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CLINOCLASITE

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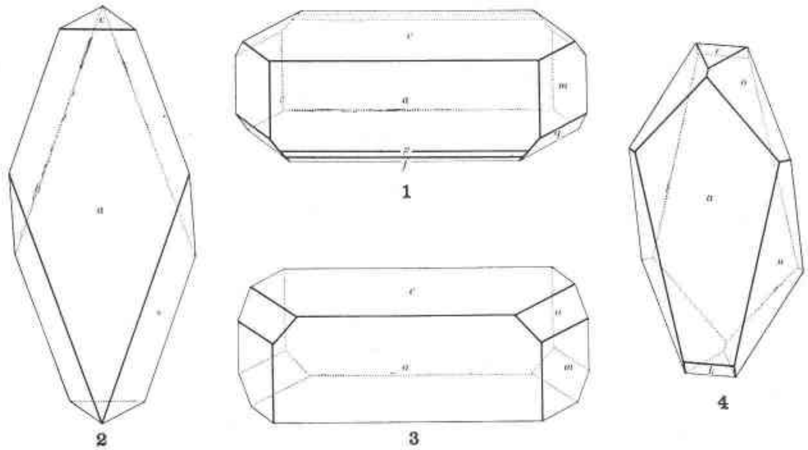
ABSTRACT

Clinoclasite, $Cu_3AsO_4(OH)_3$, is described from a new locality, Majuba Hill, Nevada, from Cornwall, and from Utah, with complete revision of its morphology. Monoclinic; prismatic—$P2_1/a$. $a:b:c=1.9109:1:1.1223$, $\beta=99°22'$; $p_0:q_0:r_0=0.5873:1.1073:1$, $\mu=80°38'$; $a_0=12.36$, $b_0=6.45$, $c_0=7.23$Å, $\beta=99°30'$. Forms: $c(001)$, $a(100)$, $m(110)$, $g(\bar{2}01)$, $o(111)$, $q(\bar{1}11)$ and others less certain. The relations of the new elements to those hitherto used are explained. There are 4 units of the formula given above in the unit cell. An x-ray powder photograph is given.

The copper arsenate clinoclasite was first found among the numerous gossan minerals of the copper mines of Cornwall. It was striking in color and in the very symmetrical spherical and cylindrical shapes of the aggregates in which it commonly occurred. Single crystals were rare and the measurements recorded by Brooke (1822) and Phillips (1823) were stated to be approximate only, because of the small size and warped faces of the crystals studied. No better crystals have been found up to the present time, although some of different habit and likewise yielding only approximate measurements were described by Hillebrand and Washington (1888) from Tintic, Utah. All crystallographic data for clinoclasite rest then on imperfect measurements. The mineral remains a rare one, only two or three additional localities having been recorded for it.

Clinoclasite crystals, identified on specimens from Majuba Hill, Nevada, sent to the Harvard Mineralogical Laboratory for examination by Professor V. P. Gianella, proved to be suitable for exact goniometric study. The results of this examination lead to so considerable a revision of the elements, forms and setting of the species that it seems desirable to place them on record. The relations of the new data to the old will be discussed after the newly won facts are presented.

The Nevada clinoclasite consists in part of slender needles, isolated or loosely grouped on a siliceous matrix,—in part of small rosettes of similar needles grouped in spherical radiations. The needles are so dark a blue as to appear black in reflected light. The rosettes and any bruised crystals show the pearly cleavage and the lovely greenish-blue color so characteristic of the mineral.



FIGS. 1–4.—Clinoclasite crystals. FIG. 1.—Nevada, with forms: *c*(001), *a*(100), *m*(110), *f*($\bar{3}$02), *g*($\bar{2}$01), *q*($\bar{1}$11). FIG. 2.—Cornwall, with forms: *c*(001), *a*(100), *s*($\bar{5}$52). FIG. 3.—Utah, with forms: *c*(001), *a*(100), *m*(110), *o*(111). FIG. 4.—Utah, with forms: *c*(001), *a*(100), *k*($\bar{4}$01), *o*(111), *u*($\bar{9}$72).

Clinoclasite is monoclinic and it was evident that these needles were elongated parallel to the symmetry axis *b*. There was some difficulty in detaching crystals free from distortion due to the easy gliding transverse to the basal cleavage, but several were obtained practically undisturbed. The crystals were mostly implanted by one end of the *b*-axis, but occasionally doubly terminated needles could be found. Their size averages 0.1 mm. in diameter by 1 mm. in length.

The *b*-axis and the orthopinakoid zone were adjusted to the axis of the vertical circle of the goniometer, and all measurements in what follows were made in this position of second permutation with (010) as pole. Calculations of the observed angles followed the method given by Wolfe (1941) for this position.

The crystals proved to be terminated generally by two pairs of excellent faces taken respectively as unit prism {110}* and negative unit prism {$\bar{1}$11}. If one pair was missing, it was always the latter. The strongest form in the zone [010] was that to which the perfect cleavage is parallel, {001}; but scarcely less well developed was a pinakoid in a radial zone with the prism {110}, hence to be taken as {100}. Other forms than these were confined to slight striated areas between them, indexed with uncertainty as orthopinakoids {301}, {$\bar{3}$02}, {$\bar{2}$01}, and {$\bar{5}$02}. The appearance of the crystals is shown in Fig. 1; the measurements are presented on a later page in Table 1 together with those of other clinoclasite crystals. There was no ambiguity in the choice of axes and indices for the main forms as shown in gnomonic projection; the axes so chosen were confirmed by the *x*-ray study recorded on a later page by Dr. Hurlbut.

While there was good agreement between the position of some of the forms found on the Nevada clinoclasite and the recorded data, the differences were so considerable for others that it was evidently important to measure and compare with these crystals others from Cornwall and Tintic. Search of the collection finally revealed two specimens, one from each locality, which provided crystals of surprisingly good quality.

The Cornish crystals are shown in Fig. 2. They are tiny tablets 0.1−0.25 mm. by 0.1−0.2 mm. which show but three forms, the two pinakoids {001} and {100} and a steep negative prism {$\bar{h}kl$}. The measurements obtained from four of them are contained in Table 1. The two pinakoids gave excellent signals despite their small size and there was no trace of other forms in the zone with them. The faces of the prism, however, were uneven and gave a group of poor signals separated both in ϕ and ρ by several degrees so that the positions given in the table for it are approximations only.

The crystals from the Tintic specimen proved to be the best ones found. They differ from the Nevada crystals but little in general form as shown by Fig. 3. The slender needles are elongated on [010] and have as terminal faces generally two pairs of faces belonging to the unit prism {110} and the positive unit prism, {111}, both of which gave good and consistent position angles. If one pair was lacking, it was the prism {110}. The measurements of four of these Tintic crystals form the last group of Table 1. There were no indications either on these or on the Cornwall crystals of any faces in the orthodome zone except the two pinakoids.

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* Nomenclature of monoclinic prisms follows Federov as modified by Rogers, *Am. Mineral.*, **20**, 838 (1935).

TABLE 1. MEASUREMENTS OF CLINOCLASITE CRYSTALS
(010) as pole

	Number of		Qual.	ϕ_2	ρ_2	Range	
	crysts.	faces				ϕ_2	ρ_2
			(a) Nevada				
c 001	9	16	fair	80°53′	90°00′	80°19′– 81°40′	—
a 100	9	18	good	0 00	90 00	—	—
m 110	9	10	good	0 00	28 02	—	27°55′–28°20′
h $\bar{5}02$	1	1	poor	144 05	90 00	—	—
f $\bar{3}02$	5	7	poor	127 41	90 00	125 54–128 28	—
g $\bar{2}01$	4	6	poor	134 17	90 00	131 22–136 07	—
d 301	1	1	good	27 56	90 00	—	—
o 111	2	44	v. poor	52 40	48 28	52 19– 52 55	48 13 –48 45
q $\bar{1}11$	7	10	good	113 11	44 15	112 31 –113 49	44 00 –44 35
s $\bar{5}52$	1	1	v. poor	140 14	31 20	—	—
			(b) Cornwall				
c 001	4	7	good	80 32	90 00	80 26 – 80 41	—
a 100	4	7	good	0 00	90 00	—	—
s $\bar{5}52$?	2	3	v. poor	144 28	33 38	142 22 –146 17	33 32 –33 50
	2	4	v. poor	148 43	33 40	148 11 –149 00	33 10 –34 00
			(c) Tintic, Utah				
c 001	3	6	v. good	80 31	90 00	80 26 – 80 36	—
a 100	3	6	v. good	0 00	90 00	—	—
m 110	3	4	good	0 00	28 10	—	28 00 –28 18
o 111	3	5	v. good	52 40	48 10	52 08 – 52 58	48 05 –48 25

Examining the data of Table 1, it may be seen that the values marked *good* and *very good* relate in all three localities to the two pinakoids *a* and *c*; and on the Nevada and Utah crystals to the prism {110} and the two prisms {*hkl*} *o* and *q*. The general average of the ϕ_2 angles of {001} is $80°38' = \mu = 180° - \beta$. After calculating the elements of the Nevada and Utah crystals separately (the Cornwall crystals could not be used because the symbol of the prism {*hkl*} is uncertain) it was concluded that the best treatment was to use the position angles of *o* {111} and *q* {$\bar{1}11$} in one operation, although these values were derived from sets of crystals from two localities. The results are as follows:—

$$r_2 = 0.9031 \qquad a = \frac{1}{p_2 \sin \mu} = 1.9109$$

$$p_2 = 0.5304 \qquad c = \frac{1}{r_2 \sin \mu} = 1.1223$$

$$\mu = 80°38' \qquad \beta = 99°22'$$

From these elements the angle table, Table 2, was calculated.

TABLE 2. ANGLE TABLE FOR CLINOCLASITE
Monoclinic; prismatic

$a:b:c=1.9109:1:1.1223$; $\beta=99°22'$, $r_2:p_2:q_2=0.9031:0.5304:1$
$p_0:q_0:r_0=0.5873:1.1073:1$; $\mu=80°38'$, $p_0'=0.5953$, $q_0'=1.1223$, $x_0'=0.1650$

	ϕ	ρ	ϕ_2	ρ_2=B	C	A
c 001	90°00′	9°22′	80°38′	90°00′	—	80°38′
a 100	90 00	90 00	0 00	90 00	80°38′	—
m 110	27 56½	90 00	0 00	27 56½	85 37½	62 03½
d 301	90 00	62 51½	27 08½	90 00	53 29½	27 08½
f $\bar{3}02$	−90 00	36 03	126 03	90 00	45 25	126 03
g $\bar{2}01$	−90 00	45 43½	135 43½	90 00	55 05½	135 43½
h $\bar{5}02$	−90 00	52 55½	142 55½	90 00	62 17½	142 55½
o 111	34 07	53 35	52 45	48 13½	48 46	63 10
q $\bar{1}11$	−20 58½	50 14½	113 17	44 07½	54 06½	105 58½
s $\bar{5}52$?	−25 15	72 08	142 56½	30 35½	76 18½	113 57
**k*($\bar{4}01$)?	−90 00	65 43	155 43	90 00	75 05	155 43
($\bar{9}72$)?	−34 38½	78 10	159 46	36 22	83 35	123 48
**u*($\bar{7}61$)?	−30 43½	82 43½	165 58	31 29½	87 34	120 27

* Doubtful additional forms noted by Berry.

The comparison of measured (average) angles with calculated values shown in Table 3 reveals only a moderately good agreement, but this is perhaps as might be expected from the somewhat meager material upon which the calculated angles are based.

TABLE 3. COMPARISON OF MEASURED (AVERAGE) AND CALCULATED ANGLES

	Measured (aver.)		Calculated	
	ϕ_2	ρ_2	ϕ_2	ρ_2
001	80°38′	90°00′	80°38′	90°00′
110	0 00	28 06	0 00	27 56½
111	52 40	48 10	52 45	48 13½
$\bar{1}11$	113 11	44 15	113 17	44 07½

X-Ray Crystallography by C. S. Hurlbut, Jr. One of the crystals in which the *a* and *c* faces could be easily recognized was used for *x*-ray study. Rotation and zero- and first-layer line Weissenberg photographs were taken with *b* [010] the axis of rotation. From the zero-layer Weissenberg photograph the spacings $d_{(100)}=12.17$ Å and $d_{(001)}=7.11$ Å were determined. A zero-layer Weissenberg photograph was taken with *c*[001] the axis of rotation, from which $d_{(010)}=6.42$ Å was obtained. This corresponds closely to a spacing of $d_{(010)}=6.40$ Å obtained from the rotation photograph about *b*[010]. From calculations made from *x*-ray data the angle $\mu=79°57'$. The value of $\mu=80°38'$ obtained from morphological crystal measurements is believed to be the more accurate and was, therefore, used to calculate the absolute lengths of the axes, which are:

$$a_0=12.33\text{Å},\ b_0=6.42\text{Å},\ c_0=7.21\text{Å}.$$

The ratios of these lengths are:

$$a_0:b_0:c_0=1.921:1:1.122.$$

From the criteria

hkl present in all orders.
h0l present only with *h* even.
0*k*0 present only with *k* even.

The space group was determined to be $P2_1/a$.

Optical Properties. Dr. Hurlbut re-determined the optical properties of clinoclasite from Majuba Hill and from Tintic, Utah. He confirmed the orientation given in Larsen's tables but revised the refractive index data as follows:—

$$\alpha=1.756,\ \beta=1.874,\ \gamma=1.896,\ 2V=50°.$$

In order to bring out the relation of the new data on clinoclasite to the morphology as recorded in the literature, there is presented in Table 4 a tabulation taken from *Goldschmidt's Winkeltabellen* for "Abichite" (an old name for clinoclasite) transformed to the position of second permutation as used in this paper.

TABLE 4. ANGLE TABLE FOR "ABICHITE," GOLDSCHMIDT

$r_2=0.2633$		$p_2=0.5317$	$\mu=80°30'$
		ϕ_2	ρ_2
c	001	80°30′	90°00′
a	100	0 00	90 00
m	110	0 00	28 00
r	101	24 18	90 00
s	$\bar{3}02$	161 00	90 00
t	$\bar{1}11$	151 59	28 56
p	$\bar{1}13$	117 15½	41 14

On first inspection there is great resemblance between this table and the corresponding angles of Tables 1 and 2. There is essential identity as regards the mutual attitude of the pinakoids, the angle of the prism $\{110\}$, and the value of p_2 ($p_2 = \tan \rho_{110}$). But beyond this the resemblance is not so close. r_2 of Table 4 is approximately one-third of r_2 of Table 2 (0.3010). This is equivalent to considering the new value of c as one-third of the old one; otherwise stated, the form $p\{\bar{1}13\}$ becomes $\{\bar{1}11\}$ in the new position, an identity which was at first accepted in this study.

			ϕ_2	ρ_2
Table 4	p	$\bar{1}13$	117°15½′	41°14′
Table 2	q	$\bar{1}11$	113 17	41 07½

But this apparent resemblance is fallacious. Examination of the figures of clinoclasite in *Dana* or in *Goldschmidt's Atlas*, Vol. **5**, Plate 16, shows that on every one $m\{110\}$ is a dominant form, the other two principal forms being $c\{001\}$ and $s\{\bar{3}02\}$, the latter often with other lettering. More striking is the absence on most of the figures of $a\{100\}$, which on all our crystals is a dominant form. It is to be remembered that the axial ratio of Phillips, used also by *Dana* and *Goldschmidt*, was calculated from approximate measurements on crystals from Cornwall. His position was probably chosen to enable a value for the ratio of a to c to be calculated from the faces of the orthopinakoid zone, since the prism $\{hkl\}$ was probably difficult to measure exactly and could thus be made the prism $\{110\}$. If Dana's Fig. 2 be compared to Fig. 2 on a preceding page, it will be seen that they are essentially identical, but Dana's figure must be turned front for back and then tilted forward until the face s is vertical for the identity to appear fully. Our morphological study and the x-ray analysis prove that our position for a crystal of this type is the correct one.

The figures of Tintic crystals shown in *Dana* were drawn by Washington (1888) when a student under Penfield at Yale. He followed Phillip's setting, as was quite natural, as he states that his crystals did not admit of accurate measurement. His figures are comparable to our Fig. 3 except that the orthopinakoid $s\{h0l\}$ should be made the front pinakoid as just explained, and his prism $\{110\}$ would then become a negative prism $\{\bar{h}kl\}$. Furthermore, it is to be noted with regard to the two forms $t\{\bar{1}11\}$ and $p\{\bar{1}13\}$ of Table 4, which were established by Washington, that the faces were poor and that the calculation of the symbol, at least for p, is in error. Washington's measured angles, plotted stereographically on Phillips' axes, do not fall within many degrees of the position of $\{\bar{1}13\}$. They yield rather a symbol near $\{\bar{5}.3.10\}$; and all of the angles calculated for the new form p were wrong, corrected long ago by *Dana* in the *System*. In short, the terminal face which in Table 3 seemed to be equivalent to the new $\{\bar{1}11\}$ has no existence in reality. The form *t* may have been the equivalent of our form $\{\bar{5}52\}$, but the one angle given for it is insufficient to determine its nature.

When Phillip's angles are plotted stereographically with his axes and then subjected to the rotation described above as necessary to bring them to our position, the angles of the new positions can be used to calculate the transformed symbols. They are as follows:—

Phillips		Palache	
c	001	*c*	001
s	$\bar{3}02$	*a*	100
a	100		$\bar{5}01$
r	101		$\bar{2}01$
m	110		$\bar{5}51$

But our measurement of the prism $\{\bar{h}kl\}$ on Cornish crystals seemingly equivalent to the $\{110\}$ of Phillips is much nearer to $\{\bar{5}52\}$. It is clear that there has been some mistake in angles, probably those of the poor prism $\{\bar{h}kl\}$ form. It seems an odd chance that Phillips' angle *c* to *s*, which is 80°30′, should be identical with the angle *a* to *c*. This, too, might well have led to error or confusion. It was thought that this transposition could be expressed in a transformation formula. A very complex formula was obtained which, however, failed for two of the five forms and the attempt was abandoned in the certainty that there is a concealed error in Phillips' original measurements.

Our conclusion, then, is that the current crystallographic data for the mineral clinoclasite are erroneous and that the published figures are incorrect. It is hoped that the present study will adequately replace both data and illustrations.

SUPPLEMENTARY OBSERVATIONS

L. G. Berry

In the course of an *x*-ray investigation of clinoclasite and other mineral phosphates, arsenates, and vanadates of the type $A_3XO_4(OH)_3$, it was learned that Professor Palache had prepared the foregoing account of his observations on clinoclasite. Since the writer's observations on clinoclasite confirm and amplify the work done at Harvard University they are included in the present paper. These additional observations were made on four specimens, three of which were kindly loaned from the Royal Ontario Museum by Professor V. B. Meen:

1. Clinoclasite (Queen's University collection), St. Day, Cornwall, England; dark greenish-blue crystals aggregated in diverging groups.

2. Clinoclasite (Royal Ontario Museum, M/8000, Montgomery collection), Tintic District, Utah; single crystals ½ mm. long on quartz and radiating aggregates of crystals up to 3 mm. long.

3. Clinoclasite (ROM, M/11801), Bullion Beck Mine, Tintic District, Utah; nearly spherical aggregate of radiating crystals 1¼ inches in diameter.

4. Clinoclasite (ROM, M/12644), Wheal Gorland, Cornwall, England; radiating aggregates of fine crystals up to 1 cm. in diameter.

Professor M. A. Peacock, University of Toronto, was kind enough to transmit these results to the Harvard Mineralogical Laboratory.

Geometrical crystallography. Clinoclasite from Utah (material 2) offered the only chance of good goniometric measurements. It consists in part of small isolated crystals about ½ mm. long perched on quartz crystals or on a massive quartz matrix. Five crystals were chosen for goniometric measurement (Table 5); four were adjusted on *c*[001] and one on *b*[010].

TABLE 5. CLINOCLASITE: CRYSTAL MEASUREMENTS

		Number of		Quality	Average		Range	
		crys-tals	faces		ϕ	ρ	ϕ	ρ
c	(001)	3	3	good	90°00′	9°26′	—	9°21′– 9°32′
a	(100)	3	6	good	90 00	90 00	—	—
k	$(\bar{4}01)$	2	2	poor	−90 00	63 34	—	63 26 –63 41
g	$(\bar{2}01)$	1	1	poor	−90 00	48 30	—	—
o	(111)	3	6	fair	34 31	53 34	34°00′– 35°25′	52 58 –54 07
u	$(\bar{9}72)$	2	6	v. poor	−35 05	78 27	−33 07 – 37 40	76 43 –82 04
	$(\bar{7}61)$	1	2	v. poor	−31 01	82 53	−29 42 – 32 21	82 50 –82 57
					ϕ_2	ρ_2	ϕ_2	ρ_2
c	(001)	1	1	good	80°28′	90°00′	—	—
a	(100)	1	2	good	0 00	90 00	—	—
k	$(\bar{4}01)$	1	1	poor	155 34	90 00	—	—
o	(111)	1	1	poor	52 29	47 30	—	—
u	$(\bar{7}61)$	1	2	v. poor	162 24	32 25	162°03′–162°46′	27°39′–37°11′

These crystals (Fig. 4) proved to be somewhat similar to the Cornwall crystal (Fig. 2), elongated parallel to the vertical axis with the pinakoid *a*(100) as the most prominent form. The crystals are generally terminated by the basal pinakoid *c*(001), the unit positive prism *o*(111), and a steep negative prism *u*$(\bar{9}72)$ or $(\bar{7}61)$, in a similar general position to *s*$(\bar{5}52)$ (Fig. 2). Other forms are confined to a striated zone between *c*(001) and *a*$(\bar{1}00)$ indexed with uncertainty as *g*$(\bar{2}01)$ and *k*$(\bar{4}01)$.

The faces of *u* are very uneven, giving a large number of poor signals spread over several degrees in ϕ and ρ. The values given in the table for this form represent the center of the group of signals; the indices given are uncertain.

A comparison of the measured (average) and calculated angles (from Palache's geometrical elements) for the forms observed here is given in Table 6. The measured angles for the forms *c*(001), *a*(100), and *o*(111) compare closely with the calculated angles. The comparison is poor in the case of *u*($\bar{9}72$) or ($\bar{7}61$), *g*($\bar{2}01$), and *k*($\bar{4}01$), which is to be expected from the poor quality of those doubtful forms.

TABLE 6. CLINOCLASITE: COMPARISON OF MEASURED AND CALCULATED ANGLES

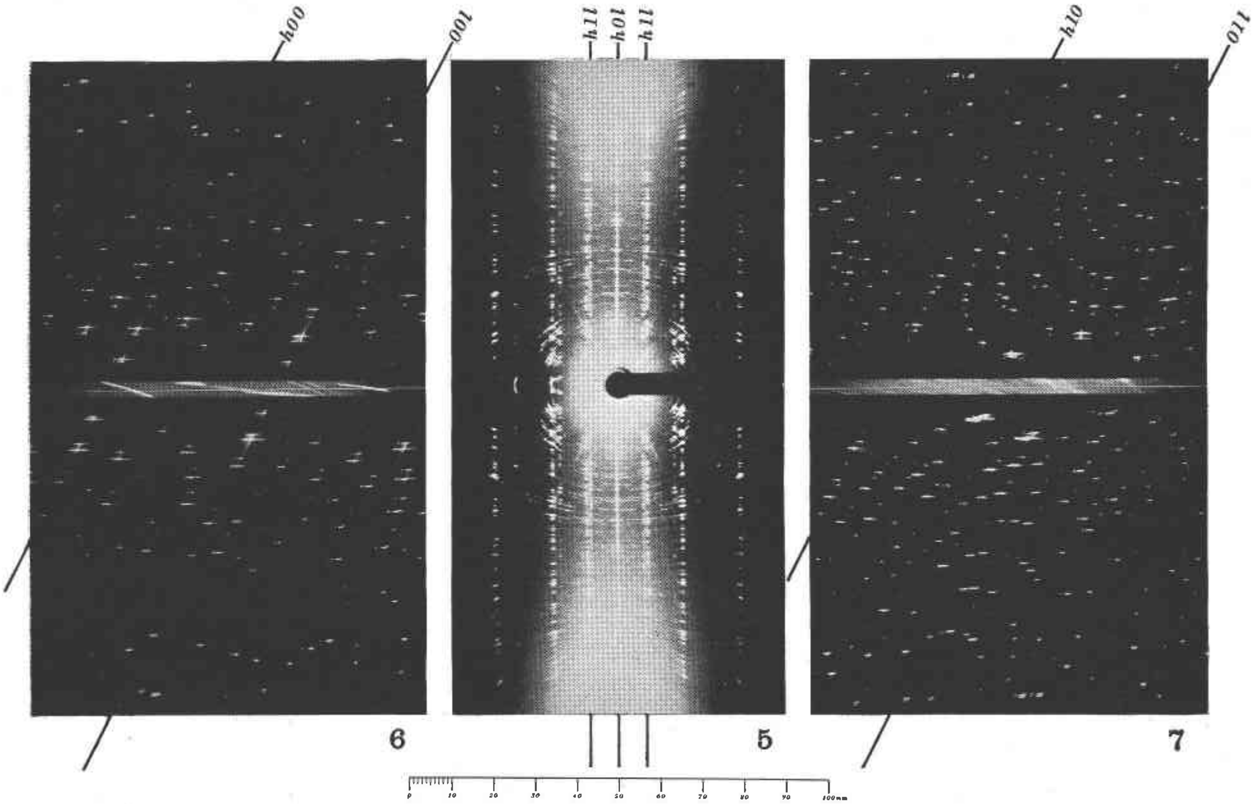
		Measured (average)		Calculated	
		ϕ	ρ	ϕ	ρ
c	(001)	90°00′	9°26′	90°00′	9°22′
k	($\bar{4}01$)	−90 00	63 34	−90 00	65 43
g	($\bar{2}01$)	−90 00	48 30	−90 00	45 43⅐
o	(111)	34 31	53 34	34 07	53 35
u	($\bar{9}72$)	−35 05	78 27	−34 38½	78 10
	($\bar{7}61$)	−31 01	82 53	−30 43½	82 43½
		ϕ_2	ρ_2	ϕ_2	ρ_2
c	(001)	80°28′	90°00′	80°38′	90°00′
k	($\bar{4}01$)	155 34	90 00	155 43	90 00
o	(111)	52 29	47 30	52 45	48 13½
u	($\bar{7}61$)	162 24	32 25	165 58	31 29½

X-ray crystallography. Cleavage fragments of clinoclasite suitable for single crystal *x*-ray measurements were readily obtained from material 1 (Cornwall). Rotation, zero, and first-layer Weissenberg photographs about *b*[010] (Figs. 5–7) lead to a monoclinic lattice with dimensions:

$$b = 6.45 \pm 0.02,\ d(100) = 12.19 \pm 0.04,\ d(001) = 7.13 \pm 0.02\ kX$$

and axial angle $ac = 80°30' \pm 15'$. A zero-layer Weissenberg photograph about the normal to the cleavage *c*(001) gave $d(010) = 6.43\ kX$. The measured spacings together with the axial angle give the absolute cell dimensions:

$$a = 12.36,\ b = 6.45,\ c = 7.23\ kX;\ \beta = 99°30'.$$



FIGS. 5–7.—Clinoclasite, Cornwall (material 1); single crystal x-ray photographs with unfiltered Cu-radiation; camera radius 360/4πmm. The scale gives millimeters or degrees of θ. FIG. 5.—Rotation about [010]. FIG. 6.—Weissenberg resolution of the layer ($h0l$). FIG. 7.—Weissenberg resolution of the layer ($h1l$).

The observed diffractions conform to the conditions: (hkl) present in all orders, $(0kl)$ present in all orders, $(hk0)$ present in all orders, $(h0l)$ present only with $h=2n$, $(0k0)$ present only with $k=2n$; these criteria are characteristic of the single space-group, $C_{2h}^5-P2_1/a$.

Rotation and zero-layer Weissenberg photographs of one crystal from material 2 (Utah), rotated about $b[010]$, give the following lattice dimensions:

$$b=6.45\pm0.02,\ d(100)=12.20\pm0.03,\ d(001)=7.14\pm0.02\ kX$$

axial angle $ac=80°35'\pm10'$, and absolute cell dimensions:

$$a=12.37,\ b=6.45,\ c=7.24\ kX;\ \beta=99°25'$$

in close agreement with the measurements on the Cornwall clinoclasite given above.

These determinations of the cell dimensions of clinoclasite from Cornwall and Utah agree closely with the results obtained by Hurlbut on clinoclasite from Nevada:

$$a=12.33,\ b=6.42,\ c=7.21\ \text{Å};\ \beta=99°22'.$$

The structural axial ratios also compare closly with the geometrical ratio given by Palache:

$a:b:c=1.916:1:1.121$, $\beta=99°30'$ (Berry, x-ray, Cornwall)
$a:b:c=1.917:1:1.122$, $\beta=99°25'$ (Berry, x-ray, Utah)
$a:b:c=1.921:1:1.122$, $\beta=100°03'$ (Hurlbut, x-ray, Nevada)
$a:b:c=1.9109:1:1.1223$, $\beta=99°22'$ (Palache, goniometer)

Composition and cell content. The cell dimensions of clinoclasite combined with the highest measured specific gravity, 4.38 (Hillebrand and Washington, 1888), give the molecular weight of the unit cell contents, $M=1509$. In Table 7 this value has been used to obtain the atomic contents of the unit cell from six of the available analyses of clinoclasite.

TABLE 7. CLINOCLASITE: ANALYSES AND CELL CONTENT
$M=1509$

	1	2	3	4	5	6	A	B
CuO	62.80	60.00	61.68	62.47	62.34	62.72	62.00	62.71
Fe_2O_3	0.49	0.39	n.d.	—	0.12	—	0.17	—
CaO	—	0.50	—	—	ZnO 0.06	—	0.08	—
As_2O_5	27.08	29.71	29.36	30.98	29.59	30.08	29.47	30.19
P_2O_5	1.50	0.64	—	—	0.05	—	0.36	—
H_2O	7.57	7.64	7.31	6.62	7.73	(7.20)	7.35	7.10
	99.44	100.00[1]	98.35	100.07	99.95[2]	100.00	99.43	100.00
Cu	11.97	11.51	11.89	11.84	11.83	11.89	11.88	12.00
Fe	0.10	0.08	—	—	0.02			
Ca	—	0.13	—	—	Zn 0.01	—		
As	3.58	3.95	3.92	4.06	3.90	3.95	3.97	4.00
P	0.32	0.14	—	—	0.02	—		
H	12.76	12.94	12.44	11.08	12.98	12.06	12.38	12.00
O	28.25	28.44	27.91	27.53	28.16	27.79	28.01	28.00

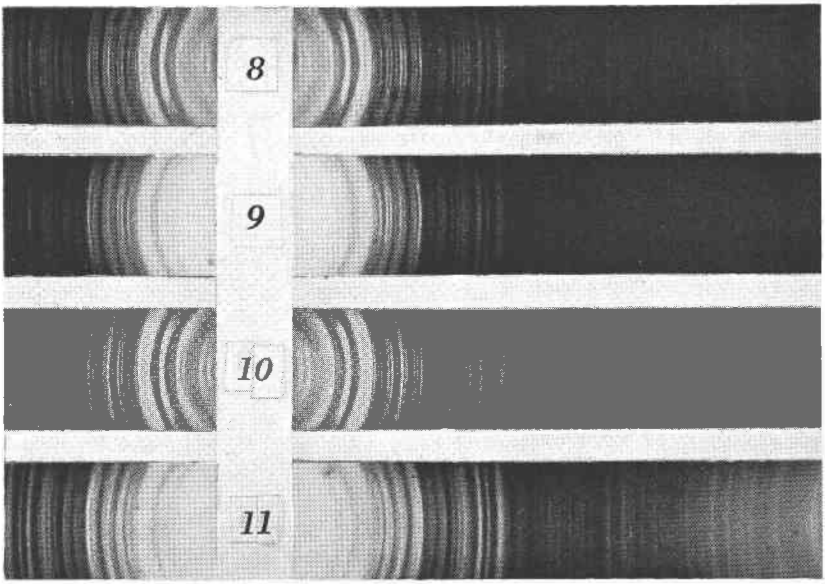
1. Cornwall; anal. Damour (1845). 2. Cornwall; anal. Rammelsberg (1846); [1]incl. SiO_2 1.12. 3. Mammoth Mine, Tintic District, Utah; anal. Pearce (1886). 4. Anal. Coloriano (1886). 5. Mammoth Mine, Tintic District, Utah; anal. Hillebrand (Hillebrand and Washington, 1888); [2]incl. SiO_2 0.06. 6. Anal. Church (1895). A. Average. B. Ideal composition and cell content for $4[Cu_3AsO_4(OH)_3]$.

The values obtained clearly indicate the structural formula:

$$Cu_{12}As_4H_{12}O_{28}=4[Cu_3AsO_4(OH)_3]$$

and the average values (A) approach closely the ideal values (B) for this structural formula. This unit cell content gives the calculated specific gravity 4.42, in good agreement with the measured value. This affords complete confirmation of the generally accepted formula of clinoclasite.

X-ray powder photograph. Clinoclasite from each of the four materials listed above gave identical x-ray powder patterns (Fig. 8–11). The measured spacings and estimated intensities for Cu-radiation are listed in Table 8 with the indices and calculated spacings of the reflecting planes. Card number II-791 of the A. S. T. M. X-ray Diffraction Data Cards



FIGS. 8–11.—Clinoclasite: x-ray powder photographs with Cu-radiation (Ni-filter); camera radius $360/4\pi$ mm. FIG. 8.—St. Day, Cornwall (material 1). FIG. 9.—Tintic District, Utah (material 2). FIG. 10.—Bullion Beck Mine, Tintic District, Utah (material 3). FIG. 11.—Wheal Gorland, Cornwall (material 4). Actual size.

gives a pattern for clinoclase, Wheal Gorland, Cornwall, taken with Cu-radiation, Al-window (BM = British Museum), which agrees substantially with ours. The three strongest lines of the BM pattern are 3.63 (1.0), 3.14 (0.8), 2.05 (0.7) as compared to our 3.55 (10), 3.13 (8), 4.3 (6).

TABLE 8. CLINOCLASITE—$Cu_3AsO_4(OH)_3$: X-RAY POWDER PHOTOGRAPH
Monoclinic, $P2_1/a$; $a=12.36$, $b=6.45$, $c=7.23$ kX, $\beta=99°30'$; $Z=4$

I(Cu)	θ(Cu)	d(meas.)	(hkl)	d(calc.)
3	6.0	7.55	(001)	7.13 kX
3	7.0	6.3	(200)	6.10
1	9.4	4.7	$(\bar{1}11)$	4.63
(3) 6	10.4	4.3	(201)	4.30
			(111)	4.29
½	11.1	3.99	$(\bar{2}11)$	3.98
(1) 10	12.5	3.55	(211)	3.57
			(002)	3.56
(2) 8	14.2	3.13	$(\bar{1}12)$	3.13
			(012)	3.12
			(120)	3.12
3	14.9	2.99	$(\bar{4}01)$	2.99
			$(\bar{2}12)$	2.96
4	15.5	2.88	$(\bar{1}21)$	2.90
			(202)	2.88
3	15.7	2.84	(220)	2.85
			(121)	2.81
1	16.1	2.77	(410)	2.76
3	16.8	2.66	$(\bar{3}12)$	2.67
			(401)	2.65
4	17.7	2.53	$(\bar{4}02)$	2.53
			(320)	2.53
4	18.0	2.49	$(\bar{3}21)$	2.46
			(411)	2.45
3	18.8	2.38	$(\bar{1}22)$	2.40
			(022)	2.39
			(003)	2.38
5	19.5	2.30	(312)	2.32
			$(\bar{2}22)$	2.31
			(321)	2.31
			(122)	2.30
4	20.1	2.24	$(\bar{1}13)$	2.26
			(013)	2.23
3	21.0	2.14	(402)	2.148 kX
			(222)	2.147
			(113)	2.136
4	21.5	2.10	(203)	2.100
			$(\bar{3}13)$	2.094
5	22.0	2.05	(031)	2.058
			(421)	2.047
			$(\bar{1}31)$	2.046
			$(\bar{6}01)$	2.045
			$(\bar{4}03)$	2.045
			(412)	2.038
½	23.0	1.967	$(\bar{2}31)$	1.979
			(322)	1.968
1	23.7	1.912	$(\bar{6}02)$	1.906
2	24.7	1.839	$(\bar{1}32)$	1.844
			(032)	1.841
			(313)	1.839
2	25.4	1.792	(512)	1.799
			$(\bar{2}04)$	1.792
			(422)	1.787
3	26.6	1.717	(014)	1.718
2	27.1	1.687	$(\bar{6}03)$	1.688
			(710)	1.681
			$(\bar{3}14)$	1.681
			(413)	1.680
2	27.9	1.643	$(\bar{6}22)$	1.641
			(204)	1.640
			$(\bar{4}32)$	1.639
2	28.5	1.611	(040)	1.612
			$(\bar{4}14)$	1.610
4	29.9	1.542	$(\bar{8}01)$	1.543
			$(\bar{3}33)$	1.543

I(Cu)	θ(Cu)	d(meas.)
3	31.0	1.492
1	31.6	1.467
3	32.6	1.427
3	32.9	1.415
1	33.6	1.389
1	33.8	1.382
1	34.7	1.350
1	39.1	1.219
½	39.8	1.201
2	40.5	1.184
½	40.9	1.174
2	41.9	1.151
1	42.8	1.131
2	43.4	1.119
½	44.7	1.093
2	47.2	1.048
2	48.8	1.022
1	51.5	.982
½	53.3	.959
1	57.1	.9155
½	59.4	.8930
1	60.8	.8806
1	62.8	.8642
1	64.7	.8502
½	65.9	.8421
½	69.4	.8212
1	74.5	.7977
½	81.6	.7770

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