

ANTOFAGASTITE AND BANDYLITE, TWO NEW COPPER MINERALS FROM CHILE

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ABSTRACT

Antofagastite $2[\text{CuCl}_2 \cdot 2\text{H}_2\text{O}]$. Orthorhombic dipyramidal ($2mm$). Space group ($P\bar{b}mn$). $a_0=7.38\text{\AA}$, $b_0=8.04\text{\AA}$, $c_0=3.72\text{\AA}$; $a_0:b_0:c_0=.918:1:1.462$ (artificial). Crystals rare. Curved and vermiform shapes. Cleavage $m(110)$ perfect, $c(001)$ good. Brittle. Conchoidal fracture. H $2\frac{1}{2}$. G 2.4 (natural crystals). Vitreous luster. Bluish green. Bx positive. $2V\ 75^\circ$. $r < v$. X = $b[010]$ = bright green = 1.646, Y = $c[001]$ = olive green = 1.685, Z = $a[100]$ = pale blue = 1.745. Occurs in Calama, Antofagasta, Chile, as a crust, with bandylite and atacamite. Named after the province.

Bandylite. $\text{CuB}_2\text{O}_4 \cdot \text{CuCl}_2 \cdot 4\text{H}_2\text{O}$. Tetragonal holohedral ($4/m\ 2/m\ 2/m$). Space group $P\ 4/nmm$. $c=.907$, $a_0=6\ 13\text{\AA}$, $c_0=5.54\text{\AA}$. Thick tabular crystals. Cleavage $c(001)$ perfect. Flexible. H $2\frac{1}{2}$. G 2.810. Deep blue. Uniaxial negative; $\omega=1.692$ = deep cendre blue, $\epsilon=1.640$ = pale greenish yellow. Decomposed by water, CuCl_2 going into solution with green copper borate as a residue. Occurs in Calama, Chile, with antofagastite and atacamite as a crust on rock joints. Named after Mark C. Bandy, who collected the original material.

During the summer of 1935 Mr. Mark C. Bandy went to northern Chile to collect minerals in the joint interest of the U. S. National Museum and the Harvard Mineralogical Museum. Mr. Bandy's long service on the geological staff of the Chile Exploration Company at Chuquicamata had made him well acquainted with the local conditions, and the chief result of his work was a large suite of gossan minerals, largely sulphates, from three localities. The study of this suite of minerals has been carried on at Washington and Harvard, and the general results will be published soon by Mr. Bandy. This paper is confined to the description of two new copper minerals discovered among them.

These minerals occur together with atacamite near the surface at Mina Quetena, west of Calama, Chile. They are in a leached zone above massive iron sulphates. Crystals of both species are implanted on the surface of heavily iron-stained rock and quartz. The first mineral is known in artificial crystals but has not before been reported in a natural occurrence; the second appears to be quite new.

ANTOFAGASTITE

The first mineral to be described is a simple hydrous copper chloride, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, similar to the well known artificial compound. We propose the name *antofagastite*, from the Province of Antofagasta in which

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Calama is situated. It forms lichen-like splotches on the rock. The center of these splotches is occupied by small deeply grooved spires up to 5 mm. long, often bent or entirely recurved, much in the manner of some gypsum, chalcantite or similar soluble salts. About these columnar masses are areas of lighter colored efflorescence; other areas are little more than stain.

Chemical properties. Antofagastite is a hydrous chloride of copper, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$. This is the common laboratory hydrate but has never before been reported in nature. A small but carefully picked sample was available which, except for a slight admixture of gangue, was pure and homogeneous. The analysis of this material yielded the results given in Table 1.

TABLE 1. ANALYSIS OF ANTOFAGASTITE FROM MINA QUETENA, CALAMA, CHILE

	I	II
Insol.	0.95	
Cu	36.89	37.22
Fe_2O_3	0.20	
CaO	0.15	
MgO	0.04	
Cl	40.68	41.52
H_2O	20.81	21.26

I Analysis of antofagastite from Mina Quetena, Calama, Prov. of Antofagasta, Chile.
William F. Foshag, *analyst*.

II Theoretical composition for $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$.

Pyrognostics: Antofagastite is easily and completely soluble in water to a pale blue solution and in ammonium hydroxide to an intense blue solution. Before the blowpipe it fuses easily, coloring the flame green, blue near the assay; in a closed tube it yields water and fuses easily, recrystallizing to a yellow or light brown anhydrous chloride.

Crystallography. A few measurable crystals were found which gave the angles contained in Table 2. The elements calculated from these angles are very close to those previously determined on artificial crystals of this salt.¹

Antofagastite is orthorhombic dipyramidal.

$$a:b:c = 0.9177:1:0.4631.$$

$$p_0:q_0:r_0 = 0.5046:0.4631:1.$$

The structure lattice has been determined recently by Harker.² The

¹ Marignac, *Mem. Soc. Phys. Geneve*, vol. 14, p. 219, 1855; and Groth, *Chem. Cryst.*, vol. 1, p. 238, 1906. Artificial crystals: $a:b:c = 0.9174:1:0.4643$.

² Harker, *Zeits. Kryst.*, vol. 93, p. 136, 1936.

TABLE 2. ANTOFAGASTITE. MEASURED AND CALCULATED ANGLES

Forms	Calculated		Measured		No. of faces
	ϕ	ρ	ϕ	ρ	
<i>c</i> 001	—	0°00'	—	0°00'	2
<i>b</i> 010	0°00'	90 00	0°00'	90 00	11
<i>a</i> 100*	90 00	90 00	—	—	—
<i>m</i> 110	47 27½	90 00	47 28	90 00	9
<i>t</i> 520	69 50½	90 00	69 49	90 00	8
<i>q</i> 103*	90 00	9 33	—	—	—
<i>r</i> 101*	90 00	26 46½	—	—	—
<i>s</i> 301	90 00	56 33	90 00	56 38	3
<i>p</i> 111	47 27½	34 24½	47 20	34 12	1

* Forms found only on artificial crystals, together with *c*, *b*, *m* (see footnote 1).

unit cell has dimensions $a_0 = 7.38$, $b_0 = 8.04$, $c_0 = 3.72$; $a:b:c = 0.918:1:0.462$. It contains $\text{Cu}_2\text{Cl}_4 \cdot 4\text{H}_2\text{O}$. Space group (*P b m n*).

Physical properties. Antofagastite is brittle with a conchoidal fracture and a perfect cleavage parallel to *m*(110), good cleavage parallel to *c*(001). The specific gravity is 2.4, determined on natural crystals. Hardness 2.5. Luster vitreous. Color bluish-green to greenish blue with at times a yellowish tinge.

	$n(\text{Na})$	Positive
X=[010] bright green	$\omega = 1.646$	$2V = 75^\circ$
Y=[001] olive green	$\beta = 1.685$	$r < v$
Z=[100] pale blue	$\gamma = 1.745$	

BANDYLITE

For the second species we propose the name *bandykite*, in honor of Mark C. Bandy, mining engineer, who collected this material and who has made a study of the sulphates and related minerals of the locality from which these two new species come.

Bandykite is tetragonal and occurs always in crystals and crystal aggregates. The crystals are sometimes attached to the rock as symmetrical pseudocubic or tabular individuals. More commonly a single distorted crystal, or cluster of several subparallel individuals spreads out in an irregular or circular button-like or lichen-like group. The crystals in these groups are much flattened parallel to the base or to the face of a pyramid. The groups are sometimes isolated, or sometimes united to cover considerable surfaces. They rest either on joint faces of altered volcanic rock or the walls of narrow cracks in vein quartz. Occasionally crystals of bandykite are implanted on iron-stained quartz crystals in vugs of the veins.

Composition. In order to obtain a suitable sample for analysis the material had to be carefully picked by hand under the binocular microscope. In this way a satisfactory sample was finally obtained, containing only a small per cent of admixed gangue but contaminated by a few per cent of antofagastite and atacamite. Analysis of this material yielded the results given in Table 3.

TABLE 3. ANALYSIS OF BANDYLITE, CALAMA, CHILE

	I	II	III
Insol.	1.84		
Cu	34.94	.5498	35.74
CaO	0.05		
MgO	0.05		
Na ₂ O	0.40		
K ₂ O	None		
Fe ₂ O ₃	0.35		
Cl	19.47	.5490	19.94
B ₂ O ₄	23.35	.2715	24.08
SO ₃	0.05		
H ₂ O	19.60	1.0888	20.24
Sum	100.10		

I Bandykite, Mina Quetena, near Calama, Chile. William F. Foshag, *analyst*.

II Molecular ratios from Col. I.

III Theoretical composition for $\text{CuB}_2\text{O}_4 \cdot \text{CuCl}_2 \cdot 4\text{H}_2\text{O}$.

The chemical analysis corresponds closely to the composition $\text{CuB}_2\text{O}_4 \cdot \text{CuCl}_2 \cdot 4\text{H}_2\text{O}$. The higher ratios of the Cu and Cl, above those of B_2O_4 are probably to be ascribed to the admixed antofagastite $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ and to atacamite.

Pyrognostics. Before the blowpipe bandylite colors the flame green, pale blue near the mineral fragment. In a closed tube it yields water and a yellow crystalline sublimate; in an open tube it yields water and a yellow sublimate that oxidizes black. The mineral is decomposable by water, copper chloride going into solution, verdigris-green copper borate remaining as an insoluble residue. Easily and quickly soluble in ammonium hydroxide to an intense blue solution; more slowly soluble in hydrochloric and nitric acids.

Crystallography. Bandykite is tetragonal, holohedral. Four crystals, including one doubly terminated individual, were measured; they gave excellent reflections and very consistent angles. The readings on nine faces of the form taken as (201) and thirteen faces of the form (111) on the four crystals were employed in calculating the axial ratio.

Forms	No. of faces	Mean		Range	
		ϕ	ρ	ϕ	ρ
$g(201)$	9	0°00'	61°05'	±0°05'	60°53'–61°11'
$p(111)$	13	45 00	52 06	±0 05	51 58 –52 15

From (201): $c = \frac{1}{2} \tan \rho = 0.9051$
 (111): $c = \sin \phi \tan \rho = 0.9083$
 Weighted mean: $c = 0.9070$

The cell dimensions of the simple tetragonal lattice, determined by Dr. Berman, are a_0 6.13 Å, c_0 5.54 Å, with $a_0:c_0 = 1:0.904$, a ratio in good agreement with the morphological ratio $a:c = 1:0.9070$. Since the morphology indicates the holohedral crystal class $4/m \ 2/m \ 2/m$ the space group is $P \ 4/n \ m \ m$, fixed by the following observed reflections: hkl all orders present, $hk0$ only with $h+k$ even, and $0kl$ all orders present.

The molecular weight of the unit cell, $M = 354$, agrees excellently with that of the empirical formula, $M = 356$.

The forms observed and the angles, measured and calculated are contained in Table 4.

TABLE 4. BANDYLITE. MEASURED AND CALCULATED ANGLES

Forms	Calculated		$a:c = 1:0.9070$		$\rho_0 = 0.9070$		No. of faces	Quality
	ϕ	ρ	Mean		Range			
			ϕ	ρ	ϕ	ρ		
<i>c</i> 001	0°00'	0°00'	0°00'	0°00'	—	—	5	very good
<i>a</i> 010	0 00	90 00	0 00	90 00	—	—	2	very poor
<i>m</i> 110	45 00	90 00	45 00	90 00	±3'	—	3	very poor
<i>d</i> 012	0 00	24 23½	0 00	24 31	±3'	24°25'–24°55'	7	good
<i>e</i> 023	0 00	31 09½	0 00	31 13	—	—	1	poor
<i>f</i> 011	0 00	42 12½	0 00	42 17½	±5'	42 10–42 26	6	good
<i>g</i> 021	0 00	61 08	0 00	61 05	±5'	60 53–61 11	9	very good
<i>o</i> 112	45 00	32 40½	45 00	32 44½	±2'	32 43–32 46	2	good
<i>p</i> 111	45 00	52 03½	45 00	52 06	±5'	51 58–52 15	13	very good
<i>q</i> 221	45 00	68 42	45 00	68 33	±5'	68 16–69 00	5	poor

As shown in Figs. 1 and 2, the dominant forms are $c(001)$, $p(111)$, $g(201)$, and $m(110)$. Tabular crystals are the rule and these may be fully symmetrical with a square basal plane or with a rectangular outline. However, irregular development is much more common, and pyramidal faces may be largely developed. The base can generally be recognized by its superior lustre, occasionally pearly where cleavage is developed, and by frequently developed, low quadrangular terraces.

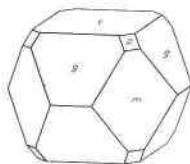


FIG. 1

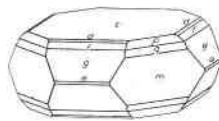


FIG. 2

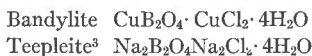
Physical and optical properties. The cleavage is basal (001), perfect and easy. Hardness $2\frac{1}{2}$. Specific gravity 2.810 by pycnometer (Berman). Very flexible and easily deformed.

The color is deep blue with greenish lights, cendre to Italian blue (Ridgway), becoming greener from atacamite inclusions. It is pale blue when bruised or powdered. The mineral is optically uniaxial and negative. Undistorted crystals, carefully removed from the matrix are either completely uniaxial or show a slight opening of the cross. Pleochroism strong, *a* deep cendre blue, *c* pale greenish yellow. Indices of refraction (Na) $\omega = 1.691$, $\epsilon = 1.641$ (Berman); $\omega = 1.692$, $\epsilon = 1.640$ (Foshag).

RELATIONSHIPS

Except for the complex and anomalous mineral boracite, bandylite is the only reported borate and chloride mineral. It differs essentially from boracite in type in being a well defined double salt borate-chloride rather than a chloro-borate. In the same way it differs from such minerals as fluoborite, $6\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 6(\text{F},\text{OH})$ and avogadrite $(\text{K},\text{Cs})\text{BF}_4$, which are borofluorides and not double salts.

The mineral bandylite, however, shows some interesting relationships to the artificial borate-chloride of sodium.³



Both of these minerals are tetragonal.

Both antofagastite and bandylite are obviously secondary products. They are usually intimately associated with atacamite, which is probably slightly later than the antofagastite. Certain areas of bandylite are surrounded by antofagastite but there is no residual copper borate to suggest that the chloride is derived from the double salt by aqueous decomposition. It appears more likely that both minerals are essentially contemporaneous and have deposited from solutions in which copper chloride was in excess. The atacamite, sparingly associated with these minerals, is sometimes earlier but usually is later than these two minerals.

³ This salt has been found occurring naturally at Borax Lake, Lake Co., California, by Dr. W. A. Gale and Mr. M. Vonsen, and will shortly be described under the mineral name teepelite. The artificial salt is described by John E. Teeple: *The Industrial Development of Searles Lake Brines*, p. 33, 1929.