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BROCHANTITE

CHARLES PALACHE, *Harvard University, Cambridge, Mass.*

ABSTRACT

Brochantite is proved by crystallographic, *x*-ray, and optical study to be monoclinic. The common orthorhombic pseudosymmetry is due to twinning on (100). New elements and many new forms are presented in the new monoclinic position. Crystals described by earlier authors are analyzed with reference to the monoclinic setting.

The symmetry of brochantite has been in doubt since Schrauf (1873) published his monograph on the species. Originally described as orthorhombic by Levy (1824), there is no doubt that the vast majority of crystals hitherto studied are at least pseudo-orthorhombic in appearance. Schrauf concluded from his usual careful measurements that his crystals were either monoclinic or even triclinic with but slight deviation from orthorhombic symmetry, and that their pseudosymmetry was due to complex twinning on one or more of several laws. His stated failure to find optical confirmation of this conclusion was not regarded by him as a valid objection. No other student of the species except his colleague Brezina could verify Schrauf's findings, and brochantite appears in modern descriptions as orthorhombic with an expressed doubt as to its true symmetry. Goldschmidt (1897) with good right explains this lasting uncertainty as due to the poor quality of the crystals studied.

The writer approached the study of brochantite in an attempt to discover whether or not antlerite* had been mistaken for it in other cases than that at Chuquicamata (Palache and Warren, 1908, emended by Ungemach, 1924). New material was at hand for the study, in part already examined by Dr. Foshag of the U. S. National Museum, who had measured crystals of undoubted monoclinic symmetry and kindly loaned his crystals for this investigation. The new specimens were from the Shattuck Mine, Bisbee, Arizona. They consist of a number of masses of loosely coherent aggregates of coarse prismatic crystals of the usual type, in the interstices of which well-terminated crystals could be found. These were of two habits:— slender prisms with complex terminations; and short, tabular crystals of minute size and perfect quality always implanted on the surface of the earlier prismatic crystals. Crys-

* Compare the paper on Antlerite by the author, *Am. Mineral.*, **24**, 293–302, 1939.

tals of both habits showed individuals of well-marked monoclinic development, and also twins on the orthopinacoid {100}, which were pseudo-orthorhombic. The tabular crystals were frequently doubly terminated and so clear-cut and perfectly developed that their study left no doubt of their truly monoclinic character. The outcome of the morphologic, x-ray and optical examination is to compel the belief that brochantite is monoclinic but in a sense wholly different from Schrauf's interpretation, and that its pseudo-orthorhombic appearance is the result of almost universally present twinning. The presentation of the new data of observation will be followed by a brief review of previously described crystals in the light of the new interpretation.

Brochantite from the Shattuck Mine, Bisbee, Arizona

Type one, prismatic crystals. The crystals range from needles of extreme slenderness to stout prisms. All tend to be striated in the prism zone and the larger ones are apt to be subparallel aggregates. All are attached at one extremity and many have all the appearance of being simple individuals. Figures 1 and 2 show typical illustrations of this type, the first pseudo-orthorhombic, the second monoclinic. It is evident, however, on consulting the figures that the first may be interpreted as a symmetrical twin-group of two individuals like the second, with {100} as twinning plane. The cleavage, always previously orientated as brachypinacoidal, is parallel to the twinning plane and normal to the single plane of symmetry. It becomes therefore {100} in the monoclinic setting. Since no crystal of this type was found doubly terminated, there was no possibility of proving the presence of twinning by the observation of a re-entrant angle. The forms present are discussed below.

Type two, tabular crystals. These crystals were first found loose among the debris of prismatic crystals when a cavity had been opened. Later they were found in no small number, lightly attached to the surfaces of crystals of the dominant habit. Rarely more than a millimeter in maximum diameter, and of so consistent a monoclinic habit, they were at first supposed to be of another mineral; but measurement and optical character identified them as certainly brochantite. Figures 3 and 4 illustrate their appearance, the first an individual, the second a twin. The drawings faithfully reproduce the perfect regularity of these crystals. The twin shown in Fig. 4*b* was mounted by Dr. Berman for optical examination with the twin plane vertical. The two members of the twin showed a distinct optical discontinuity; so slight, however, was the deviation of the position of extinction of each from the common cleavage and twin plane {100} that Dr. Berman hesitated to evaluate an extinction angle, although he was convinced that the discontinuity existed. The optical orientation is indicated in Fig. 34. The cleavage {100} is so perfect that most grain mounts show only cleavage flakes, and therefore twinning is not ordinarily observable.

Crystal Measurements. Upwards of thirty crystals were measured with concordant results, as may be seen from Table 1. Here are shown the angles of the seven untwinned crystals only. They agree well with the general average collected from measurements of sixteen crystals, twinned and untwinned.

TABLE 1. BROCHANTITE: MEASURED ANGLES OF SEVEN UNTWINNED CRYSTALS.

Forms	No. of faces	Mean		Range		Calculated	
		ϕ	ρ	ϕ	ρ	ϕ	ρ
c 001	9	90°00′	13°21′	90°00′–90°09′	13°17′–13°26′	90°00′	13°21′
a 100	3	90 09	90 00	90 00 –90 27	—	90 00	90 00
l 120	2	21 17½	90 00	21 13 –21 22	—	21 09	90 00
m 110	16	37 47	90 00	37 29 –37 57	—	37 44	90 00
d 210	13	57 01	90 00	56 49 –57 13	—	57 08	90 00
p 011	7	21 04	33 23	20 35 –21 26	33 15 –33 34	21 09	33 20½
q 021	1	10 36	51 18	—	—	10 57	51 20
r 031	3	7 29	61 40	7 19 – 7 43	61 31 –61 48	7 21	61 41
z 104	2	90 00	19 36	—	19 33 –19 40	90 00	19 36
y 201	4	90 00	49 46	—	49 40 –49 51	90 00	49 53
x $\bar{7}04$	1	−90 00	30 38	—	—	−90 00	30 41
ξ $\bar{2}01$	1	−90 00	35 17	—	—	−90 00	35 27
P 111	6	49 10	43 16	48 55 –49 32	43 00 –44 00	49 15	43 13½
π $\bar{1}11$	6	−21 10	33 27	20 47 –21 33	33 18 –33 33	−21 09	33 20½
B 211	4	62 32	53 10	62 14 –62 41	53 00 –53 18	62 40	53 11
β $\bar{2}11$	3	−49 25	43 19	49 10 –49 47	43 15 –43 27	−49 15	43 13½
Ψ $\bar{1}31$	2	− 7 09	61 42	− 6 56 – 7 22	61 34 –61 50	− 7 21	61 41

One hundred faces of twelve forms were used to calculate new elements, which seem to be definitely more reliable than those of Koksharov. The calculation was made for the orthorhombic position and the results compare as shown below with other elements used.

	a : *b* : *c*
Koksharov	0.7739:1:0.4871
Goldschmidt (mean of 3)	0.7777:1:0.4906
Palache	0.7738:1:0.4747

The monoclinic position requires the following equivalent forms:—

Orthorhombic	Monoclinic
001	$\bar{1}02$
100	010
$0\bar{1}0$	100
$0\bar{1}2$	001
$2\bar{1}2$	011

Transformation formulae:—

Orthorhombic to Monoclinic $0\bar{1}\frac{1}{2}/100/001$

Monoclinic to Orthorhombic $010/\bar{1}0\frac{1}{2}/001$

The elements as given above, transformed to the monoclinic position, become $a:b:c=1.3283:1:0.6135$; $\beta=103°21'$. From these elements was calculated the new angle table shown in Table 2.

TABLE 2. BROCHANTITE: ANGLE TABLE.

Brochantite—$Cu_4(SO_4)(OH)_6$
Monoclinic; prismatic—$2/m$
$a:b:c=1.3283:1:0.6135$; $\beta=103°21'$
$p_0:q_0:r_0=0.4619:0.5969:1$; $\mu=76°39'$
$r_2:p_2:q_2=1.6753:0.7738:1$;
$p_0'=0.4747$, $q_0'=0.6135$; $x_0'=0.2373^5$

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A	Orth.
c 001	90°00′	13°21′	76°39′	90°00′	—	76°39′	*e* $0\bar{1}2$
b 010	0 00	90 00	—	0 00	90°00′	90 00	*a* 100
a 100	90 00	90 00	0 00	90 00	76 39	—	*b* $0\bar{1}0$
E 140	10 57	90 00	0 00	10 57	87 29	79 03	$4\bar{1}0$
l 120	21 09	90 00	0 00	21 09	85 13½	68 51	* $2\bar{1}0$
m 110	37 44	90 00	0 00	37 44	81 52½	52 16	*h, m* $1\bar{1}0$
n 430	45 53½	90 00	0 00	45 53½	80 27½	44 06½	*n* $3\bar{4}0$
d 210	57 08	90 00	0 00	57 08	78 49	32 52	*d* $1\bar{2}0$
F 410	72 05½	90 00	0 00	72 05½	77 18½	17 54½	$1\bar{4}0$
o 012	37 44	21 12	76 39	73 23	16 37	77 13	*o* $1\bar{1}2$
p 011	21 09	33 20½	76 39	59 10	30 50	78 34	*p* $2\bar{1}2$
q 021	10 57	51 20	76 39	39 57	50 03	81 28½	* $4\bar{1}2$
r 031	7 21	61 41	76 39	29 11	60 49	83 32	* $6\bar{1}2$
z 104	90 00	19 36	70 24	90 00	6 15	70 24	* $0\bar{3}4$
i 102	90 00	25 23½	64 36½	90 00	12 02½	64 36½	*i* $0\bar{1}1$
u 304	90 00	30 41	59 19	90 00	17 20	59 19	* $0\bar{5}4$
y 201	90 00	49 53	40 07	90 00	36 32	40 07	* $0\bar{5}2$
γ 702	90 00	62 13½	27 46½	90 00	48 52½	27 46½	*γ* $0\bar{4}1$
δ $\bar{1}02$	−90 00	0 00	90 00	90 00	13 21	90 00	*c* 001
ε $\bar{1}01$	−90 00	13 21	103 21	90 00	26 42	103 21	*e* 012
χ $\bar{7}04$	−90 00	30 41	120 41	90 00	44 01	120 41	* 054

TABLE 2. (*Continued*)

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A	Orth.
ξ $\bar{2}01$	−90 00	35 27	125 27	90 00	48 48	125 27	* 032
θ $\bar{3}01$	−90 00	49 53	139 53	90 00	63 14	139 53	* 052
ν $\bar{4}01$	−90 00	58 57½	148 57½	90 00	72 18½	148 57½	* 072
P 111	49 15	43 13½	54 33	63 27	34 01½	58 44½	* $2\bar{3}2$
π $\bar{1}11$	−21 09	33 20½	103 21	59 10	39 54½	101 26	p 212
Σ $\bar{3}31$	−32 49	65 27½	139 53	40 08	73 07	119 32	* 652
A 162	14 27½	62 15	64 36½	31 01½	59 43½	77 14	* $3\bar{1}1$
V $\bar{1}22$	0 00	31 32	90 00	58 28	33 58	90 00	v 101
x $\bar{1}42$	0 00	50 49	90 00	39 11	52 04	90 00	x 201
α $\bar{1}62$	0 00	61 29	90 00	28 31	62 19½	90 00	* 301
t 252	24 54	59 24	54 33	38 40½	54 37	68 45	t $5\bar{3}2$
ω $\bar{2}12$	−37 44	21 12	103 21	73 23	31 07½	102 47	o 112
Ψ $\bar{1}31$	− 7 21	61 41	103 21	29 11	64 10½	96 28	* 612
B 211	62 40	53 11	40 07	68 26	41 39	44 40	* $2\bar{5}2$
β $\bar{2}11$	−49 15	43 13½	125 27	63 27	53 54	121 15½	* 232
Δ $\bar{1}\bar{1}.4.4$	−60 07½	50 55½	136 53	67 15	62 45	132 19	* 494
Φ $\bar{3}11$	−62 40	53 11	139 53	68 26	65 14½	135 20	* 252

* New Forms.

Figure 33 represents a gnomonic projection based upon this angle table. It presents features which seem to call for comment.

The projection of a monoclinic crystal can approach orthorhombic symmetry in either of two ways: if the angle β is nearly or exactly 90° (case of humite), the projection of {001} falls nearly or exactly in the center of the projection; but the center of the projection also becomes a point on the lattice if the relation of μ and p_0'[1] is such that $\cot \mu = x_0' = \frac{1}{2} p_0'$. That is exactly the case in the projection of brochantite, as may be seen by inspection. It is nearly true in some other monoclinic species, such as orthoclase, diopside, hornblende and colemanite. This leads, of course, to difficulty in recognizing from the projection the true symmetry of the crystal represented. It also leads, in some instances, to pairs of forms, positive and negative respectively, such as y and θ, p and π, P and β, etc., which have identical ρ angles and ϕ angles differing only in sign. These pairs in the case of the projection of brochantite are

[1] $p_0' = \dfrac{c}{a \sin \beta}$.

the equivalents respectively of pairs or groups of faces of what were in the orthorhombic interpretation a single form. If this projection is viewed from the direction of the *b* axis it is, as regards dimensions, a true presentation of *orthorhombic* brochantite; the extent to which face-poles to the right and the left of the median line fail to be symmetrically present reflects the actual observations made upon indubitably monoclinic crystals.

It is, of course, also true that twinning on {100} may have the effect of producing full orthorhombic symmetry in the projection. Since, unless the crystal is doubly terminated, there is no sure way of recognizing the presence of twinning in brochantite, it was concluded that only those forms should be listed in the monoclinic interpretation which had actually been observed on crystals either simple or unequivocally twinned.

In Table 3 may be found a tabulation of the combinations studied. Many of these are also shown in the numerous figures of Plates I and II. The dominant habit is prismatic on [001]; but elongation on [010] and more rarely on [100] was also found. The forms most commonly developed are comparatively few. *c* {001} is rarely absent, but its correlative form ϵ $\{\bar{1}01\}$ was seen but twice. The prism zone rarely fails to show all three of the forms *a*{100}, *m*{110} and *d*{210}. *p*{011} and $\pi\{\bar{1}11\}$ are rarely lacking; together they are the equivalent of the orthorhombic pyramid *p*{212}, which was the only common and well-established pyramid form previously known. *y*{201}, $v\{\bar{1}22\}$ and *B*{211} are also common forms.

TABLE 3. BROCHANTITE: COMBINATIONS OF FORMS ON CRYSTALS STUDIED.

	Bisbee																																
Crystal	1	2	3	4	5	6	7	8	9	10	11	12	13	17	18	19	21	22	23	24	25	26	29	Algiers	Tsumeb	Chile A	Chile B	Cornwall	Frisco 1	Frisco 2	Tintic 1	Tintic 2	Vasko
c 001	x	x	x		x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x			x				x	x	x	x
b 010																					x			x	x						x		x
a 100	x	x	x	x		x		x	x	x	x			x	x	x	x	x	x		x	x	x		x	x	x	x	x		x	x	x
l 120		x	x		x			x						x								x			x								x
m 110	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
d 210	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x
p 011					x	x	x	x	x				x	x			x	x	x		x	x		x							x	x	
q 021													x																				
r 031					x		x				x		x				x																
z 104															x	x												x					
i 102											x	x			x																		
u 304																							x										
y 201	x				x			x		x	x				x				x		x	x	x										x
δ $\bar{1}02$																													x				
ε $\bar{1}01$																					x												x
χ $\bar{7}04$																		x															
ξ $\bar{2}01$															x		x					x	x										
θ $\bar{3}01$																				x													
ν $\bar{4}01$					x										x								x				x						
P 111								x	x			x		x			x	x	x		x												
π $\bar{1}11$	x				x		x					x	x	x		x	x	x	x	x	x	x	x										
Σ $\bar{3}31$																						x											
A 162		x	x	x			x								x																		
V $\bar{1}22$		x	x	x	x								x		x									x	x	x	x					x	x
α $\bar{1}62$		x		x	x								x	x	x										x		x					x	
ω $\bar{2}12$								x																									
Ψ $\bar{1}31$													x																				
B 211					x	x				x	x		x					x	x		x	x	x										
β $\bar{2}11$									x			x		x		x	x			x		x	x										
Δ $\bar{1}\bar{1}.4.4$																		x															
Φ $\bar{3}11$					x									x	x	x				x													
Twin						T														T		T			T		T	T		T		T	
Figure	2							3				9				6		7		5	10	4	8	11	12	13	14	15	16	17	18	19	20

The angle table contains a number of forms equivalent to forms unknown to orthorhombic brochantite. These new forms are collected together with the determining angles in Table 4.

Table 4. Brochantite: Measurements of New Forms.

		Mean		Range		No.	Qual.	Orth.
		ϕ	ρ	ϕ	ρ			
l	120	21°14′	90°00′	20°51′–21°31′	—	10	fair	$2\bar{1}0$
q	021	10 50	51 20	—	—	1	good	$4\bar{1}2$
r	031	7 11	61 41	7 02 – 7 19	61°34′–61°50′	5	good	$6\bar{1}2$
z	104	88 52	20 16	88 11 –90 00	19 40 –20 33	4	poor	$0\bar{3}4$
u	304	90 00	29 54	—	—	1	excellent	$0\bar{5}4$
y	201	90 00	49 46½	89 57 –90 00	49 18 –50 00	12	excellent	$0\bar{5}2$
χ	$\bar{7}04$	−90 00	30 38	—	—	1	poor	054
ξ	$\bar{2}01$	−89 43	35 17	89 27 –90 00	35 17 –35 18	2	excellent	032
θ	$\bar{3}01$	−88 35	49 40	—	—	1	poor	052
ν	$\bar{4}01$	−89 42	58 44	89 08 –89 59	58 00 –59 10	3	poor	072
P	111	49 14	43 14½	48 55 –49 32	43 07 –43 22	7	fair	$2\bar{3}2$
Σ	$\bar{3}31$	−32 38	65 25	—	—	1	excellent	652
A	162	14 14	62 25	13 55 –15 00	61 57 –62 34	5	excellent	$3\bar{1}1$
α	$\bar{1}62$	0 36	61 29	0 00 – 1 00	61 11 –61 43	4	poor	301
ψ	$\bar{1}31$	− 6 54	61 50	—	—	1	excellent	612
B	211	62 35	53 10	62 14 –62 48	52 54 –53 28	12	good	$2\bar{5}2$
β	$\bar{2}11$	−49 24½	43 18	−49 04 –49 55	43 06 –43 27	7	poor	232
Δ	$\overline{11}.4.4$	−60 19	50 55	−50 55 –60 10	—	2	good	494
Φ	$\bar{3}11$	−62 35	53 02	−62 28 –62 46	52 48 –53 10	5	fair	252

The occurrence of these new forms on the crystals studied may be seen in Table 3. Many of them occur frequently and are certainly established. Those reported but once may perhaps be regarded as calling for confirmation, but they were not accepted without remeasurement in each case to make sure that each represents a distinct face. Most of them were confined in their occurrence to the Bisbee crystals.

Twinning. The almost universal presence of twinning on the orthopinacoid in brochantite must be related in a definite manner with its structure. At the request of the author, this matter was examined by Mr. Wolfe, who made the following report on it.

Twinning of brochantite on {100} produces a precise coincidence of lattice points of the twinned and untwinned individuals (within the limits of measurement), but the crystal motif of one is reversed with respect to the other. This is a common form of twinning. When such coincidence of twinned lattices occurs, the probability of twinning, according to the theory of twinning of Friedel, is large. In terms of his theory, this twin law is a case of twinning by pseudo-reticular merohedry with an obliquity of 0° ± and an index of 1.

Although the limits of measurement do not indicate any deviation from twinning by reticular merohedry, the twinning must be by pseudo-reticular merohedry, since the former is not possible in the monoclinic system. The lattice row [201], consequently, must deviate somewhat from the normal to the twin plane, although the geometrical elements adopted indicate precise coincidence. (In the morphological description $\{\bar{1}02\}$ is precisely normal to [001].) Pseudo-reticular merohedry is further indicated by the planar rather than irregular nature of the composition surface.

Doubtful forms. Several forms reported by Schrauf seem highly doubtful for various reasons; most of them were described as measured on curved or imperfect faces. In the following list we have attempted to give a monoclinic interpretation of them.

Schrauf		Monoclinic	
μ	730	370	probably vicinal to {120}
λ	610	160	described as having curved faces
f	616	$\bar{2}33$	very close in position to $\{\bar{1}22\}$
g	313	$\bar{5}66$	probably vicinal to $\{\bar{1}11\}$
s	136	$\bar{6}16$	close to $\{\bar{1}01\}$
k	12.1.4	3.12.4	close to the common form $\{\bar{1}62\}$. Compare Fig. 16, Pl. II. The faces of *k* are described as always curved.

ρ{1.16.0} of Jeremejew is probably vicinal to {100}. {140} and {410} are prisms reported by Schoep (1927) and shown in our Fig. 32. He also found {340} as did Biehl (1919) on a crystal from Tsumeb, which he did not figure.

Many observations of single faces with poor reflections were made on our crystals but these forms, although mostly with simple indices, seemed too doubtful to record.

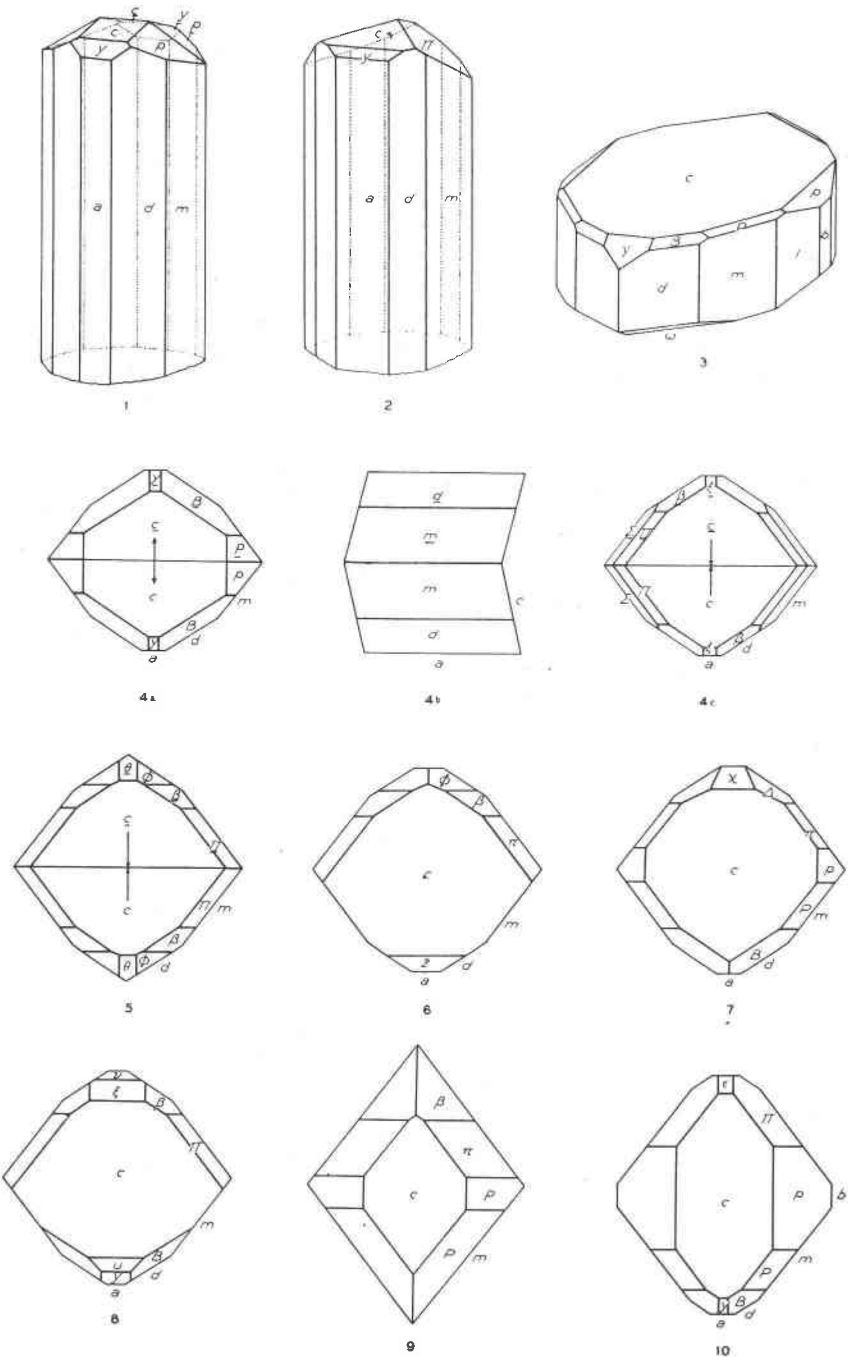


PLATE I. BROCHANTITE

All crystals illustrated on this plate are from Bisbee, Arizona.

FIG. 1. Prismatic crystal, twinning on {100}. Pseudo-orthorhombic.

FIG. 2. Similar crystal, untwinned. No. 2 of Dr. Foshag.

FIG. 3. Tabular crystal (No. 8) doubly terminated. Such crystals sometimes show a fine twin-lamella traversing the basal pinacoid parallel to {100}.

FIGS. 4*a*, *b*, *c*. Doubly terminated twin crystal (No. 26).

a. Top of crystal in plan; arrows show slope of basal planes.

b. Side elevation without truncating terminal planes.

c. Bottom of crystal in plan.

FIG. 5. Twin crystal, doubly terminated, in plan.

FIGS. 6, 7, 8, 9, and 10. Tabular crystals, each doubly terminated, in plan, showing various combinations of forms. All show pronounced monoclinic symmetry both in general form and especially in the varying distribution of the orthodome forms.

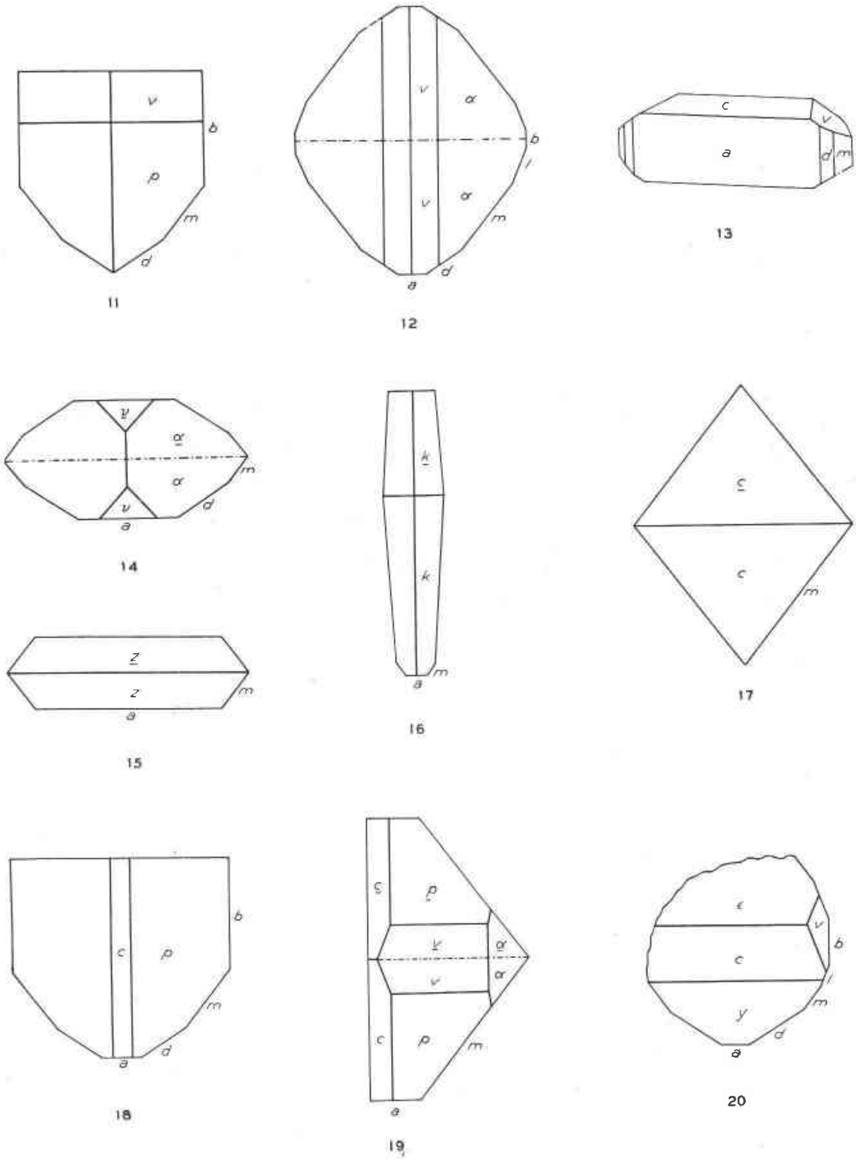


PLATE II. BROCHANTITE

FIG. 11. Bon Thaleb, Algeria (No. 88658). Plan of a thick, stubby crystal somewhat elongated on [100]. It is alike above and below and shows no evidence of twinning. Crystal of poor quality.

FIG. 12. Tsumeb, S. W. Africa (No. 93927). Plan of a stout prismatic crystal elongated on [001]. Regarded as a twin. No re-entrants since terminal faces are normal to twin plane.

FIG. 13. Chile (Micromount). Projection of a crystal, thin tabular and elongated on [010]. It is untwinned and was confirmed as brochantite by optical tests.

FIG. 14. Collahurasi, Chile (Micromount). Plan of a crystal, thick tabular and elongated on [010]. Drawn as a twin but shows no re-entrant, as the form α is normal to the twin plane.

FIG. 15. Cornwall (Micromount). Plan of a tablet, thin parallel to {100} and elongated on [010]. Interpreted as a twin because no negative form corresponding to {104} was found on untwinned crystals.

FIG. 16. Tintic, Utah. Reproduction of Figure 2 in Dana, *System*, page 926. See section on uncertain forms.

FIG. 17. Frisco, Utah (Micromount). Plan of a twin crystal, elongated on [001]. The simplest combination found.

FIG. 18. Eureka Hill, Tintic, Utah (No. 92374). Plan of a crystal like Figure 11, untwinned and elongated on [100]. Terminated in the back by a cleavage plane.

FIG. 19. Same locality as last (No. 92390). Plan of a crystal without re-entrants. Crystal of poor quality.

FIG. 20. Vaskö, Banat, Hungary. Plan of a crystal fragment, untwinned.

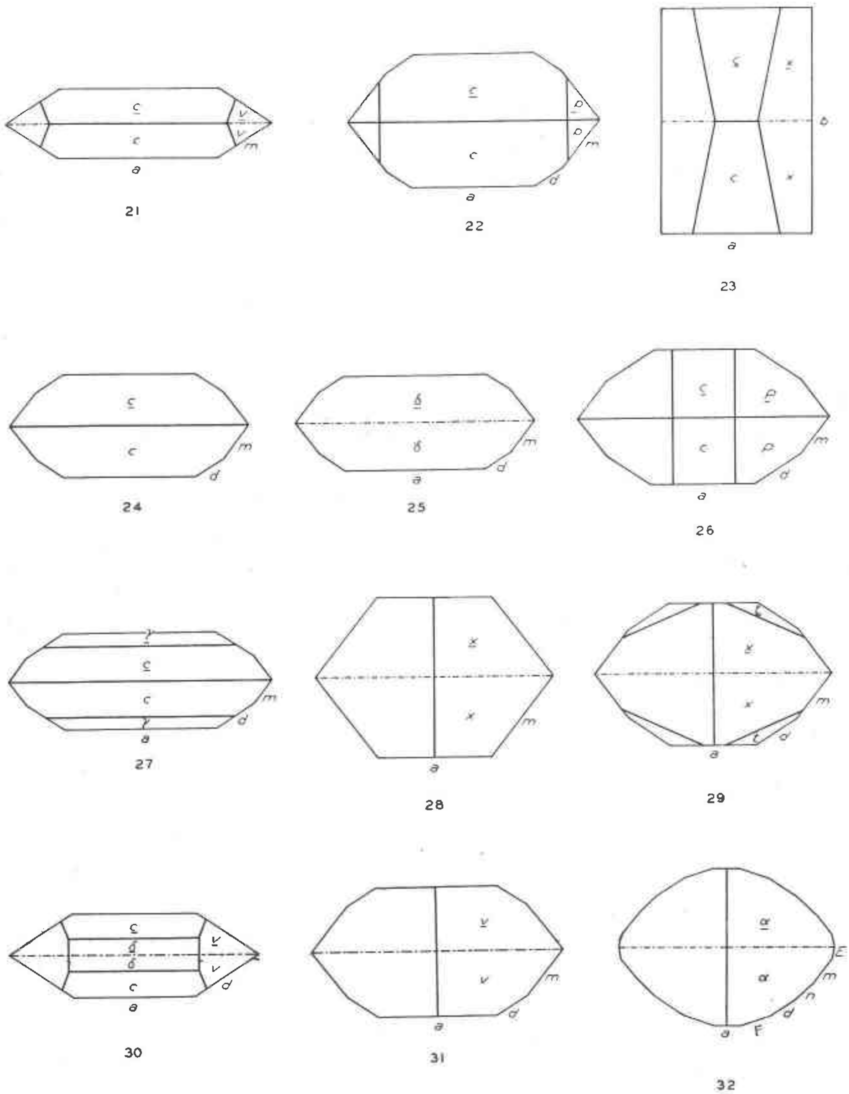


PLATE III. BROCHANTITE

Monoclinic interpretations of published figures of other authors. The figures are drawn in plan and are in part schematic. References are to the numbered figures in Goldschmidt's *Atlas*, Vol. I.

FIG. 21. A twin. Siberia, Gdt. Fig. 4 and perhaps Roughten Gill, Fig. 12. Both these figures are drawn in our position.

FIG. 22. A twin. Rezbanya, Hungary, Gdt. Figs. 7, 21, 22, and 23. We regard the slight re-entrants shown on the face *e* in some of Schrauf's drawings, and regarded by him as evidence of twinning, as oscillatory striation, common on this face of brochantite.

FIG. 23. A twin elongated on [100]. Siberia. Variety "königine." Gdt. Figs. 31 and 34. Gdt. Figs 3 and 30 are the same combination in another position. Gdt. Figs. 2 and 6 are the same but without the basal plane.

FIG. 24. A twin. The commonest habit of brochantite. Gdt. Figs. 5, 8 (which lacks {100}), 9, 10 and 18. In Fig. 40 *m* is replaced by a vicinal ρ. This habit is shown in both Dana and Hintze.

FIG. 25. A twin. Siberia. Variety "Warringtonite." Gdt. Fig. 29. We regard the re-entrants shown by Schrauf on the faces of *m* as due to subparallel growth and not to twinning.

FIG. 26. A twin. Rezbanya. Gdt. Figs. 13, 14, 17 and 20.

FIG. 27. Vaskö, Hungary. Gdt. Fig. 44. The same figure is given by Eakle (1908) for Cerro Gordo, Calif. Eakle figures as a simple crystal what we interpret as a twin but states that the crystals have commonly but one face of *e*, which would indicate then an untwinned crystal.

FIG. 28. Tintic, Utah. Gdt. Fig. 37. This is probably a twin but would show no re-entrant. Dana, Fig. 4. Figured by Lacroix (1910) from Maures, France.

FIG. 29. Tintic, Utah, Gdt. Fig. 41. Twinning inferred, as the form *x* would show no re-entrant. The form *t* {252} known only from this figure. Elongation on [001].

FIG. 30. New Caledonia. Gdt. Fig. 42. Interpreted as a twin without re-entrants. Elongation on [010].

FIG. 31. Collahurasi, Chile. Gdt. Fig. 43. A twin without re-entrants. Elongation on [001]. Compare our Fig. 14, Pl. II.

FIG. 32. Katanga, Belgian Congo. Schoep (1927), Fig. 3. A twin without re-entrants. Elongation on [001]. The only reported occurrence of the prisms *E* and *F*.

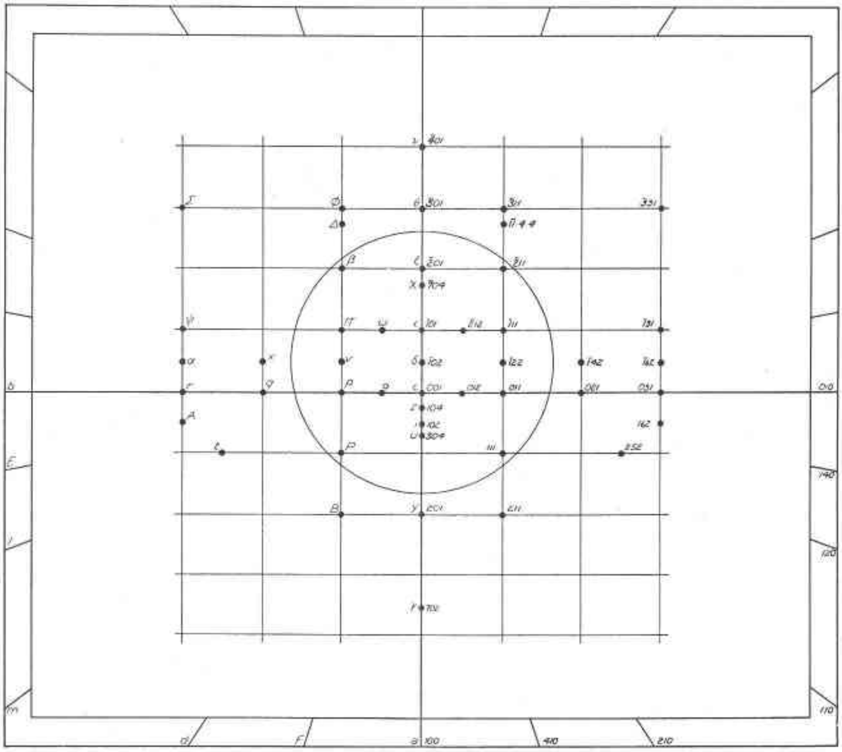
Interpretation of older drawings of brochantite. In Goldschmidt's *Atlas*, vol. **I,** Plates 233–235, there are forty illustrations of brochantite crystals. In our Plate III we have reproduced in plan a number of these crystals with the new position and lettering. Our interpretation is, of course, open to doubt but in most cases is highly probable. Many of the figures are shown as doubly terminated crystals, but careful reading of the original papers shows that this is rarely justified by the material studied. For example, in the many figures of Schrauf, but one, Fig. 13, was doubly terminated and that shows, as it should in the sense of our monoclinic setting, a deep re-entrant due to twinning. Figures 28, 32 and 33 have not been reproduced in our series; the interpretation is not clear unless it is assumed that the form *k* be taken as the equivalent of our $\{\bar{1}62\}$. Since this form is normal to the twinning plane, it forms no re-entrant; but it is usually rounded and difficult to measure accurately. In that case, these figures are somewhat like our Fig. 14 but with different modifying planes. The explanations accompanying Plate III indicate our analysis of many of the figures.

Reference has already been made to the peculiar difficulty of proving the presence of twinning by the optical method and the reason for it. The new setting requires a revised statement of the optical orientation which is now as follows, with the data of Larsen's tables:—

Biaxial negative. $2V=77°\pm2°$. $r<v$ medium.
Slightly pleochroic in bluish greens.

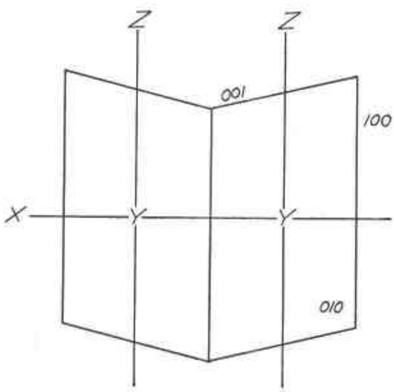
$X=a$ very nearly $=1.728$
$Y=b$ $=1.771$
$Z=c$ very nearly $=1.800$

Figure 34 is intended to show this orientation in the case of a twin crystal.



33

FIG. 33. Gnomonic projection of the forms of brochantite.



34

FIG. 34. Optical orientation of twin crystal of brochantite.

X-RAY STUDY OF BROCHANTITE

By W. E. Richmond

The x-ray study was made on a transparent crystal approximately equidimensional, about 0.5 mm. in diameter. It was free from twinning except for a minute lamella, which could just be seen as a line on the basal plane parallel to {100}.

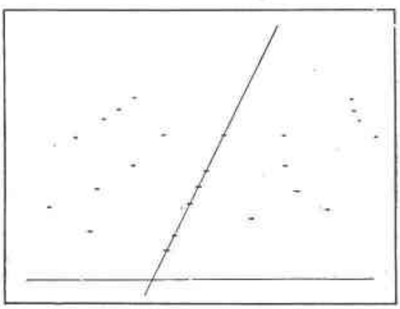
Rotation and Weissenberg zero and first layer-line photographs were taken rotating about [010]. A Weissenberg zero layer-line photograph was also taken about [001]. The calculation of these photographs yielded the following values:—

$a_0 = 13.05$	$a_0:b_0:c_0 = 1.328 : 1 : 0.611^5$, $\beta = 103°22'$
$b_0 = 9.83$	$a : b : c = 1.3283 : 1 : 0.6135$, $\beta = 103°21'$ (morphology)
$c_0 = 5.85$	
$V_0 = 750$ cubic Å	

The space group is $C_2^5 - P\,2/a$ determined from the following reflections:

(hkl) with all orders present
($h0l$) with h even
($0k0$) with k even

Symmetry. The first layer-line Weissenberg photographs about [010] confirm the monoclinic symmetry, as may be seen in Fig. 35, which is a tracing of the photograph of the first layer line. The absence of symmetry in the arrangement and intensities of the spots here, in contrast to the symmetry shown in Fig. 36, traced from a similar photograph of a twin crystal, leave no doubt that the crystal is monoclinic.



35

Fig. 35. Tracing of a Weissenberg x-ray photograph of the first layer-line about [010] of an untwinned crystal of brochantite.

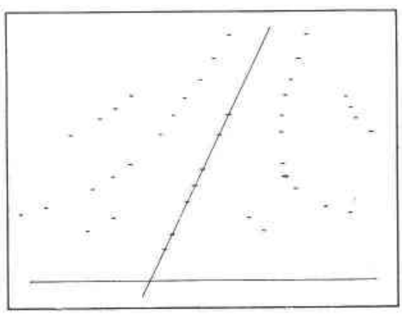


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Fig. 36. Tracing of a Weissenberg x-ray photograph of the first layer-line about [010] of a twinned brochantite crystal.

Content of the unit cell. An analysis by Ford (1910) and a new specific gravity determination (3.97*) was used for computing the content of the

* On a single crystal, by the *torsion microbalance*.

unit cell, the results of which are given in the following table:

	1	2	3		4	5	6
CuO	70.29	70.43	0.885	Cu	0.885	15.98	16
SO_3	17.54	17.58	0.220	S	0.220	3.98	4
H_2O	11.96	11.99	0.667	H	1.334	24.10	24
				O	2.212	39.95	40
	99.79	100.00					

1. Average of two analyses; analyst, W. E. Ford.
2. Analysis calculated to 100%.
3. Molecular proportions.
4. Atomic proportions.
5. Number of atoms in the unit cell.
6. Theoretical number of atoms in the unit cell.

This gives the formula $Cu_4(SO_4)(OH)_6$, and the unit cell contains four such molecules.

Acknowledgments

The author is unwilling to bring this paper to a close without expressing his indebtedness to those who have aided him in its preparation. Dr. Foshag not only loaned me his measured crystals for study but permitted me to publish the facts of the monoclinic character of brochantite, which he had established. Dr. Tunell confirmed our *x*-ray analysis of the symmetry of brochantite. Dr. Berman studied the optics and specific gravity. Miss Dowse and Mr. Switzer prepared the illustrations after the author's sketches.

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