Crystallography of aramayoite.

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[Read November 9, 1939.]

THE original description of aramayoite by Spencer in 1926[1] contained only a qualitative discussion of the crystallography, because suitable crystals for a more rigorous treatment were not found. The pseudo-tetragonal symmetry was recognized, and cleavages were noted, but only one was defined. Twinning was later observed in polished section by Schneiderhöhn and Ramdohr,[2] but undefined. Yardley[3] demonstrated the triclinic symmetry of aramayoite by the Laue method, and determined the spacings of a considerable number of planes in the crystal. From these data she formulated a unit cell and correlated the X-ray data with Spencer's crystallographic results.

Several specimens of aramayoite found in our recently acquired Ahlfeld Bolivian collection contained small but excellent crystals. Measurement of these indicated that the Yardley X-ray crystallography was not consistent with an adequate morphological treatment of the form-development. The twenty-seven forms found by us lead to an obvious crystallographic unit (fig. 1), bearing a rather complex relationship to the Yardley unit. In order to test the suitability of the latter, we repeated the X-ray examination by the modern Weissenberg method and found complete accordance with our morphological treatment, as will be shown below.

Crystal Measurements.—The axis [001] of the zone containing the perfect platy cleavage (010) and the good cleavage (100) was set vertical for the two-circle measurements in order to facilitate the graphical choice of the proper unit.

Table I is a resume of the measurements, together with observations of frequency and quality for forms, on four of the best measured crystals. Fig. 2 is a drawing of crystal number 8 with the more prominent forms figured. About half of the forms are obtained from 'A' measurements.

[1] L. J. Spencer, Min. Mag., 1926, vol. 21, p. 156.

[2] H. Schneiderhöhn and P. Ramdohr, Lehrbuch der Erzmikroskopie, 1931, vol. 2, p. 388.

[3] K. Yardley, Min. Mag., 1926, vol. 21, p. 163.

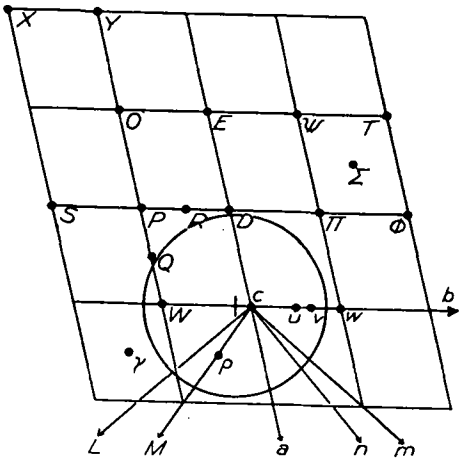

FIG. 1. Aramayoite: gnomonic projection.

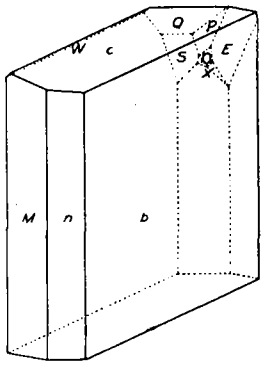

FIG. 2. Crystal of aramayoite.

All of the pinakoidal forms were present on two crystals; 0*kl*, *h*0*l*, and *hk*0 forms with simple indices were found on most crystals. The indices of no form are greater than 3, indicating a simple relation between the chosen unit and the form development.

TABLE I. Aramayoite: Crystallographic Measurements.

Forms.	Measured range.				Faces measured.	Crystal number.	Weighted average.		General quality ('A'-best).
	ϕ.		ρ.			2 6 7 8	ϕ.	ρ.	
(001)	−0° 19′	−0° 22′	11° 00′	10° 41′	3	— × × ×	0° 00′	10° 41′	B striat.
(010)	—	—	—	—	8	× × × ×	0 00	90 00	A cleav.
(100)	75 52	76 34	90 00	90 00	4	× × — ×	75 52	90 00	C line cleav.
(110)	41 25	—	—	—	1	× — — —	41 25	90 00	C line
(1$\bar{1}$0)	−55 36	56 43	—	—	5	× × × ×	−56 10	90 00	A med.
(2$\bar{3}$0)	−40 25	—	—	—	1	— × — —	−40 25	90 00	C striat.
(320)	—	—	—	—	1	— — — ×	50 13	90 00	A med.
(012)	—	—	34 32	35 02	3	× × — ×	0 00	34 43	A med.
(023)	—	—	39 39	40 43	3	× × — ×	0 00	40 16	B sm.
(011)	—	—	49 28	49 35	2	— × × —	0 00	49 32	A sm.
(0$\bar{1}$1)	—	—	—	—	1	— — — ×	180 00	38 02	A sm.
(1$\bar{0}$1)	—	—	—	—	1	× — — —	−94 35	46 42	D lge.
(2$\bar{0}$1)	−99 35	−99 42	64 57	65 17	2	× — — ×	−99 39	65 07	A lge.
(1$\bar{1}$1)	—	—	—	—	1	— — × —	−49 44	54 26	C dot
(3$\bar{3}$2)	—	—	—	—	1	— — × —	−52 04	64 06	C dot
(2$\bar{2}$1)	—	—	—	—	1	— — × —	−38 46	72 45	C dot
(1$\bar{2}$1)	−28 29	−29 39	65 04	65 27	2	— × × —	−29 04	65 16	A lge.
(2$\bar{1}$1)	—	—	—	—	1	— — × —	−72 26	67 10	D sm.
(1$\bar{1}$1)	—	—	—	—	1	— — — ×	−134 57	56 49	B sm.
(1$\bar{2}$2)	—	—	—	—	1	— — — ×	−150 16	46 50	A med.
(2$\bar{1}$2)	—	—	—	—	1	× — — —	−119 54	50 56	D line
(1$\bar{2}$1)	−152 24	−152 30	66 16	66 46	2	× — — ×	−152 30	66 46	B sm.
(2$\bar{1}$1)	—	—	—	—	1	— — — ×	−121 51	68 30	A med
(3$\bar{1}$1)	—	—	—	—	1	— — — ×	−116 36	74 29	B sm.
(3$\bar{2}$1)	—	—	—	—	1	— — — ×	−129 29	76 49	E dot
(1$\bar{1}$2)	—	—	—	—	1	— — — ×	+106 42	31 22	D sm.
(1$\bar{3}$2)	—	—	—	—	1	— — — —	+149 10	53 00	C dot

TABLE II. Aramayoite: Angle Table.

Triclinic; pinakoidal—$\bar{1}$.

$a : b : c = 0{\cdot}8753 : 1 : 0{\cdot}9406$; $\alpha = 100° 22'$, $\beta = 90° 00'$, $\gamma = 103° 54$

$p_0 : q_0 : r_0 = 1{\cdot}0889 : 0{\cdot}9690 : 1$; $\lambda = 79° 19'$, $\mu = 87° 24\frac{1}{2}'$, $\nu = 75° 52'$

$p_0' = 1{\cdot}1081$, $q_0' = 0{\cdot}9861$; $x_0' = 0° 00'$, $y_0' = 0{\cdot}1887$

Form.	ϕ.	ρ.	A.	B.	C.	Z.*
c (001)	0° 00′	10° 41′	87° 24½′	79° 19′	—	90° 00′
b (010)	0 00	90 00	75 52	—	79° 19′	—
a (100)	75 52	90 00	—	75 52	87 24½	0 00
m (110)	40 32	90 00	35 20	40 32	81 54	0 00
n (320)	49 11	90 00	26 41	49 11	83 02½	0 00
M (1$\bar{1}$0)	123 39½	90 00	47 47½	123 39½	95 54	180 00
L (2$\bar{3}$0)	138 21½	90 00	62 29½	138 21½	97 58	180 00
u (012)	0 00	34 17	82 05½	55 43	23 36	90 00
v (023)	0 00	40 14	80 55½	49 46	29 33	90 00
w (011)	0 00	49 35½	79 17	40 24½	38 54½	90 00
W (0$\bar{1}$1)	180 00	38 34	98 45½	128 34	49 15	270 00
D ($\bar{1}$01)	−94 21½	47 08½	136 04	93 11½	48 57	−42 56½
E ($\bar{2}$01)	−99 19	65 20½	154 54	98 27½	67 29½	−24 57
P ($\bar{1}\bar{1}$1)	−134 49½	56 34½	135 52	126 02½	64 23½	−42 56½
ρ (1$\bar{1}$2)	107 28	29 23½	65 17½	98 28	34 01	−118 15
Π ($\bar{1}$11)	−49 55½	54 33	118 27	58 22	48 09	137 03½
Σ ($\bar{3}$32)	−51 56½	63 58	123 25½	56 22	57 43½	148 11
T ($\bar{2}\bar{2}$1)	−53 00	69 37	126 01½	55 39½	63 27½	155 03
Q (1$\bar{2}\bar{2}$)	−150 03½	47 06½	120 38½	129 24½	56 33	−61 45
Y (1$\bar{3}$2)	155 03½	51 52	81 31	135 30	61 40½	−118 15
R (2$\bar{1}$2)	−118 09	50 38	138 35½	111 23½	56 14½	−42 56½
S (1$\bar{2}$1)	−152 23	66 40	127 41½	144 27	76 12½	−42 56½
Φ ($\bar{1}$21)	−29 37	65 18	104 02	37 50	56 09	137 03½
O (2$\bar{1}$1)	−121 55	68 27	152 20	119 27	74 21	−24 57
Ψ ($\bar{2}$11)	−73 30	65 57½	141 47½	74 58	63 21½	155 03
Y (3$\bar{1}$1)	−116 31½	74 29½	160 14½	115 29½	79 27½	−17 14
X ($\bar{3}$21)	−128 50	76 25	152 01	127 33½	83 14	−17 14

* Z = meridian co-ordinate with (010) polar and meridian co-ordinate of (100) = 0° 00′. 'B' or its supplement = angular distance to (010) as pole. The relationship is $Z = \cot X' = \cot \xi_0$.

The elements in table II were calculated from measurements of 'A' quality forms. In addition to the co-ordinate angles and interfacial angles to the pinakoids, the last column, 'Z', is the meridian co-ordinate from (100) as zero when (010), the platy face, is polar; the column 'B' gives the angular distance in this orientation. For purposes of comparison between measurements of different crystals these co-ordinate angles for the polar face-adjustment, following Hey,[1] have been found useful. The angle table, therefore, serves as a means of checking measurements in both settings.

[1] M. H. Hey, Min. Mag., 1934, vol. 23, p. 560.

The orientation here given differs from that of Yardley in the following way:

Yardley.	Berman & Wolfe.
$(\bar{3}\bar{3}1)$	(600)
(001)	$(0\frac{3}{2}0)$
$(\bar{3}31)$	(006)
(010)	$(\bar{1}01)$
(101)	$(\bar{1}2\bar{1})$
(100)	$(\bar{1}\frac{1}{2}\bar{1})$

The transformation formulae are:

Yardley to Berman & Wolfe	$(\bar{1}\bar{1}0)/(\frac{1}{2}0\frac{3}{2})/(\bar{1}10)$
Berman & Wolfe to Yardley	$(\frac{1}{2}0\frac{1}{2})/(\frac{1}{2}0\frac{1}{2})/(\frac{1}{6}\frac{1}{6}\frac{1}{6})$

The cleavage, observed by Spencer and made $(\bar{3}\bar{3}1)$ by Yardley, is (100) in our orientation. As will be shown in the X-ray discussion, the second-order reflection (002) of Yardley is our third-order reflection (030); the $(\bar{3}31)$ of Yardley is our (006); the $(\bar{3}\bar{3}1)$ of Yardley is our (600). These relations introduce the complexities of the transformation formulae.

Twinning.—Many cleavage plates from our specimens showed a sharp line running diagonally across the plate. Several inferior crystals with poor faces showed that this line on the cleavage surface represented the trace of the composition-plane of a twin. The measurements indicated that the twinning is about the axis $[\bar{1}01]$ with the composition plane near $(\bar{1}01)$.

A gnomonic projection with $[\bar{1}01]$ as pole shows an axis of two-fold pseudosymmetry. Under these circumstances twinning on the axis produces a near superposition of the projection of one individual on the other. In the Friedel sense the twinning has an index of 1, with a small obliquity. When no re-entrant angle shows on the crystals, twinning may well be concealed. A well-defined parting is developed parallel to the composition-plane $(\bar{1}01)$.

X-ray measurements.—A crystal plate showing the two cleavages was used for the X-ray examination with the Weissenberg goniometer. Rotation was about the [001] axis; zero-layer and first-layer pictures were studied (figs. 3 and 4). The periodicity along [001] was obtained from the rotation picture. On the zero-layer, fifty-three reflections were indexed. For $0k0$, reflections at $k = 3, 6, 9$ were observed; for $h00$, reflections for $h = 2, 6$ were observed. In general, the reflections with h odd were weak or missing. In the first-layer series $hk1$, the reflections for h = odd were well shown. The projected reciprocal lattice, derived

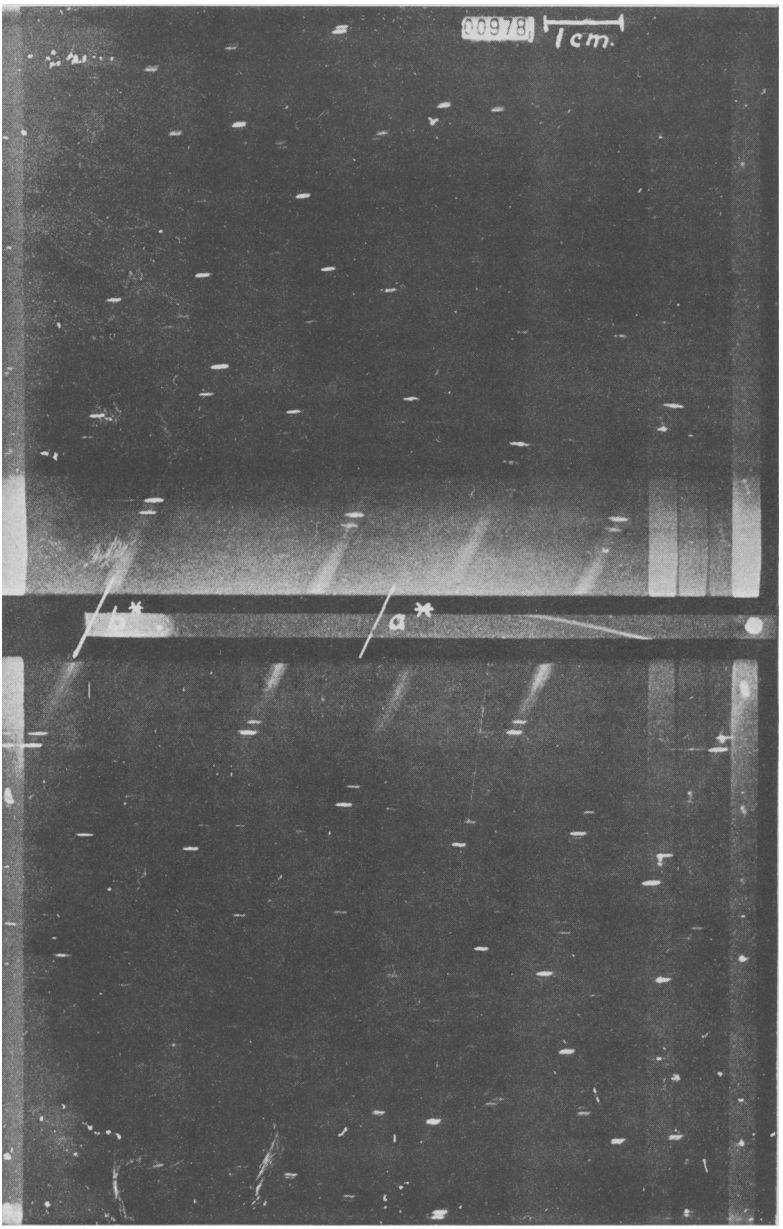

FIG. 3. Aramayoite: zero-layer Weissenberg picture about [001]; Cu-K_α unfiltered radiation; camera radius 90/π mm.; reciprocal lattice axes are indicated.

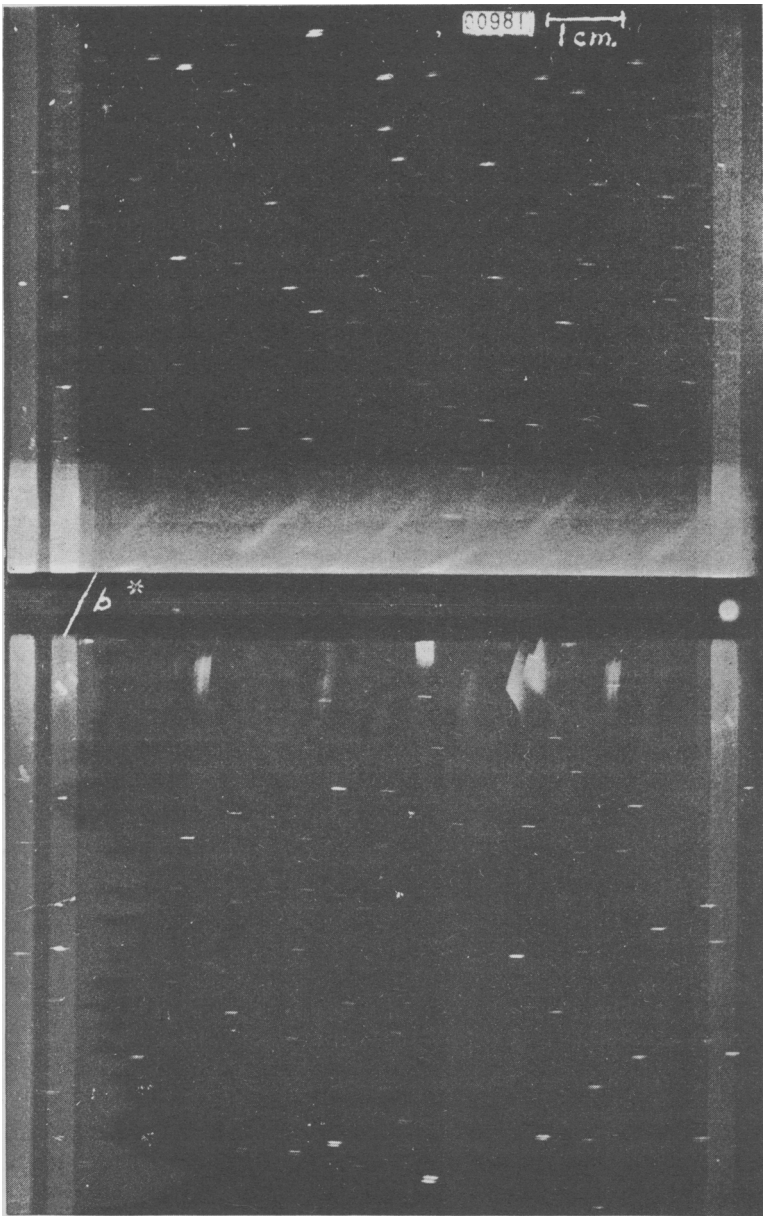

FIG. 4. Aramayoite: first-layer Weissenberg picture about [001]; Cu-K_α radiation, nickel filter.

from the X-ray pictures, gave good agreement with the morphological data:

$$a^* : b^* : c^* = 1{\cdot}0856 : 0{\cdot}9741 : 1$$
$$p_0 : q_0 : r_0 = 1{\cdot}0889 : 0{\cdot}9690 : 1$$

Angular elements of the reciprocal lattice projection are generally not as reliable as morphological measurements; we have, therefore, used the angular relations of the pinakoids, derived from our morphological elements (see table II), for the calculation of the unit cell. The following are the dimensions:

$a_0 = 7{\cdot}76$ Å.	$\alpha = 100° 22'$
$b_0 = 8{\cdot}79$	$\beta = 90\ 00$
$c_0 = 8{\cdot}34$	$\gamma = 103\ 54$

with $a_0 : b_0 : c_0 = 0{\cdot}8828 : 1 : 0{\cdot}9488$.

This cell contains $Ag_6(Sb,Bi)_6S_{12}$ in the unit and is thus three times the volume of the Yardley cell. Our third-order (010) with the measured spacing 2·81 Å. is equivalent to the second-order (001) of Yardley, with the spacing 2·81 Å. Also the $(\bar{3}\bar{3}1)$ reflection of Yardley with the spacing 1·26 Å. corresponds to our sixth-order (100) with the measured spacing 1·25 Å.

Fig. 3 shows the axial directions as chosen. The periodicities along these directions define the smallest cell consistent with all the reflections. The first-layer picture (fig. 4) corroborates the evidence in fig. 3.

The following table gives a further comparison of some of our spacings and angles with those measured by Yardley:

Index		Measured spacings		Angle to best cleavage	
Yardley.	Berman & Wolfe.	Yardley.	Berman & Wolfe.	Yardley (001).	Berman & Wolfe (010).
(010)	$(\bar{1}01)$	5·67 Å.	—	86° 52′	86° 48½′
(001)	$(0\frac{3}{2}0)$	5·61	5·62 Å.	0 00	0 00
(111)	$(\bar{2}20)$	3·24	3·25	56 10	56 20½
$(33\bar{1})$	$(\bar{6}00)$	1·26	1·25	75 44	75 52
$(\bar{3}31)$	(006)	1·355	1·36	79 07	79 19

Recalculating the Yardley cell dimensions into our orientation:

$$a_0 = 7{\cdot}80,\ b_0 = 8{\cdot}86,\ c_0 = 8{\cdot}26 \text{ Å.},$$

in close agreement with our values, as given above.

Relation to other minerals.—Miargyrite, aramayoite, and matildite have the type formula ABX_2. In the following table a comparison of cell dimensions is given:

	Cell contents.	a_0.	b_0.	c_0.	Reference.
Miargyrite ...	$8AgSbS_2$	13·17	4·39	12·83Å.	Hofmann[1]
Aramayoite ...	$6Ag(Sb,Bi)S_2$	7·76	8·79	8·34	Berman & Wolfe
Matildite ...	$4AgBiS_2$	8·14	7·87	5·69	Ramdohr[2]

Aramayoite and matildite are similar in two dimensions and the c_0 of the latter is about $2/3b_0$ of the former. The b_0 of miargyrite is almost half of the b_0 of aramayoite, but the other dimensions are not simply related.

[1] W. Hofmann, Sitzungsber. Preuss. Akad. Wiss., Phys.-math. Kl., 1938, p. 111. [M.A. 7–387.]

[2] P. Ramdohr, Fortschr. Min. Krist. Petr., 1936, vol. 20, p. 56; Sitzungsber. Preuss. Akad. Wiss., Phys.-math. Kl., 1938, p. 82. [M.A. 7–104, 3b4.]