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Xocomecatlite, $Cu_3TeO_4(OH)_4$, and tlalocite, $Cu_{10}Zn_6(TeO_3)(TeO_4)_2Cl(OH)_{25}\cdot 27H_2O$, two new minerals from Moctezuma, Sonora, Mexico

S. A. WILLIAMS

Phelps Dodge Corporation, Douglas, Arizona, U.S.A.

SUMMARY. Xocomecatlite and tlalocite were found at the Bambollita mine near Moctezuma, Sonora. Xocomecatlite is probably orthorhombic, and an indexed cell based on the powder data gave *a* 12·140 Å, *b* 14·318, *c* 11·662. Based on this cell, the empirical contents are $Cu_{36\cdot6}\,Zn_{1\cdot7}\,(TeO_4)_{12\cdot5}\,(OH)_{51\cdot6}$ or $Cu_3TeO_4(OH)_4$. Tellurate was found both microchemically and by spectrophotometry. Colour rich green (R.H.S. 132A) with pale streak, H = 4. Optically negative with $\alpha = 1\cdot775$, $\beta = 1\cdot900$, $\gamma = 1\cdot920$. G = 4·65.

Tlalocite is optically orthorhombic but the cell could not be indexed; only powder data are presented. Chemical analysis showed both tellurite and tellurate and led to the formula

$$Cu_{10}Zn_6(TeO_3)(TeO_4)_2Cl(OH)_{25}\cdot 27H_2O.$$

Colour pale blue (R.H.S. 121A) with a whitish streak; H = 1, gummy and sectile. G = 4·55.

Plotting stability fields for various Te species at 25 °C in terms of Eh and pH showed that $TeO_4^{2-}\cdot aq$ can exist in nature over a wide pH range, but only under extreme conditions of oxidation.

Xocomecatlite

Occurrence. Xocomecatlite was discovered in samples collected underground in the Bambollita Mine (La Oriental) by Peter Embrey and Pierre Bariand. Specimens containing this new species were found only in one drift, and it is such material that also provided carlfriesite and cesbronite. Xocomecatlite occurs on altered rhyolite adjacent to oxidized vein matter, or in the vein material (quartz–barite–altered-sulphides) as a late oxide-zone mineral.

Physical properties. Xocomecatlite occurs as isolated or clustered spherules that seldom exceed 0·15 mm in diameter. These spherules are composed of radially disposed needles that seldom attain 5 μm in width, and individual crystals are unknown. The colour is a rich green, near emerald green, and the best match is R.H.S. 132A. For such a rich colour, the streak is a remarkably pale green, almost white. The Mohs hardness is 4 and spherules are tough and brittle. No fluorescence was observed in short or long wavelength U.V. The specific gravity was determined by sink-float methods in Clerici solution at 23·0 °C as 4·65±0·1; the spherules used behaved identically to stibnite (measured 4·65).

Chemistry. Microchemical, spectrographic, and qualitative electron-probe examination indicated only major Cu and Te with minor Zn and trace Fe and Ag. Microchemical testing also gave a strong positive reaction for tellurate ion.

Copper and zinc were determined in 1:1 HNO_3 by atomic absorption. Tellurium was determined by dissolving the mineral in 1:1 HNO_3 and evaporating to dryness. Upon cooling, the residue was taken up in 3*N* HBr and read spectrophotometrically at 440 nm and scanned from 540 to 400 nm to correct for Cu interference; in this case no Te was found since the peak at 440 nm is due to Te^{iv}. Heating the HBr solution to dryness reduced Te^{vi} to Te^{iv}. The residue was again dissolved in 3*N* HBr and run as before at 440 nm for total tellurium.

TABLE I. *Chemical analyses of xocomecatlite and tlalocite*

	1	2		3		4	5		6
CuO	51·3	53·0	Cu^{2+}	36·6	CuO	31·0	31·4	Cu^{2+}	0·390
ZnO	2·4	—	Zn^{2+}	1·7	ZnO	19·3	19·3	Zn^{2+}	0·237
TeO_2	nil	—	TeO_4^{2-}	12·5	TeO_2	6·1	6·3	TeO_3^{2-}	0·033
TeO_3	38·7	39·0	OH^-	51·6	TeO_3	15·0	13·8	TeO_4^{2-}	0·074
H_2O	8·0	8·0			Cl	1·3	1·4	Cl^-	0·037
	100·4	100·0			H_2O	27·7	28·1	OH^-	0·251
						100·4	100·3	H_2O	1·129
					Less				
					O Cl	0·3	0·3		
						100·1	100·0		

1. Xocomecatlite. CuO and TeO_3 on 348 μg, ZnO on 73 μg and 259 μg, H_2O on 645 μg, all corrected for 12·4 % insolubles. Anal. Miss M. Duggan. Methods see text.
2. Theory for $Cu_3TeO_4(OH)_4$.
3. Empirical unit-cell contents of xocomecatlite.
4. Tlalocite. CuO and ZnO on 87 μg, TeO_2 and TeO_3 on 123 μg, Cl on 272 μg, H_2O on 174 μg. Anal. Miss M. Duggan. Methods see text.
5. Theory for $Cu_{10}Zn_6TeO_3(TeO_4)_2Cl(OH)_{25}\cdot27H_2O$.
6. Ionic ratios for tlalocite.

Results of the analysis, shown in Table I, give empirical cell contents

$$Cu_{36\cdot6}Zn_{1\cdot7}(TeO_4)_{12\cdot5}(OH)_{51\cdot6} \text{ or } Cu_3TeO_4(OH)_4.$$

Optics. Xocomecatlite is a rich green in thin section and resembles pseudomalachite. It occurs invariably in spherules showing a radial fibrous structure but individual crystallites are much too small to extend from the centre to the rim. They occur in subparallel bunches that are intertwined and twisted, and individual crystals are lath shaped, averaging about $1\times4\times7$ μm in size. The acute bisectrix (α) is normal to the largest dimensions; γ is sensibly parallel to their length. Since crystals are so minute and intertwined the spherules never extinguish.

Indices of refraction for the D line are: α 1·775, β 1·900, γ 1·920 (all ±0·005) so that $2V_\alpha = 41°$ (calc.). Dispersion is evidently quite low. Pleochrosim is in rich bluish greens with $\gamma > \alpha = \beta$.

Crystallography. The crystallography of xocomecatlite is not known, although it may be inferred from the optics as probably orthorhombic. No single crystal suitable for X-ray study was found and X-ray examination was confined to the powder method. Powder patterns give relatively diffuse lines and are simple. Attempts at indexing finally led to a possible cell with a 12·140±0·06 Å, b 14·318±0·10, c 11·662±0·06. An indexed pattern is presented in Table II. Using this imaginary cell, the calculated density is 4·42 g/cm^3 if $Z = 12$.

TABLE II. *Indexed powder pattern for xocomecatlite*, Cr-$K\alpha$ *radiation, 114 mm Straumanis camera*

I	d_{meas}	d_{calc}	hkl	I	d_{meas}	d_{calc}	hkl	I	d_{meas}
1	5·858	5·831	002	—	—	3·083	240	1	2·206
2	5·311	5·256	102	2	2·955	2·959	142	1	2·170
—	—	5·384	201	3	2·831	2·835	104	2	2·120
10	4·627	4·630	220	2	2·725	2·726	242	2	2·103
1	4·326	4·303	221	—	—	2·728	332	3	2·075
1	4·146	4·151	131	6	2·673	2·681	340	1	1·856
2	3·896	3·894	310	3	2·628	2·633	043	2b	1·577
2	3·568	3·572	231	—	—	2·628	204	2	1·538
4	3·439	3·433	140	4b	2·434	2·437	134	2	1·510
3	3·320	3·325	302	—	—	2·436	342		
1	3·236	3·238	312	3	2·314	2·315	440		
4	3·099	3·087	330						

Miscellany. About two dozen pieces containing xocomecatlite were found during the first visit and upon a subsequent one. These represent probably no more than 100 mg of the mineral. Type specimens will be provided to the British Museum (Natural History) and the University of Paris.

The species is named in allusion to its resemblance, in clusters of green spherules, to bunches of grapes. The Nahua (Mexican) word for grapes is xocomecatl. The name should be pronounced zho-ko-mecatl-ait.

Tlalocite

Occurrence. Tlalocite was first found in the ore pile at Nacozari in which quetzalcoatlite was first noted. Most pieces in my possession were obtained by combing through this material. Small amounts were also found in the Bambollita mine at the bottom of a winze sunk on the same vein that provided so many other new tellurium oxysalts.

Tlalocite occurs in or near the richest ore but is generally found only on fracture surfaces that have been subject to the most severe oxidation. It may be accompanied by tenorite, azurite, malachite, and an amorphous pea-green Cu–Te mineral.

Physical properties. Tlalocite occurs as delicate blue, velvety crusts, plastered on rock surfaces or in cavities representing relic sulphides. The colour is near Capri blue, and the best match is R.H.S. 121A; the streak is a very pale blue. The Mohs hardness is 1 and tlalocite is gummy and sectile. No fluorescence was observed in long or short wavelength U.V. The specific gravity was estimated as 4·55±0·1 by sink-float methods in Clerici solution at 23·0 °C.

Chemistry. Microchemical tests showed major Cu, Zn, Te, and Cl, results subsequently confirmed by electron-probe examination. Additionally, a spectrogram showed traces of Ag.

Chemical analysis for tellurium was performed in the same manner as for xocomecatlite except that in this case both Te^{vi} and Te^{iv} were found. Copper and zinc were determined by atomic absorption in 1:1 HNO_3, and chlorine was determined spectrophotometrically by the mercuric thiocyanate method. Water was liberated in abundance in the closed tube, and was determined gravimetrically in this fashion.

The results of analyses, presented in Table I, lead to the formula

$$Cu_{10}Zn_6(TeO)_3(TeO_4)_2Cl(OH)_{25}.27H_2O.$$

TABLE III. *X-ray powder data for tlalocite*, Cr-*K*α *radiation*, *114 mm Straumanis camera*

I	d_{meas}	I	d_{meas}	I	d_{meas}	I	d_{meas}
10	16·787	1	3·569			2	2·390
8	8·394	2	3·442	2	2·969	½	2·329
½	5·895	6	3·355	1	2·830	3	2·110
1	5·593	½	3·204	3	2·796	2	1·860
10	4·201	2	3·095	2	2·700	2	1·817
1	4·101	1	3·026	3B	2·588	4	1·560
1	3·912			3B	2·473		

Optics. (The optics were studied by BaSaw Khin who reports as follows): In thin section, tlalocite is pale-green in colour and resembles rosasite. The usual occurrence is in the form of spherules or arcuate bands of subparallel, small crystals, although incipient crystallites may show random orientation. Individual crystals are lath-shaped and may range from 0·5 μm in length to larger crystals averaging approximately 1×1·5×10 μm. Parallel extinction in all orientations suggests orthorhombic symmetry. The largest dimension coincides with γ, and β is normal to the plane of flattening.

The refractive indices for the D line are: α 1·758 (±0·002), β 1·796 (±0·002), and γ 1·810 (±0·005), and $2V_\alpha = 61°$ (calc.), 64° (meas.). Pleochroism is in bluish green for γ and β, and yellowish green for α, with $\gamma > \beta > \alpha$.

Crystallography. As noted above, tlalocite appears to be orthorhombic optically, but no measurable crystals, or even fragments large enough for single crystal X-ray work, were found. The mineral gives reasonably good powder patterns but they are complex and lines become very broad and hazy below d 2 Å. The powder data are presented in Table III.

Attempts at indexing the pattern failed. Two axes, 12·062 Å and 16·782 Å will index most of the lines nicely, and after this much progress, failure to discover a third axis, assuming an orthorhombic cell, suggests that the mineral is monoclinic. Alternatively, as most of the remaining unindexed lines are faint, poorer *d*-values may account for the problem.

Miscellany. There are some 50 pieces containing tlalocite, many with enough material on fracture surfaces to be readily visible to the unaided eye. Nevertheless, the total quantity is small, perhaps 25 mg of tlalocite in sum. Type specimens will be provided to the British Museum (Natural History) and the University of Paris.

The mineral is named in allusion to its high water content. Tlaloc was the powerful god of rain in both Toltec and Aztec mythology. The name should be pronounced tla-lawk-ait. In Spanish it should be pronounced tlalocquita.

Discussion. The Bambollita mine, located as the La Oriental by Benjamin Soto of Moctezuma, is a small mine north-east of the Bambolla mine. The latter mine has also been a prolific producer of tellurium oxysalts, and has been described by Gaines (1965).

Both mines are in volcanics, a complex pile of rhyolitic breccias, tuffs, and flows that comprises much of the Sierra La Huerta. Ores occur in irregular veins and breccia zones with a gangue of quartz, baryte, and minor calcite. Although native tellurium and pyrite were abundant at the Bambolla, pyrite is rare and native tellurium lacking at the Bambollita. Primary ore minerals were galena, bornite, hessite, and tetrahedrite (a tellurian variety).

There are two distinct veins in the Bambollita mine; one of these has provided all of the new species described thus far. On the main tunnel level of the mine the vein is exposed at a level about 10 m below the surface. Oxidation here has been intense. There is a winze on the vein exposing it another 10 m deeper. Oxidation at this deeper level is partial. Relicts of sulphides occur with cerussite, teineite, linarite, and quetzalcoatlite. Fractures cutting the vein in this spot show complete oxidation, and carry tlalocite, tenorite, malachite, and azurite.

On the main tunnel level sulphides generally occur only as powdery relics composed of cerussite, tenorite, and iron oxides, sometimes stippled with electrum. Carlfriesite generally occurs close to these relics. Fractures cutting the vein and wallrock show more thorough oxidation, carrying cesbronite and, finally, xocomecatlite.

The product of most complete oxidation at 10 m, then, is xocomecatlite, a tellurate. Incipient thorough oxidation at 20 m has produced tlalocite, a tellurate–tellurite.

Because these are the first tellurates known in nature, an effort was made to assess the conditions for their stability. Free-energy data taken from Garrels and Christ (1965) for all Te species cited were used to plot stability fields in terms of Eh and pH at 25 °C. An activity of 10^{-3} was chosen for total Te species; 10^{-6} was also tried but has little effect except to eliminate the stability field of TeO_2. In view of the abundance of tellurite and paratellurite at the Bambolla mine, this value seems unreasonably low.

The results of this effort are shown in fig. 1. Note that a narrow stability field for TeO_4^{2-} aq. lies just below the line at which water is unstable. This field of stability is unaffected by Te-species activity. The existence of this narrow field indicates that, under extreme oxidizing conditions, Te^{vi} can exist in nature over a wide pH range. This is comforting to know, of course, and the Bambollita mine is ideally located, in terms of climate, to provide such a high Eh during oxidation.

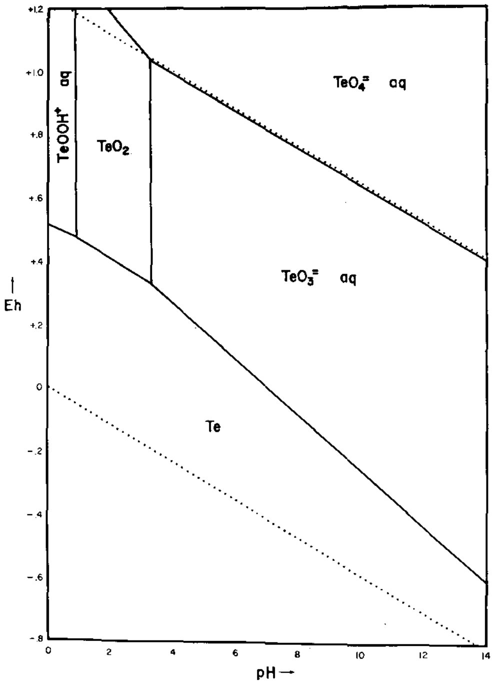

FIG. 1. Estimated stability fields in the system Te–O–H_2O at 25 °C.

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