *a* = 6.416, *b* 19.45, *c* = 8.941 Å. The strongest diffraction lines are [*d* in Å, (*hkl*), (*I*)] 9.75 (020) (10); 3.208 (200,132) (9); 3.047 (061,220) (5); 4.476 (1002) (4) and 2.680 (240,113) (4). The mineral is optically negative with a small 2*V*; α = 1.94, β = 2.05, γ = 2.06. Hardness = 3, D<sub>meas</sub> = 4.23, D<sub>calc</sub> = 4.15 g/cm<sup>3</sup> for Z = 2.

KEYWORDS: tooeleite, new mineral, Tooele County, Utah.

## Introduction

A single sample of tooeleite was found in 1964 at the locality, but more material was not located until 1984, at which time the mineral was found in some abundance. The first specimen had been collected underground, and occurred with crystalline kaatialaite which had not yet been found as a species but was known artificially. Subsequently the mine access was sealed, but a small area rich in the new mineral was located on the dump.

Type material will be deposited in the collection of mineralogy, at the Ecole Nationale Supérieure des Mines, Paris.

The mineral and name have been approved in advance of publication by the Commission on New Minerals and New Mineral Names, IMA. The name should be pronounced too.ELLA.ait.

## Occurrence

Tooeleite was found on waste dumps of the U.S. Mine at Gold Hill, Tooele County, Utah. The mineral occurrences in the Gold Hill district have been described by Nolan (1935). During World War II, the U.S. Mine produced gold and arsenic from pyrite-arsenopyrite replacement ores in thermally metamorphosed limestone. It is one of several mines of this type in the district, all of them located in proximity to an intrusive stock.

Tooeleite is an oxide zone mineral. It formed from a primary ore composed of granular pyrite

and arsenopyrite which were thickly disseminated (ca. 50% by volume) in a quartz-diopside host rock. The volume ratio of the two sulfides in tooeleite-bearing samples is invariably about 1:1. This ratio and the unreactive nature of the host rock are factors believed to be important for tooeleite formation. Ores with other sulfide ratios or with carbonate as gangue do not produce the mineral. The rate of oxidation that produced tooeleite is believed to have been catastrophic, occurring before any mining began.

Early oxidation first produced massive scorodite which contains numerous small voids lined with drusy crystals; many of the voids are filled or lined with compact crystalline jarosite. Voids free of jarosite may contain occasional tiny native sulfur crystals. Tooeleite encrusts both jarosite and scorodite, covering fracture surfaces or void walls as crystalline crusts of some few cm<sup>2</sup> and five to ten millimetres thick. Other species found in the specimens collected include galena, sphalerite, goethite, and gypsum, all of which are uncommon.

## Physical and optical properties

Tooeleite is typically cadmium orange (RHS 23B), ranging toward more brownish or yellowish colours on occasion. The streak is also cadmium orange (RHS 23C or 23B). The Mohs' hardness is 3, and massive crusts seem slightly gummy when

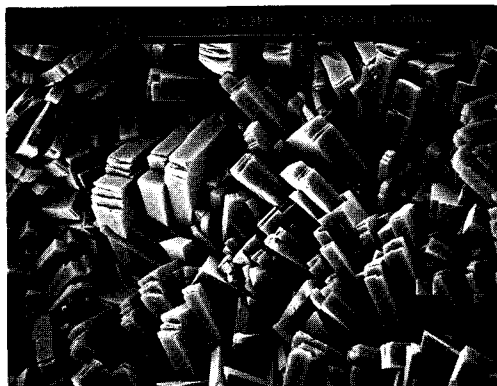


FIG. 1. SEM photograph of typical tooeleite crystal terminations, magnified about 500 times. The white bar at the top of the photograph is 50  $\mu\text{m}$  long.

scratched. Minute crystals are perfectly transparent and display a greasy lustre. No fluorescence was seen in short or long wavelength ultraviolet radiation.

The specific gravity was determined in toluene with the Berman balance, using various 5 to 10 mg samples. The results of five determinations yielded 4.23(8).

Because no crystals suitable for goniometry could be found, an effort to learn the morphology was based on thin-section study. Straight extinction in all primary orientations led us to believe, at this point in the study, that the symmetry was orthorhombic. Crystals are elongate blades up to 10 mm; this direction of elongation was chosen as [001] and coincides with Y. The shortest dimension of crystals was chosen as [010] = Z and is normal to the one good cleavage found. The intermediate direction [100] = X. Cleavage surfaces are invariably wrinkled and are often striated parallel to [001]. Small, well-formed terminations that may project above compact crystalline crusts are bounded by {010}, {304}, and {100} (Fig. 1).

The extinction on [001] is invariably parallel. The measured 2V angle of 2–5°, obtained with the universal stage, is low in comparison with the calculated 2V of 32°. This is surely due to wrinkles in the crystal surfaces, to subparallel groupings and to some uncertainty in the measured indices of refraction. The indices were measured in white light as  $\alpha = 1.94$ ,  $\beta = 2.04$ , and  $\gamma = 2.05$ . The pleochroism is not strong, according to the scheme  $Y > Z = X$  with Y = orange, Z = X = lemon yellow. Dispersion of the optic axes is slight,  $\rho > \nu$ .

Tooeleite could be confounded with beraunite in thin section but the mineral assemblage should

always serve to distinguish the two species. Crystals attach directly to massive granular scorodite and show no sign of replacing it, but when they encrust jarosite they show textures suggestive of replacement of that substrate.

### Chemistry

Preliminary DC arc spectrography and X-ray fluorescence analyses showed major Fe and As and minor to trace Mo, Mn and Al. Molybdenum was not found by subsequent analytical techniques.

Tooeleite was analysed with a CAMECA electron microprobe using the following standards:  $\text{Fe}_2\text{O}_3$  for Fe; FeAsS and synthetic AsGa for As; and  $\text{FeS}_2$  for S. Analysis also found Al, Mg, and Mn; Al is usually absent and did not exceed 0.03%  $\text{Al}_2\text{O}_3$ ; Mg was invariably found but did not exceed 0.08%; and Mn is erratic in concentration, ranging from nil to 0.13% MnO. These elements thus were not considered further. Water was determined (and observed) by the Penfield method using a 27.465 mg sample.

Analytical results are presented in Table 1. The formula was established on the basis of  $\text{As}^{5+} + \text{S}^{6+} = 6$ . Thus, for electrical neutrality  $\text{Fe}^{3+} = 7.58$ . This leads to the formula  $(\text{Fe}_{7.58}^{3+})[(\text{As}_{0.79}\text{S}_{0.21})\text{O}_4]_6(\text{OH})_6 \cdot 4.66\text{H}_2\text{O}$ . Vacancies in the  $\text{Fe}^{3+}$  site are thus due to partial replacement of  $\text{As}^{5+}$  by  $\text{S}^{6+}$ .

The generalized formula can be written  $\text{Fe}_{8-2x}[(\text{As}_{1-x}\text{S}_x)\text{O}_4]_6(\text{OH})_6 \cdot 5\text{H}_2\text{O}$  with  $x \approx 0.2$  and  $Z = 2$ . In the eleven microprobe analyses used for this study  $x$  ranged from 0.20 to 0.23 and there seems no likelihood that a hypothetical  $\text{Fe}_8$ -

Table 1. Chemical analysis of tooeleite

	1	2	3
$\text{Fe}_2\text{O}_3$	43.39%	43.56%	$\text{Fe}^{3+} = 7.68$
$\text{As}_2\text{O}_5$	39.05	38.61	$\text{As}^{5+} = 4.73$
$\text{SO}_3$	7.23	7.26	$\text{S}^{6+} = 1.27$
$\text{H}_2\text{O}$	10.33	9.80	$\text{H}^+ = 15.31$
Total	100.00	99.21	

(1) Theoretical composition for  $\text{Fe}_{8-2x}[(\text{As}_{1-x}\text{S}_x)\text{O}_4]_6(\text{OH})_6 \cdot 5\text{H}_2\text{O}$ ;  $x=0.21$

(2) Average of eleven analyses

(3) Atomic ratios on the basis  $\text{As}^{5+} + \text{S}^{6+} = 6$ .

(AsO<sub>4</sub>)<sub>6</sub>(OH)<sub>6</sub>·5H<sub>2</sub>O end-member exists at the locality. A problem arises, however, concerning the number of H<sub>2</sub>O molecules in the cell, for the numbers of equivalent positions must be equal to 8 and 4 for *Pbcm* and 4 for *Pbc2*<sub>1</sub> space groups. Thus, formulae with 4 or 6 H<sub>2</sub>O (still with Z = 2) would be more suitable. For example, with x = 0.21 and 4H<sub>2</sub>O, the theoretical composition would be Fe<sub>2</sub>O<sub>3</sub> = 43.95%, As<sub>2</sub>O<sub>5</sub> = 39.56, SO<sub>3</sub> = 7.33, H<sub>2</sub>O = 9.16; and D<sub>calc</sub> = 4.10.

Another possibility would be to consider a variable number of hydroxyl groups for charge balance. Then the formula could be written Fe<sub>8</sub><sup>3+</sup>[(As<sub>1-x</sub>S<sub>x</sub>)O<sub>3+x</sub>(OH)<sub>1-x</sub>]<sub>6</sub>(OH)<sub>12</sub> with Fe<sub>2</sub>O<sub>3</sub> = 44.51%, As<sub>2</sub>O<sub>5</sub> = 37.95, SO<sub>3</sub> = 7.03, H<sub>2</sub>O = 10.51; and D<sub>calc</sub> = 4.25. Determination of the correct formula will require a structure analysis of the phase.

We assume that iron is trivalent because of the mineral's position in the paragenetic sequence (post-jarosite). No direct proof of valence was established.

When heated in the closed tube tooeleite produces a sparkling crystalline sublimate of As<sub>2</sub>O<sub>3</sub> crystals and an infusible black magnetic scoriaceous residue. Tooeleite is easily soluble in cold 16% HCl but dissolves only slowly, and with gentle warming in 16% HNO<sub>3</sub>. It decomposes to a flaky red substance in cold 20% KOH.

#### X-ray study

Rotation and zero-level Weissenberg photographs were obtained using a tiny 1 mm by 0.1 mm subparallel aggregate of crystals rotated on [001]. Exposures of 50 to 100 hours were required, using Cu-Kα radiation. Useable higher level photographs could not be obtained.

Examination of the diagrams supports the optical characterization of the mineral as orthorhombic and suggests the space group *Pbcm* or *Pbc2*<sub>1</sub>. The unit cell was refined from powder data obtained by the Straumanis method with a 114 mm camera utilizing Cr-Kα radiation. The values obtained are a = 6.416(4), b = 19.45(17), c = 8.941(8) Å. An indexed powder pattern is provided in Table 2. X-ray powder data were also obtained using Cu-Kα radiation and a focussing Guinier de Wolff camera with quartz as an internal standard. The results (not presented herein) were virtually identical to those reported.

The space group(s) possible are based largely on indexing of the powder pattern and thus are highly ambiguous.

Table 2.

Indexed X-ray powder diffraction data for tooeleite

$\bar{I}$	d <sub>meas</sub>	d <sub>calc</sub>	hkl	$\bar{I}$	d <sub>meas</sub>	d <sub>calc</sub>	hkl
10	9.75	9.725	020	2	2.430	2.431	080
½	5.015	5.035	111			2.429	162
4	4.476	4.471	002	2	2.354	2.362	143
½	4.092	4.062	131	2	2.278	2.280	260
		4.062	022	3	2.236	2.235	004
1	3.892	3.875	140	4	2.153	2.139	300
3	3.664	3.668	102	2	2.086	2.089	320
3	3.462	3.432	122	½	1.974	1.981	331
3	3.244	3.242	060	1	1.896	1.894	281
9	3.208	3.208	200			1.892	322
		3.192	132	2	1.857	1.855	154
5	3.047	3.047	061	3	1.733	1.731	313
		3.046	220	2	1.690	1.688	193
2	2.824	2.850	023	2	1.666	1.665	371
2	2.758	2.753	161	4	1.604	1.604	400
4	2.680	2.678	240	3	1.583	1.583	420
		2.677	113	3	1.574	1.574	411
1	2.589	2.583	212			1.571	1.12.0
3	2.534	2.541	043	3	1.563	1.559	2.10.2

Note: Measured d values were obtained by the Straumanis method, using a 114mm camera and CrKα radiation.

#### Discussion

Minerals with similar chemistry are few. Only zykaite has a similar composition but it is a higher hydrate and the indices correspondingly lower. No other similar arsenate-sulfates or phosphate-sulfates were found in the literature.

#### Acknowledgements

We are grateful to Michel Tallet and Christian Gilles who assisted in the electron microprobe analyses and to Helène Vachey for the Penfield analysis. Lance Talley kindly provided an initial spectrographic analysis.

#### Reference

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[Manuscript received 28 February 1991]