Juabite, $Cu_5(Te^{6+}O_4)_2(As^{5+}O_4)_2 \cdot 3H_2O$, a new mineral species from the Centennial Eureka mine, Juab County, Utah

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Abstract

Juabite, ideally $Cu_5(Te^{6+}O_4)_2(As^{5+}O_4)_2 \cdot 3H_2O$, is triclinic, space-group choices $P1(1)$ or $P\bar{1}(2)$, with unit-cell parameters refined from powder data: a = 8.984(5), b = 10.079(7), c = 8.975(5) Å, α = 102.68(7)°, β = 92.45(6)°, γ = 70.45(5)°, V = 746.8(8) Å^3, a:b:c = 0.8914:1:0.8905, Z = 2. The strongest seven reflections of the X-ray powder-diffraction pattern [d in Å (I)(hkl)] are: 9.28 (70)(010), 4.65 (70)(020), 3.097 (100)$(030,\bar{2}11)$, 3.018 (60)(212), 2.658 (50)$(\bar{3}01)$, 2.468 (50)$(\bar{2}2\bar{2})$ and 1.740 (50)$(\bar{1}1\bar{5}, 521, \bar{1}5\bar{1})$. The mineral is an extremely rare constituent on the dumps of the Centennial Eureka mine, Juab County, Utah, U.S.A., where it occurs as crystalline platy masses that average 0.2–0.3 mm in longest dimension within small interconnected vugs of drusy quartz. Associated minerals are enargite, beudantite, and an undefined, possible Pb-analogue of arsenobismite. Individual crystals are subhedral to euhedral and average 125 × 100 × 1–2 μm in size. Cleavage {010} perfect. Forms are: {010} major; {100}, $\{\bar{1}01\}$, and {101} minor. The mineral is translucent (masses) to transparent (crystals), emerald-green, with a pale green streak, and an uneven to subconchoidal fracture. Juabite is vitreous to adamantine (almost gemmy) on cleavage faces, brittle, and nonfluorescent; H (Mohs) 3–4; D (calc.) 4.59 g/cm^3 for the idealised formula. In polished section, juabite is white in plane-polarised reflected light in air with ubiquitous turquoise-blue internal reflections; bireflectance and anisotropy are unknown (due to interference from internal reflections). Averaged electron-microprobe analyses yielded CuO 38.25, PbO 0.57, TeO_3 32.58, As_2O_5 22.81, H_2O (calc. assuming $3H_2O$) [5.19], total [99.40] wt.%, leading to the empirical formula $(Cu_{5.01}Pb_{0.03})_{\Sigma 5.04}(TeO_4)_{1.93}(AsO_4)_{2.07} \cdot 3.00H_2O$ based on O = 19. The infrared absorption spectrum shows definite bands for structural H_2O with an O-H stretching frequency centred at 3283 cm^{-1} and a H-O-H flexing frequency centred at 1642 cm^{-1}. The mineral name is for the county within the state of Utah in which the Centennial Eureka mine is located.

KEYWORDS: juabite, new mineral, Centennial Eureka mine, Juab County, Utah, U.S.A., X-ray data, electron-microprobe analyses, reflectance data, infrared spectroscopy.

Mineralogical Magazine, Vol. 61, February 1997, pp. 139–144

Introduction

JUABITE, ideally $Cu_5(Te^{6+}O_4)_2(As^{5+}O_4)_2 \cdot 3H_2O$, is a newly recognised mineral species which was first encountered during megascopic examination, scanning electron energy-dispersion study, and routine X-ray powder diffraction characterisation of a suite of secondary Cu- and Te-bearing minerals. This suite of samples was collected by one of us (MCJ) in July 1992 from dumps rich in ore-grade material adjacent to the Centennial Eureka mine, Tintic District, Juab County, Utah, U.S.A. This mineral is the sixth of at least seven new secondary Cu- and Te-bearing phases that will eventually be characterised.

The mineral name is for the county within the state of Utah in which the Centennial Eureka mine (and associated dumps) is located. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, I.M.A. Holotype material, consisting of one specimen, one SEM stub, several single-crystal mounts, some loose crystals with enargite and one Gandolfi powder camera mount, is preserved in the Systematic Reference Series of the National Mineral Collection, Geological Survey of Canada, Ottawa, Ontario, Canada under the catalogue number NMCC 67959. The polished section used for both the electron-microprobe analyses and the attempted reflectance study is preserved at The Natural History Museum, Great Britain, as BM 1997,1.

Occurrence and associated minerals

Juabite has been identified on only a single specimen collected from the dumps of the Centennial Eureka mine, Tintic District, Juab County, Utah, U.S.A. (latitude 39°56′38″ N, longitude 112°07′18″ W), about 1.5 km southwest of the historic town of Eureka. This copper, gold, and silver property, worked primarily from 1876 to 1927, was the most productive and profitable deposit in the district. The immense dumps of the mine were largely removed and processed for their low-grade concentrations of gold in late 1991. At this time, a wide variety of mineralised samples were exposed, including several boulders which contain the new Cu- and Te-bearing assemblages. Additional information regarding the geology, mineralogy, and history of the Centennial Eureka mine and surrounding environs can be found in Marty *et al.* (1993) and on page 419 of the formal description of mcalpineite (Roberts *et al.*, 1994).

Juabite is extremely rare; only about 1 mg of the mineral is presently known. On the holotype specimen, which measures 14 × 10 × 8 mm, it is confined to one area of the specimen where it is found as platy masses in three adjacent drusy quartz-lined cavities that are approximately 1 mm long by less than 0.5 mm wide. Associated minerals are black metallic enargite (with which it is intimately associated), beudantite (as a mustard yellow crystalline crust) and an ill-defined mineral which may be a Pb-analogue of arsenobismite (as a green-yellow opaque crystalline crust). It is believed that juabite formed from the breakdown and partial replacement of enargite by Te-enriched fluids.

Additional Cu- and Te-bearing secondary minerals that have been identified by X-ray powder-diffraction methods on similar specimens from the Centennial Eureka mine dumps include mcalpineite (Roberts *et al.*, 1994), frankhawthorneite (Roberts *et al.*, 1995; Grice and Roberts, 1995), jensenite (Roberts *et al.*, 1996*a*; Grice *et al.*, 1996), leisingite (Roberts *et al.*, 1996*b*), utahite (Roberts *et al.*, 1997), xocomecatlite, cesbronite, dugganite, quetzalcoatlite and two additional crystalline unnamed Cu- and Te-bearing phases which are currently under investigation. A list of the many primary and secondary minerals identified at the Centennial Eureka mine has been published by Marty *et al.* (1993).

Physical properties

Juabite occurs as crystalline subhedral platy masses that are up to 0.2–0.3 mm in longest dimension. Platy {010} euhedral crystals are relatively scarce. Individual plates average 125 × 100 × 1–2 μm in size. An SEM photomicrograph of a broken platy aggregate is presented in Fig. 1. In addition to {010}, SEM study shows possible minor {100}, {$\bar{1}$01} and {101}. Twinning was not observed megascopically nor was it found in X-ray single-crystal studies.

Juabite masses are gemmy emerald-green; thin crystals are a very much lighter green. The streak is pale green. The lustre is vitreous to adamantine on

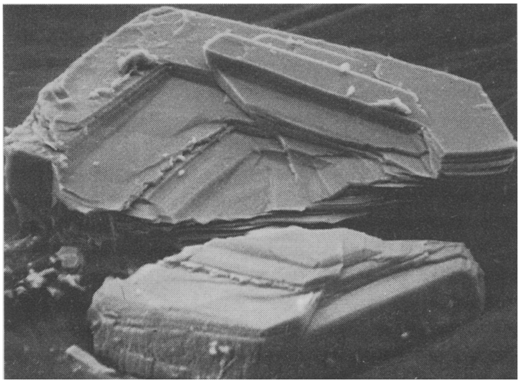

FIG. 1. Scanning electron photomicrograph of a broken juabite platy aggregate which shows the perfect {010} cleavage. (Scale bar: 50 μm).

cleavage faces. The mineral is brittle, possesses an uneven, almost subconchoidal, fracture, and is translucent (masses) to transparent (thin plates). It possesses perfect {010} cleavage, has an estimated Mohs hardness of 3–4, and is nonfluorescent under both long-and short-wave ultraviolet light. The density could not be measured owing to the size of available specimens, size of crystals, and dearth of pure material.

X-ray powder and single-crystal study

Two crystals of juabite were examined by single-crystal precession methods employing Zr-filtered Mo radiation. One crystal was mounted such that a^*, and the other crystal such that b^*, was parallel to the precession camera dial axis. The reciprocal lattice levels collected were: $0kl \rightarrow 3kl$, $hk0 \rightarrow hk3$, $\bar{1}01^* \wedge b^*$, $103^* \wedge b^*$, $301^* \wedge b^*$, $101^* \wedge b^*$ and $h0l \rightarrow h3l$. Juabite is triclinic with space-group choices $P1(1)$ or $P\bar{1}(2)$ (diffraction aspect P^*). The refined unit-cell parameters: a = 8.984(5), b = 10.079(7), c = 8.975(5) Å, α = 102.68(7)°, β = 92.45(6)°, γ = 70.45(5)°, V = 746.8(8) $Å^3$, a:b:c = 0.8914:1:0.8905, are based on 19 reflections, between 4.22 and 1.687 Å, in the X-ray powder pattern for which unambiguous indexing was possible. All possible reflections down to 1.53 Å were visually examined on single-crystal precession films. Fully indexed 114.6 mm Debye-Scherrer camera X-ray powder data are presented in Table 1. The data are unique and do not bear resemblance to any inorganic compound listed in the PDF up to and including Set 45. The only other known non-metallic Te-and As-bearing phase is dugganite $Pb_3(Zn,Cu)_3(Te^{6+}O_6)(AsO_4)(OH)_3$.

The largest crystal used for the aforementioned precession single-crystal study was also used to attempt to determine the crystal structure of the mineral. Unfortunately, the crystal was too small to acquire any meaningful counting statistics, even after prolonged exposure to the X- ray beam (L.A. Groat, pers. comm., 1995). No larger single crystals are currently available for structure analysis.

Chemistry

A 0.5 × 0.2 mm fragment of juabite was analysed with a JEOL 733 electron microprobe using Tracor-Northern 5500 and 5600 automation. The wavelength-dispersion mode was used. Data reduction was done with a conventional ZAF routine in the Tracor-Northern TASK series of programs. The operating conditions were as follows: operating voltage of 15 kV, a beam current of 20 nA and a beam 20 μm in diameter. Data for the sample were collected for 25 seconds or to 0.50% precision (depending on which was obtained first) except for Pb where data were collected for 50 seconds. Data were also collected for the standards for 50 seconds (or to a precision of 0.25%). A 100 second energy-dispersion scan indicated that no elements with Z > 8 other than those reported here. S and Hg were sought for but not detected. The following standards were employed: synthetic $FeTe_2O_5(OH)$(Te-$L\alpha$), natural cuprite (Cu-$K\alpha$), natural mimetite (As-$L\alpha$) and natural crocoite (Pb-$M\alpha$). No zoning was detected in backscatter images. The paucity of pure uncontaminated material prevented the quantitative determination of H_2O by classical methods. However, its presence as molecular H_2O was confirmed by infrared spectroscopic analysis. H_2O was therefore calculated by stoichiometry. The valence state of tellurium was assumed to be Te^{6+} as no secondary Te-bearing mineral from this occurrence has been shown by crystal-structure analysis to possess Te^{4+} in its structure. Crystal-structure analysis of cesbronite from this locality indicates a probable revision of its symmetry, cell parameters and chemical formula (T.S. Ercit, pers. comm., 1995). These preliminary results also indicate that cesbronite is most likely a tellurate. We have also assumed that all As is present as As^{5+}. All the As-bearing secondary minerals found at the Centennial Eureka mine which had their crystal structures determined in recent years are arsenates (Marty *et al.*, 1993).

The average result of three analyses gave CuO 38.25 (range 38.11–38.48), PbO 0.57 (range 0.41–0.74), TeO_3 32.58 (range 32.44–32.75), As_2O_5 22.81 (range 22.48–23.04), H_2O [5.19] (calculated assuming $3H_2O$), total [99.40] wt.%. With O = 19, the empirical formula is $(Cu_{5.01}Pb_{0.03})_{\Sigma 5.04}(Te^{6+}O_4)_{1.93}(As^{5+}O_4)_{2.07}\cdot 3H_2O$. The ideal formula, $Cu_5(Te^{6+}O_4)_2(As^{5+}O_4)_2\cdot 3H_2O$ requires CuO 38.51, TeO_3 34.00, As_2O_5 22.25, H_2O 5.23, total 100.00 wt.%. The density, calculated for the ideal formula and Z = 2, is 4.59 g/cm^3. There are no other Cu-tellurate-arsenate-hydrate compounds known to occur naturally or known from synthetic studies.

Optical properties

In polished section, the fragment of juabite is approximately 0.5 mm × 0.2 mm in size. It consists of a cluster of radiating fibres and only small areas (30–50 μm) of the plane surface were polishable (and these with difficulty).

In plane-polarised reflected light at high magnification, the polished surface of the mineral appears white by comparison with the low reflecting plastic and the unpolished mineral. The fibrous nature of the mineral is evident, with brownish white fibres alternating with fibres that are bluish from internal

TABLE 1. X-ray powder data for juabite

$I_{est.}$	d Å$_{(meas.)}$	d Å$_{(calc.)}$	*hkl*	$I_{est.}$	d Å$_{(meas.)}$	d Å$_{(calc.)}$	*hkl*
70	9.28	9.270	010	* 15	2.297	2.292	232
20	8.46	8.461	100	3	2.214	2.214	$34\bar{1}$
10	7.61	7.648	110	* 10	2.194	2.192	$11\bar{4}$
10	5.99	5.984	$\bar{1}01$	* 5	2.168	2.167	$12\bar{4}$
5	4.94	4.945	$\bar{1}1\bar{1}$	5	2.146	2.152	411
5	4.80	4.795	120			2.142	$\bar{1}1\bar{4}$
70	4.65	4.635	020	20	2.033	2.041	$\bar{4}01$
20	4.35	4.376	002			2.034	$\bar{1}4\bar{2}$
		4.326	$\bar{1}11$			2.030	$\bar{2}31$
* 10	4.22	4.231	200			2.025	114
25	4.08	4.083	$21\bar{1}$			2.020	$21\bar{4}$
		4.070	$11\bar{2}$	20	2.000	2.003	$03\bar{4}$
* 10	3.879	3.881	121			2.001	$41\bar{2}$
* 10	3.758	3.760	$\bar{2}01$	* 25b	1.938	1.940	242
20b	3.601	3.626	$12\bar{2}$	* 30	1.855	1.854	050
		3.597	$02\bar{2}$	25b	1.820	1.822	151
		3.591	$\bar{1}20$			1.820	$15\bar{3}$
		3.574	112			1.814	$25\bar{3}$
* 5	3.443	3.440	$\bar{2}10$			1.813	$24\bar{4}$
10b	3.293	3.315	$13\bar{1}$	50	1.740	1.743	$\bar{1}1\bar{5}$
		3.276	130			1.741	521
100	3.097	3.090	030			1.734	$\bar{1}5\bar{1}$
		3.090	$\bar{2}11$	* 5	1.717	1.718	$\bar{3}31$
* 60	3.018	3.017	212	* 10	1.687	1.688	531
* 40	2.869	2.872	$11\bar{3}$	3	1.668	1.672	501
* 40	2.814	2.815	$32\bar{1}$	10	1.650	1.650	$15\bar{4}$
* 40	2.759	2.758	$12\bar{3}$			1.648	043
* 50	2.658	2.659	$\bar{3}01$	20b	1.614	1.617	$42\bar{4}$
3	2.580	2.573	$\bar{2}12$			1.612	$43\bar{4}$
* 5	2.553	2.552	$33\bar{1}$	3	1.572	1.575	$41\bar{4}$
3	2.510	2.510	$31\bar{2}$			1.571	$16\bar{3}$
* 50	2.468	2.472	$\bar{2}2\bar{2}$	3	1.561	1.564	$53\bar{3}$
* 25	2.423	2.422	$\bar{1}13$	40	1.547	1.548	414
15	2.324	2.331	$\bar{3}11$			1.545	060
		2.313	$24\bar{2}$				

114.6 mm Debye-Scherrer powder camera; Cu radiation, Ni filter (λ Cu-$K\alpha$ = 1.54178 Å)
Intensities estimated visually; b = broad line
Not corrected for shrinkage and no internal standard; * = lines used for unit-cell refinement
Indexed with a = 8.984, b = 10.079, c = 8.975 Å, α = 102.68°, β 92.45°, γ = 70.45°

reflection. Between crossed polars, the mineral appears to be entirely coloured by turquoise-blue internal reflections. When immersed in oil, in plane-polarised light, the polished surface appears as an incoherent intergrowth of fawn to brown micro-crystallites and blue, internally reflecting, micro-crystallites. The colours noted between crossed polars in air are similarly enhanced in oil: here, the bundle of crystallites produces a luminous blue-green colour reminiscent of that of a morph butterfly wing, and probably caused, in part, by constructive interference.

From these descriptions, it should be evident why the accuracy of reflectance measurements would be impaired: internal reflections and interference effects would contribute an unwanted component of diffuse reflectance to the specular reflectance. In air, this could have a significant effect on the reflectances and

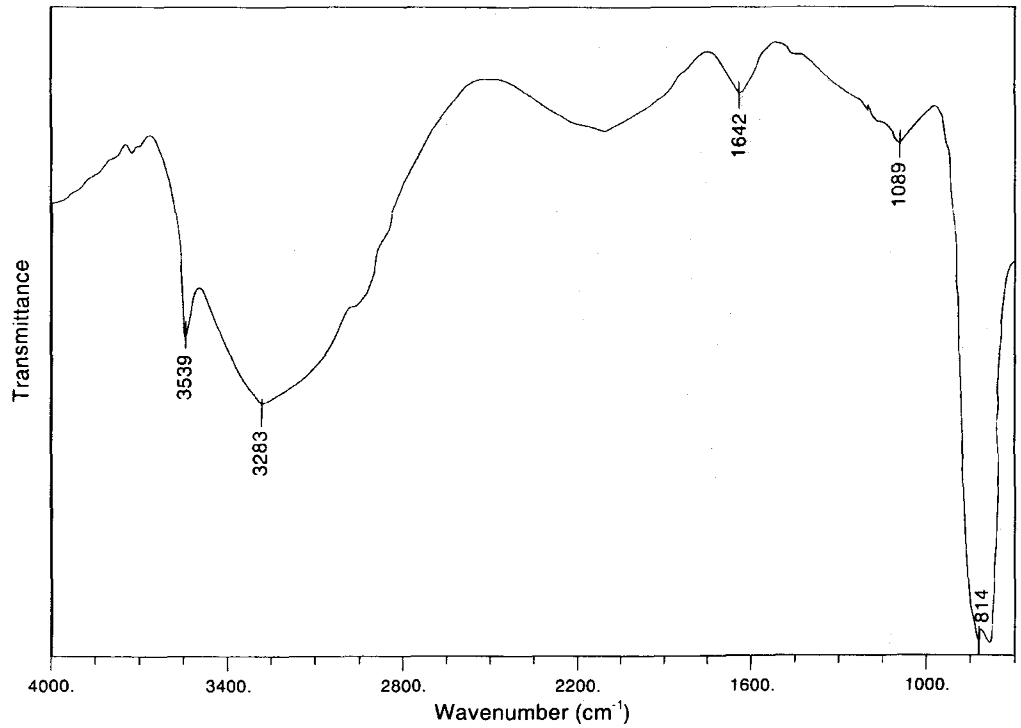

FIG. 2. Infrared-absorption spectrum for juabite.

on the refractive indices derived from them; in oil, this effect would be greater still. Measurements were attempted, however, with a Zeiss MPM 800 microscope spectrophotometer and with SiC (Zeiss no. 472) and cubic zirconia reflectance standards. These spectral reflectances have not been reported since, for the reasons noted above, we feel that they serve no useful purpose. The reflectances at 590 nm are 6.79 and 7.10 and the corresponding refractive indices (assuming zero absorption coefficients) are 1.71–1.73. As anticipated, the refractive indices derived from measurement in oil immersion (and their intrinsic errors) were much higher.

Infrared-absorption study

The equipment and procedures for acquiring the infrared-absorption spectrum for juabite are identical to those used to obtain the spectrum for mcalpineite (Roberts *et al.*, 1994) and need not be repeated here. The spectrum (Fig. 2) clearly shows absorption bands for structural H_2O. A very strong, broad absorption, which peaks at 3283 cm^{-1}, is due to O-H stretching and a medium weak absorption, which peaks at 1642 cm^{-1}, is due to H-O-H bending in the H_2O molecules.

Acknowledgements

The authors thank A. Tsai (GSC) for the scanning electron photomicrograph reproduced in Figure 1 and P. O'Regan (GSC) for redrafting Figure 2.

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[*Manuscript received 22 May 1996*]