THE AMERICAN MINERALOGIST
JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 25 AUGUST, 1940 No. 8

BELLINGERITE, A NEW MINERAL FROM CHUQUICAMATA, CHILE

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(Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 225.)

ABSTRACT

Bellingerite. Triclinic pinacoidal. $a:b:c=0.9264:1:1.0149$; $\alpha=105°06'$, $\beta=96°57\frac{1}{2}'$, $\gamma=92°55'$. $a_0=7.22$Å, $b_0=7.82$ Å, $c_0=7.92$Å. Contains $3Cu(IO_3)_2 \cdot 2H_2O$ in unit cell. Habit prismatic [001] and somewhat tabular {100}. Twinning on {$\bar{1}$01} common. Conchoidal fracture. Moderately brittle. H=4. G=4.89±0.01. Color light sulphate green. Optics:

	Orientation		*n*	*Absorption*	*Bx*(+), 2V med.,
	ϕ	ρ	589		$r>v$, strong
X	−70°	70°	1.890	light blue green	
Y	175	38	1.90	light blue green	
Z	34	59	1.99	blue green	

Occurs as distinct crystals in veinlets with leightonite and gypsum in massive quartz at Chuquicamata, Chile.

Named in honor of Mr. H. C. Bellinger, Vice President of the Chile Exploration Company and for many years associated with mining at Chuquicamata.

arly in January of this year the New York office of the Chile Exploration Company, through Mr. H. C. Bellinger, sent to the Harvard Mineralogical Museum some specimens recently found at their mines in Chuquicamata, Chile, for further study in our laboratory. Among these was an iodine mineral, first recognized as probably a new species by the Chuquicamata geological staff and now described in this paper. We are very grateful to the Company, which kindly furnished us with the material for our investigation and an adequate account of its occurrence at the mine.

The mineral is found as tiny, brilliant green crystals of much the same color as the recently described salesite.[1] The crystals are generally less than a millimeter in largest dimension, and often doubly terminated. On some specimens they are perched on blades of leightonite or lying between crystals of that mineral, and on other specimens they are similarly situated on gypsum. The mineral occurs as veinlets not more than a quarter of an inch thick and a few inches long, and as linings in

[1] Palache and Jarrell, Salesite, a new mineral from Chuquicamata, Chile: *Am. Mineral.*, **24**, 388–392 (1939).

fractures and cracks in an intensely sericitized and silicified granitic rock containing irregular bodies and veins of massive, highly fractured quartz. Earlier fractures in the quartz and granitic rock have been filled with jarosite and minor amounts of iron oxide. The iodine mineral appears to be the latest mineral deposited. It occurs within five meters of the surface at the northwest end of Bench D-1 (Co-or. N4850, E3200).[2]

We take great pleasure in naming this new mineral *bellingerite* in honor of Mr. Herman Carl Bellinger, Vice-President of the Chile Exploration Company, who has by his constant interest helped us in the study of Chuquicamata minerals.*

Crystallography

Morphological crystallography. The form distribution as found in the five measured crystals proved beyond a doubt that the mineral is tri-

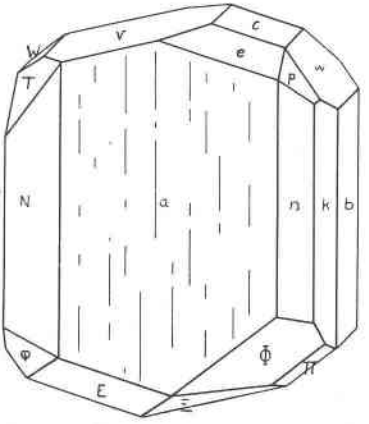

Fig. 1. Bellingerite—Chuquicamata

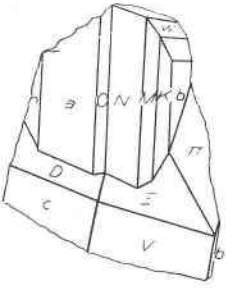

Fig. 2. Bellingerite Twin—Chuquicamata

clinic. The optical and *x*-ray examinations, as given in another part of this paper, are in agreement with this conclusion. Doubly terminated crystals with the same forms top and bottom indicate that the symmetry class is pinacoidal. The crystals are generally tabular and often elongated in the direction of rather fine striae on the tabular face (Fig. 1).

[2] We are indebted to Mr. Lester G. Zeihen of the Chuquicamata staff for the foregoing account of the occurrence.

* Mr. Bellinger was General Manager of the Chile Exploration Company at Chuquicamata from 1916 to 1920, and during that time introduced efficient mine methods and mine equipment. From 1920 to date he has been Vice-president in charge of operations for the Chile Exploration Company in New York. Under Mr. Bellinger's direction during this time, complete electrification of the mine, improvement of the bench mining system, and the introduction of liquid oxygen explosives have made Chuquicamata one of the great mines of the world.

TABLE 1. BELLINGERITE: CRYSTALLOGRAPHIC OBSERVATIONS

Forms	*No. of Faces Observed*	*Size*	*Qual.*	*Measured Range*		*Weighted Mean*		*Calculated Values*	
				ϕ	ρ	ϕ	ρ	ϕ	ρ
c 001	2	M	A	23°21′– 23°54′	17°05′–17°09′	23°37′	17°07′	23°26′	17°03½′
b 010	5	M	A	0 00 0 10	90°00′	0 00	90 00	0 00	90 00
a 100	6	L	A	85 00 – 85 14	90 00	85 03	90 00	85 03	90 00
k 120	2	M	A	26 38 – 26 40	90 00	26 40	90 00	26 36	90 00
n 210	5	M	A	60 36 – 60 54	90 00	60 37	90 00	60 33	90 00
N 2$\bar{1}$0	3	M	B	110 59 –111 14	90 00	111 00	90 00	111 22½	90 00
M 1$\bar{1}$0	2	S	C	130 45 –131 18	90 00	130 50	90 00	131 00½	90 00
K 1$\bar{2}$0	2	S	B	151 11 –151 48	90 00	151 15	90 00	151 17	90 00
w 011	2	M	A	5 17 – 5 20	53 15 –53 20	5 19	53 18	5 14	53 19
x 021	1	S	C	2°59′	67 20	2 59	67 20	2 56	67 20½
V 0$\bar{1}$2	3	L	A	153 03 –154 31	14 33 –15 16	153 13	15 15	153 00½	15 06½
W 0$\bar{1}$1	3	S	B	170 56 –171 33	37 38 –37 59	171 01	37 57	171 00	38 04½
X 0$\bar{2}$1	2	S	B	176 02 –176 08	61 21	176 03	61 21	176 10	61 23
Y 0$\bar{3}$1	1	VS	B	177°26′	70 32	177 26	70 32	177 34	70 53½
d 102	2	S	D	63 37 – 64 38	36 44 –36 50	63 40	36 48	63 58½	36 53
e 101	2	S	C	72 49 – 72 53	52 04 –52 10	72 50	52 09	73 09½	52 01½
D $\bar{1}$02	1	M	B	–61°41′	26 00	– 61 41	26 00	– 61 26½	26 03
E $\bar{1}$01	1	L	D	–78 47	46 50	– 78 47	46 50	– 79 16½	44 57½
p 111	1	M	A	40 31	62 05	40 31	62 05	40 34	62 03½
P 1$\bar{1}$1	1	VS	E	119 23	55 38	119 23	55 38	118 56½	54 29
Ξ $\bar{1}$1$\bar{2}$	3	L	A	–124 22 –124 26	27 29 –27 30	–124 24	27 30	–124 23½	27 29½
Π $\bar{1}$1$\bar{1}$	3	S	B	131 33 –131 54	52 30 –52 43	–131 34	52 34	–131 32½	52 39½
S 1$\bar{2}$2	2	S	B	137 00 –137 16	44 32 –44 45	137 06	44 40	137 06	44 44
σ $\bar{1}$22	1	VS	E	–18 09	53 30	– 18 09	53 30	– 18 25½	53 38½
T 1$\bar{2}$1	2	M	A	144 29 –144 35	64 43 –64 51	144 32	64 45	144 43½	64 47
τ $\bar{1}$2$\bar{1}$	2	M	A	–152 52 –153 03	65 07 –65 10	–152 57	65 09	–152 59	65 09½
ϕ $\bar{2}$11	1	M	B	–61 20	–67 10	– 61 20	67 10	– 61 13	67 12
Φ $\bar{2}$1$\bar{1}$	3	L	A	–113 23 –114 59	66 26 –66 33	–114 56	66 28	–114 50	66 28½

The tabular face has been taken as $a\{100\}$ and the direction of the striae on that face as [001]. This orientation is chosen principally because of its suitability for measurement on the two-circle goniometer. The conventional orientation would make the tabular face $\{001\}$, and the [001] zone would then consist of a narrow girdle of small, not easily recognizable faces. The axial directions chosen yield a simple form series (Table 2)

TABLE 2. BELLINGERITE: ANGLE TABLE

Triclinic; pinacoidal $-\bar{1}$

$a:b:c=0.9264:1:1.0149$; $\alpha=105°06'$, $\beta=96°57\frac{1}{2}'$, $\gamma=92°55'$
$p_0:q_0:r_0=1.0591:1.0088:1$; $\lambda=74°23\frac{1}{2}'$, $\mu=81°59'$, $\nu=85°03'$
$p_0'=1.1078$, $q_0'=1.0552$; $x_0'=0.1225$, $y_0'=0.2815$

Forms		ϕ	ρ	A	B	C
c	001	23°26′	17°03½′	81°59′	74°23½′	—
b	010	0°00	90 00	85 03	—	74 23½
a	100	85 03	90 00	—	85 03	81 59
k	120	26 36	90 00	58 27	26 36	72 58
n	210	60 33	90 00	24 30	60 33	76 28½
N	$2\bar{1}0$	111 22½	90 00	26 19½	111 22½	89 24
M	$1\bar{1}0$	131 00½	90 00	45 57½	131 00½	95 05
K	$1\bar{2}0$	151 17	90 00	66 14	151 17	100 22
w	011	5 14	53 19	81 51½	37 00½	37 23
x	021	2 56	67 20½	82 44	22 50½	51 33
V	$0\bar{1}2$	153 00½	15 06½	84 23½	103 25½	29 02
W	$0\bar{1}1$	171 00	38 04½	87 30½	127 31½	53 08
X	$0\bar{2}1$	176 10	61 23	90 59	151 09	76 45½
Y	$0\bar{3}1$	177 34	70 53½	92 22½	160 44½	86 21
d	102	63 58½	36 53	55 56½	74 44	26 02½
e	101	73 09½	52 01½	39 31½	76 48	42 27½
D	$\bar{1}02$	− 61 26½	26 03	111 29	77 53	29 30
E	$\bar{1}01$	− 79 16½	44 57½	132 52	82 26½	50 53
p	111	40 34	62 03½	50 55½	47 51	45 55½
P	$1\bar{1}1$	118 56½	54 29	47 29½	113 12	57 50
Ξ	$\bar{1}\bar{1}2$	−124 23½	27 29½	113 42	105 07	42 49½
Π	$\bar{1}\bar{1}1$	−131 32½	52 39½	129 40½	121 49	68 22½
S	$1\bar{2}2$	137 06	44 44	64 21½	121 02	53 24½
σ	$\bar{1}22$	− 18 25½	53 38½	100 49	40 10½	42 02½
T	$1\bar{2}1$	144 43½	64 47	62 49	132 23½	74 22
τ	$\bar{1}21$	−152 59	65 09½	118 43	143 57	82 11½
φ	$\bar{2}11$	− 61 13	67 12	140 03	63 39	66 41½
Φ	$\bar{2}\bar{1}1$	−114 50	66 28½	149 34	112 39	79 35

and coincide with the independently determined axial directions found in the *x*-ray study.

The crystals are rich in forms, most of which are of excellent reflecting quality. We have not examined many crystals in order to attain a large list of forms, but certainly the most important ones are included in the list given in Table 1. In this table the range of angles, general quality, and number of readings are given for each of the forms on four crystals. The agreement between measured and calculated angles is, in general, very good.

Table 2 is the calculated angle table. The adequacy of the orientation is indicated by the preponderance of forms with unit indices.

X-ray crystallography. One of the crystals used for the morphological study was also used for the *x*-ray work. Weissenberg pictures about [001] and [100] were taken, and these verified the morphological choice of axial directions and unit form. The absolute dimensions of the axes are:

$$a_0 = 7.22 \text{ Å}, \qquad b_0 = 7.82 \text{ Å}, \qquad c_0 = 7.92 \text{ Å}$$
$$a:b:c = 0.9235:1:1.0128$$

with the axial angles taken from the morphological measurements because those determined from the *x*-ray photographs are probably not as accurate as the morphological angles. A comparison of the two sets of angles shows that they are in fair agreement:

Morphological—$\alpha = 105°06'$, $\beta = 96°57\frac{1}{2}'$, $\gamma = 92°55'$
X-ray—$\alpha = 104°29'$, $\beta = 97°15'$, $\gamma = 93°11'$

The computed volume of the unit cell (V_0) is 427.78 Å^3, and from this and the measured specific gravity the molecular weight of the unit cell (M_0) is 1267.93.

The *x*-ray elements, together with the found density, yield a satisfactory chemical formula for the unit, as shown in a later part of this paper.

Twinning. Twins of the new mineral occur on one of the examined specimens. The twinning is on $\{\bar{1}01\}$, producing a combination with a large re-entrant (Fig. 2), or, more often, a thick crystal without re-entrants in which the twinning can most easily be detected under the microscope. The tabular crystals are not twinned. In the Friedel sense the twins have an index of 1, with an obliquity of 3°20′, so that the lattices of both individuals are closely coincident in their twinned positions, and a good geometrical basis for the twin law is established.

Physical Properties

The fracture of the mineral is subconchoidal, without any cleavage

direction observed. The crystals are moderately brittle; hardness is about 4. The specific gravity, $4.89 \pm .01$, was measured on six crystal fragments varying from 9.03 to 21.87 mg.

The color is light sulphate green (39′B-G.b of Ridgway); streak very pale green.

Optical properties. A crystal, previously measured on the goniometer, was mounted in arochlor ($n = 1.66 \pm$), and used for a study of the optical orientation with the Fedorov stage. Some difficulty was encountered in measuring the positions of the small faces under the microscope because of the large difference in the refractive index between the mounting medium and the mineral. Mounting media of the requisite high index (1.90) have too high a melting point, since the mineral dissociates easily with heat. The position of the indicatrix, as given by the angles below, is accordingly only accurate within a few degrees:

	ϕ	ρ
X	$-70°$	70°
Y	175	38
Z	34	59

On {100}, the flat face, the extinction is essentially parallel to the zone edge $[0\bar{1}1]$ and $X' \wedge [001] = 37°$. The mineral is biaxial positive, with 2V medium, and a strong dispersion, $r > v$. Some absorption in blue-green is noted in thicker crystals with $Z > X$ and Y.

Refractive indices, measured in sodium light, with phosphorus-sulphur-methylene iodide liquids, are:

$$\alpha = 1.890, \qquad \beta = 1.90, \qquad \gamma = 1.99$$

Chemistry

A part of the large sample prepared at the Chuquicamata laboratory was further purified by us and analyzed by Mr. Gonyer. The results are included in the following table:

Table 3. Analysis of Bellingerite

	A	B	1	2	3	C
I_2O_5	77.55	78.00	.2337	2.96	78.47	77.59
CuO	18.65	18.76	.2357	2.99	18.70	18.37
H_2O	3.22	3.24	.1798	2.28	2.83	[4.04]
Total	99.42	100.00			100.00	100.0
G	4.89				4.92	4.876

A. Analysis (Harvard 95026). F. A. Gonyer, *analyst.*

B. Corrected to 100 per cent.

1. Molecular proportions of B.

2. Molecular proportions xM_0 (where $M_0=1267.93=V_0d/A$). The figures in the column are the computed numbers of the oxide in the unit cell.

3. Calculated composition and specific gravity for $3Cu(IO_3)_2\cdot 2H_2O$.

C. Analysis of artificial crystals by Granger and de Schulten (*Bull. soc. min., France*, **27**, 137–146, 1904).

The analysis yields the formula $3Cu(IO_3)_2\cdot 2H_2O$, in close agreement with the required molecular weight for the x-ray unit, as shown in column 2 of Table 3. The formula originally proposed for the artificial crystals by Granger and de Schulten was $Cu(IO_3)_2\cdot H_2O$, but this does not fit our data so well as our formula. The analysis (C of Table 3) upon which the old formula rests, gave the water by difference; Mr. Gonyer made a direct determination in his analysis here recorded.

Bellingerite is only slightly soluble in hot water, the crystal edges becoming somewhat rounded on boiling for some time. It is easily soluble in dilute HCl. On heating in the closed tube, it shows the immediate evolution of a heavy purple iodine vapor, which crystallizes on the walls of the tube.

Artificial Crystals

Granger and de Schulten prepared triclinic crystals of a supposed cupric iodate monohydrate which conform with our mineral in all respects. The chemical similarity has been shown in the previous section. The crystal orientation by Granger and de Schulten is related to ours as follows:

Granger and de Schulten to Berman and Wolfe

$$00\bar{1}/110/\bar{1}10$$

and conversely, from our setting to theirs is:

$$0\tfrac{1}{2}\tfrac{\bar{1}}{2}/0\tfrac{1}{2}\tfrac{1}{2}/\bar{1}00$$

Their axial ratio is:

$$a':b':c'=1.2898:1:1.5188$$
$$\alpha'=82°38', \qquad \beta'=95°0', \qquad \gamma'=91°6'^{*}$$

Converted to our orientation this yields:

$$a:b:c=0.9402:1:1.0205$$

in fairly good agreement with our ratio (Table 2).

We believe our orientation to be more suitable for the discussion of the crystallography of the species, because the forms are somewhat simplified, but principally because our orientation and unit represent the shortest periodicities in the lattice, as verified by the x-ray study.

* In the original paper, the angles were transposed.

The color and specific gravity are also in good agreement with our data and we can safely assume that the natural and artificial material are the same.

Relation to Other Minerals

Bellingerite is the fourth iodate recorded as a mineral. Salesite, the recently described basic cupric iodate, $Cu(IO_3)$ (OH), is also from Chuquicamata; and lautarite, the calcium iodate $Ca(IO_3)_2$ is from Atacama, as is dietzeite, the complex iodate and chromate of calcium. The new mineral shows no special relationship to these.