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JENSENITE, $Cu_3Te^{6+}O_6{\cdot}2H_2O$, A NEW MINERAL SPECIES FROM THE CENTENNIAL EUREKA MINE, TINTIC DISTRICT, JUAB COUNTY, UTAH[1]

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ABSTRACT

Jensenite, ideally $Cu_3Te^{6+}O_6{\cdot}2H_2O$, is monoclinic, $P2_1/n$ (14), with unit-cell parameters refined from powder data: a 9.204(2), b 9.170(2), c 7.584(1) Å, β 102.32(3)°, V 625.3(3) Å^3, a:b:c 1.0037:1:0.8270, $Z = 4$. The strongest six reflections of the X-ray powder-diffraction pattern [d in Å(I)(hkl)] are: 6.428(100)($\bar{1}01$,110), 3.217(70)($\bar{2}02$), 2.601(40)(202), 2.530(50)(230), 2.144(35)($\bar{3}31$) and 1.750(35)($\bar{4}32$). The mineral is found on the dumps of the Centennial Eureka mine, Juab County, Utah, where it occurs as isolated crystals or as groups of crystals on drusy white quartz. Associated minerals are mcalpineite, xocomecatlite and unnamed $Cu(Mg,Cu,Fe,Zn)_2Te^{6+}O_6{\cdot}6H_2O$. Individual crystals of jensenite are subhedral to euhedral, and form simple rhombs that are nearly equant. Some crystals are slightly elongate [101], with a length-to-width ratio up to 2:1. The largest crystal is approximately 0.4 mm in size; the average size is between 0.1 and 0.2 mm. Cleavage {$\bar{1}01$} fair. Forms are: {$\bar{1}01$} major; {110} medium; {100} minor; {301}, {201}, {203}, {$\bar{1}02$}, {010} very small. The mineral is transparent, emerald green, with a less intense streak of the same color and an uneven fracture. Jensenite is adamantine, brittle and nonfluorescent; H (Mohs) 3–4; D (calc.) 4.78 for the idealized formula, 4.76 g/cm^3 for the empirical formula. In a polished section, jensenite is very weakly bireflectant and nonpleochroic. In reflected plane-polarized light in air, it is a nondescript grey, and in oil, it is a much darker grey in color with a brownish tint, with ubiquitous bright green internal reflections. Anisotropy is not detectable. Measured values of reflectance, in air and in oil, are tabulated. Electron-microprobe analyses yielded CuO 50.91, ZnO 0.31, TeO_3 38.91, H_2O (calc.) [8.00], total [98.13] wt.%. The empirical formula, derived from crystal-structure analysis and electron-microprobe analyses, is $(Cu_{2.92}Zn_{0.02})_{\Sigma 2.94}Te^{6+}_{1.01}O_{5.97}{\cdot}2.03H_2O$, based on O = 8. The mineral name honors Martin C. Jensen, Reno, Nevada, who discovered the mineral.

Keywords: jensenite, new mineral species, tricopper tellurate dihydrate, X-ray data, electron-microprobe data, reflectance data, Centennial Eureka mine, Juab County, Utah.

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SOMMAIRE

La jensenite, de composition idéale $Cu_3Te^{6+}O_6{\cdot}2H_2O$, est monoclinique, $P2_1/n$ (14), et possède les paramètres réticulaires suivants, affinés à partir des données de diffraction X obtenues sur poudre: a 9.204(2), b 9.170(2), c 7.584(1) Å, β 102.32(3)°, V 625.3(3) Å^3, $a{:}b{:}c$ 1.0037:1:0.8270, $Z = 4$. Les six raies les plus intenses du cliché de diffraction X [d en Å(I)(hkl)] sont: 6.428(100)($\bar{1}$01,110), 3.217(70)($\bar{2}$02), 2.601(40)(202), 2.530(50)(230), 2.144(35)($\bar{3}$31) et 1.750(35)($\bar{4}$32). La jensenite a été découverte sur les amas de rebus à la mine Centennial Eureka, dans le comté de Juab, au Utah, et se présente en cristaux isolés ou en groupes de cristaux sur du quartz laiteux tapissant une cavité. Lui sont associés mcalpinéite, xocomecatlite, et un minéral sans nom, $Cu(Mg,Cu,Fe,Zn)_2Te^{6+}O_6{\cdot}6H_2O$. Les cristaux individuels sont subidiomorphes à idiomorphes, et se présentent en rhomboèdres simples presque équidimensionnels. Certains cristaux sont légèrement allongés selon [101], avec un rapport de longueur à largeur de 2:1. La taille maximale est de 0.4 mm, mais les cristaux sont entre 0.1 et 0.2 mm, en général. Le clivage {$\bar{1}$01} est convenable; les formes sont: {$\bar{1}$01} majeur, {110} moyen, {100} mineur, et {301}, {201}, {203}, {$\bar{1}$02}, {010} minuscules. Le minéral est transparent, vert émeraude, avec une rayure de la même couleur mais moins intense. La cassure est inégale et l'éclat, adamantin. La jensenite est cassante et non fluorescente. La dureté de Mohs est entre 3 et 4. La densité calculée est 4.78 pour la formule idéale, et 4.76 pour la formule empirique. Dans une section polie, la jensenite est très faiblement biréflectante et non pléochroïque. Dans la lumière réfléchie polarisée, dans l'air, elle est gris ordinaire, et dans l'huile, elle devient beaucoup plus foncée avec un tein brunâtre et de multiples réflexions internes vert brillant. Nous ne décelons aucune anisotropie. Nous documentons la réflectance, dans l'air et dans l'huile. Les analyses à la microsonde électronique ont donné CuO 50.91, ZnO 0.31, TeO_3 38.91, H_2O (calc.) [8.00], total [98.13]% (poids). La formule empirique, dérivée des résultats d'une analyse de la structure cristalline et d'analyses chimiques à la microsonde électronique, est $(Cu_{2.92}Zn_{0.02})_{\Sigma 2.94}Te^{6+}_{1.01}O_{5.97}{\cdot}2.03H_2O$ pour huit atomes d'oxygène. Le minéral honore Martin C. Jensen, de Reno, Nevada, qui en fait la découverte.

(Traduit par la Rédaction)

Mots-clés: jensenite, nouvelle espèce minérale, tellurate bihydraté de cuivre, données de diffraction X, données de microsonde électronique, données de réflectance, mine Centennial Eureka, comté de Juab, Utah.

INTRODUCTION

Jensenite, ideally $Cu_3Te^{6+}O_6{\cdot}2H_2O$, is a newly recognized mineral species that was first encountered during megascopic examination, scanning electron energy-dispersion study and routine X-ray powder-diffraction characterization of a suite of secondary Cu- and Te-bearing minerals. This suite of samples was collected in July 1992 from the mineralized dumps adjacent to the Centennial Eureka mine, Tintic district, Juab County, Utah. This mineral is the third of at least eight new secondary Cu- and Te-bearing phases that will eventually be characterized; it was given the designation "unknown no. 2" in Marty *et al.* (1993), who described the primary and secondary minerals found at the Centennial Eureka mine.

The mineral is named *jensenite* in honor of Mr. Martin C. Jensen (1959–) of Reno, Nevada, who first collected and subsequently recognized this species as potential new mineral. Mr. Jensen, an avid mineral collector and noted scanning electron-microprobe specialist, has coordinated numerous mineralogical studies of mines and prospects throughout the western United States, in particular Utah and Nevada. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, I.M.A. Holotype material, consisting of four specimens and eleven single-crystal mounts, is housed in the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada, Ottawa, Ontario under catalogue number NMC 67424.

OCCURRENCE AND ASSOCIATED MINERALS

Jensenite has been identified on at least twelve specimens collected from the dumps of the Centennial Eureka mine, Tintic district, Juab County, Utah (lat. 39°56′38″N, long. 112°7′18″W). This copper, gold and silver property, worked primarily from 1876 to 1927, was formerly 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 mineralized samples were exposed, including several boulders that contain the new Cu- and Te-bearing assemblages. Jensenite was observed in several of these boulders, but must be considered very rare; only about 10 mg of the mineral is presently known. On the holotype material, the mineral is found as isolated crystals or groups of crystals that are perched on drusy white to colorless quartz. Associated minerals are thin lime-green stains and dark green-black microspherules of mcalpineite (Roberts *et al.* 1994), green nodules of xocomecatlite and pale yellow transparent hexagonal plates of unnamed $Cu(Mg,Cu,Fe,Zn)_2Te^{6+}O_6{\cdot}6H_2O$ (designated as UKCE–10). Additional Cu- and Te-bearing secondary minerals that have been identified by X-ray powder-diffraction methods on similar specimens include cesbronite, frankhawthorneite (Roberts *et al.* 1995, Grice & Roberts 1995), dugganite, quetzalcoatlite and four additional unnamed Cu- and Te-bearing phases currently under investigation.

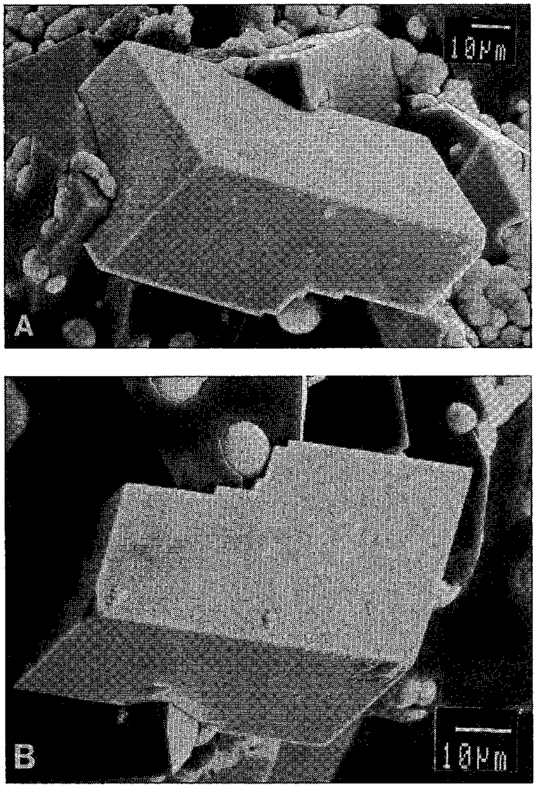
Additional information regarding the geology and mineralogy of the Centennial Eureka mine can be found in Marty *et al.* (1993). Jensenite is a secondary mineral that formed from the breakdown of primary Cu- and Te-bearing sulfides.

PHYSICAL PROPERTIES

Jensenite crystals are emerald green and transparent; the streak is the same color but less intense relative to the uncrushed material. The mineral is brittle, possesses an uneven fracture and an adamantine luster, and is nonfluorescent under both long- and short-wave ultraviolet radiation. The density could not be measured owing to the size of available specimens and dearth of material. The calculated density based on the empirical formula is 4.76 g/cm^3; that based on the idealized formula is 4.78 g/cm^3. The Mohs hardness is estimated to be 3–4.

CRYSTAL MORPHOLOGY

Jensenite occurs on drusy quartz as isolated single crystals or as groupings of several crystals. Individual crystals are subhedral to euhedral, and consist of simple rhombs that are nearly equant. Some crystals are slightly elongate [101], with a length-to-width ratio up to 2:1. There is a fair $\{\bar{1}01\}$ cleavage. SEM photomicrographs of several individual crystals, scattered on quartz and associated with mcalpineite, are presented in Figures 1A and 1B. The largest known crystal is approximately 0.4 mm in longest dimension, but the average size of the crystals is between 0.1 and 0.2 mm. The observed forms, measured with a two-circle optical goniometer and supported by X-ray single-crystal studies, are: major $\{\bar{1}01\}$ (orthopinacoid); medium {110} (prism); minor {100}; very small {301}, {201}, {203}, $\{\bar{1}02\}$, and {010}. Interestingly, the forms {100}, {301}, and $\{\bar{1}02\}$ all give a blue-colored signal on the goniometer; the reason for this is unclear at this time. Twinning was not found in X-ray single-crystal studies; however, megascopic examination of jensenite *in situ* on mineral specimens shows some interpenetrating crystals that may possess a twin plane.



FIGS. 1A, B. SEM photomicrographs of nearly euhedral crystals of jensenite showing well-developed $\{\bar{1}01\}$ and {110} forms. Associated minerals are mcalpineite (spherules) and quartz (matrix). Scale bars: 10 µm.

X-RAY CRYSTALLOGRAPHY

Two crystals of jensenite were examined by single-crystal precession methods employing Zr-filtered Mo radiation. One was mounted such that $\bar{1}01^*$, and the other such that 101*, is parallel to the dial axis. Precession films indicate monoclinic symmetry, and systematic absences ($h0l$ with $h + l \neq 2n$ and $0k0$ with $k \neq 2n$) dictate that the space group is uniquely determined as $P2_1/n$ (14). Crystal-structure analysis (Grice *et al.* 1996) has confirmed that this is the correct space-group. The refined unit-cell parameters, a 9.204(2), b 9.170(2), c 7.584(1) Å, β 102.32(3)°, V 625.3(3) Å^3, $a{:}b{:}c$ = 1.0037:1:0.8270, and Z = 4, are based on the d values of 24 X-ray powder lines between 3.896 and 1.317 Å for which unambiguous indexing was possible, based on visual inspection of precession single-crystal films. All reflections down to 1.28 Å were visually examined on the precession films. A fully indexed powder pattern is presented in Table 1. The powder data are unique and bear no resemblance to any other inorganic or mineral phase listed in the Powder Diffraction File.

OPTICAL PROPERTIES

The polished section previously used for electron-microprobe analyses was buffed with a slurry of aluminum oxide in distilled water on Pellon cloth to expose the fragment of jensenite for optical investigation. This fragment turned out to be fractured; the largest individual fragment is 20 µm in maximum dimension.

In polished section, the mineral is very weakly bireflectant and nonpleochroic. In plane-polarized reflected light, jensenite is a nondescript grey, but is a

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

*I*est.	*d*Åmeas.	*d*Åcalc.	*hkl*
100	6.428	6.431	$\bar{1}01$
		6.420	110
10	5.763	5.763	011
3	5.293	5.265	$\bar{1}11$
30	4.523	4.523	111
10b	4.058	4.085	120
		4.037	210
10	3.896	3.899	021
20	3.738	3.733	$\bar{1}21$
5	3.443	3.444	$\bar{1}12$
		3.439	121
70	3.217	3.216	$\bar{2}02$
5	3.129	3.124	$\bar{2}21$
5	3.028	3.034	$\bar{2}12$
		3.016	112
10b	2.878	2.894	130
		2.887	$\bar{1}22$
		2.882	022
		2.861	$\bar{3}11$
15	2.639	2.635	131
40	2.601	2.600	202
50	2.530	2.528	230
10	2.434	2.433	$\bar{1}13$
30	2.357	2.358	032
30	2.257	2.262	222
		2.248	400
3	2.219	2.221	140
3	2.191	2.190	041
35	2.144	2.145	$\bar{3}31$
5	2.028	2.028	123
3	1.985	1.986	411
20	1.946	1.946	$\bar{1}33$
30	1.853	1.852	004
3	1.779	1.780	051
35	1.750	1.750	$\bar{4}32$
5	1.720	1.722	$\bar{2}24$
*5	1.702	1.703	313
3b	1.638	1.641	511
		1.636	$\bar{3}24$
20	1.609	1.608	$\bar{4}04$
20	1.588	1.588	$\bar{2}34$
5	1.564	1.566	$\bar{3}43$
		1.562	$\bar{4}42$
30	1.527	1.528	060
		1.527	432
20	1.507	1.508	333
		1.506	$\bar{6}02$
15	1.487	1.487	$\bar{1}61$
10	1.463	1.464	531
15	1.436	1.437	$\bar{5}33$
15	1.416	1.415	234
3	1.399	1.398	115
10	1.381	1.380	$\bar{2}62$
15	1.346	1.346	630
25	1.317	1.317	262

114.6 mm Debye–Scherrer powder camera employing Ni–filtered Cu radiation (λCu *K*α = 1.54178 Å). Intensities estimated visually; b = broad line. Not corrected for shrinkage and no internal standard used. Indexed on *a* 9.204, *b* 9.170, *c* 7.584 Å, *ß* 102.32°.

much darker grey, though with a brownish tint, if immersed in oil (N_D = 1.515). Bright green internal reflections occur at the grain boundaries. These "flood" the mineral, when it is observed between crossed polars, and effectively mask any anisotropy (if, indeed, it is present). Qualitatively, it would be very difficult to distinguish jensenite from another recently described copper tellurate, mcalpineite (Roberts *et al.* 1994).

TABLE 2. REFLECTANCE DATA AND COLOR VALUES FOR JENSENITE

λnm	R_1	R_2	$^{im}R_1$	$^{im}R_2$	λnm	R_1	R_2	$^{im}R_1$	$^{im}R_2$
400	—	—	—	—	560	10.15	10.3	1.59	1.80
420	11.0	11.3	—	—	580	9.9	10.0	1.51	1.68
440	10.8	11.2	—	—	589	9.8	9.9	1.47	1.62
460	10.7	11.1	1.71	1.93	600	9.6	9.8	1.40	1.55
470	10.7	11.0	1.67	1.95	620	9.4	9.6	1.31	1.41
480	10.7	11.0	1.72	1.99	640	9.25	9.4	1.24	1.28
500	10.7	10.8	1.69	1.97	650	9.15	9.4	1.23	1.30
520	10.6	10.7	1.68	1.97	660	9.15	9.3	1.23	1.30
540	10.4	10.5	1.65	1.90	680	9.0	9.2	1.21	1.28
546	10.4	10.4	1.63	1.88	700	9.1	9.2	1.22	1.27

Color Values

	CIE Illuminant A:					CIE Illuminant C:			
x	0.435	0.436	0.423	0.418	*x*	0.299	0.298	0.290	0.287
y	0.408	0.406	0.412	0.416	*y*	0.311	0.308	0.310	0.314
Y%	10.0	10.1	1.51	1.70	*Y*%	10.1	10.3	1.56	1.77
λ_d	496	491	498	500	λ_d	485	482	487	490
P_e%	2.9	2.9	5.6	6.8	P_e%	4.6	5.2	8.0	8.9

for ^{im}R, N_D 1.515

The largest area of jensenite was used for a measurement of reflectance; the procedures and equipment used were as described by Criddle *et al.* (1983). The ×40 dry and immersion objectives (adjusted to provide effective numerical apertures of 0.26) were found to provide insufficient flux of reflected light for reliable measurement at lower wavelengths, and hence the tabulated data (Table 2) omit air and oil reflectances at 400 nm and oil reflectances at 420 and 440 nm. Application of the procedures recommended by Embrey & Criddle (1978) for the evaluation of the reliability of measured reflectance data proves that the values measured in oil, particularly those for $^{im}R_2$, are the least reliable of the four data-sets, and that this is a consequence of an unavoidable contribution from internal reflections (as a diffuse component) to the specular reflectance of the mineral. Jensenite is close to being optically isotropic; however, small but measurable differences, dependent on optical orientation, were detected photometrically, thus conforming with its monoclinic symmetry. The reflectance spectra are compared with those of mcalpineite (from which it differs appreciably) in Figure 2. The indices of refraction of jensenite, calculated from the more reliable reflectances in air at 590 nm (assuming k = 0) are 1.91–1.92 (those incorporating the oil reflectances in the Koenigsberger equations are 1.87–1.89, yet another indication that the values in oil are somewhat suspect).

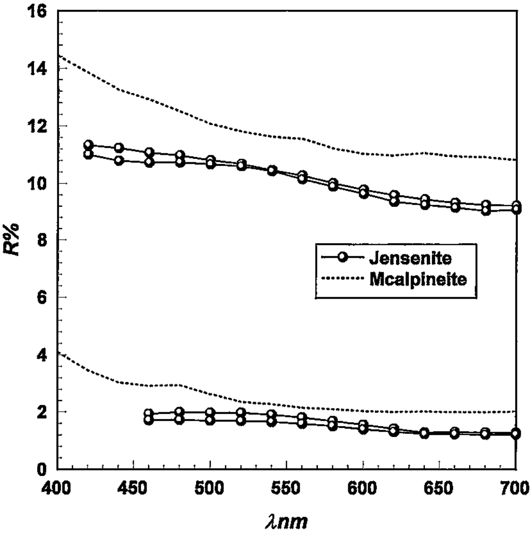


FIG. 2. Reflectance spectra of jensenite measured in air and in oil (N_D = 1.515) and compared with mcalpineite.

CHEMISTRY

Crystals of jensenite were analyzed 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 conditions were as follows: operating voltage 15 kV, beam current 20 nA, and beam 20 μm in diameter. Data for the sample were collected for 25 seconds or 0.50% precision, whichever was obtained first, and for the standards, 50 seconds or 0.25% precision, whichever was obtained first. A 100-second energy-dispersion scan indicated that no elements with $Z > 8$ other than those reported here are present. The following standards were employed: natural cuprite (Cu*K*α), synthetic $ZnSeO_3$ (Zn*L*α) and synthetic $Fe^{3+}Te_2O_5(OH)$ (mackayite) (Te*L*α). The valence states for both Cu and Te, as well as the number of O atoms, were determined by crystal-structure analysis (Grice *et al.* 1996) prior to final interpretation of the electron-microprobe results. The paucity of pure uncontaminated material prevented the quantitative determination of H_2O by classical methods. However, its presence as bonded H_2O was confirmed by both crystal-structure analysis and a powder infrared-absorption study; the formula was therefore calculated to give $2H_2O$. The average result of two analyses gave CuO 50.91 (range 50.89–50.92), ZnO 0.31 (range 0.31–0.31), TeO_3 38.91 (range 38.90–38.91), H_2O [8.00], total [98.13] wt.%. With O = 8, the empirical formula for this tricopper tellurate dihydrate is $(Cu_{2.92}Zn_{0.02})_{\Sigma 2.94}Te^{6+}_{1.01}O_{5.97}\cdot 2.03H_2O$. The ideal formula, $Cu_3Te^{6+}O_6\cdot 2H_2O$, requires CuO 53.00, TeO_3 39.00, H_2O 8.00, total 100.00 wt.%. This is yet another example of the use of crystal-structure analysis in order to determine the precise chemical formula of a complex mineral species (Hawthorne & Grice 1990).

The Gladstone–Dale constants of Mandarino (1981) and the oxide proportions determined from the electron-microprobe data and from the crystal structure lead to K_C values of 0.185 and 0.184, respectively. K_P, calculated using the average index of refraction, 1.92, and the calculated density derived from the empirical formula, is 0.194; for the same average index of refraction and the calculated density derived from the idealized formula, K_P is 0.192. The compatibility index is –0.048 for the empirical formula and –0.043 for the idealized formula, indicating good compatibility (Mandarino 1981) between the physical and chemical data.

INFRARED SPECTROSCOPY

The infrared spectrum of jensenite was obtained using a Spectra-Tech IR-Plan infrared microscope interfaced to a Bomem Michelson MB–120 Fourier-transform infrared spectrometer, which utilizes a 0.25 mm liquid-nitrogen-cooled mercury cadmium telluride detector. A small amount of the pure mineral was mounted in a diamond-anvil microsample cell,

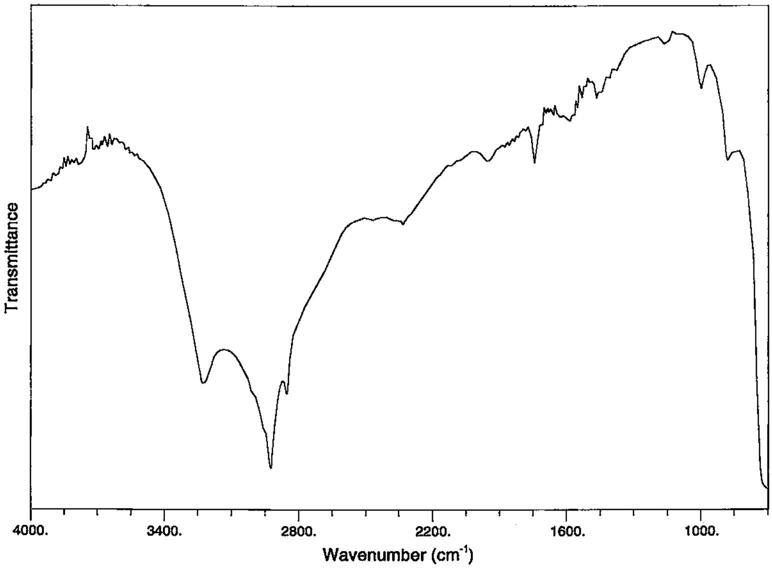


FIG. 3. Infrared-absorption spectrum of jensenite.

then pressure was applied to crush the mineral and cause it to spread as a randomly oriented powder; after crushing, the pressure was released. The diamond cell was then positioned in the microscope accessory, and the powdered sample masked, so as to isolate a circular area measuring 100 μm in diameter and between 1 and 5 μm in uniform thickness. Two hundred scans were collected and co-added at 4 cm^{-1} resolution, from 700 to 4000 cm^{-1}. The transmittance spectrum (Fig. 3) was produced by taking the ratio of the single-beam spectrum of the specimen in the diamond-anvil cell against a single-beam spectrum of the empty diamond anvil cell collected with the same parameters. The spectrum shows a major band, centered on 3220 cm^{-1}, which is due to O–H stretching and confirms the presence of structurally bound H_2O. The rather sharp peaks at 2928 and 2857 cm^{-1}, and probably the peak at 1742 cm^{-1}, are most likely aliphatic C–H stretching vibrations due to a contaminant such as grease. Grease was used on the tip of a needle to facilitate transfer of the very small grains to the diamond-anvil microsample cell.

RELATIONSHIP TO KNOWN SPECIES

Jensenite is the second confirmed copper tellurate hydrate known in nature. The first is mcalpineite, $Cu_3TeO_6{\cdot}H_2O$ (Roberts *et al.* 1994). There are no hydrated synthetic compounds listed in the Powder Diffraction File.

Xocomecatlite, $Cu_3Te^{6+}O_4(OH)_4$, originally described by Williams (1975), has the same Cu:Te ratio and the same number of O atoms. The possibility certainly exists that jensenite and xocomecatlite are polymorphs. Unfortunately, this cannot be determined at present; neither the type locality, the Bambollita mine, Moctezuma, Sonora, Mexico, nor the Centennial Eureka mine provide xocomecatlite material that is suitable for crystal-structure analysis.

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