

ANTLERITE

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Antlerite was first described by Hillebrand (1889) who gave an incomplete physical description and a chemical analysis, naming the mineral from its place of occurrence, the Antler mine, Arizona. Ten years later it was described under the name stelznerite from Chile. The study by Arzruni and Thaddéeff (1899) was communicated posthumously by Dannenberg. Schaller (1911) proved the identity of the two minerals optically and advocated the use of the prior name, a usage which has been followed except in German publications. The fullest description of the crystallography of antlerite is by Ungemach (1924), who seems to have been the first to recognize the mineral at Chuquicamata, Chile. It had been commonly mistaken there for brochantite, but is now known to be the principal ore (Audrieth, 1925; Bandy, 1938) in this largest of the world's copper mines.

The author became interested in the study of antlerite through a specimen from Bisbee, Arizona, brought to his attention by Dr. Tunell. These crystals were derived from a single and very handsome specimen in the U. S. National Museum, the antlerite being implanted on brochantite. At about the same time a series of complex crystals of antlerite were sent to the Harvard Mineralogical Laboratory by O. W. Jarrell, then of the geological staff at Chuquicamata. The results of the study of these crystals are presented below.

Search of the specimens of brochantite in the Harvard collections to see if any were mislabeled and were really antlerite was largely negative. Only one specimen labeled brochantite was found to be antlerite, the crystals forming a fine felt embedding earlier atacamite. The locality given, La Lama, Chile, could not be found on our maps. The specimen is very similar in appearance to one from the original stelznerite locality, Remolinos, Vallenar, Chile.

Additional localities for antlerite represented in the Harvard collection are Sierra Mojada, Coahuila, Mexico, a mass of finely fibrous material, quite friable, of a light green color; and a specimen of similar appearance collected by Dr. Foshag at Northern Light Mine, Warsuk Range, near Black Mountain, Nevada. Antlerite was found among the oxidation products of chalcocite in the Jumbo Mines, Kennecott, Alaska, by Bateman and McLaughlin (1920). The crystallography of the mineral from Chuquicamata, Chile, and from Bisbee, Arizona, will be described below.

Posnjak and Tunell (1929) have made an exhaustive study of the artificial formation of this and other sulphates of copper.

Ungemach, in describing antlerite, adopted the position previously employed in descriptions of the artificial salt. This position makes the main zone and the elongation of most crystals the direction of the *a*-axis. Following the newer usage of this laboratory, the author places this dominant zone vertical, thus interchanging the *a* of Ungemach with his *c*-axis, which change leaves the perfect cleavage parallel to (010). A second cleavage, much poorer, is parallel to (100). The transformation formula, Ungemach to Palache, is 001/010/100.

This position brings out the close similarity between antlerite and atacamite. Because of their deep green color and perfect (010) cleavage, these two minerals can hardly be distinguished except by crystallographic or optical measurements. Brochantite is also indistinguishable from either by inspection alone. In the accepted orthorhombic interpretation of brochantite, the perfect cleavage is likewise (010); and, as pointed out by Tunell (1929, p. 23), the minerals have similar refractive indices, in the same optical orientation. But the new monoclinic interpretation of brochantite* makes the cleavage (100), and the parallelism between the properties of these three similar minerals is thus modified.

The optical characters of antlerite, as given by Tunell (1929) and in the tables of Larsen but oriented to the new position are:

Optically positive. $2V = 53^\circ$
 $X = b$, 1.726; yellow green
 $Y = a$, 1.738; blue green
 $Z = c$, 1.789; green

The specific gravity, as determined by Dr. Berman on two samples on the micro-torsion balance, is $3.88 \pm .005$.

Antlerite crystals from Bisbee are illustrated in Fig. 1. The crystals are thick tabular with dimensions of about 3 by 3.5 mm. and 2 mm. thick. They are dark green and appear almost black except on cleavages. Their faces are brilliant and free from striations, except a series of rather deep grooves on the faces of (011) parallel to [100] and not shown in the drawing. The numerous pyramid forms shown are somewhat exaggerated in the figure, especially (311); they are, however, present on all the crystals and generally with their full number of faces. Three crystals were measured and yielded a form list including most of Ungemach's forms and several new ones. Almost all of these new forms reappeared on the Chilean crystals, a welcome confirmation.

* Unpublished study, soon to appear.

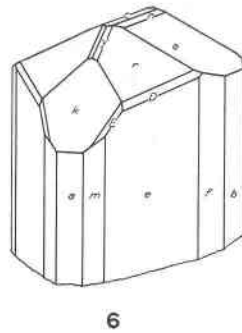
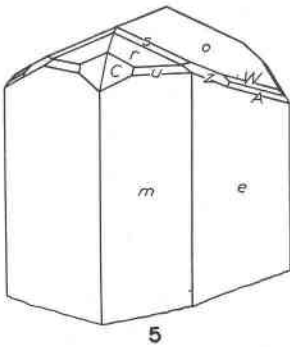
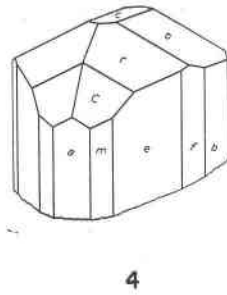
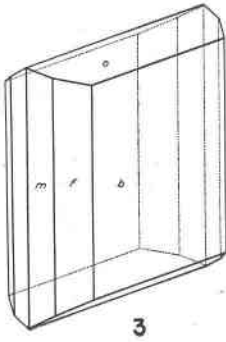
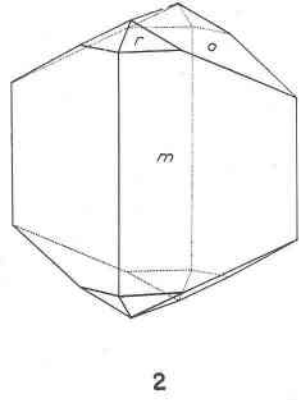
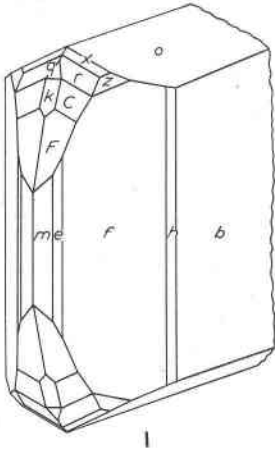


FIG. 1. Crystal of antlerite, Bisbee, Arizona.
 FIG. 2. Crystal of antlerite, Chuquicamata, Chile. The commonest type of crystal.
 FIG. 3. Crystal of antlerite, tabular habit, Chuquicamata.
 FIGS. 4, 5, 6. Crystals of antlerite, prismatic habit, Chuquicamata.

The most important locality for antlerite is, however, that of Chuquicamata, where it constitutes the main ore mineral. Its typical mode of occurrence is in cross-fibre veins ranging in thickness from thin films up to as much as 2.5 cm. in section. The crystals are of extremely diverse habit. Most common is such a simple combination as was shown by Ungemach, reproduced except for (010) in Fig. 2. The double termination, as shown here, is very exceptional and was seen only when the mineral was embedded in kroehnkite. Generally, the crystals are implanted by an end of the vertical axis and are slightly elongated on [001]; but they may be thin tabular parallel to (010) as in Fig. 3 or stout, and rather stubby, square prisms as in Figs. 4, 5 and 6.

Table 1 shows the observed combinations of the antlerite forms. The last two columns refer to the two crystals figured by Ungemach (1924). From this table it is evident that the dominant forms on antlerite crystals are $b(010)$, $e(120)$, $m(110)$, $o(011)$, $k(201)$, $r(111)$ and $C(211)$. The forms $h(140)$, $f(403)$, and $B(151)$ were found only on the Bisbee crystals. It will be noted that of the forms found by Ungemach only $g(560)$ and $t(133)$ were not again found on our crystals.

The new forms accepted as established and indicated in the angle table by an asterisk are based on the observations of Table 2. Three Arizona crystals and eight from the Chilean locality were measured. All the measurements were made in the position of Ungemach, since the author only after long deliberation decided to change the orientation. The angles are presented as measured and can be compared with the values of the angle table by taking $\phi = 90 - \phi_1$, $\rho = \rho_1$. It will be noted that several forms are based on a single measurement; but, in all but one of these, position of the face in a zone, together with the angles, seemed enough to assure the form.

Axial ratios were calculated for both lots of crystals, and results were obtained very similar to those of Ungemach. The author's more abundant observations have been averaged with his, and the angle table is calculated on the new elements and in the changed position. This table supersedes that published from this laboratory in 1933.

TABLE 1. ANTLERITE COMBINATIONS

		Arizona			Chuquicamata, Chile									
		1	2	3	4	5	6	7	8	9	10	11	12	13
<i>c</i>	001							x			x			x
<i>b</i>	010	x		x	x	x	x	x		x	x	x	x	x
<i>a</i>	100			x				x			x	x		
<i>h</i>	140	x	x											
<i>f</i>	130	x	x				x	x		x	x	x		x
<i>e</i>	120	x	x			x	x	x	x	x	x	x		x
<i>i</i>	230						x							x
<i>g</i>	560													x
<i>m</i>	110	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>n</i>	013										x			
<i>o</i>	011	x	x	x	x	x		x	x		x		x	x
<i>q</i>	403	x	x	x										
<i>k</i>	201	x	x	x						x	x	x		x
<i>r</i>	111	x	x	x	x			x	x	x	x	x	x	x
<i>u</i>	221								x					
<i>v</i>	123											x		
<i>t</i>	133													x
<i>s</i>	122	x	x	x					x	x				x
<i>w</i>	142								x					
<i>x</i>	233	x	x	x								x		
<i>y</i>	313										x	x		
<i>z</i>	121	x	x	x			x		x					
<i>A</i>	131		x	x			x		x		x			
<i>B</i>	151		x	x										
<i>C</i>	211	x	x	x			x	x		x				
<i>D</i>	231										x	x		
<i>E</i>	522										x	x		
<i>F</i>	311	x	x	x							x	x		
Fig.		1			2	3	4	5		6			U	U

TABLE 2. ANTLERITE: MEASURED ANGLES OF NEW FORMS

Form	Crystals		Cal. angles		Meas. angles		Range		In zone
	Ariz.	Chile	ϕ	ρ	ϕ	ρ	ϕ	ρ	
100	1	2	90°00'	90°00'	(used for orientation)				[001]
013	—	2	80 29	90 00	81°22'	90°00'	23'	0°	[100] and [031]
403	3	—	90 00	45 41½	90 04	46 00	4	38	[010]
221	—	1	44 50½	44 05	44 50	44 10	—	—	[110]
123	—	1	71 28	76 58½	71 45	76 30	—	—	
142	—	1	44 50½	75 31½	44 50	76 00	—	—	[211]
233	2	1	63 18½	66 26½	63 32	66 34½	2	9	
313	—	2	80 29	54 10	80 32	54 14	23	10	
121	3	2	44 50½	62 41½	44 50	62 48	25	28	[111]
131	2	3	33 32½	67 58½	33 23	68 02	89	78	[211]
151	2	—	21 40½	74 51½	21 33	75 09	36	35	
211	3	3	63 18½	37 23½	63 19	37 19	12	12	
231	—	1	33 22½	51 01½	34 39	51 30	—	—	[211]
522	—	2	63 18½	31 27	63 19½	31 30	1	3	[214]
311	3	1	63 18½	27 00	63 12	27 04	40	44	

TABLE 3. ANTLERITE: ANGLE TABLE
 Antlerite— $\text{CuSO}_4 \cdot 2\text{Cu}(\text{OH})_2$
 Orthorhombic; dipyramidal— $2/m \ 2/m \ 2/m$

		$a:b:c=0.6867:1:0.5027;$ $q_1:r_1:p_1=0.6867:1.3659:1;$			$p_0:q_0:r_0=0.7321:0.5027:1$ $r_2:p_2:q_2=1.9891:1.4562:1$		
Forms	ϕ	$\rho=C$	ϕ_1	$\rho_1=A$	ϕ_2	$\rho_2=B$	
<i>c</i>	001	—	0°00'	0°00'	90°00'	90°00'	90°00'
<i>b</i>	010	0°00'	90 00	90 00	90 00	—	0 00
* <i>a</i>	100	90 00	90 00	—	0 00	0 00	90 00
<i>h</i>	140	20 00½	90 00	90 00	69 59½	0 00	20 00½
<i>f</i>	130	25 53½	90 00	90 00	64 06½	0 00	25 53½
<i>e</i>	120	36 03½	90 00	90 00	53 56½	0 00	36 03½
<i>i</i>	230	44 09	90 00	90 00	45 51	0 00	44 09
<i>g</i>	560	50 30½	90 00	90 00	39 29½	0 00	50 30½
<i>m</i>	110	55 31½	90 00	90 00	34 28½	0 00	55 31½
* <i>n</i>	013	0 00	9 31	9 31	90 00	90 00	80 29
<i>o</i>	011	0 00	26 41½	26 41½	90 00	90 00	63 18½
* <i>q</i>	403	90 00	44 18½	0 00	45 41½	45 41½	90 00
<i>k</i>	201	90 00	55 40	0 00	34 20	34 20	90 00
<i>r</i>	111	55 31½	41 36½	26 41½	56 48½	53 47½	67 55
* <i>u</i>	221	55 31½	60 37½	45 09½	44 05	34 20	60 26½
* <i>v</i>	123	36 03½	22 31	18 32	76 58½	76 17	71 58
<i>t</i>	133	25 53½	29 12	26 41½	77 42	76 17	63 58
<i>s</i>	122	36 03½	31 52½	26 41½	71 53½	69 53½	64 43½
* <i>w</i>	142	20 00½	46 56½	45 09½	75 31½	69 53½	46 38½
* <i>x</i>	233	44 09	35 01	26 41½	66 26½	63 59	65 41
* <i>y</i>	313	77 06½	36 54½	9 31	54 10	53 47½	82 18
* <i>z</i>	121	36 03½	51 12	45 09½	62 41½	53 47½	50 57
* <i>A</i>	131	25 53½	59 11	56 27½	67 58½	53 47½	39 24½
* <i>B</i>	151	16 14½	69 05½	68 19½	74 51½	53 47½	44 42
* <i>C</i>	211	71 03	57 08½	26 41½	37 23½	34 20	74 10
* <i>D</i>	231	44 09	64 33½	56 27½	51 01½	34 20	49 37
* <i>E</i>	522	74 38½	62 13	26 41½	31 27	28 39	76 27
* <i>F</i>	311	77 06½	66 04	26 41½	27 00	24 29	78 14

Uncertain: 160, 570, 580, 015, 255, 161 of Ungemach.

* New form.

X-RAY STUDY OF ANTLERITE

by W. E. RICHMOND

A crystal of antlerite approximately 1.0 mm. long and 0.5 mm. in cross section was used to determine the lattice constants. Rotation and Weissenberg photographs were taken about the $a[100]$ and $b[010]$ axes. The measurements and calculations of these photographs give the following data:

$$\begin{array}{ll} a_0 = 8.22 \text{ \AA} & a_0:b_0:c_0 = 0.687:1:0.503 \\ b_0 = 11.97 \text{ \AA} & V_0 = 592.3; \text{ Space group } D_{2h}^{16} - Pnam \\ c_0 = 6.02 \text{ \AA} & \end{array}$$

The space group was determined from the following reflections:

$$\begin{array}{l} (hkl) = \text{with all orders present} \\ (0kl) = \text{with } k+l \text{ even} \\ (h0l) = \text{with } h \text{ even} \\ (hk0) = \text{with all orders present} \end{array}$$

Content of the unit cell. The original analysis by Thaddéeff (1899), the new specific gravity (3.88), and the lattice constants were used to compute the atomic content of the unit cell. The following table summarizes these results:

	1	2	3		4	5	6
CuO	67.08	67.28	0.846	Cu	0.846	11.79	12
SO ₃	22.40	22.47	0.281	S	0.281	3.91	4
H ₂ O	10.22	10.25	0.569	H	1.138	15.86	16
Fe ₂ O ₃	0.34			O	2.258	31.45	32
CaO	0.06						
Insol.	0.48						
	100.58	100.00					

1. Analysis of antlerite from Remolinos, Chile; analyst Thaddéeff (1899).
2. Analysis calculated to 100%.
3. Molecular proportions.
4. Atomic proportions.
5. Atomic content of the unit cell.
6. Theoretical number of atoms in the unit cell.

The formula is therefore $\text{Cu}_3\text{SO}_4(\text{OH})_4$ and the unit cell contains four such molecules. The calculated density is 3.93. The formula deduced from the very similar analysis of Audrieth (1925) yields substantially the same result.

Buttgenbach (1926) described under the name heterobrochantite a mineral from Chile with the composition of antlerite but differing from that mineral in its optical properties. He also described the optical properties of an artificial copper sulphate with antlerite composition

prepared by Atanasesco (1885), and found it to constitute still a third optical variety of antlerite. Tunell (1929, p. 21) has shown that the latter distinction is based on insufficient evidence. We believe that the same is true of the supposed distinctive properties of heterobrochantite and that it also is antlerite. Mr. Jarrell, who has familiarized himself with antlerite during several years of intensive study of the Chuquicamata ores while resident there, is very definitely of this opinion. He points out in a letter to the author, "Apparently he (Buttgenbach) mistook obtuse bisectrix figures obtained on his (010) grains for flash figures. This assumption explains practically all the discrepancies between his data and the data for antlerite." Without samples of the heterobrochantite to test it is, however, not possible to state positively that it is antlerite, but Buttgenbach's evidence does not prove unambiguously that a distinction really exists.

I am indebted to Miss Alice Dowse and Mr. George Switzer for the crystal drawings.

OCCURRENCE OF ANTLERITE AT CHUQUICAMATA

Note by O. W. JARRELL

Antlerite is the principal oxide mineral of copper at Chuquicamata. It fills fracture planes that run in all directions through the altered granodiorite. The antlerite is dark green and coarsely crystalline; but, as most of the veinlets, which are up to 2.5 cm. thick, are of a cross-fiber nature, with the *c*-axes of the crystals normal to the walls of the veinlets, good terminated crystals are not common. The antlerite in these veinlets is "transported"; that is, it has not replaced directly any sulphide mineral, but has been deposited in the fractures of the rock by solutions percolating through them.

There are also not infrequently masses, up to several inches thick, of fine-grained, lighter green antlerite, found in the oxidized portions of the original sulphide veins. Besides these two principal types, there is some antlerite disseminated throughout the rock, and a little antlerite is sometimes present in masses of other minerals, such as atacamite, chalcantinite, kroehnkite, or natrochalcite. However, most of the antlerite of the ore body is not associated with other copper minerals.

The occurrence of antlerite, in relation to the other copper sulphates, conforms to the results obtained by Posnjak and Tunell (1929) in their investigation of the system $\text{CuO}-\text{SO}_3-\text{H}_2\text{O}$. Their diagrams show that in a closed system, at any given pressure and temperature, the stability range of the different copper sulphates is governed principally by the concentration of the sulphate radical in the system. With decreasing concentration of SO_3 , chalcantinite, antlerite, and brochantite are stable in

that order. At Chuquicamata antlerite is formed in some places directly from chalcocite; but, if there is much pyrite present in the oxidizing sulphides, antlerite is not stable in the immediate vicinity, but chalcantite, kroehnkite, or natrochalcite may form. Brochantite is rare at Chuquicamata, and the few genuine specimens that have been found have come from areas which indicate that it was stable only where the sulphate concentration was low. At Potrerillos, Chile, on the other hand, the primary mineralization was less pyritic than at Chuquicamata, and the presence of limestones (there are none at Chuquicamata) would be expected to reduce the sulphate concentration of the oxide zone. Eighteen specimens examined from Potrerillos were all brochantite.

Similar conclusions as to the dominance of antlerite over other copper sulphates at Chuquicamata have been presented by Bandy (1938, p. 693).

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