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From the
DEPARTMENT OF GEOLOGICAL SCIENCES
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EXTENDING this Journal's practice of occasionally publishing the portrait of a Canadian mineralogist, it is proposed with this issue to commence the regular publication of the portraits of outstanding mineralogists, without regard to nationality or place of residence, together with a word on their lives and achievements. In this way members of the Walker Mineralogical Club may become better acquainted with the personalities and accomplishments of the men who have contributed most to mineralogy. First in this series we present:

After the painting by
IRWIN D. HOFFMAN, 1940

Harvard Mineralogical Museum
Cambridge, Massachusetts

CHARLES PALACHE

. . . to have students, many of whom stayed to become followers and then leaders on their own account; and to be able at all times to indulge my greatest interest of studying, measuring and comparing crystals — are not these abounding gifts which make for happiness?—C. PALACHE

CHARLES PALACHE was born in San Francisco seventy-six years ago; and now, after long and distinguished service to Mineralogy, as collector and curator, investigator and writer, teacher and administrator, he still enjoys vigorous health and undiminished pleasure in scientific work. Ph.D. in Petrography, University of California, 1894; advanced study in crystallography, mineralogy, and petrography, at Leipzig, Heidelberg, and Munich; Assistant, Instructor, Professor of Mineralogy, Harvard University, and Curator of the Harvard Mineralogical Museum 1895-1940; LL.D., 1941; Geologist with the United States Geological Survey, 1901-1919; Fellow, former President, and first Roebling Medallist of the Mineralogical Society of America; Fellow and former President of the Geological Society of America; Honorary Member of the Mineralogical Society of Great Britain; Member of the National Academy of Sciences and of other Societies at home and abroad; describer of twelve new mineral species; author of one hundred and forty-two papers, replete with exact observations, on mineralogy and crystallography; author of the famous monograph on the minerals of Franklin, New Jersey; senior author of the new *System of Mineralogy* founded on Dana: these are some of the highlights of the professional life and work of this distinguished man whom we are proud to count as a member of our Club and a contributor to our Journal.

CRYSTALLOGRAPHY OF COPIAPITE

By

CHARLES PALACHE
Harvard University, Cambridge, Massachusetts
M. A. PEACOCK
University of Toronto, Toronto, Ontario
and
L. G. BERRY
Queen's University, Kingston, Ontario

THIS joint work is the result of interrupted studies which commenced in 1934 when Palache measured a number of crystals of copiapite from Chile and found them to be triclinic with a well developed form-series. In this part of the work the senior author received some assistance from Berman and Wolfe, and also from Peacock, who critically examined the chosen setting in relation to the general problem of choosing triclinic elements from goniometric data, and later made a direct determination of the crystal lattice from single crystal x-ray photographs which were kindly prepared by Buerger.

About this time Ungemach's important monograph on the sulphate minerals of Chile (1935) was received. In this detailed work, which includes descriptions of four new minerals and single-circle measurements on five triclinic species, Ungemach also discovered the triclinic symmetry of copiapite and described a most elaborate development of forms. However, it was found that Ungemach had chosen an entirely different setting from the one adopted at Harvard, and that his elements and angles do not agree closely with ours when transformed to our setting. Although Ungemach had given much thought to the setting of copiapite he generously conceded the propriety of the Harvard setting when the results of the x-ray measurements were known;[1] however the differences in angles remained and no sufficient explanation for this was immediately apparent.

[1]The results were transmitted personally to Ungemach in Strasbourg by Donnay, only a few days before Ungemach's untimely death on June 11, 1936. At that time Ungemach also bequeathed his large collection of measured crystals to Donnay, who in turn kindly placed the copiapite crystals at our disposal for further study.

In 1937-8, Berry undertook a study of the crystallography and crystal chemistry of copiapite during his first year of graduate study at Toronto. Peacock collaborated in this work which is described in an unpublished M.A. Thesis (Berry, 1938*a*), but only part of the work, that dealing with Ungemach's "pseudocopiapite" (Berry, 1938*b*), was published. Several abstracts of projected papers on copiapite and matters arising out of the study of that mineral have appeared: one announcing the "Harmonic-Arithmetic Rule" (Peacock, 1937); one giving the new geometrical and structural elements of copiapite (Peacock, 1939); and one on the variation of the composition and optical properties of the mineral (Berry, 1939).

During the past summer Palache returned to copiapite and, with Berry's Thesis and an angle-table by Peacock at hand, computed a complete angle-table for a projected volume of crystallographic tables, and a shorter presentation of the crystallography of the mineral for the second volume of the new *Dana*. When this was done it seemed proper that the previous scattered and interrupted work should be assembled in a single paper on the crystallography of this unusually interesting triclinic species. In the present account Palache is responsible for the measurements and calculations on the crystals from Chuquicamata (Table 1) and the formal angle-table (Table 4), while Peacock has prepared the rest of the paper with much assistance in the formal work by Berry. It is hoped that the results on the composition and optics of copiapite will be presented on another occasion.

EARLIER OBSERVATIONS

When distinctly crystallized, copiapite forms minute translucent yellow plates with perfect cleavage and pearly lustre on the plane of platy development. These plates are often rhombic in outline with principal optical directions practically coinciding with the normal to the plate and the diagonals of the rhomb. Copiapite was therefore considered to be orthorhombic by Bertrand (1881) and Des Cloizeaux (1881) and again by Posnjak & Merwin (1922).

On crystals showing small edge-faces Linck (1889) derived monoclinic elements:

$$a : b : c = 0.4791 : 1 : 0.9759; \beta = 108° 04'$$

and a series of forms most of which have complex symbols. Linck's

elements are reproduced in Hintze (1930, p. 4,415), while Dana (1892, p. 964) gave slightly different values which were adopted by Goldschmidt (1913, p. 187); Scharizer (1913, p. 384) recomputed Linck's measurements in an endeavour to simplify the symbols, and these recomputed values are given by Doelter (1929, p. 556).

OBSERVATIONS ON CRYSTALS FROM CHUQUICAMATA

Two-circle measurements. The true triclinic symmetry of copiapite was discovered independently at Harvard and at Strasbourg (Alsace), where Ungemach made a thorough re-examination of the material which had been studied by Linck. Some correspondence can be found between Linck's angles and those of Ungemach and the present authors, but there is no doubt that Linck's unnatural crystallography is due to a misconception of the symmetry of copiapite, and that his results should be discarded as erroneous.

The crystals measured in 1934 by Palache were obtained from Chuquicamata, Chile. They are small, often somewhat elongated plates, bevelled by several zones of narrow facets. Of these zones two are particularly strong; they have an average interzonal angle of 77° 48½′ and they tend to give the plates their pseudorhombic appearance. Of these zones, the one with the generally longer edge was chosen as the (*hk*0)-zone, the other as the (0*kl*)-zone, with the plane of flattening and perfect cleavage as (010). These two zones could never be safely distinguished by inspection, and therefore a preliminary measurement with (010) as the pole-face (Berry, 1938*b*, p. 11) preceded the regular two-circle measurement with adjustment on the vertical crystal axis.

The composite plot from half a dozen crystals gave a typical triclinic projection in which nearly all the poles of the terminal faces lie at the nodes of an oblique eccentric net. In the one position which gives the *a*-axis shorter than the *b*-axis and makes the *c*-plane slope to the front and to the right of the *a*-plane, the mean measured angles gave the projection elements: $p_0' = 1.0353$, $q_0' = 0.4117$; $x_0' = 0.2156$, $y_0' = 0.1078$, $\nu = 79° 34'$ and hence the polar and linear elements:

$p_0 : q_0 : r_0 = 1.0065 : 0.4002 : 1$; $\lambda = 83° 59'$, $\mu = 76° 59\frac{1}{2}'$, $\nu = 79° 34'$
$a : b : c = 0.4058 : 1 : 0.4039$; $\alpha = 93° 50'$, $\beta = 102° 10'$, $\gamma = 99° 21\frac{1}{2}'$

TABLE 1

COPIAPITE: MEASURED AND CALCULATED ANGLES ON CRYSTALS FROM CHUQUICAMATA

Forms	Measured		Calculated					Obs.
	φ	ρ	φ	ρ	A	B	C	
(001)	63°11′	13°36′	63°26′	13°33′	76°59½′	83°59′	0°00′	5
(010)	0 00	90 00	0 00	90 00	79 34	0 00	83 59	14
(100)	79 34	90 00	79 34	90 00	0 00	79 34	76 59½	10
(110)	59 41	90 00	59 31½	90 00	20 02½	59 31½	76 29	3
(1$\bar{1}$0)	102 33	90 00	102 25	90 00	22 51	102 25	79 30½	8
(2$\bar{3}$0)	112 56	90 00	112 53½	90 00	33 19½	112 53½	81 14½	1
(1$\bar{2}$0)	122 08	90 00	121 59	90 00	42 25	121 59	82 58½	10
(2$\bar{5}$0)	129 45	90 00	129 34½	90 00	50 00½	129 34½	84 33½	1
(1$\bar{3}$0)	135 56	90 00	135 49	90 00	55 35½	135 49	85 55	2
(1$\bar{7}$0)	159 42	90 00	159 18	90 00	79 44	159 18	91 22½	2
(011)	22 35	29 17	22 32½	29 21½	74 31½	63 04½	20 54½	3
(021)	13 08	43 09	13 02	43 42½	74 01½	47 41½	36 17½	1
(0$\bar{1}$1)	144 28	20 36	144 39	20 26	81 32½	106 32½	22 33½	2
(0$\bar{2}$1)	162 40	36 46	163 14	36 46½	86 13	124 58½	40 59½	1
(0$\bar{3}$1)	169 33	49 37	169 10½	48 56	89 41½	137 46½	53 47½	1
(101)	76 15½	51 51½	76 32½	51 45	38 21	79 28	38 38½	2
($\bar{1}$02)	−86 11	16 04	−87 15	16 22½	105 56	89 13½	28 56½	1
($\bar{1}$01)	−96 08	38 47½	−95 40½	38 53½	128 44	93 33½	51 44½	6
($\bar{2}$01)	−97 36	61 22	−98 21	61 29	151 24½	97 20	74 25	3
($\bar{1}$11)	−67 27	40 53	−67 31½	40 58½	123 24	75 29	50 42½	6
($\bar{1}\bar{1}$1)	−121 56	43 43	−121 28½	43 15½	129 46	110 58	56 46½	2
($\bar{1}$32)	−26 22	34 18	−24 55½	34 51½	98 13½	58 47	36 43	1
(121)	44 54	60 18	47 48	59 01	43 12½	54 50½	46 03½	1
(131)	39 13	62 56	38 52½	63 02½	47 29	46 03½	50 53½	1
($\bar{1}$31)	−34 22	54 55	−34 47	54 35½	109 38½	47 58½	57 35½	1
($\bar{2}$11)	−87 05	61 06	−85 28	61 18	147 55½	86 01	73 05½	1
(4$\bar{5}$2)	−68 16	62 52	−67 17½	63 08	138 19½	69 51½	72 21	1
($\bar{2}$31)	−63 15	64 25	−62 00½	64 07½	134 49	65 01	72 25½	1
(4$\bar{7}$2)	−57 28	64 58	−57 11½	65 13½	131 24½	60 32	72 26	2

The mean measured angles are summarized with angles calculated from these elements in Table 1.

Fig. 1 shows a crystal of copiapite from Chuquicamata with distinct elongation in the direction of the chosen vertical axis and somewhat irregular development of the bevelling zones. This crystal was sketched and measured by Berman and it was subsequently used for the *x*-ray measurements by Peacock; it is also representative of the material which was analysed by Gonyer with the results given later. Other crystals showed further variations of the tabular habit with occasional approach to the pseudorhombic habit of the crystal from Sierra Gorda shown in Fig. 3.

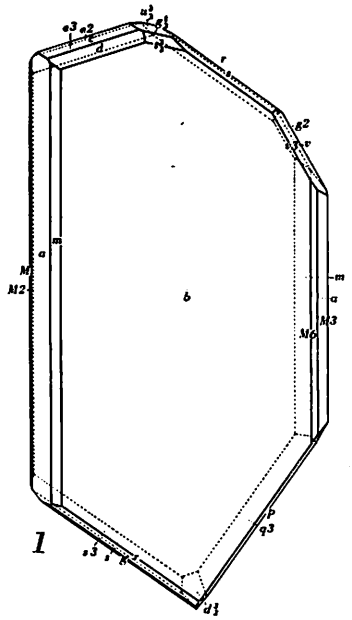
X-ray measurements. The crystal shown in Fig. 1 was adjusted, as for two-circle measurement, to rotate about the long axis. Using cobalt radiation, a rotation photograph was taken giving a direct measurement of the *c*-period; a Weissenberg resolution of the zero-layer line gave the principal spacings, $d(100)$ and $d(010)$, and the angle ν (or γ^*) included by the normals to these sets of planes; and a Weissenberg resolution of the first layer-line gave the offset of this layer of the reciprocal lattice from which the remaining angles λ (or α^*) and μ (or β^*) were calculated. By methods of calculation which are now standard practice these quantities give the elements of the crystal lattice cell:

$a = 7.33$, $b = 18.15$, $c = 7.27$ kX; $\alpha = 93°51'$, $\beta = 101°30'$, $\gamma = 99°23'$

The reciprocal lattice projection of the first layer-line is geometrically similar to the gnomonic net of the $(hk1)$ planes, and the procedure of choosing the single position of the *x*-ray projection and naming its elements is strictly analogous to the procedure in discussing the geometrical projection. It can easily be shown that the edges of the chosen lattice cell are the three shortest non-coplanar periods of the lattice, and that this cell is set in the usually preferred single setting which conforms to the rules: $c < a < b$; α and β obtuse.

The geometrical and structural axial ratios of copiapite from Chuquicamata compare as follows:

$a : b : c$	α	β	γ	
0.4058 : 1 : 0.4039	93°50′	102°10′	99°21½′	(Gon., Palache)
0.4037 : 1 : 0.4005	93°51′	101°30′	99°23′	(*X*-ray, Peacock)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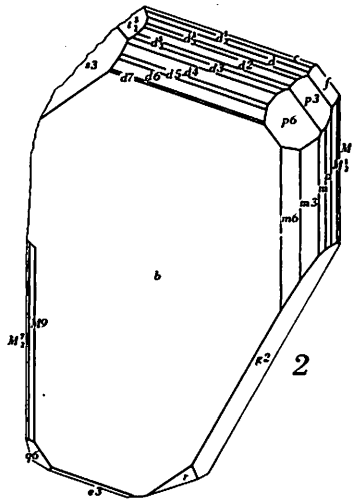
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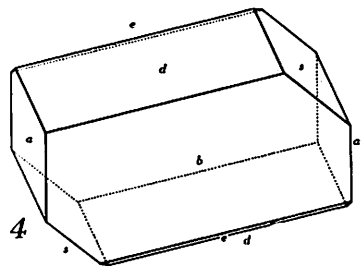
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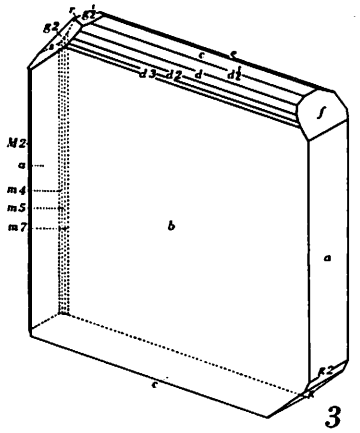
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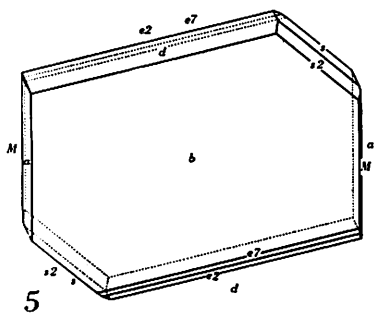
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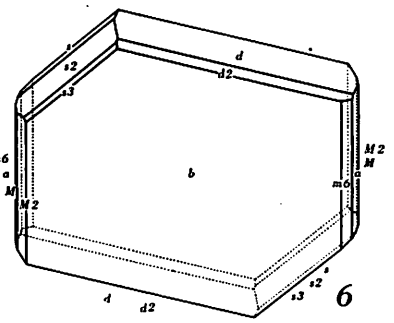
6

The substantial agreement shows that the morphological and structural methods led to one and the same crystal lattice cell.

Composition. On this material Berman measured the specific gravity 2.154 and Gonyer made the analysis given in Table 2.

TABLE 2

COPIAPITE: ANALYSIS (GONYER) AND CELL CONTENT

Analysis		Atoms in Unit Cell					
FeO	0.44	Fe″	0.08	Oxygen	0.08	0.70	25.24
Al_2O_3	1.72	Al	0.41		0.62		
Fe_2O_3	27.28	Fe‴	4.18		6.27		
SO_3	39.83	S	6.09		18.27		
H_2O	29.92	H_2O	20.34				
Insol.	0.55						
	99.74						

The atomic content approaches $X(OH)_2Fe'''_4(SO_4)_6.nH_2O$ where X is one oxygen equivalent of (Fe‴, Al) and n appears to be 19. A fuller discussion of this and other analyses of copiapite is reserved for the projected paper on the composition and optics of the mineral.

OBSERVATIONS ON CRYSTALS FROM SIERRA GORDA

Ungemach's extensive work on copiapite (1935) was done on complex crystals from Sierra Gorda. Adopting at first a setting with the plane of platy development and cleavage as the base ("orientation ancienne") he finally changed to a setting in which this plane is the side pinakoid ("notation définitive"). In this respect Ungemach's final setting resembles ours but otherwise it is

FIGS. 1-6.—Crystals of copiapite from Chile. FIG. 1.—Chuquicamata; material used for 2-circle measurement, x-ray measurement, and analysis. FIGS. 2, 3.—Sierra Gorda; two of Ungemach's crystals remeasured and redrawn in new position. FIGS. 4, 5, 6.—Tierra Amarilla (pseudocopiapite); three of Ungemach's crystals remeasured and redrawn in new position. In Figs. 1, 4, 5 the positive end of the c-axis is directed upward and the crystals are viewed from the direction of $b(010)$; in Figs. 2, 3, 6, representing crystals which are mainly developed at the negative end of the c-axis, this end is directed upward and the crystals are viewed from the direction of $b(0\bar{1}0)$.

radically different. Ungemach's preliminary setting is related to ours by the formula:

Ungemach (prelim.) to Authors: $\frac{1}{2}\bar{1}0/001/\frac{1}{2}\bar{1}0$
Authors to Ungemach (prelim.): $10\bar{1}/\bar{3}0\bar{3}/010$

The final setting of Ungemach stands in no less complicated relation to ours, since it defines a 12-fold cell in the structural lattice (Fig. 7):

Ungemach (final) to Authors: $\frac{1}{2}0\bar{1}/\frac{1}{2}\bar{1}0/\bar{1}0\bar{1}$
Authors to Ungemach (final): $10\bar{1}/\bar{1}2\bar{1}/\bar{3}0\bar{3}$

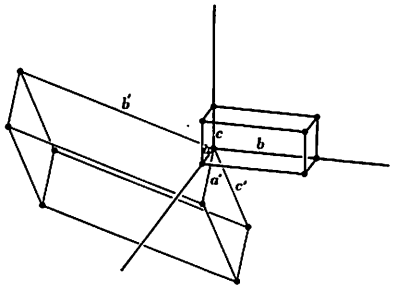

FIG. 7.—Crystal lattice of copiapite showing Ungemach's 12-fold morphological cell with $a'[10\bar{1}]$, $b'[\bar{1}21]$, $c'[\bar{3}0\bar{3}]$, in relation to the unit cell a, b, c, which conforms to the rules $c < a < b$, α and β obtuse.

The complexity of Ungemach's settings is indicated, as in other similar cases, by the weakness of the chosen vertical zone. The axes of weak zones correspond to relatively long lattice periods and if such axes are taken as crystal axes the geometrical elements are likely to define multiple and therefore unsuitable lattice cells. One must admire Ungemach's consummate skill with the single-circle goniometer, but his critical remarks about the two-circle instrument (1935, p. 99) are the less effective when we note that the use of this instrument leads one always to choose the strongest zone axis (usually the shortest lattice period) as the vertical axis, and thus to avoid the unfortunate settings that result from a feeble vertical zone.

The geometrical elements of Ungemach in his final setting:

$a : b : c = 0.3010 : 1 : 0.7295$; $\alpha = 99°46'$, $\beta = 90°30'$, $\gamma = 104°21'$

give the following comparison with the elements of Palache and Peacock when transformed to our setting:

$a : b : c$	α	β	γ	
0.4005 : 1 : 0.3971	93°58½′	102°08′	98°50′	Ungemach
0.4058 : 1 : 0.4039	93°50′	102°10′	99°21½′	Palache
0.4037 : 1 : 0.4005	93°51′	101°30′	99°23′	Peacock

Ungemach noted 146 forms on copiapite from Sierra Gorda, and represented a number of the elaborately developed crystals by skilful portrait drawings.

By combining Ungemach's geometrical cell with the absolute length of the vertical axis, $c = 7.27$ kX, and the specific gravity, $G = 2.134$, both measured by Berry on a typical crystal from Ungemach's collection, and using the resulting molecular weight of the unit cell content, $M = 1212.5$, Ungemach's analysis of his material from Sierra Gorda may be expressed in terms of atoms in the unit cell:

TABLE 3

COPIAPITE: ANALYSIS (UNGEMACH) AND CELL CONTENT

Analysis		Atoms in Unit Cell				
Fe_2O_3	31.92	Fe'''	4.85	Oxygen	7.27	24.94
SO_3	38.89	S	5.89		17.67	
H_2O	[29.19]	H_2O	19.66			
	100.00					

Again the cell content can be expressed as $X(OH)_2Fe'''_4(SO_4)_6.nH_2O$ in which X is one oxygen equivalent of Fe''' and n is apparently 19.

In view of the differences between the three sets of elements listed above, which correspond to angular differences sometimes exceeding half a degree, Peacock measured some of Ungemach's crystals which had kindly been made available by Donnay. The reflections obtained were only fair, probably due in part to some deterioration of the crystals brought about by atmospheric changes;[2] but it was possible to verify nearly all the forms noted by Ungemach on these particular crystals. The measurements, which are hardly worth presenting since so many reflections were poor, often fall somewhere between the angles calculated from Palache's and Unge-

[2]In the warm dry atmosphere of the Mineralogical Laboratories at Harvard University whole drawers of salts from Chile have unfortunately crumbled to powder with loss of water of crystallization.

mach's elements. It was not felt that these measurements should be given much weight in considering the question of the best geometrical elements for the mineral. Two of the remeasured crystals of Ungemach from Sierra Gorda are shown redrawn in our setting (Figs. 2, 3). Both crystals were more fully developed at the negative end of the *c*-axis which has therefore been directed upward while the broad face to the front is $b(0\bar{1}0)$.

OTHER OBSERVATIONS

In addition to normal copiapite, Ungemach distinguished an aberrant variety from Tierra Amarilla, Chile, which he named "pseudocopiapite." This material, which was said to have the same composition as normal copiapite, gave triclinic elements differing significantly from those of normal copiapite only in regard to the interaxial angles. Berry (1938*b*) remeasured fifteen crystals of Ungemach's pseudocopiapite and obtained elements which compare as follows with those of Ungemach transformed to our setting:

$a : b : c$	α	β	γ	
0.3938 : 1 : 0.3951	91°18½′	102°04′	98°59′	Ungemach
0.4007 : 1 : 0.4005	91°22′	102°22′	98°50′	Berry

Comparing these values with the previously given elements for normal copiapite one sees that there is now a significant difference only in the interaxial angles α. This difference might be due to an undetected difference in chemical composition which is allowed by variation in the terms X and n of the proposed general formula.

It remains to note some observations on very imperfect crystals of a cuprian copiapite from Chuquicamata, Chile, named *cuprocopiapite* by Bandy (1938). The material consists of tiny packs of minute weakly cohering nearly parallel green plates with the typical rhombic outline of copiapite. The broad face has a pearly lustre and even when freshly cleaved gives only a blurred signal. With the cleavage polar, trains of feeble reflections were obtained from the edges of the rhombic plates. From twelve pairs of measurements the average interzonal angle is 77° 42′, which is close to the interzonal angle [001] : [100] of copiapite, for which Ungemach gives 77° 48½′, Palache 77° 50′. In one of these zones a fair reflection is frequently seen at the mean polar distance $B = 84°\ 13'$ as compared to Palache's $B = 83°\ 59'$ for (001). In the other zone several signals

gave the mean angle $B = 83° 22'$ which is only roughly similar to the angle to (100) for which Palache gives $B = 79° 34'$, Ungemach $B = 80° 04\frac{1}{2}'$. Thus the copper salt is close to copiapite in form, but the crystals do not permit a determination of the elements.

FORMAL CRYSTALLOGRAPHIC PRESENTATION

Setting, elements, and angles. We are now in a position to present the geometrical crystallography of copiapite in formal tabular and graphical manner. The crystallographic setting is, we believe, well established, since it conforms to the properly chosen cell of the structural lattice in a widely used unique conventional orientation which was accepted for copiapite by Ungemach.

In regard to the choice of the numerical values for the geometrical elements, we have considered several alternatives: (1) Palache's values, which agree best with the measurements on the analysed material from Chuquicamata; (2) Ungemach's values, which accord best with his measurements on analyzed material from Sierra Gorda; (3) average values, which might take Peacock's x-ray results into account. The differences between the several sets of elements that have been derived for copiapite may be due in part to the quality of the crystals which generally give only fair reflections; probably of greater importance is the considerable variation in chemical composition which will be further brought out in the projected paper on composition and optics. In that case it will be better to retain a set of values associated with a particular composition rather than to submerge real variation in a general average. Since Ungemach's measurements represent much the largest number of crystals, and his analysis indicates pure ferrian copiapite ($X = Fe'''$) without monovalent or divalent bases, we have decided to adopt these values in our setting. In this way Ungemach's calculated angles (*hkl*) : (010) also afforded a useful check on our corresponding B-angles.

Table 4 gives the adopted elements and calculated angles for the commoner forms of copiapite as indicated by Ungemach's frequency statistics and our observations. In addition to the standard two-circle angles, φ, ρ, and the interfacial angles to the axial planes, A, B, C, we give the interzonal angle Z which, together with B,

TABLE 4

COPIAPITE—$R(OH)_2Fe'''_4(SO_4)_620H_2O$*

Triclinic; pinakoidal—$\bar{1}$

$a : b : c = 0.4005 : 1 : 0.3971$; $\alpha = 93°58\frac{1}{2}'$, $\beta = 102°08'$, $\gamma = 98°50'$

$p_0 : q_0 : r_0 = 1.0010 : 0.3929 : 1$; $\lambda = 83°58'$, $\mu = 77°03\frac{1}{2}'$, $\nu = 80°04\frac{1}{2}'$

$p_0' = 1.0301$, $q_0' = 0.4043$, $x_0' = 0.2161$, $y_0' = 0.1081$

Forms		φ	ρ	A	B	C	Z
c	(001)	63°25½′	13°35′	77°03½′	83°58′	0°00′	77°48½′
b	(010)	0 00	90 00	80 04½	0 00	83 58	0 00
a	(100)	80 04½	90 00	0 00	80 04½	77 03½	0 00
m	(110)	60 10½	90 00	19 54	60 10½	76 26½	0 00
$M\frac{1}{2}$	(2$\bar{1}$0)	91 23½	90 00	11 19	91 23½	78 01½	0 00
M	(1$\bar{1}$0)	102 36	90 00	22 31½	102 36	79 30½	0 00
$M2$	(1$\bar{2}$0)	121 53	90 00	41 48½	121 53	82 56½	0 00
$M3$	(1$\bar{3}$0)	135 34½	90 00	55 30	135 34½	85 52½	0 00
$d\frac{1}{2}$	(012)	34 51½	20 42½	75 34½	73 08	10 50	77 48½
d	(011)	22 52	29 04½	74 44½	63 24	20 34	77 48½
$d2$	(021)	13 16	43 17	74 20	48 08½	35 49½	77 48½
$d3$	(031)	9 17½	53 14	74 42½	37 45½	46 12½	77 48½
e	(0$\bar{1}$1)	143 53	20 08	81 15½	106 09	22 11	77 48½
f	(101)	76 56	51 38½	38 28	79 47½	38 35½	39 05½
$g\frac{1}{2}$	($\bar{1}$02)	−86 12	16 16½	105 47½	88 56	28 44½	106 14½
g	($\bar{1}$01)	−94 58	38 43	128 32½	93 06½	51 29½	128 36½
$g2$	($\bar{2}$01)	−97 45	61 21½	151 17	96 48	74 13½	151 08
$u\frac{3}{2}$	($\bar{1}$32)	−153 37	33 14	108 56½	119 24½	44 45	106 14½
$p3$	(131)	39 24	62 43½	47 37	46 37½	50 29½	39 05½
$r\frac{1}{2}$	($\bar{2}$1$\bar{2}$)	−108 47	40 09	129 34½	101 59	53 38	128 36½
r	($\bar{1}$1$\bar{1}$)	−120 40½	42 52½	129 31	110 18½	56 26	128 36½
$r2$	($\bar{1}$2$\bar{1}$)	−137 42½	49 53	127 11	124 27	62 41½	128 36½
s	($\bar{1}$11)	−67 15	40 53½	123 26	75 20	50 36½	128 36½
$s2$	($\bar{1}$21)	−47 12½	47 25	116 29½	59 59½	53 22	128 36½
$w3$	($\bar{2}$3$\bar{1}$)	−128 50	66 45	143 32½	125 11	80 03	151 07½
$w6$	($\bar{2}$6$\bar{1}$)	−145 50½	72 48	131 39	142 14	84 44	151 07½
$v3$	($\bar{2}$31)	−61 57½	64 03	135 08½	64 59½	72 21½	151 07½

*Composition indicated by a large number of analyses.

gives azimuth and distance from the normal to (010). Comparison with Table 1 will show the differences between corresponding angles according to the two sets of elements. It will be interesting to see how future measurements on analysed materials compare with these alternative values.

Form-list and projection. To conclude the descriptive crystallography we give a complete list of the observed forms (Table 5) and a gnomonic projection of the whole form-system (Fig. 9). In view of the complicated relation between Ungemach's notation and ours, and the fact that Ungemach's form-letters represent a "Millerized Lévy" notation in the discarded setting, it will be useful to give the full list of forms in both notations. To indicate the relative importance of the forms we have marked with x the forms noted by any one of us while Ungemach's actual number of observations is noted after each of his symbols. From the numbers of observations given in Tables 1 and 4 the forms are classed as common (**) and entered in the formal angle-table (Table 4), less common (*), and rare (without distinguishing mark).

The form-list of copiapite presented a special problem. In text and tables forms can be denoted simply by their Miller indices, but in drawings and projections briefer symbols, usually single italic letters, are convenient and generally used. Long form-lists always present a problem. In the case of well known species in an undisputed setting, such as calcite (Palache, 1943), there is no alternative to retaining and, if necessary, adding to the best current set of form-letters, drawing on Roman, Greek, and German alphabets, lower case and capitals, and combining these with additional symbols such as single, double, or triple dots, to produce the necessary number of distinct characters. But this procedure leads to practical difficulties and errors even in the hands of careful and scholarly workers. The relatively little known copiapite, on the other hand, has no traditional set of form-letters, and the previous setting has been drastically altered to a new one which we hope will recommend itself and remain unchanged. An appropriate set of new symbols may therefore be used to denote the numerous crystal forms.

The forms of copiapite all lie on a sheaf of zones meeting in *b* and *b'* (Fig. 8). The transverse zone [*aca'*] cuts this sheaf into zone-

segments which originate at their intersections with the zone [*aca'*] and terminate at *b* and *b'*. Conventional letters are given to the unit forms of the zone-segments as tabulated below.

Zone-Segment	Unit Form	Zone-Segment	Unit Form
(100)—(010)	$m(110)$	$(\bar{1}01)$—$(0\bar{1}0)$	$r(\bar{1}\bar{1}1)$
(100)—$(0\bar{1}0)$	$M(1\bar{1}0)$	$(\bar{1}01)$—(010)	$s(\bar{1}11)$
(001)—(010)	$d(011)$	$(\bar{1}02)$—(010)	$t(\bar{1}22)$
(001)—$(0\bar{1}0)$	$e(0\bar{1}1)$	$(\bar{1}02)$—$(0\bar{1}0)$	$u(\bar{1}\bar{2}2)$
(001)—(100)	$f(101)$	$(\bar{2}01)$—(010)	$v(\bar{2}11)$
(001)—$(\bar{1}00)$	$g(\bar{1}01)$	$(\bar{2}01)$—$(0\bar{1}0)$	$w(\bar{2}\bar{1}1)$
(101)—(010)	$p(111)$	(401)—(010)	$x(411)$
(101)—$(0\bar{1}0)$	$q(1\bar{1}1)$	(401)—$(0\bar{1}0)$	$y(4\bar{1}1)$
		$(\bar{5}01)$—(010)	$z(\bar{5}11)$

Any pole in a zone-segment, other than the end-poles and the units, are simply designated by the letter of the unit followed by a number which gives the gnomonic distance of the pole from the

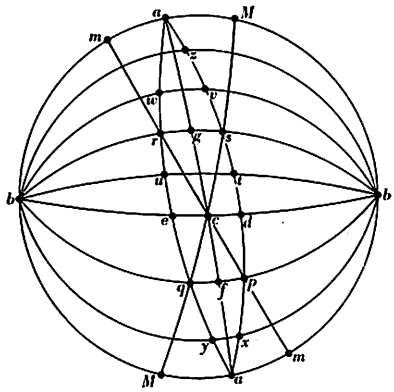

FIG. 8.—Stereographic projection of the principal zones of copiapite with the letters used to denote the forms in each zone-segment.

origin in terms of the unit gnomonic distance. For example, the pole (131) lies on the zone-segment *f*—*b* at a distance from the origin *f* which is three times the unit distance *f*-*p*. The form (131) therefore receives the symbol $p3$. Similarly (292) is lettered $p\frac{9}{2}$, $(2\bar{7}0)$

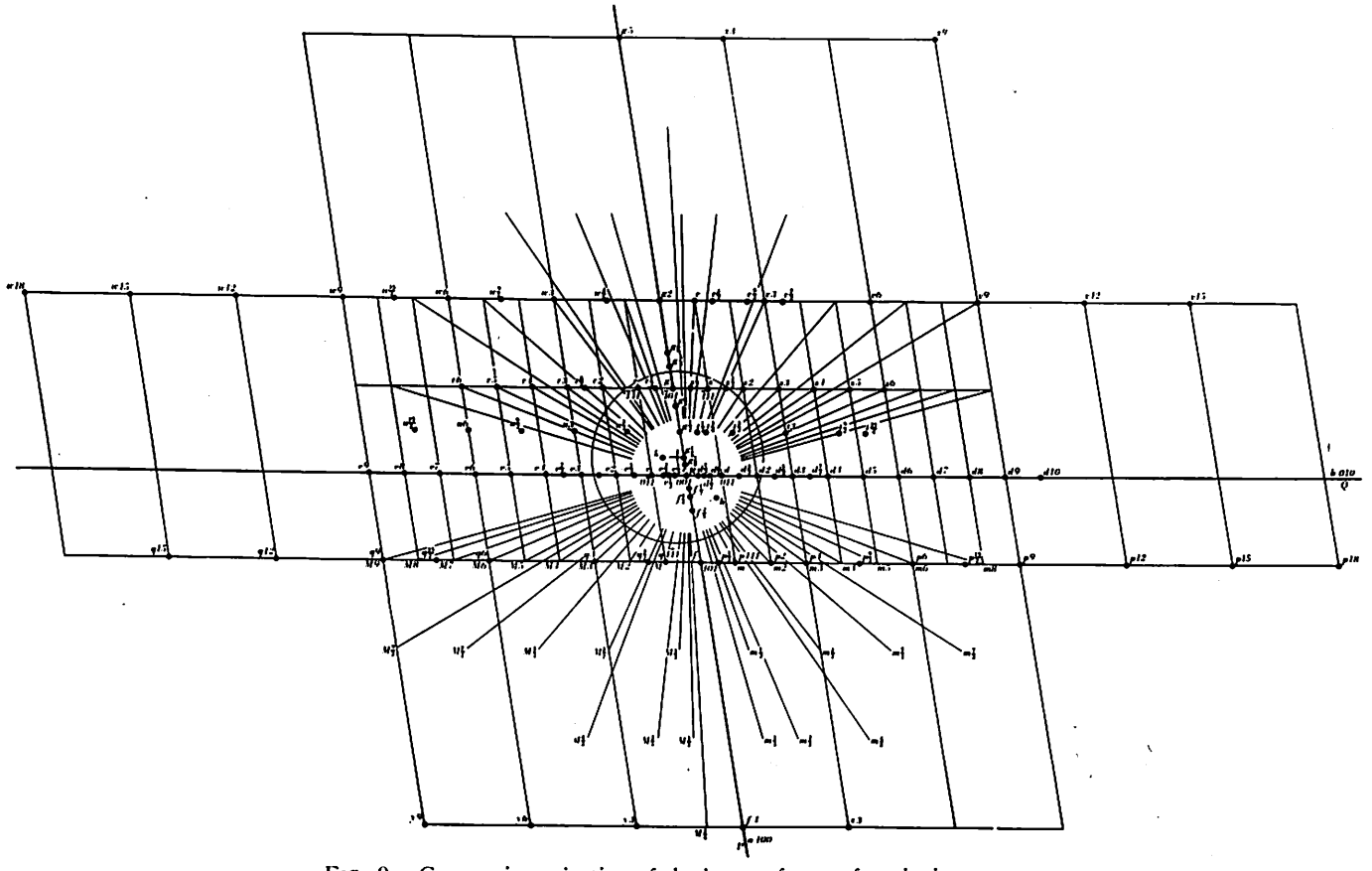

FIG. 9.—Gnomonic projection of the known forms of copiapite.

TABLE 5

COPIAPITE: OBSERVED FORMS

Authors		Obs.	Ungemach		Obs.	Authors		Obs.	Ungemach		Obs.
c	(001)**	x	δ_1	(1$\bar{1}$3)	28	$g\frac{5}{4}$	($\bar{5}$04)*	–	$c\frac{1}{6}$	($\bar{3}$31)	2
b	(010)**	x	g^1	(010)	2	$g\frac{7}{5}$	($\bar{7}$05)	–	$c\frac{1}{4}$	($\bar{2}$21)	1
a	(100)**	x	γ_1	(1$\bar{1}$3)	30	$g2$	($\bar{2}$01)**	x	c_1	(1$\bar{1}$1)	21
$m8$	(180)	–	γ_{17}	($\bar{1}$.17.3)	1	$g5$	($\bar{5}$01)*	–	c^1	(1$\bar{1}$2)	8
$m7$	(170)	x		($\bar{1}$.15.3)	–	k	(13$\bar{5}$)	–	λ	(12$\bar{2}$)	3
$m6$	(160)	x	γ_{13}	($\bar{1}$.13.3)	2	h	(134)	–	$f\frac{5}{2}$	(115)	1
$m5$	(150)	x	γ_{11}	($\bar{1}$.11.3)	2	$t\frac{1}{2}$	(1$\bar{1}$2)	x		(3$\bar{1}$3)	–
$m4$	(140)	x	γ_9	(1$\bar{9}$3)	2	$t\frac{3}{4}$	($\bar{2}$34)	–	o^1	(101)	2
$m\frac{7}{2}$	(270)	–	γ_8	(1$\bar{8}$3)	1	$t\frac{3}{2}$	(1$\bar{3}$2)*	x	f_1	(111)	8
$m3$	(130)*	x	γ_7	(1$\bar{7}$3)	6	$t3$	(1$\bar{6}$2)*	–	f_3	(131)	5
$m\frac{5}{2}$	(250)	–	γ_6	(1$\bar{6}$3)	1	$t\frac{9}{2}$	(1$\bar{9}$2)	–	f_5	(151)	2
$m2$	(120)*	x	γ_5	(1$\bar{5}$3)	6	$t\frac{2\,1}{4}$	($\bar{2}$.21.4)	–	f_6	(161)	1
$m\frac{3}{2}$	(230)*	–	γ_4	(1$\bar{4}$3)	4	$u\frac{3}{4}$	($\bar{2}$34)*	–	d_2	(12$\bar{1}$)	4
$m\frac{4}{3}$	(340)	–	$\gamma\frac{1\,1}{3}$	($\bar{3}$.11.9)	2	$u\frac{3}{2}$	(1$\bar{3}$2)**	–	d_3	(13$\bar{1}$)	10
m	(110)**	x	γ_3	(1$\bar{3}$3)	14	$u3$	(1$\bar{6}$2)*	–	d_5	(15$\bar{1}$)	5
$m\frac{2}{3}$	(320)	–	$\gamma\frac{7}{3}$	($\bar{3}$79)	3	$u\frac{9}{2}$	(1$\bar{9}$2)*	–	d_7	(17$\bar{1}$)	8
$m\frac{1}{2}$	(210)*	–	γ_2	(1$\bar{2}$3)	9	$u6$	($\bar{1}$.12.2)	–	d_9	(19$\bar{1}$)	3
$m\frac{1}{3}$	(310)	–	$\gamma\frac{5}{3}$	($\bar{3}$59)	3	$u\frac{1\,5}{2}$	($\bar{1}$.15.2)	–	d_{11}	(1.11.1)	3
$M\frac{1}{4}$	(41$\bar{0}$)	–	$\gamma\frac{1}{2}$	($\bar{2}$16)	3	$p\frac{1}{2}$	(212)	x		(016)	–
$M\frac{1}{3}$	(31$\bar{0}$)*	–	$\gamma\frac{1}{3}$	($\bar{3}$19)	6	p	(111)	x		(013)	–
$M\frac{1}{2}$	(21$\bar{0}$)**	x	a^3	(1$\bar{0}$3)	10	$p2$	(121)	x		(023)	–
$M\frac{2}{3}$	(32$\bar{0}$)*	–	$\beta\frac{1}{3}$	(3$\bar{1}$9)	5	$p3$	(131)**	x	i_1	(011)	10
M	(1$\bar{1}$0)**	x	β_1	(11$\bar{3}$)	24	$p\frac{9}{2}$	(292)	–	$i\frac{3}{2}$	(032)	1
$M\frac{4}{3}$	(34$\bar{0}$)	–	$\beta\frac{5}{3}$	(3$\bar{5}$9)	1	$p6$	(161)*	x	i_2	(021)	7
$M\frac{3}{2}$	(23$\bar{0}$)*	x	β_2	(12$\bar{3}$)	5	$p\frac{1\,5}{2}$	(2.15.2)	–	$i\frac{5}{2}$	(052)	2
$M2$	(12$\bar{0}$)**	x	β_3	(13$\bar{3}$)	10	$p9$	(191)	–	i_3	(031)	3
$M\frac{5}{2}$	(25$\bar{0}$)	x	β_4	(14$\bar{3}$)	2	$p12$	(1.12.1)	–	i_4	(041)	2
$M3$	(13$\bar{0}$)**	x	β_5	(15$\bar{3}$)	10	$p15$	(1.15.1)	–	i_5	(051)	2
$M\frac{7}{2}$	(27$\bar{0}$)	x		(16$\bar{3}$)	–	$p18$	(1.18.1)	–	i_6	(061)	2
$M4$	(14$\bar{0}$)*	–	β_7	(17$\bar{3}$)	7	q	(1$\bar{1}$1)	–	$e\frac{1}{3}$	(01$\bar{3}$)	1
$M\frac{9}{2}$	(29$\bar{0}$)	–	β_8	(18$\bar{3}$)	1	$q\frac{3}{2}$	(23$\bar{2}$)	–	$e\frac{1}{2}$	(01$\bar{2}$)	1
$M5$	(15$\bar{0}$)*	–	β_9	(19$\bar{3}$)	8	$q3$	(13$\bar{1}$)*	x	e_1	(01$\bar{1}$)	9
$M6$	(16$\bar{0}$)	x	β_{11}	($\bar{1}$.11.3)	2	$q6$	(16$\bar{1}$)*	x	e_2	(02$\bar{1}$)	7
$M7$	(17$\bar{0}$)	x	β_{13}	($\bar{1}$.13.3)	2	$q\frac{1\,5}{2}$	(2.15.2)	–	$e\frac{5}{2}$	(05$\bar{2}$)	1
$M8$	(18$\bar{0}$)	–	β_{15}	($\bar{1}$.15.3)	3	$q9$	(19$\bar{1}$)	–	e_3	(03$\bar{1}$)	2
$M9$	(19$\bar{0}$)	–	β_{17}	($\bar{1}$.17.3)	1	$q12$	($\bar{1}$.12.1)*	–	e_4	(04$\bar{1}$)	4
$d\frac{1}{3}$	(013)*	–	$\delta\frac{1}{3}$	(3$\bar{1}$9)	6	$q15$	($\bar{1}$.15.1)	–	e_5	(05$\bar{1}$)	2
$d\frac{1}{2}$	(012)**	x	o^3	(103)	10	$r\frac{1}{2}$	($\bar{2}$12)**	–	$\frac{3}{2}g$	(23$\bar{0}$)	10

**Common forms. *Less common forms. Remaining forms rare.

TABLE 5.—*Continued*

Authors		Obs.	Ungemach		Obs.	Authors		Obs.	Ungemach		Obs.
$d\frac{2}{3}$	(023)	–	$a\frac{1}{3}$	(319)	1	r	$(\bar{1}\bar{1}1)$**	x	$_2g$	$(1\bar{2}0)$	17
d	(011)**	x	a_1	(113)	19	$r2$	$(\bar{1}2\bar{1})$**	–	$_3g$	$(1\bar{3}0)$	11
$d\frac{3}{2}$	(032)	x	a_2	(123)	1	$r\frac{5}{2}$	$(\bar{2}5\bar{2})$	–	$\frac{7}{2}g$	$(2\bar{7}0)$	1
$d2$	(021)**	x	a_3	(133)	13	$r3$	$(\bar{1}3\bar{1})$*	–	$_4g$	$(1\bar{4}0)$	7
$d\frac{5}{2}$	(052)	x	a_4	(143)	3	$r4$	$\bar{1}4\bar{1})$*	–	$_5g$	$(1\bar{5}0)$	7
$d3$	(031)**	x	a_5	(153)	11	$r5$	$(\bar{1}5\bar{1})$	–	$_6g$	$(1\bar{6}0)$	3
$d\frac{7}{2}$	(072)	–	a_6	(163)	1	$r6$	$(\bar{1}6\bar{1})$	–	$_7g$	$(1\bar{7}0)$	1
$d4$	(041)*	x	a_7	(173)	8	$s\frac{1}{2}$	$(\bar{2}12)$	–	$_2h$	$(2\bar{1}0)$	3
$d5$	(051)*	x	a_9	(193)	4	s	$(\bar{1}11)$**	x	h^1	(100)	20
$d6$	(061)	x	a_{11}	(1.11.3)	2	$s\frac{3}{2}$	$(\bar{2}32)$*	–	h_2	(210)	5
$d7$	(071)*	x	a_{13}	(1.13.3)	4	$s2$	$(\bar{1}21)$**	x	t	(110)	11
$d8$	(081)	–	a_{15}	(1.15.3)	1	$s3$	$(\bar{1}31)$*	x	g_2	(120)	9
$d9$	(091)	–	a_{17}	(1.17.3)	1	$s4$	$(\bar{1}41)$*	–	g_3	(130)	6
$d10$	(0.10.1)	–	a_{19}	(1.19.3)	2	$s5$	$(\bar{1}51)$*	–	g_4	(140)	4
$e\frac{1}{4}$	$(0\bar{1}3)$*	–	$\delta\frac{5}{3}$	$(3\bar{5}9)$	7	$s6$	$(\bar{1}61)$	–	g_5	(150)	1
$e\frac{1}{2}$	$(0\bar{1}2)$*	–	δ_2	$(1\bar{2}3)$	7	$w\frac{3}{2}$	$(\bar{4}32)$*	–	c_2	$(\bar{1}21)$	4
$e\frac{2}{3}$	$(0\bar{2}3)$*	–	$\delta\frac{7}{3}$	$(3\bar{7}9)$	4	$w3$	$(\bar{2}31)$**	–	c_3	$(\bar{1}31)$	10
e	$(0\bar{1}1)$**	x	δ_3	$(1\bar{3}3)$	15	$w\frac{9}{2}$	$(\bar{4}92)$	–	c_4	$(\bar{1}41)$	2
$e\frac{3}{2}$	$(0\bar{3}2)$*	–	δ_4	$(1\bar{4}3)$	5	$w6$	$(\bar{2}61)$**	–	c_5	$(\bar{1}51)$	11
$e2$	$(0\bar{2}1)$*	x	δ_5	$(1\bar{5}3)$	8	$w\frac{1.5}{2}$	$(\bar{4}.1\bar{5}.2)$	–	c_6	$(\bar{1}61)$	1
$e\frac{5}{2}$	$(0\bar{5}2)$	–	δ_6	$(1\bar{6}3)$	3	$w9$	$(\bar{2}91)$*	–	c_7	$(\bar{1}71)$	6
$e3$	$(0\bar{3}1)$*	x	δ_7	$(1\bar{7}3)$	4	$w12$	$(\bar{2}.1\bar{2}.1)$	–	c_9	$(\bar{1}91)$	3
$e\frac{7}{2}$	$(0\bar{7}2)$	–	δ_8	$(1\bar{8}3)$	2	$w15$	$(\bar{2}.1\bar{5}.1)$	–	c_{11}	$(\bar{1}.11.1)$	1
$e4$	$(0\bar{4}1)$*	–	δ_9	$(1\bar{9}3)$	5	$w18$	$(\bar{2}.1\bar{8}.1)$	–	c_{13}	$(\bar{1}.13.1)$	2
$e5$	$(0\bar{5}1)$*	–	δ_{11}	$(1.\bar{11}.3)$	4	v	$(\bar{2}11)$	x		$(\bar{3}13)$	–
$e6$	$(0\bar{6}1)$	–	δ_{13}	$(1.\bar{13}.3)$	2	$v\frac{3}{2}$	$(\bar{4}32)$*	–	a^1	$(\bar{1}01)$	5
$e7$	$(0\bar{7}1)$	–	δ_{15}	$(1.\bar{15}.3)$	3	$v\frac{5}{2}$	$(\bar{4}52)$	x		$(\bar{3}23)$	–
$e8$	$(0\bar{8}1)$	–	δ_{17}	$(1.\bar{17}.3)$	1	$v3$	$(\bar{2}31)$**	x	b_1	$(\bar{1}11)$	9
$e9$	$(0\bar{9}1)$	–	δ_{19}	$(1.\bar{19}.3)$	1	$v\frac{7}{2}$	$(\bar{4}72)$	x		$(\bar{3}43)$	–
$f\frac{1}{7}$	(107)	–	d^2	$(11\bar{4})$	2	$v6$	$(\bar{2}61)$*	–	b_3	$(\bar{1}31)$	4
$f\frac{1}{4}$	(104)*	–	$d\frac{5}{2}$	$(11\bar{5})$	7	$v9$	$(\bar{2}91)$*	–	b_5	$(\bar{1}51)$	4
$f\frac{2}{5}$	(205)	–	$d\frac{7}{2}$	$(11\bar{7})$	2	$v12$	$(\bar{2}.12.1)$	–	b_7	$(\bar{1}71)$	1
f	(101)**	x	p	(001)	17	$v15$	$(\bar{2}.15.1)$	–	b_9	$(\bar{1}91)$	1
$f4$	(401)*	–	$c\frac{5}{2}$	$(\bar{1}15)$	4	$x3$	(431)	–	ϑ	$(\bar{1}35)$	1
$g\frac{1}{8}$	$(\bar{1}08)$	–	$d\frac{7}{6}$	$(3\bar{3}7)$	3	$y3$	$(4\bar{3}1)$	–	$\beta\frac{5}{2}$	$(\bar{1}1\bar{5})$	2
$g\frac{1}{5}$	$(\bar{1}05)$*	–	d^1	$(1\bar{1}2)$	9	$y6$	$(4\bar{6}1)$	–	η_3	$(\bar{1}35)$	1
$g\frac{1}{2}$	$(\bar{1}02)$**	x	d_1	$(1\bar{1}1)$	18	$y9$	$(4\bar{9}1)$	–	η_5	$(\bar{1}55)$	1
$g\frac{4}{5}$	$(\bar{4}05)$	–	$d\frac{1}{6}$	$(3\bar{3}1)$	1	$z9$	$(\bar{5}31)$	–	a^2	$(\bar{1}02)$	1
g	$(\bar{1}01)$**	x	m	$(1\bar{1}0)$	21	$z3$	$(\bar{5}91)$	–	ϵ	$(\bar{1}22)$	1

**Common forms. *Less common forms. Remaining forms rare.

becomes $M\frac{7}{2}$, and so on. Only a few italic letters are used and the attached whole numbers or vulgar fractions are always written after the letter and on the same level. This gives a simple system which should present no typographic difficulty and could be adapted to other complex form-lists.

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MINERALS FROM THE HIGHLAND-BELL SILVER MINE BEAVERDELL, BRITISH COLUMBIA[1]

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THE Highland-Bell Mine is now the only producing property on Wallace Mountain, which is near Beaverdell in the Greenwood Mining Division, about 23 miles east of Penticton, southern British Columbia. The ore deposits of the Beaverdell area were described by Reinecke (1915) who mentions, among other ore minerals, pyrargyrite, tetrahedrite, and native silver. McKinstry (1928) has discussed the silver mineralization at Beaverdell, noting the foregoing minerals and also argentite and polybasite. The present paper is concerned mainly with the silver minerals of the Highland-Bell Mine, their modes of occurrence, outward appearance, specific gravities, and chemical compositions. It is proposed to discuss their paragenetic relations elsewhere. The authors are indebted to Mr. R. B. Staples, Managing Director of the Highland-Bell Mine, for permission to publish this paper, and to Mr. R. N. Williams, of Vancouver, B.C., for the eleven new analyses made on samples of which many weighed only 0.25 to 0.50 gm.

The ore-bearing veins of the Highland-Bell Mine lie in the Westkettle Quartz Diorite (Jurassic), around the later Beaverdell Quartz Monzonite. The veins range from a few inches to several feet in thickness, with an average of about one foot, and they are offset by numerous faults. The silver minerals in the veins are argentian tetrahedrite (freibergite), pyrargyrite, polybasite, acanthite, and native silver, all of which are described below. Some details are also given of the associated sphalerite and galena. Quartz and pyrite are found in abundance but calcite and arsenopyrite are less widespread. Specular hematite, molybdenite, and scheelite have been found by the authors but they are rare. Ankerite (?) or siderite (?) have been noted and fluorite is found with some samples of

[1]Descriptive mineralogy, abstracted by the editor with the approval of the authors, from a longer manuscript.

native silver and acanthite. Stephanite and the arsenical silver minerals have been suspected but not identified.

SPHALERITE AND GALENA

Sphalerite varies in colour from light amber to black. The amber coloured mineral is apparently purer than the black, which shows inclusions of copper, iron, and silver minerals in polished sections, and is likely to carry good silver values. A sample of the cleanest sphalerite gave analysis 1. The Cu is probably due to included chalcopyrite which can be seen in most polished sections, while the Mn may explain the manganese stains which appear to be derived from weathered sphalerite.

Galena is widespread and abundant, usually coarsely crystalline but also fine-grained; it is commonly associated with pyrite and sphalerite and in polished sections inclusions of tetrahedrite, pyrargyrite, and polybasite are common, but inclusions of acanthite and native silver are rare. Assays of clean looking galena usually give 0.3—0.5 per cent Ag but most of this is due to included silver minerals. Fragments of clean material with smooth cleavage surfaces gave specific gravities in the range 7.50 ± 0.04, and yielded analysis 2. In this analysis the absence of Ag is difficult to reconcile with the results of many assays on similar material, and the presence of one-half per cent of Fe is surprising.

	1		2
Zn	58.30	Pb	85.69
Cd	0.55	Ag	none
Fe	7.15	Fe	0.52
Mn	0.09	Zn	none
Cu	1.20	Cu	none
S	32.27	As	none
As	trace	Sb	0.45
Sb	trace	S	13.04
Pb	none	Insol	0.20
Insol	0.24		99.90
	99.80		

1. Sphalerite, with Au 0.02 oz./ton, Ag 4.57 oz./ton. 2. Galena, clean cleavage material; sp. grav. 7.50 ± 0.04.

ARGENTIAN TETRAHEDRITE (FREIBERGITE)

Tetrahedrite is dull gray and fine-grained in the Beaverdell ore and consequently rather inconspicuous in hand specimens; but in polished sections this mineral is seen to be generously disseminated through the ore. A black mineral with high metallic lustre, resembling some occurrences of tetrahedrite, proves to be polybasite. Much of the gray copper is too finely disseminated to be detected by the naked eye; but occasionally it occurs in masses large enough to be easily seen. In such cases it is closely associated with galena and difficult to separate from this mineral. Two relatively pure samples were eventually prepared for analyses; one gave specific gravities 5.02 ± 0.02 (analysis 3), the other 4.94 ± 0.04(analysis 4).

	3	4
Ag	25.25	26.40
Cu	17.85	18.06
Fe	6.68	5.30
Zn	3.03	3.59
Pb	0.44	0.44
Sb	21.20	21.17
As	1.55	1.20
S	22.86	22.91
Insol	1.09	0.84
	99.95	99.91

3. Argentian tetrahedrite (freibergite), sp. grav. 5.02 ± 0.02. 4. Argentian tetrahedrite (freibergite), sp. grav. 4.94 ± 0.04.

These analyses are remarkable in their high Ag values, as compared to the range of Ag, 5—18 per cent, in analyses of typical argentian tetrahedrite. The economic significance of this tetrahedrite in the Highland-Bell ore can be appreciated when it is realized that 1 per cent of this mineral will give a silver value of 75 oz./ton.

PYRARGYRITE

This is one of the best known and most conspicuous of the silver minerals in the mine. It occurs disseminated in various other minerals, massive in lenses and stringers, and as crystals in vugs and irregular cavities.

Disseminated pyrargyrite, although inconspicuous, is an important contributor of silver. The host minerals are galena, and more rarely sphalerite, freibergite, pyrite, and quartz. Commonly the disseminated pyrargyrite occurs in grains measuring 10—200 microns, showing smooth contacts with galena and the other silver minerals.

Lenses and stringers of massive pyrargyrite are for the most part only a few feet long, a few feet high, and from fractions of an inch to two or three inches thick, occasionally yielding magnificent specimens of ruby silver. Smaller bodies grade down to the dimensions of the disseminated material. Fragments from selected massive pyrargyrite gave specific gravities 5.63 ± 0.03, while polished sections revealed particles of non-metallic minerals as the only impurities. The composition is given under analysis 5.

Good crystals of pyrargyrite are rarely obtained but crystal fragments, showing only the prism *a* and the rhombohedron *e* were observed. These gave specific gravities 5.82 ± 0.02 and the composition shown in analysis 6.

	5	6
Ag	58.15	59.85
Sb	21.70	20.51
As	0.52	1.75
S	18.15	17.67
Cu	none	none
Zn	trace	0.15
Fe	trace	none
Pb	0.10	none
Insol	0.75	none
	99.37	99.93

5. Pyrargyrite, massive, with sp. grav. 5.63 ± 0.03. 6. Pyrargyrite, crystal fragments, with sp. grav. 5.82 ± 0.02.

POLYBASITE

Polybasite was not recognized in the early days of the camp, partly because the mineral is rare in Canada and consequently not expected, and partly because it may be mistaken for freibergite. However, polybasite can usually be distinguished from freibergite by its softer more brittle character and its tendency to show crystal

faces. Although polybasite may be cherry red in thin splinters this property does not prove useful in distinguishing the mineral in hand specimens; also, after exposure, polybasite loses some of its lustre and thus tends to resemble gray copper.

Like pyrargyrite, polybasite occurs disseminated, massive in veinlets and stringers, as crystals in vugs and cavities, and also as a coating. Disseminated polybasite is less conspicuous than disseminated pyrargyrite, but it probably contributes largely to the silver value of the ore. The largest veinlets and stringers of polybasite might reach a foot or two in length and height and 1/4 inch in thickness; much commoner are bodies an inch wide and perhaps 1/16 inch thick. Fragments of material of this kind gave specific gravity 6.26 ± 0.03 and analysis 7.

Occasionally polybasite has been found in cavities as good six-sided tabular crystals with triangular striations on the base, but usually polybasite occurs as small incomplete crystals. A sample of picked crystal fragments gave specific gravities 6.33 ± 0.03 and analysis 8, in which the presence of considerable amounts of Bi, Fe, and Pb is unexpected in view of the apparent purity of the material.

Thin coatings of polybasite occur on sulphides and also in joint planes and minor faults. Occasionally freshly broken ore from the deepest levels show paper-thin films which may be polybasite or in some cases freibergite or acanthite. Fragments of polybasite from coatings, with specific gravities 6.28 ± 0.05 gave analysis 9.

	7	8	9
Ag	69.72	67.13	69.80
Cu	3.70	2.23	4.25
Bi	....	0.80	....
Sb	10.15	9.50	10.72
As	0.63	0.78	0.58
S	15.68	16.94	15.57
Zn	none	trace	none
Fe	none	0.31	none
Pb	none	2.41	none
	99.88	100.10	100.92

7. Polybasite, from veinlets, with sp. grav. 6.26 ± 0.03. 8. Polybasite, crystal fragments, with sp. grav. 6.33 ± 0.03. 9. Polybasite, from thin coatings, with sp. grav. 6.28 ± 0.05.

ACANTHITE

This mineral was formerly taken to be argentite at the Highland-Bell Mine, but in the past few years numerous crystals have been found which are certainly not isometric but are frequently slender prisms of orthorhombic appearance. These crystals were found growing on polybasite indicating their later formation. Acanthite has been found from top to bottom of the mine; it occurs principally as coatings along joints and minor faults, and as masses and crystals in vugs.

The coatings of acanthite, unless too thin, can be determined by their sectility, which distinguishes them from polybasite which is brittle. Otherwise the two minerals are similar, both being jet black with a brilliant lustre which fades on exposure. Acanthite is apparently less abundant than pyrargyrite or polybasite, and it was not possible to prepare a sample of the coatings for analysis. Acanthite is also found in vugs, usually in shapeless masses entirely without crystal faces or with only a few planes. There is no obvious difference between the vugs which contain massive acanthite and those in which the acanthite is partially crystallized. Samples of the crystallized acanthite gave the specific gravities 7.24 ± 0.04 and analysis 10, while the massive crystalline material gave 7.00—7.21 and analysis 11.

	10	11
Ag	86.37	86.14
Cu	0.23	0.36
Fe	0.25	0.21
Zn	0.40	0.31
Sb	trace	0.57
As	none	none
S	12.72	12.39
	99.97	99.98

10. Acanthite, crystallized, with sp. grav. 7.24 ± 0.04. 11. Acanthite, massive, with sp. grav. 7.00—7.21.

NATIVE SILVER

Although specimens of silver of one to two pounds have been found in the Highland-Bell Mine, the native metal is not the most important contributor to the Ag value of the ore. Native silver is

of late formation and it occurs in cavities, along joints, faults and slip planes, and disseminated in massive sulphides and sulphosalts.

In cavities native silver is found "growing" in arborescent and wiry forms with reddish yellow tarnish, from massive and crystallized acanthite, less commonly from polybasite, rarely from pyrargyrite. The cavities may reach several cubic inches in size and they also contain crystals of quartz, calcite, and fluorite. Less conspicuous is the silver which occurs in shreds, flakes, and minute grains along joint, fault, and slip planes both in the upper and the lower levels of the mine. The disseminated silver is seen only in polished sections as particles of late formation in acanthite, pyrargyrite, and galena.

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NAGYAGITE

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NAGYAGITE is an uncommon ore mineral which occurs chiefly in the well known gold deposits of Transylvania and has been noted with gold and telluride ores in other parts of the world. Published observations on nagyagite refer almost entirely to material from the original locality (Nagyág, Transylvania). The square tabular crystals are described as tetragonal, orthorhombic, or monoclinic. The many analyses indicate a complex composition with lead, gold, sulphur, tellurium, and antimony as chief constituents, and numerous empirical formulae have been proposed to represent the composition. In the recently published seventh edition of Dana's *System of Mineralogy* (Palache, Berman & Frondel, 1944), nagyagite is appended to the Tetradymite Group with which it has properties in common, but the uncertainties regarding the true nature of this mineral remain without a satisfactory solution.

The material used in the present study consists of two specimens of nagyagite, both from Nagyág, Transylvania, from the mineral collections of Queen's University. Specimen 1 contains square, thin-tabular crystals up to 5 mm. wide and 0.5 mm. thick, often grown together in sub-parallel or curved aggregates, with small quartz crystals, in irregular openings in the rock. Specimen 2 contains curved foliated crystals of nagyagite, often 1 cm. or more in width and less than 0.5 mm. thick, embedded in fine-grained carbonate rock. The study of this material was aided by Professor M. A. Peacock of the University of Toronto, to whom the writer is indebted for the use of the Berman balance at Toronto and for helpful advice throughout the course of this work.

PHYSICAL PROPERTIES

Three determinations of the specific gravity were made with the Berman balance on clean crystals from specimen 1. One crystal weighing 5.35 mg. gave 7.45 and 7.55, a second crystal weighing 6.50 mg. gave 7.48, yielding an average value of 7.49, as compared

to 7.347 (Hankó, 1890), 7.4613 (Sipöcz, 1885, p. 267), 7.40 (Frondel in Palache, Berman & Frondel, 1944, p. 169).

In reflected light a polished section of nagyagite is grey-white and distinctly anisotropic, with polarization colours light grey to darker grey in sections which traverse the cleavage; sections nearly parallel to the cleavage show no appreciable anisotropism. The Talmadge hardness is B—, estimated with a needle. The standard etch tests give the following reactions: HNO_3 slowly stains iridescent; HCl negative; KCN negative; $FeCl_3$ negative; KOH negative; $HgCl_2$ negative. These characters agree substantially with those given by Schneiderhöhn & Ramdohr (1931, p. 329) and Short (1940, p. 147).

A polished section of a number of crystals from specimen 1 shows about 2 per cent of altaite and a polished section of specimen 2 shows about 15 per cent of altaite in the nagyagite crystals. No twinning was observed in these polished sections.

STRUCTURAL CRYSTALLOGRAPHY

Material suitable for single crystal *x*-ray photographs was readily obtainable from specimen 1. The perfect basal cleavage provides a simple way of breaking a larger crystal in order to obtain a cleavage fragment of suitable size. The cleavage flakes, which bend very easily, were flattened by gentle pressure between glass plates before mounting. Occasionally the cleavage flakes show straight edges parallel to [110] in the structural lattice. The following rotation and Weissenberg photographs were made on three different crystals: crystal 1, a cleavage fragment ($0.6 \times 0.3 \times 0.1$ mm.) with one straight edge parallel to [110], rotation and zero-layer Weissenberg resolutions about [110]. Crystal 2, a cleavage fragment ($0.5 \times 0.5 \times 0.1$ mm.), rotation, zero, first, second, and tenth-layer Weissenberg resolutions about [001], the cleavage-normal. Crystal 3, a nearly square tablet ($0.7 \times 0.6 \times 0.3$ mm.), rotation and zero-layer Weissenberg resolution about [110], the diagonal of the square; rotation, zero, and first-layer Weissenberg resolutions about [100], the edge of the square.

The films obtained from crystals 1 and 2 are only fair and the diffraction spots are relatively large or drawn out parallel to the rotation axis. The rotation photograph about [001] shows diffrac-

tions drawn out in powder curves. These imperfections in the films are largely due to mechanical deformation of the cleavage fragments. The films obtained from crystal 3 show relatively sharp diffraction spots.

The Weissenberg photographs and the reciprocal lattice projections of these photographs indicate tetragonal symmetry in the Laue class D_{4h}—$4/mmm$, but, as shown later, the true symmetry is probably in the lower Laue class, C_{4h}—$4/m$. The zero-layer Weissenberg resolutions about [100] and [110] show diffractions ($00l$) up to $l = 38$, ($h00$) up to $h = 5$ and ($hh0$) up to $h = 3$. The zero-layer Weissenberg resolution about [001] shows diffractions ($h00$) up to $h = 5$, ($hh0$) up to $h = 3$, and (130), (240), (150). The films lead to a tetragonal cell:

$$a = 4.14 \pm 0.02 \text{ kX}; \; c = 30.15 \pm 0.08 \text{ kX}$$

These dimensions compare closely with the values of Gossner (1935):

$$a/3 = 4.17 \text{ Å}; \; c = 30.35 \text{ Å}$$

Gossner (1935, p. 322) gives $a = 12.5$ Å; this value is based upon the appearance of a layer-line consisting of a single spot on a rotation photograph about [010]. Evidence for the 3-fold multiplicity of a was not observed by Gossner on other rotation films about [110], [310], and [210]. The films obtained in the present study show no evidence for a larger value of a. The rotation photograph about [100] was heavily exposed and only the zero, first, and second layer-lines appear, giving $a = 4.14$ kX.

The observed diffractions conform to the conditions: hkl present in all orders; $0kl$ present in all orders; $hk0$ present only with $h + k = 2n$; hhl present in all orders; $00l$ present only with $l = 2n$. These conditions are characteristic of the space group C_{4h}^4—$P4_2/n$, but the twinning, described later, indicates still lower symmetry.

GEOMETRICAL CRYSTALLOGRAPHY

In early descriptions (Phillips, 1852, p. 137; Dana, 1882, p. 82) crystals of nagyagite are given as tetragonal, but the measurements are very meagre due to the universal poor quality of the crystals.

Schrauf (1878, pp. 239—242) gives measurements on five crystals from Nagyág and derives monoclinic elements with the cleavage plane as (010):

$$a : b : c = 0.2807 : 1 : 0.2761; \; \beta = 90°$$

The observations indicated that the (*hk*0) and 0*kl*) zones, which are equivalent in the tetragonal setting, differ both in the angular measurements and in the faces present. The edges of the crystals and the striations on (010) parallel to [001] and [100] are at 90°. Less important striations on (010), interpreted as [101] and [$\bar{1}$01], are at approximately 42½° and 47½° to the axial striations. The observations do not suggest any difference in development in the zones (*hkh*) and ($\bar{h}$*kh*).

TABLE 1

NAGYAGITE: COMPARISON OF ELEMENTS

Berry.....	Cleavage (001)	
	$a = 4.14$; $c = 30.15$ kX	$a : c = 1 : 7.283$
Gossner (1935).....	Cleavage (001)	
	$a = 12.50$; $c = 30.25$ Å	$a : 3c = 1 : 7.260$
Niggli (1926).....	Cleavage (001)	
	$a : b : c = 0.9836 : 1 : 3.5624$	$a : 2c = 1 : 7.244$
		$b : 2c = 1 : 7.125$
Goldschmidt (1897).	Cleavage (001)	
	$a : b : c = 0.9836 : 1 : 1.7812$	$a : 4c = 1 : 7.244$
		$b : 4c = 1 : 7.125$
Schrauf (1878).....	Cleavage (010)	
	$a : b : c = 0.2807 : 1 : 0.2761$; $\beta = 90°$	$a : 2b = 1 : 7.127$
		$c : 2b = 1 : 7.246$

Fletcher (1880, p. 188) gives observations on six crystals from the same locality. The setting of Schrauf is retained and measured angles are given for two forms not previously observed. The observations do not indicate as great a difference in development of zones (*hk*0) and (0*kl*) as suggested by Schrauf's observations.

In Dana (1892, p. 106) nagyagite is given as orthorhombic but the setting and axial ratio of Schrauf (1878) are retained. Goldschmidt (1897, p. 245; 1920, p. 68) and Niggli (1926, p. 228) give orthorhombic elements derived from the earlier measurements in a setting in which the cleavage becomes (001). Gossner (1935) gives the dimensions of a tetragonal structural lattice and finds no evidence for lower symmetry. Palache, Berman & Frondel (1944, p. 168) retain the monoclinic setting and elements of Schrauf (1878),

but they point out that the measurements are inadequate to prove monoclinic symmetry.

Table 1 gives a comparison between the new lattice constants and the various previously published elements.

The older settings are related to the present structural setting by the following reversible transformation formulae:

Gossner to Berry	$\frac{1}{3}00/0\frac{1}{3}0/001$
Berry to Gossner	300/030/001
Niggli to Berry	$\frac{1}{2}00/0\frac{1}{2}0/001$
Berry to Niggli	200/020/001
Goldschmidt to Berry	$\frac{1}{4}00/0\frac{1}{4}0/001$
Berry to Goldschmidt	400/040/001
Schrauf to Berry	$00\frac{1}{2}/\frac{1}{2}00/010$
Berry to Schrauf	020/001/200

A comparison of the measured angles of Schrauf (1878) and Fletcher (1880) and the calculated angles of the structural lattice is given in Table 2.

TABLE 2

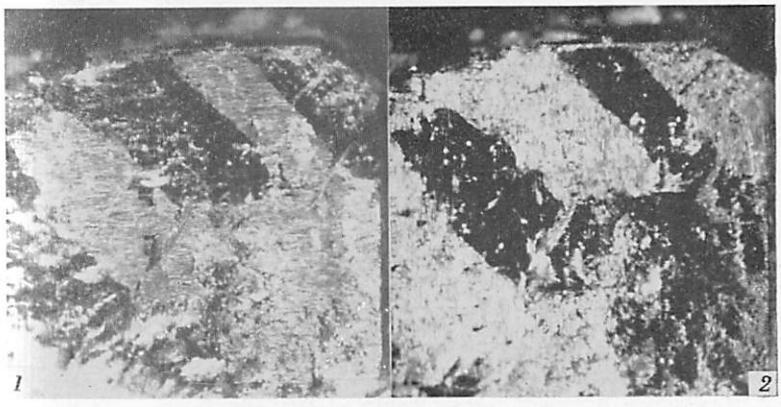
NAGYAGITE: MEASURED AND CALCULATED ANGLES FROM THE CLEAVAGE PLANE

Measured, Schrauf (1878)		Calculated for the Structural Lattice	
$b(010) : \epsilon(101)$	= ———	$c(001) : m(110)$	= 90°00′
$o(160)$	= 30°15′—30°30′ (4)	$o(0.1.12)$	= 31 $15\frac{1}{2}$
$g(051)$	= 35 30	$g(0.1.10)$	= 36 04
$i(130)$	= 49	$i(016)$	= 50 31
$f(031)$	= 50 30		
$e(120)$	= 60 20—60 40 (4)	$e(014)$	= 61 $13\frac{1}{2}$
$m(110)$	= ———	$d(012)$	= 74 38
$d(011)$	= 74 00—74 34 (3)		
*$y(141)$	= 51 45	$y(118)$	= 52 $09\frac{1}{2}$
*$x(131)$	= 59 00	$x(116)$	= 59 $46\frac{1}{2}$
$p(252)$	= 63 50	$p(115)$	= 64 06
$r(121)$	= 68 00—69 00 (3)	$r(114)$	= 68 $46\frac{1}{2}$
$s(343)$	= 75 30	$s(338)$	= 75 29
$t(111)$	= 78 30—79 10 (2)	$t(112)$	= 79 $00\frac{1}{2}$

*Fletcher (1880).

Considering the often reported poor quality of crystals of nagyagite there is good agreement between the structural ratio and the

$c : 2b$ ratio of Schrauf, and corresponding agreement in the measured and calculated angles in his $(0kl)$ zone. There is equally good agreement between the measured angles in the (hkh) zone of Schrauf and the calculated angles in the (hhl) zones of the structural lattice. The discrepancy between the measured angles in the $(hk0)$ zone of Schrauf and the calculated angles in the structural lattice is less than one degree in the two commonly observed forms. The observations given by Schrauf appear to be inadequate to prove the monoclinic symmetry of the crystals.



FIGS. 1, 2.—Nagyagite: photomicrograph of the natural crystal face (001) of a twinned crystal. The edges of the crystal plate, [100] and [010], are parallel to the edges of the photograph. Directed oblique illumination from Leitz Ultrapak Illuminator. FIG. 1.—Light incident obliquely from above and below showing horizontal striations on (001) of one twinned individual, the second individual is dark. FIG. 2.—Light incident obliquely from right and left showing vertical striations on the second individual of the twin while the first is dark. × 31.

The crystals on specimen 1 are nearly square plates with perfect cleavage (001) parallel to the platy development. The edges of the plates are parallel to [100] and [010], and the corners of the plates are often truncated parallel to [110] and [1$\bar{1}$0]. The $(h0l)$ and $(0kl)$ zones give almost continuous reflection with $\rho = 50°$ to 90°, measured from (001); the truncated corners of the plates are very rough

and give no reflections. The basal planes are heavily striated parallel to [100] or [010], the striations giving continuous reflection with $\rho = 0°$ to about 40°.

The basal plane of one crystal is composed of irregular bands which are roughly parallel to [110] or [1$\bar{1}$0]. Each of these bands is striated only in one direction, [100] or [010], while the striations on adjoining bands are at right angles to each other(Figs. 1, 2). A similar appearance is illustrated by Schrauf (1878, Plate X, Fig. 30) and mentioned by Schneiderhöhn & Ramdohr (1931, p. 330): "Schnitte || (010)"—our (001) —"lassen eine parkettförmige Zwillingsbildung erkennen." It can be explained in the tetragonal system as supplementary twinning about the axis [1$\bar{1}$0] in the disphenoidal class, $\bar{4}$, in which (0*kl*) and (*h*0*l*) are different forms and consequently striations parallel to [100] or [010] might occur separately. The non-equivalence of the zones (0*kl*) and (*h*0*l*) observed by Schrauf and Fletcher may be taken as evidence for the disphenoidal class rather than for orthorhombic or monoclinic symmetry. In twinning about [1$\bar{1}$0] the composition surface might be (110) or (001), as in mica and other platy minerals, and thus even small crystals would imitate the higher Laue symmetry D_{4h}—4/*mmm*.

The true symmetry of nagyagite will probably remain uncertain until the atomic arrangement has been worked out. From the available evidence the space-group S_4^1—$P\bar{4}$ (Laue symmetry C_{4h}—4/*m*, class S_4—$\bar{4}$) appears to be the most likely. This space-group explains the observed non-equivalence of the zones (*h*0*l*) and (0*kl*) and the twinning about [1$\bar{1}$0]. It also provides one-fold positions for the single gold atom in the unit cell whereas no space-group with essential missing spectra has one-fold positions. $P\bar{4}$ is a possible space-group if the missing reflections are due to atoms in special positions; and the apparent Laue symmetry, D_{4h}—4/*mmm*, shown rather inconclusively by single crystal photographs, can be due to twinning of the *x*-ray crystal.

Composition and Cell Content

The new cell dimensions and measured specific gravity of nagyagite give the molecular weight of the cell contents, $M = 2346$. In Table 3 this value has been used to obtain the atomic contents of

TABLE 3

NAGYAGITE: ANALYSES AND CELL CONTENTS
$M = 2346$

		1	2	3	4	5	6	7	8	9	10	11	12	13	A	B
Analyses	Au	7.51	7.41	7.61	8.32	8.52	8.46	7.65	7.57	8.02	8.03	8.18	9.47	10.16	7.94	8.34
	Pb	56.81	57.16	54.50	55.40	55.60	55.44	56.36	56.45	56.31	56.06	55.95	53.55	52.55	55.00	55.66
	Sb	7.39	6.99	8.62	6.59	6.77	6.48	8.16	8.16	8.40	7.70	8.01[7]	6.05	7.00	7.57	7.47
	Fe	0.41	0.32	0.93	0.62	0.51	0.64	...	...	...	...	...	...	...	0.31	0.47
	Te	17.72	17.87	17.80	19.14	18.72	18.91	16.24	16.54	15.55	16.86	16.36	18.99	18.80	17.43	17.54
	S	10.76	10.01	9.10	9.69	9.69	9.69	11.38	11.87	11.21	11.67	11.03	11.90	8.62	10.56	10.51
		100.60	100.04[1]	100.68[2]	100.04[3]	100.16[4]	99.91[5]	99.79	100.55	99.77[6]	100.32	100.00[8]	100.52[9]	98.25[10]	99.84	100.00
Atoms in unit cell	Au	0.89	0.88	0.92	0.99	1.01	1.01	0.91	0.90	0.96	0.95	0.98	1.13	1.23	0.95	1.00
	Pb	6.39	6.49	6.26	6.29	6.31	6.30	6.39	6.36	6.41	6.33	6.36	6.07	6.06	6.35	6.35
	Sb	1.41	1.35	1.69	1.27	1.31	1.25	1.57	1.56	1.63	1.48	1.55	1.17	1.37	1.46	1.45
	Fe	0.17	0.13	0.40	0.26	0.21	0.27	...	...	...	...	...	...Ag	0.25	0.14	0.20
	Pb-Sb-Fe	7.97	7.97	8.35	7.84	7.83	7.82	7.96	7.92	8.04	7.81	7.91	7.24	7.68	7.96	8.00
	Te	3.24	3.29	3.32	3.53	3.45	3.49	2.99	3.02	2.87	3.09	3.02	3.49	3.52	3.21	3.25
	S	7.83	7.34	6.75	7.11	7.10	7.12	8.34	8.69	8.24	8.51	8.14	8.71	6.42	7.74	7.75
	Te-S	11.07	10.63	10.07	10.64	10.55	10.61	11.33	11.71	11.11	11.60	11.16	12.20	9.94	10.95	11.00
	Total	19.93	19.48	19.34	19.47	19.39	19.44	20.20	20.53	20.11	20.36	20.05	20.57	18.85	19.85	20.00

1-12. Nagyág, Transylvania. 1. Anal. Sipöcz (1886). 2. Anal. Hankó (1890), average of two analyses; [1]incl. SiO_2 0.28. 3. Anal. Endrédy (in Tokody, 1930); [2]incl. insol. 2.12. 4-6. Anal. Clauder (1931) (in Helke, 1938); [3]incl. insol. 0.28; [4]incl. insol. 0.35; [5]incl. insol. 0.29. 7-11. Anal. Giusca (1937); [6]incl. insol. 0.28; [7]by difference; [8]incl. insol. 0.42. 12. Anal. Muthmann & Schröder(1897); [9]incl. insol. 0.56. 13. Oroya, Kalgoorlie district, Western Australia; anal. Simpson & Gibson (1912, p. 108); [10]incl. Ag 1.12. A. Average composition and cell content without 12 and 13. B. Calculated for ideal cell content $Au_{1.00}Pb_{6.35}Sb_{1.45}Fe_{0.20}S_{7.75}Te_{3.25}$.

the unit cell from thirteen analyses of the mineral. The numbers of atoms of each element in the structural cell are quite consistent but these numbers approach an integral value only in the case of gold, which equals 1. The sum of all the atoms is clearly 20, while Pb + Sb + Fe equals 8, and Te + S equals 11. The average of the eleven most consistent analyses (A) is very close to the ideal atomic contents (B). The structural formula of nagyagite may therefore be written: $Au_{1.00}Pb_{6.35}Sb_{1.45}Fe_{0.20}S_{7.75}Te_{3.25}$ or

$$Au(Pb, Sb, Fe)_8(S, Te)_{11} = 20 \text{ atoms}$$

The specific gravity calculated for the cell content given in the second formula is 7.55 in close agreement with the measured value 7.49. The substructure corresponding to the pseudo-cell with $a' = a = 4.14$ kX, $c' = c/10 = 3.015$ kX, and $M' = M/10 = 234.6$, contains 2 atoms.

A number of early analyses of nagyagite quoted by Dana (1892, p. 106) and Hintze (1904, p. 899) show no antimony and differ markedly from the analyses given above. These faulty analyses and the unusual composition of nagyagite has led to a great variety of published empirical formulae. These formulae have been discussed by Boldirew (1924) and Doelter (1926, p. 882). Table 4 gives the empirical formulae proposed by various authors together with the structural formula. The last column gives the total number of atoms indicated in each formula; it is interesting to note that most of these numbers are close to 20, the true cell content, or 40. The large structural formula given by Berman (Palache, Berman, & Frondel, 1944, p. 168) is calculated for the 9-fold structural lattice cell given by Gossner (1935), one-ninth of this formula approaches the total number of atoms in our unit cell. The variation in sulphur content indicated in this formula is not borne out by the later analyses, which are remarkably consistent. The small amount of iron, which shows in several of the analyses, has been included in the cell content.

Nagyagite shows some similarity in properties with the rhombohedral bismuth tellurides of the Tetradymite Group. All of these minerals exhibit a prominent platy development and perfect basal cleavage. The spacing of planes parallel to the cleavage is by far the greatest spacing in the lattice. The indices of the strong x-ray

diffractions from the cleavage plane are divisible by a simple integer and the number of atoms in the true unit cell is divisible by the same integer. The rhombohedral unit cell of joseite (Peacock, 1941) contains Bi_4TeS_2 (= 7 atoms) and the strong diffractions (000l) occur with l a multiple of 7; thus a substructure is indicated which

TABLE 4

NAGYAGITE: CHEMICAL FORMULAE

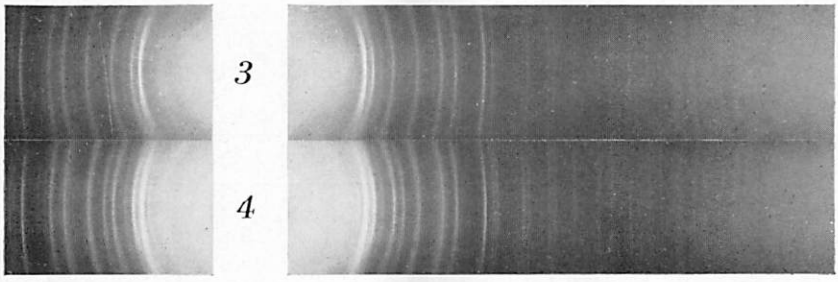
Author	Formula	No. of Atoms
Berthier (1832)	$AuPb_9SbTeS_{12}$	24
Wöhler & Schönlein (1853)	$Au_1Pb_{11}Te_{11}S_{13}$	36
Rammelsberg (1860)	(Pb, Au) $(S, Te)_2$	
	$(Pb, Au)_2(S, Te, Sb)_3$	
Sipöcz (1886)	$Au_2Pb_{14}Sb_3Te_7S_{17}$	43
Priwoznik (1897)	$AuPb_6Te_6S_8$	21
Schröder & Muthmann (1897)	$Au_2Pb_{10}Sb_2Te_6S_{15}$	35
Boldirew (1924)	4[S-Pb-(S, Te, Sb)$_2$-Pb], AuTe	22
Doelter (1926)	$Pb_{14}Au_2Sb_3Te_7S_{16}$	42
	$Pb_{10}Au_2Sb_2Te_6S_{15}$	35
	$Pb_{17}(Au, Ag)_4Sb_4Te_{10}S_{18}$	53
Gossner (1935)	$6Pb(S, Te), \frac{2}{3}Sb_2S_3.AuTe_2$	$18\frac{1}{3}$
Giusca (1937)	$AuPb_7S_9(Te, Sb)_5$	22
Berman in Palache, Berman, & Frondel (1944)	$Pb_5Au(Te, Sb)_4S_{5-8}$	15-18
Structural formula	$Pb_{50}Au_{10}(Te, Sb)_{40}S_{50-80}$	150-180
	$9[Pb_{5.5}Au_{1.1}(Te, Sb)_{4.4}S_{5.5-8.9}]$	9(17-20)
Berry	$Au(Pb, Sb, Fe)_8(S, Te)_{11}$	20
Structural formula	$Au(Pb_{6.35}Sb_{1.45}Fe_{0.20})\ (S_{7.75}Te_{3.25})$	

contains 1 atom. In the recently described hedleyite (Warren & Peacock, 1944) the rhombohedral unit cell contains 20 atoms, approximately $Bi_{14}Te_6$, and the substructure with $c' = c/20$ contains 1 atom. The cell content of hedleyite, as in nagyagite, closely approaches the total number of 20 atoms and the amount of each atom present is not represented by a whole number.

X-RAY POWDER PATTERN

The *x*-ray powder pattern (Fig. 3), given by a crystal from specimen 1, is reproduced together with the pattern (Fig. 4) from

cleavage flakes from specimen 2. This latter pattern shows a number of lines which do not appear in the first pattern; these lines correspond to the strong lines of altaite in agreement with the observations on the polished section of specimen 2. Table 5 gives the observed relative intensities and measured spacings for the pattern representing the crystals used for single crystal measurements. The pattern has been indexed as far as $\theta = 32°$; the measured spacings agree satisfactorily with one or more spacings calculated for the structural lattice and thus the pattern is adequately verified.



FIGS. 3, 4.—Nagyagite, Nagyág, Transylvania: *x*-ray powder photographs with Cu-radiation (Ni-filter); camera radius $360/4\pi$ mm. FIG. 3.—Crystals from specimen 1. FIG. 4.—Specimen 2; the extra lines are due to altaite. Actual size.

Harcourt (1942, p. 92) gives powder data for nagyagite from the same locality (Table 6). His spacings down to $d = 2.09$Å are matched by the spacings of the strong diffractions in our pattern, but below this value there is very little correspondence. The comparison of relative intensities, especially in regard to the three strongest lines which are used for identification, is not good. This difference in observed intensities may be due to some differences in the preparation of the powder sample. The powder obtained from crushing a very soft platy mineral does not consist of equidimensional grains. During the rolling of this powder in collodion alignment of the grains would probably occur resulting in relatively high intensity of diffractions (00*l*).

TABLE 5

NAGYAGITE: $Au(Pb, Sb, Fe)_8(Te, S)_{11}$

Tetragonal $P\bar{4}$; $a = 4.14$, $c = 30.15$ kX, Z = 1

I(Cu)	θ(Cu)	*d*(meas.)	(*hkl*)	*d*(calc.)	*I*(Cu)	θ(Cu)	*d*(meas.)	(*hkl*)	*d*(calc.)
vvw	12.2°	3.64 kX	(014)	3.629 kX	vvw	22.6°	2.00 kX	(1.1.11)	2.001 kX
vvw	13.2	3.37	(015)	3.413				(024)	1.996
(1)vvs	14.8	3.01	(0.0.10)	3.015	vw	23.8	1.905	(0.1.14)	1.911
vvw	15.3	2.91	(110)	2.927				(1.1.12)	1.907
			(111)	2.914	m	25.1	1.812	(1.1.13)	1.818
(3)vs	15.9	2.81	(113)	2.811				(028)	1.814
w	16.9	2.64	(115)	2.633	m	26.9	1.699	(0.2.10)	1.707
(4)s	18.5	2.42	(0.1.10)	2.437	vw	27.8	1.648	(1.1.15)	1.657
			(117)	2.421	(2)vs	30.8	1.501	(0.0.20)	1.507
vvw	19.5	2.30	(118)	2.312	w	31.8	1.459	(220)	1.464
m	21.8	2.07	(020)	2.070					
			(022)	2.051					

I(Cu)	θ(Cu)	*d*(meas.)	*I*(Cu)	θ(Cu)	*d*(meas.)	*I*(Cu)	θ(Cu)	*d*(meas.)
vvw	33.8°	1.382 kX	vw	43.7°	1.113 kX	w	50.0°	1.003 kX
vw	35.0	1.340	vw	44.4	1.099	vw	51.9	0.9768
w	36.6	1.289	vw	45.7	1.074	vw	56.3	0.9239
w	39.2	1.216	vw	47.5	1.043	vvw	58.1	0.9054
w	40.1	1.193	vw	48.4	1.028	vvw	61.9	0.8714
vw	42.5	1.138						

TABLE 6

NAGYAGITE: *X*-RAY POWDER DATA GIVEN BY HARCOURT (1942)

I(Cu)	*d*(meas.)	*I*(Cu)	*d*(meas.)	*I*(Cu)	*d*(meas.)	*I*(Cu)	*d*(meas.)
1.0	3.62 kX	2.0	2.43 kX	4.0	1.715 kX	.3	1.315 kX
3.0	3.40	(3) 4.0	2.09	1.0	1.518	.3	1.215
(2) 7.0	3.02	2.0	1.835	1.0	1.475	.2	1.142
(1) 8.0	2.83	1.0	1.790	.3	1.360	.2	1.078
.3	2.65						

SUMMARY

New observations combined with existing chemical analyses on nagyagite from Nagyág, Transylvania lead to the following description of the mineral:

Tetragonal; probably disphenoidal with space group S_4^1—$P\bar{4}$; the unit cell with $a = 4.14 \pm 0.02$, $c = 30.15 \pm 0.08$ kX, $a : c = 1 : 7.283$; contains $Au_{1.00}Pb_{6.35}Sb_{1.45}Fe_{0.20}S_{7.75}Te_{3.25}$ or $Au(Pb, Sb, Fe)_8(S, Te)_{11} = 20$ atoms; calculated specific gravity 7.55. A well marked pseudo-cell with $a' = a$, $c' = c/10$, contains 2 atoms. Crystals commonly imperfect square basal plates striated parallel to the edges, [100] and [010]; occasionally twinned with twin axis [1$\bar{1}$0], composition plane (110) or (001). Often foliated, curved, or bent. Cleavage (001), perfect, giving flexible laminae. Specific gravity 7.49.

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STUDIES OF MINERAL SULPHO-SALTS: XII—FÜLÖPPITE AND ZINCKENITE

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VOLUME I of the new Dana's System (Palache, Berman, & Frondel, 1944) gives the latest reliable data on the minerals there treated and calls attention to certain species that require further study. Two such minerals are the sulphantimonites of lead fülöppite and zinckenite, which are found associated at Nagybánya, Romania. A determination of the unit cell of fülöppite has not as yet been published; and, although the structural crystallography of zinckenite has been carefully studied (Vaux & Bannister, 1938), some questions in connection with this mineral deserve further investigation.

I am indebted to Emeritus Professor Charles Palache of Harvard University for a specimen of zinckenite, and to Professor V. B. Meen of the Royal Ontario Museum of Mineralogy for one of fülöppite. Professor M. A. Peacock kindly gave valuable advice during the course of the study and the preparation of the manuscript.

FÜLÖPPITE

The original description of fülöppite (de Finály & Koch, 1929), the last discovered member of the Plagionite Group, gives crystallographic, physical, and chemical observations but lacks structural data. A fine specimen of this rare mineral, from Nagybánya, Romania (ROM M19239), offered the possibility of contributing this information and continuing the *x*-ray study of the Plagionite Group (Nuffield & Peacock, 1944).

Fülöppite occurs as clusters of irregularly intergrown crystals associated with needles of zinckenite, sphalerite, dolomite, and sulphur. The individual crystals, up to 2 mm. in size, show the simple habit pictured by de Finály & Koch in their Fig. 1. The faces are curved and heavily striated, with a feeble metallic lustre. Unlike plagionite and semseyite, fülöppite has no cleavage. The specific gravity, measured on several clean fragments with the Berman microbalance is 5.22, in agreement with 5.23 noted by de Finály &

Koch. In polished section the colour is white with moderate anisotropism; polarization colours, bluish green to reddish brown. Etch tests gave the following reactions: HNO_3 (1 : 1), quickly stains gray; HCl (1 : 1), fumes tarnish iridescent to brown, easily rubs off; KCN (20%), negative; $FeCl_3$ (20%), negative; KOH (sat.), light brown stain, rubs off; $HgCl_2$ (sat.), negative; aqua regia, fumes tarnish iridescent, easily rubs off. These reactions agree substantially with those reported by de Finály & Koch, with one important exception: they observed no reaction with HNO_3.

The curved, rather dull crystals proved unsatisfactory on the two-circle goniometer, and the mostly vague reflections gave no hope of improving the goniometric measurements on fülöppite. A lengthy search yielded a fragment (0.2 mm.) which when suitably broken gave distinct signals from the base and a face in the (*hhl*) zone identified as ($\bar{1}11$) of de Finály & Koch. After adjusting the crystal to turn about the symmetry axis, rotation and Weissenberg *x*-ray films were obtained which showed monoclinic symmetry. These gave the constants:

$d(100) = 13.31$, $d(010) = 11.67$, $d(001) = 16.82$ kX; $(001):(100) = 85°19'$

and hence the cell dimensions:

$$a = 13.36,\ b = 11.67,\ c = 16.88 \text{ kX};\ \beta = 94°41'$$

The systematically missing spectra conform to the conditions: (*hkl*) present only with $(h + k)$ even, (*h0l*) present only with *h* even and *l* even. The possible space-groups, as in the case of plagionite and semseyite, are therefore C_{2h}^6—$C2/c$ and C_s^4—Cc, with $C2/c$ the more probable in view of the holohedral form.

In the new Dana's System (Palache, Berman, & Frondel, 1944, p. 463) Berman has modified the geometrical elements of de Finály & Koch, which were obtained on admittedly poor crystals, and has altered the setting by doubling the *c*-axis to conform with the structural setting of the other members of the Plagionite Group. These elements compare with the new ones derived from *x*-ray measurements as follows:

$$a : b : c = 1.1184 : 1 : 1.4085;\ \beta = 94°49' \text{ (goniometric)}$$
$$a : b : c = 1.1448 : 1 : 1.4464;\ \beta = 94°41' \text{ (}x\text{-ray)}$$

The wide difference in the two ratios is due mostly to a difference in the relative *b*-lengths, since the $a : c$ ratios are quite close:

$$a : c = 0.794 \text{ (goniometric)};\ a : c = 0.791 \text{ (}x\text{-ray)}$$

and in the $(h0l)$ zone the agreement between angles measured by de Finály & Koch and those calculated from the x-ray elements is good:

	de Finály & Koch meas.	Nuffield calc.
$ac = (100):(001)$	94°48′	94°41′
$a'c = (\bar{1}00):(001)$	85 10	85 19
$dc = (\bar{1}02):(001)$	33 35	33 35

A close check on the unit cell dimensions was obtained from a second set of films, got by rotating the crystal about the edge of the (hhl) zone. The rotation and zero-layer Weissenberg photographs gave the values:

$$p[\tfrac{1}{2}\tfrac{1}{2}0] = 8.87 \text{ kX}, \; d(110) = 8.80 \text{ kX}, \; d(001) = 16.83 \text{ kX}$$

From the cell dimensions these constants are $p[\frac{1}{2}\frac{1}{2}0] = \frac{1}{2}\sqrt{a^2 + b^2} = 8.87$ kX; $d(110) = 1/\sqrt{1/a^2 \sin^2\beta + 1/b^2} = 8.80$ kX; $d(001) = c \sin\beta = 16.82$ kX. This agreement gives assurance of the accuracy of the cell dimensions and the new axial ratios, which are therefore submitted as the best geometrical elements of fülöppite. Table 1 gives the two-circle angles for the eight known forms, calculated from these elements.

TABLE 1

FÜLÖPPITE—$3PbS.4Sb_2S_3$
Monoclinic—$C2/c$

$a : b : c = 1.1448 : 1 : 1.4464$; $\beta = 94°41'$
$p_0 : q_0 : r_0 = 0.8764 : 1 : 0.6937$; $\mu = 85°19'$
$p'_0 = 1.2677$, $q'_0 = 1.4464$, $x'_0 = 0.0819$

Forms	ϕ	ρ	ϕ_2	$\rho_2 = B$	C	A
$c(001)$	90°00′	4°41′	85°19′	90°00′	0°00′	85°19′
$a(100)$	90 00	90 00	0 00	90 00	85 19	0 00
$d(\bar{1}02)$	−90 00	28 54	118 54	90 00	33 35	118 54
$e(114)$	47 48	28 18	68 15½	71 26	25 00½	69 26½
$p(112)$	44 42½	45 30	54 24½	59 32½	42 18½	59 53
$t(\bar{1}13)$	−35 15	30 33½	108 49	65 28	33 27½	107 03½
$o(\bar{1}12)$	−37 21	42 17½	118 54	57 39½	45 16	114 06
$s(\bar{1}11)$	−39 21	61 52	139 51½	47 00	64 54	123 59½

The empirical molecular weight of fülöppite is $M = VG/1.649 = 8{,}302$, where V is the volume of the unit cell and G is the measured

gravity, 5.22. With this value of M, the only analysis of fülöppite leads to the ideal cell content (Table 2):

$$Pb_{12}Sb_{32}S_{60} = 4[3PbS.4Sb_2S_3]$$

This composition has been adopted by Berman in the revision of Dana's System (1944) in preference to $2PbS.3Sb_2S_3$ derived by de Finály & Koch from their analysis. A consideration of Table 2 shows that this latter composition, retained by Harcourt (1942) and the A. S. T. M. x-ray diffraction data cards (1945), cannot give a rational content for the cell. The specific gravity calculated from the molecular weight and volume of the cell, is 5.22, identical with the measured value. This provides further confirmation of the accuracy of the cell dimensions.

TABLE 2

FÜLÖPPITE: ANALYSIS AND CELL CONTENT
$M = 8{,}302$

	1	2	3	4	5
Pb	28.29	28.32	11.35	12	29.94
Sb	47.50	47.55	32.42	32	46.90
S	24.10	24.13	62.47	60	23.16
	100.08[1]	100.00			100.00

1. Nagybánya, Hungary; anal. de Finály (in de Finály & Koch, 1929). [1]Incl. SiO_2 0.19. 2. Analysis reduced to 100 per cent. 3. Atoms in the unit cell. 4. Ideal cell content. 5. Ideal percentage composition.

Fülöppite gives an even poorer powder pattern than plagionite and semseyite. Table 3 gives the intensities, I, glancing angles for Cu radiation, ϑ(Cu), and spacings, d, for the twenty-eight lines observed. To verify the pattern, it was indexed to $\vartheta = 18°$. The calculated spacings together with the indices of the corresponding planes are included in the table for the first twelve lines. The published powder pattern for fülöppite (Harcourt, 1942, p. 83; A.S.T.M., 1945, card II—1091) gives thirteen lines. All the spacings can be fairly closely matched by spacings in our pattern, but the agreement of intensities, especially for the three strongest lines, is only tolerable. Harcourt's first (d = 3.23) and second (d = 3.82) strongest lines correspond respectively to our second (d = 3.21) and first (d = 3.86).

His third strongest line (d = 3.38) roughly matches one of our very weak lines (d = 3.34). It might be proper, then, to accept the indexed spectrum given above as the standard powder pattern for fülöppite.

TABLE 3

FÜLÖPPITE: $3PbS.4Sb_2S_3$

Monoclinic, $C2/c$; a = 13.36, b = 11.67, c = 16.88 kX, β = 94°41′; Z = 4

I	ϑ(Cu)	d(meas.)	(hkl)	d(calc.)	I	ϑ(Cu)	d(meas.)	(hkl)	d(calc.)
10	11.5°	3.86 kX	($\bar{1}14$)	3.88 kX				($\bar{4}04$)	2.72 kX
			($\bar{3}12$)	3.84	1	16.4°	2.72 kX	(332)	2.72
½	11.85	3.74	(130)	3.73				($\bar{3}15$)	2.72
			(114)	3.72				($\bar{1}16$)	2.71
½	12.1	3.67	($\bar{2}04$)	3.69				(240)	2.67
			($\bar{1}31$)	3.66				($\bar{2}06$)	2.66
½	13.3	3.34	(400)	3.33	1	16.8	2.66	($\bar{2}41$)	2.65
7	13.85	3.21	(313)	3.22				($\bar{4}23$)	2.65
			(115)	3.20				(225)	2.60
½	14.15	3.14	(133)	3.14	½	17.1	2.61	($\bar{5}11$)	2.60
			($\bar{2}24$)	3.12				(510)	2.60
4	15.3	2.91	(025)	2.91				(043)	2.60
1	15.9	2.81	(006)	2.80	½	17.9	2.50	(206)	2.51

I	ϑ(Cu)	d(meas.)	I	ϑ(Cu)	d(meas.)	I	ϑ(Cu)	d(meas.)
½	18.6°	2.41 kX	1	24.8°	1.833 kX	½	29.15°	1.579 kX
1	20.6	2.18	1	25.4	1.792	½	30.0	1.537
2	21.3	2.12	1	26.3	1.735	½	31.9	1.455
½	22.2	2.03	½	27.25	1.679	½	36.6	1.289
2	22.9	1.975	½	27.7	1.654			
1	24.0	1.890	½	28.85	1.594			

Plagionite, heteromorphite, and semseyite were recognized as a natural mineral group by Spencer (1899), and fülöppite was added to the group by de Finály & Koch. It was noted that the ratio $a : b$ and the angle β was fairly constant throughout the group while $c : b$ increased with increase of PbS. In an earlier study (Nuffield & Peacock, 1944, p. 38) it was shown that the grouping of these minerals is supported by the cell dimensions of plagionite and semseyite. A summary of the data for three minerals on which x-ray measurements have now been made confirms the position of fülöp-

pite in the Plagionite Group and shows that the cell dimensions from fülöppite to semseyite increase in a very regular manner with increase of PbS. The almost constant values for a and b point to a common ground plan in the structure of the three minerals. So far it has not been possible to obtain a specimen of heteromorphite to test its position in the Plagionite Group.

	a	b	c	β	Space-group
Fülöppite.....$3PbS.4Sb_2S_3$	13.36 kX	11.67 kX	16.88 kX	94°41′	$C2/c$
Plagionite.....$5PbS.4Sb_2S_3$	13.45	11.81	19.94	107 11	$C2/c$
Heteromorphite..$7PbS.4Sb_2S_3$	...	...	...	...	..
Semseyite.....$9PbS.4Sb_2S_3$	13.61	11.99	24.52	105 49	$C2/c$

ZINCKENITE

This mineral occurs in stout to slender prismatic crystals rarely terminated by measurable faces. The symmetry was originally considered to be orthorhombic (pseudo-hexagonal), with twinning on (110), but Vaux & Bannister determined the unit cell as hexagonal, with $a = 44.06$, $c = 8.60$ Å, space-group C_6^6—$C6_3$ or C_{6h}^2—$C6_3/m$, and found no x-ray evidence for twinning. A marked pseudo-cell had the dimensions $a' = a/2$, $c' = c/2$. The composition of zinckenite was formerly taken as $PbS.Sb_2S_3$, but Vaux & Bannister found that the cell content 12 [$6PbS.7Sb_2S_3$] is more likely than 81 [$PbS.Sb_2S_3$]. Recently Berry (1943) has suggested that zinckenite might still be orthorhombic with very small departure from hexagonal symmetry, and that the cell content might then be 160 [$PbS.Sb_2S_3$]. New x-ray and specific gravity observations were therefore undertaken in an attempt to settle this question.

On a fine specimen from Wolfsberg, Harz (HMM 92554), zinckenite occurs as deeply channelled, rounded prisms measuring up to 12 mm. in length, embedded in crystallized quartz. Frequently the prisms are found growing in sub-parallel orientation. The colour is steel-gray with a bright metallic lustre only occasionally dulled by an iridescent tarnish. Broken areas exhibit a sub-conchoidal fracture. A single clean crystal weighing 23 mg. gave a specific gravity of 5.36 (two determinations) measured on the Berman microbalance. In polished section zinckenite is white with moderate anisotropism. Polarization colours are light to dark gray. Using standard reagents

the following etch reactions were obtained: HNO_3, effervesces and quickly stains dark; HCl fumes tarnish light brown; KCN, negative; $FeCl_3$, negative; KOH, etches and stains bright iridescent; $HgCl_2$, very slight iridescent stain in places. These reactions agree substantially with those given by Schneiderhöhn & Ramdohr (1931) and Short (1940). The hardness estimated with a steel needle is C (Talmadge).

A slender untwinned prism 2 mm. long, gave a rotation photograph and Weissenberg resolutions about c[0001] and about a random axis normal to c [0001] which confirmed the hexagonal symmetry, the true cell and the pseudo-cell, and the choice of space-groups found by Vaux & Bannister. The absence of vertical symmetry planes is most apparent on the zero-layer resolution about c [0001]. Here diffractions from the planes $(12h.\overline{2}h.\overline{10}h.0)$ form the most prominent row of spots on the film (Fig. 1) while the $(h0\bar{h}0)$ and $(10h.2h.\overline{12}h.0)$ diffractions are very weak. Measurement of the films gave

$$a = 44.06,\ c = 8.59 \text{ kX}$$

as the dimensions of the true cell. A rotation photograph of another crystal from Chocaya la vieja mine, Sud-Chichas, Potosi, Bolivia, gave $c = 8.61$ kX. These measurements completely confirm the cell dimensions of Vaux & Bannister.

From a rotation photograph of a needle of zinckenite from Wolfsberg, and a powder pattern, Hiller (1939) derived the orthorhombic cell dimensions:

$$a = 12.29,\ b(\text{needle axis}) = 8.66,\ c = 13.76 \text{ Å}$$

The period in the needle axis agrees with ours but the remaining periods are evidently erroneous and the suggested isotypy with emplectite and chalcostibite is without foundation.

According to Friedel's Law, x-ray diffractions cannot be used to distinguish between the presence or absence of a centre of symmetry in a crystal. In a crystal lacking a centre of symmetry the faces (hkl) and $(\overline{hkl})$ have different properties owing to a reversal in the order of which the atomic sheets are encountered in proceeding in one direction or the other, normal to the faces (Bragg, 1933, p. 94). The reflections for (hkl) and $(\overline{hkl})$ are composite waves having phases of opposite signs but equal amplitudes. Hence the intensities of

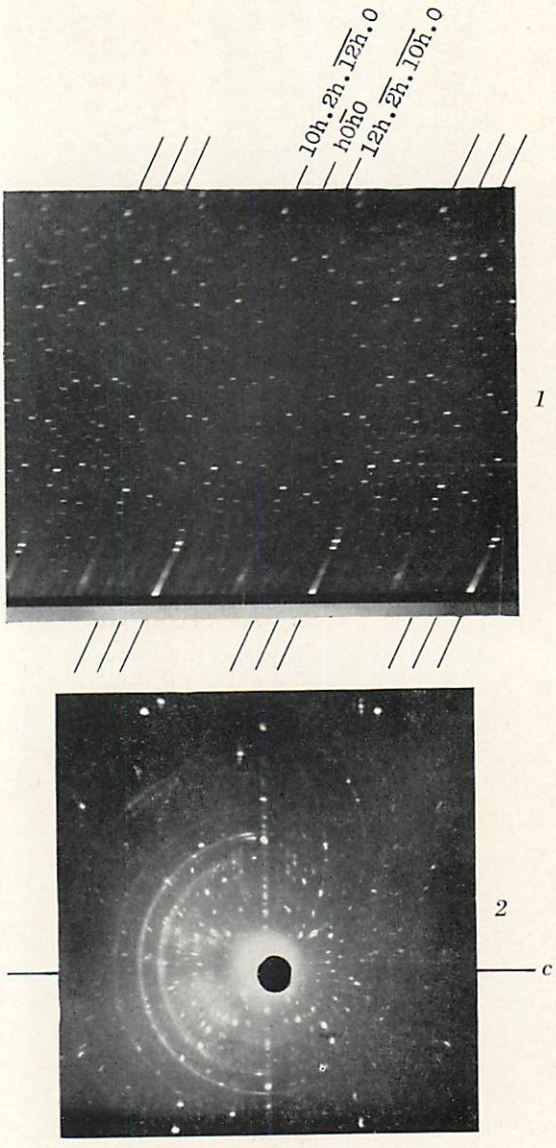


FIG. 1.—Zinckenite: Weissenberg resolution of the zero-layer line about the needle-axis [0001], showing the effect of the six-fold axis and the absence of vertical symmetry planes.

FIG. 2.—Zinckenite: Laue photograph with the beam perpendicular to the needle-axis, showing the absence of symmetry plane perpendicular to that axis. The one-sided powder rings are from an improvised lead slit.

(hkl) and ($\overline{hkl}$) are equal, resulting in centrosymmetrical diffraction patterns.

Exceptions to Friedel's Law have been recorded. Haga & Jaeger (1914) obtained Laue photographs of cordierite from plates cut parallel to the three pinakoids which showed the symmetry $mm2$. However, some of the later work of Haga & Jaeger (1916), placed some doubt on the reliability of these results, as in the case of calamine. The habit of this mineral indicates that it is hemimorphic with c[001] polar and a(100) and b(010) mirror planes. A Laue photograph of a plate cut parallel to c(001) confirmed the presence of these two symmetry planes but photographs of plates cut parallel to the other two pinakoids each showed only one symmetry plane and that was c(001). More recently, Coster, Knol, & Prins (1930) obtained a difference of intensity of reflections from positive and negative tetrahedral faces of sphalerite, when the range of wavelengths used included the Zn absorption-edge. This has been explained as an anomalous phase change resulting from scattering by the Zn atoms. In contrasting reflections from (hkl) and ($\overline{hkl}$), the sign of this anomalous phase change is not reversed, while all phase differences owing to the positions of the atoms are reversed, and hence the resultant waves have a somewhat different amplitude (Bragg, 1933, pp. 94-95).

These considerations suggested that a possibility existed of deciding between the choice of space-groups for zinckenite, $C6_3$ (hexagonal pyramidal class—6) or $C6_3/m$ (hexagonal dipyramidal class—$6/m$). Consequently a short clean prism was mounted with c [0001] normal to the x-ray beam and Laue photographs using W-radiation were obtained for two different positions of the crystal. In Fig. 2 one of these is reproduced. The direction of c [0001] is left and right and the mirror plane in question should manifest itself by a symmetry of intensity of the reflections to left and right of a line drawn vertically through the central spot. Certain obvious differences in intensity indicate the absence of such a symmetry plane and it must be concluded that zinckenite furnishes another exception to Friedel's Law, and the crystal class is 6, and hence the space-group $C6_3$.

As yet there are no first class analyses of zinckenite, and therefore the final answer to the question of the cell content cannot be

given. In Table 4 the better older analyses (1, 2, 3, 4) and a recent analysis (5, 6) are presented again, with the numbers of atoms in the unit cell calculated for the specific gravity 5.35, which fairly represents the concordant recent measurements. The alternative cell contents appear to be 81 [$PbS.Sb_2S_3$] (calc. sp. grav. 5.35), 80[$PbS.Sb_2S_3$] (calc. sp. grav. 5.28), and 12 [$6PbS.7Sb_2S_3$] (calc. sp. grav. 5.22). The first of these, 81 [$PbS.Sb_2S_3$], is supported by the latest analysis and the good agreement between the calculated and measured specific gravity (5.36); but the numbers of atoms are not in good agreement with the subdivision of the unit cell into eight pseudo-cells ($a' = a/2$, $c' = c/2$) and the atomic positions (2 and 6) in the space group $C6_3$. The second possibility, 80 [$PbS.Sb_2S_3$] fits the newer analysis equally well but the calculated specific gravity

TABLE 4

ZINCKENITE: ANALYSES AND CELL CONTENTS

$M = 46{,}907$

	1	2	3	4	5	6	A	B
Pb.....	31.84	30.80	34.33	29.33	34.58	34.58	35.79	32.60
Fe.....	...	...	0.06	0.08	0.50	0.14	...	...
Cu.....	0.42	...	0.70	...	...	...	...	...
Sb.....	44.39	46.18	42.15	46.17	42.30	42.30	42.06	44.70
As.....	...	...	...	...	0.48	...	...	...
S.....	22.58	23.04	22.63	23.10	21.84	21.63	22.15	22.70
	99.23	100.02	99.87	99.62[1]	99.70	98.65	100.00	100.00
Pb.....	72.63	69.71	77.81	67.28	78.51	79.35	81 80	72
Fe.....	...	...	0.51	0.68	4.21	1.19	... ...	...
Cu.....	3.12	...	5.17	...	...	...	... ...	...
Sb.....	172.33	177.87	162.58	180.23	163.45	165.19	162 160	168
As.....	...	...	...	...	3.01	...	... ...	...
S.....	332.94	337.03	331.53	342.50	320.50	320.80	324 320	324

1. Wolfsberg, Harz; anal. H. Rose (1826). 2. Kinzigthal, Baden; anal. Hilger (1877, in Dana, 1892). 3. Wolfsberg, Harz; anal. Guillemaine (1898). 4. Nagybánya, Romania; anal. de Finály (in de Finály & Koch, 1929). [1]Incl. insol. 0.94. 5. Bridge River district, British Columbia; anal. J. R. Williams & Son (in Warren & Thompson, 1944). 6. Anal. 5 after removal of As as FeAsS. A. Calculated for 81 or 80 [$PbS.Sb_2S_3$]. B. Calculated for 12 [$6Pbs.7Sb_2S_3$].

does not agree so well. On the other hand the full cell is divisible by 8 and the contents of the pseudo-cells are compatible with the atomic positions of the space-group. The third alternative, 12

TABLE 5

ZINCKENITE: $PbS.Sb_2S_3$

Hexagonal, $C6_3$; $a = 44.06$, $c = 8.60$ kX; $Z = 81$ or 80

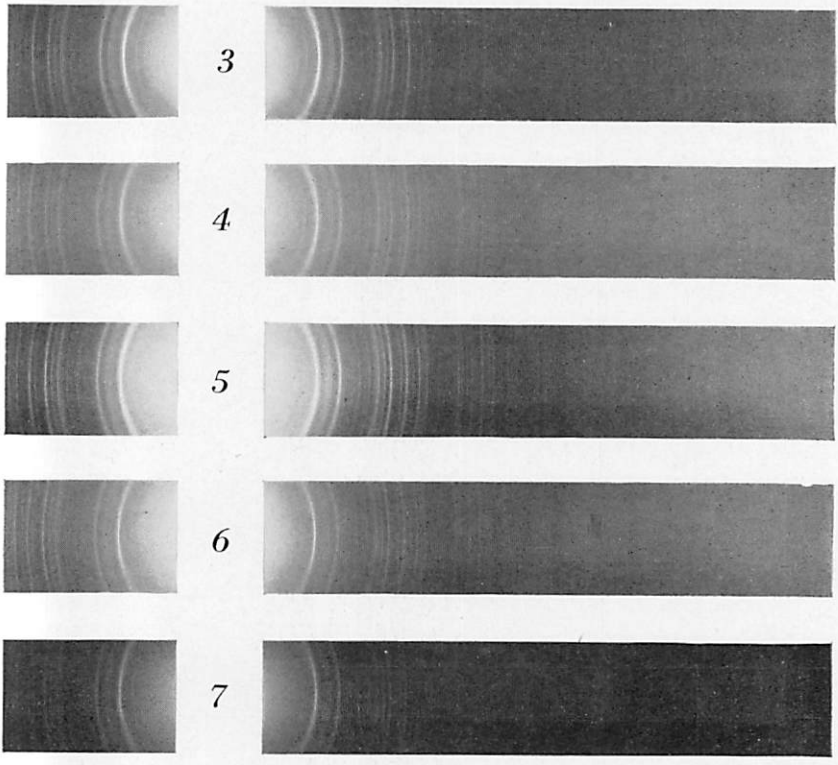
I	ϑ(Cu)	d(meas.)	$(hk\bar{i}l)$	d(calc.)	I	ϑ(Cu)	d(meas.)	$(hk\bar{i}l)$	d(calc.)
½	8.05°	5.49 kX	(44$\bar{8}$0)	5.51 kX	1	20.95°	2.15 kX	(0004)	2.15 kX
½	9.25	4.79	(08$\bar{8}$0)	4.77				(6.14.$\bar{20}$.0)	2.15
½	10.05	4.41	(4.6.$\bar{10}$.0)	4.37	2	21.2	2.13	(8.10.$\bar{18}$.2)	2.12
1	11.25	3.94	(04$\bar{4}$2)	3.92				(0.18.$\bar{18}$.0)	2.12
1	12.5	3.55	(06$\bar{6}$2)	3.56	2	21.95	2.06	(4.16.$\bar{20}$.0)	2.08
10	12.9	3.44	(2.10.$\bar{12}$.0)	3.43				(4.14.$\bar{18}$.2)	2.05
1	13.25	3.36	(44$\bar{8}$2)	3.39	3	22.85	1.980	(2.16.$\bar{18}$.2)	1.982
1	14.5	3.07	(4.6.$\bar{10}$.2)	3.07				(8.14.$\bar{22}$.0)	1.978
			(4.10.$\bar{14}$.0)	3.06	1	24.2	1.875	(4.16.$\bar{20}$.2)	1.874
2	14.8	3.01	(2.8.$\bar{10}$.2)	2.99				(0.10.$\bar{10}$.4)	1.873
½	15.35	2.90	(2.12.$\bar{14}$.0)	2.91	3	24.95	1.823	(2.10.$\bar{12}$.4)	1.823
4	15.95	2.80	(6.6.$\bar{12}$.2)	2.79	½	25.85	1.763	(6.16.$\bar{22}$.2)	1.766
½	16.6	2.69	(2.10.$\bar{12}$.2)	2.68				(6.18.$\bar{24}$.0)	1.764
			(0.12.$\bar{12}$.2)	2.56	1	26.7	1.711	(4.20.$\bar{24}$.0)	1.713
½	17.65	2.54	(6.8.$\bar{14}$.2)	2.53				(12.12.$\bar{24}$.2)	1.688
			(2.14.$\bar{16}$.0)	2.53	½	27.1	1.687	(0.14.$\bar{14}$.4)	1.688
			(2.12.$\bar{14}$.2)	2.41				(6.10.$\bar{16}$.4)	1.688
1	18.6	2.41	(6.12.$\bar{18}$.0)	2.40	1	27.7	1.654	(2.22.$\bar{24}$.0)	1.654
			(0.14.$\bar{14}$.2)	2.30				(8.18.$\bar{26}$.0)	1.654
½	19.55	2.30	(6.10.$\bar{16}$.2)	2.30				(4.14.$\bar{18}$.4)	1.580
			(4.12.$\bar{16}$.2)	2.25	½	29.15	1.579	(4.22.$\bar{26}$.0)	1.575
1	20.0	2.25	(2.16.$\bar{18}$.0)	2.23				(12.14.$\bar{26}$.2)	1.575

I(Cu)	ϑ(Cu)	d(meas.)	I(Cu)	ϑ(Cu)	d(meas.)	I(Cu)	ϑ(Cu)	d(meas.)
½	30.4°	1.519 kX	½	34.25°	1.366 kX	½	43.2°	1.123 kX
1	31.8	1.459	1	35.0	1.340	½	46.15	1.066
½	32.15	1.445	½	35.85	1.313	½	48.4	1.028
½	33.1	1.408	½	36.5	1.292			
1	33.6	1.389	½	42.25	1.143			

[$6PbS.7Sb_2S_3$] is supported by some of the earlier analyses; the cell content is divisible by 6, but the calculated specific gravity agrees poorly with recent measured values obtained on the Berman micro-

balance. Since such determinations are accurate within 1 per cent this third cell content is unlikely. Hence zinckenite appears to have the simple composition $PbS.Sb_2S_3$ with either 81 or 80 molecules in the unit cell.

Although the analyses suggest considerable variation in the chemical composition of zinckenite, *x*-ray powder patterns from the



FIGS. 3-7.—Zinckenite: *x*-ray powder photographs with Cu radiation (Ni filter); camera radius $90/\pi$ mm. (1 mm. on film = $1°\vartheta$); full size reproductions of contact prints.

FIG. 3.—Wolfsberg, Harz (HMM 92554).

FIG. 4.—Animas mine, Chocaya, Bolivia (HMM 94934).

FIG. 5.—Baia, Romania (USNM R-7811).

FIG. 6.—Bridge River district, British Columbia.

FIG. 7.—Wheaton district, Yukon Territory.

Harz, Bolivia, Romania, and British Columbia (Figs. 3-7) are practically identical, indicating that the composition is constant. A good analysis on clean zinckenite from any locality might therefore settle the question of the cell content. Table 5 gives the observed intensities and spacings for the pattern from Wolfsberg, Harz (HMM 92554). The pattern has been indexed to $29.15°\vartheta$. For each line a possible set of planes was found with good agreement between measured and calculated spacings. The only published powder pattern of zinckenite (Hiller, 1939, p. 137—A.S.T.M., Card 11–922) agrees fairly well with the new data in regard to spacings, less well as to the intensities of the lines.

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MELONITE FROM QUEBEC AND THE CRYSTAL STRUCTURE OF $NiTe_2$

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MELONITE, the natural ditelluride of nickel, is one of the rarest of the ore minerals. It was originally found at the Stanislaus [Melones] Mine, Calaveras County, California (Genth, 1868; Hillebrand, 1899), and later reported in Colorado, at Cripple Creek, Teller County, and Magnolia, Boulder County. The mineral was subsequently found near Worturpa, South Australia (Stillwell, 1931; Ramdohr, 1937). In Canada melonite has been identified by its physical properties and a microchemical test for Ni, in ore from the Tough-Oakes Mine, Kirkland Lake, Ontario (Thomson, 1922). From these occurrences, the external characters and the microscopic properties of melonite have been well described and the chemical composition has been firmly established by several good analyses. On the other hand nothing is known of the crystallography and structure of the mineral, beyond the hexagonal form, noted by Genth (1868) and questioned by Ramdohr (1937), and the list of *x*-ray powder spacings and intensities given by Harcourt (1942). A new occurrence of melonite thus gives an occasion to verify most of the described characters of the mineral and also to add the missing crystallographic details from an *x*-ray study of natural and artificial material.

Physical and Microscopical Characters

The nickel telluride was found in the remarkably rich masses of gold, tellurides, and sulphides, yielded in the period 1925-1928 by a group of claims and prospects known as the Robb-Montbray Mines, in the south-east corner of Montbray Township, Abitibi County, Quebec. The material at our disposal consisted of a score of fragments (M 15815), up to 5 cm. in greatest length, lent by the Royal Ontario Museum through Dr. V. B. Meen, and several larger unusually fine specimens kindly made available for study by R. A. Bryce, Esq. and Dr. M. H. Frohberg of the Macassa Mines Limited. For comparison we examined a sample of ore containing melonite

(ROM, M 15765) from the Cresson Mine, Cripple Creek district, Teller County, Colorado. The specimen M 15815 is material which was described by Thomson (1928), who reported gold and several tellurides and sulphides in the ore. Melonite was apparently overlooked or mistaken for pyrrhotite, which is reported by Thomson but not observed by us.

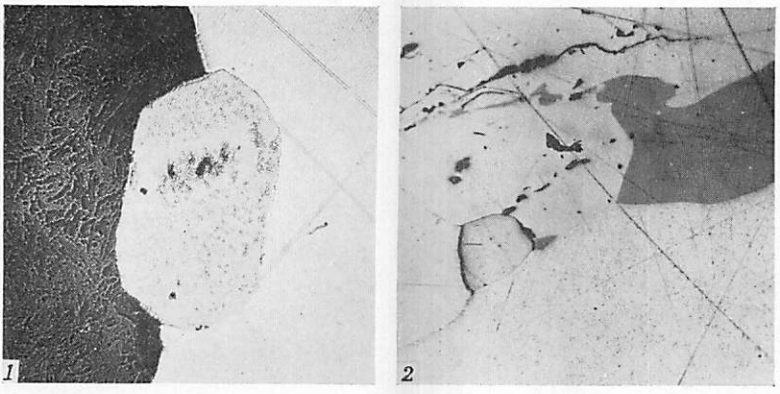
Our specimens from the Robb-Montbray Mines show abundant free gold associated with tellurbismuth, altaite, a new gold telluride resembling krennerite,[1] petzite, and melonite, together with chalcopyrite, pyrite, sphalerite, chalcocite, and marcasite. These minerals are present in varying proportions, with tellurbismuth, altaite, gold telluride, and chalcopyrite generally the major constituents. Distinct crystal form is shown only by chalcopyrite and pyrite which are embedded in compact coarsely crystalline masses of the other minerals. In these solid masses of ore the individual crystal grains reach 1 cm. in greatest width.

Melonite is a minor to accessory constituent of the Robb-Montbray ore. It was first noticed in polished sections as small rounded areas with an unfamiliar pink colour. Micro-samples from such areas gave an x-ray powder pattern in general agreement with that obtained by Harcourt (1942, p. 90) on melonite from Boulder County, Colorado; they also yielded positive chemical tests for Ni and Te. The mineral was then found in the hand-specimens in patches up to 2 mm. wide, soft and foliated and readily separated along an eminent cleavage into thin pliable leaves. Freshly exposed cleavage surfaces are light steel-gray to tin-white with a reddish cast; they tarnish quickly through yellow to light brown. Melonite somewhat resembles tellurbismuth with which it is commonly associated, but the nickel telluride can be readily distinguished by its colour, especially on tarnished surfaces, and its softer more foliaceous character.

In polished sections of the Robb-Montbray ore (Figs. 1, 2), melonite occurs occasionally in small rounded and distorted hexagonal sections entirely enclosed in plates consisting of an intergrowth of tellurbismuth and altaite. More often the melonite appears in irregular patches and stringers within the tellurbismuth-altaite intergrowth, or between this intergrowth and chalcopyrite

[1]Montbrayite, recently described in abstract by Peacock & Thompson (1945).

or petzite or gold, or in contact with the gold telluride. The colour of melonite is light pink which is particularly striking against the pure white of tellurbismuth. When a polished surface is viewed in reflected daylight under a binocular, melonite has a distinctly coppery colour, as noted by Short (1940, p. 122), and the mineral stands out in relief against tellurbismuth and gold telluride. Melonite is not perceptibly pleochroic. The anisotropism is moderately strong, with polarization colours greyish mauve to yellowish brown. Etch tests: HNO_3, instantly effervesces and stains black; HCl,



FIGS. 1, 2.—Melonite: polished sections in reflected light. FIG. 1.—Subhedral basal section of melonite against altaite. The dark area is bakelite. ×100. FIG. 2.—Small crystal of melonite, with good relief, against gold (below) and montbrayite (above). The dark area is petzite. ×90.

negative; KCN, negative; $FeCl_3$, slowly stains light brown and brings out scratches (rubs off); KOH, negative; $HgCl_2$, negative.

In most respects these observations agree with the mineralographic descriptions of melonite in Ramdohr (1937) and Short (1940). Ramdohr notes that the polishing hardness is greater than that of krennerite and gold, and, according to Stillwell (1931), even higher than that of chalcopyrite; and he remarks that such relatively high polishing hardness is common among soft minerals with layer structures. In regard to the anisotropism Ramdohr observes that basal sections are fairly certainly somewhat anisotropic and that therefore the crystal form is probably only pseudohexagonal. As

shown later, the structure of melonite is truly hexagonal and therefore any anisotropism in basal sections must be anomalous. Short (1940, pp. 115, 122) gives "pale yellow" as the colour of melonite in polished section; the description "pale coppery pink," given elsewhere for melonite by Short (1940, p. 293), in a list of coloured ore minerals, agrees with our impression of the colour in polished section.

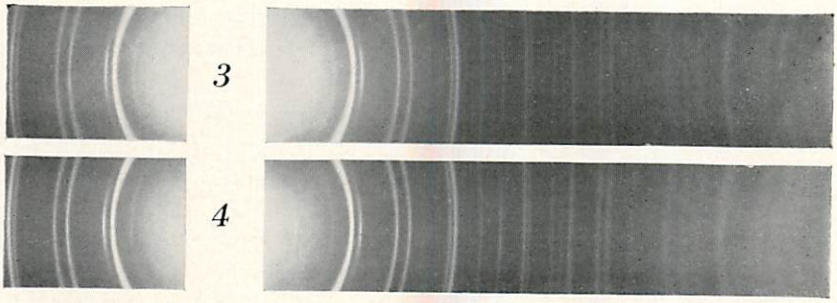
CRYSTAL FORM AND STRUCTURE

The existing information on the form and structure of melonite is very scanty. Apart from the original mention of hexagonal form, Ramdohr (1937, p. 201) has noted microscopic tabular crystals, up to 0.5 × 0.1 mm., showing the base often combined with several pyramids, embedded in krennerite, in the Kalgoorlie material. No *x*-ray work on melonite has been reported except the powder data of Harcourt (1942) which have recently been reproduced with recalculated intensities on Card 11-1694 (*X*-ray Diffraction Data, 1944).

Artificial nickel tellurides, on the other hand, have been prepared and studied röntgenographically by several authors. Oftedal (1927) found that the compound NiTe has the structure of NiAs (B8-type of the *Strukturbericht*), with $a = 3.957 \pm 3$, $c = 5.354 \pm 5$ Å. Tengnér (1938) prepared series of alloys, CoTe-$CoTe_2$ and NiTe-$NiTe_2$, in which he found continuous passage from the monotellurides with B8-type of structure to the ditellurides with C6-type. For $NiTe_2$ Tengnér measured $a = 3.861$, $c = 5.297$ Å, but he gave no comparison of observed and calculated intensities to confirm the inferred structure. Recently Klemm & Fratini (1943) further examined the series NiTe-$NiTe_2$, giving, among other measurements, for NiTe, $a = 3.975$, $c = 5.370$ Å, for $NiTe_2$, $a = 3.835$, $c = 5.250$ Å, but adding no further evidence for the structure of the ditelluride.

In approaching the problem of the structure of the mineral melonite, it was of interest first to ascertain whether the natural and artificial materials of similar composition are structurally comparable. The compounds NiTe and $NiTe_2$ were therefore prepared by fusing the powdered elements in the proper proportions in evacuated silica glass tubes and cooling in air. The compound NiTe proved to be a white brittle substance unlike melonite, and its *x*-ray powder photograph showed marked differences from that given by the

mineral. The compound $NiTe_2$, on the other hand, was similar to melonite. The platy fusion product had a faintly pinkish colour, and an excellent cleavage in the platy direction, and the polished section showed an almost homogeneous material with the colour and pleochroism of melonite. As seen in Figs. 3 and 4 the *x*-ray powder photographs of melonite and artificial $NiTe_2$ are exactly alike and therefore the two materials are structurally identical. The fact that the fusion product is platy rather than foliaceous may be attributed to differences attending the conditions of formation of the artificial and natural compounds.



FIGS. 3, 4.—Melonite, $NiTe_2$: *x*-ray powder photographs with Cu radiation (Ni filter); 1 mm. on film = $1°\vartheta$; actual size. FIG. 3.—Melonite from Quebec. FIG. 4.—Artificial $NiTe_2$.

The powder pattern of melonite led to the hexagonal cell dimensions:

$$a = 3.835,\ c = 5.255\ \text{kX}$$

which proved to be almost the same as those of Klemm & Fratini for artificial $NiTe_2$. With our cell dimensions and the cell content $NiTe_2$ the calculated specific gravity is 7.73, as compared to the highest measured value 7.72 (Hillebrand, 1899).

Thus we have satisfactory confirmation of the composition $NiTe_2$ for the mineral, as already given by the better analyses of melonite (Dana, 1914, p. 69). The original doubtful composition Ni_2Te_3, which is given in Dana (1892, p. 76) and repeated by Harcourt(1942), was founded on a recalculated analysis of very impure material. This composition could be interpreted as that of an intermediate

member of the $NiTe$-$NiTe_2$ series, but as yet there is no valid chemical evidence for a mineral of this composition. Furthermore, a mineral of intermediate composition would have intermediate physical properties and cell dimensions, but these have not been observed. There is, therefore, no doubt that the proper composition of melonite is $NiTe_2$.

The atomic arrangement attributed to $NiTe_2$ by Tengnér (1938), by analogy with $CoTe_2$, is that of CdI_2 (C6-type), which is obtained from the NiAs (B8-type) by removing the metal atoms at $00\frac{1}{2}$. The C6-type has the symmetry of the space-group D_{3d}^3—$C\bar{3}m$ (ditrigonal scalenohedral class—$\bar{3}$ $2/m$) in which there are no systematically missing spectra. In the case of $CoTe_2$ the atomic positions are Co at 000, 2Te at $\frac{1}{3}\ \frac{2}{3}\ z$, $\frac{2}{3}\ \frac{1}{3}\ \bar{z}$, with $z = 0.25 \pm 0.01$, from the intensities $(000l)$ reflections in a rotation photograph.

To test this structure for $NiTe_2$ and determine the best value of the single parameter z some calculations were made of powder intensities with the formula

$$I = n\ \frac{1 + \cos^2 2\vartheta}{\sin^2\vartheta \cos\vartheta}\ |\Sigma f_0 \cos 2\pi(hx + ky + lz)\ |^2$$

using Thomas-Fermi scattering factors f_o. These were compared with powder intensities which had been visually estimated on a scale of 10 by Thompson, in a routine measurement of a powder film of the mineral.

A comparison was first made of the calculated and observed intensities of lines of the type $(hk\bar{i}0)$ which are independent of the single variable parameter z. With the calculated intensities reduced to $I(11\bar{2}0) = 5$ the following agreement is obtained.

$(hk\bar{i}0)$	$(10\bar{1}0)$	$(11\bar{2}0)$	$(20\bar{2}0)$	$(21\bar{3}0)$	$(30\bar{3}0)$
I(calc.)	0.95	5.0	0.14	0.11	0.88
I(obs.)	1	5	0	0	$\frac{1}{2}$

The parameter z was then determined by a consideration of the variation of calculated intensities with z for all the reflections of zero or nearly zero observed intensity, and for all reflections of the type $(000l)$. This soon showed that z cannot differ greatly from 0.250 at which value there is satisfactory agreement between the calculated and observed intensities. At $z = 0.255$ I(calc.) for (0003) is already large enough to give a visible line, considering the advantage held

by reflections from cleavage planes in powder photographs; and at $z = 0.245$ I(calc.) for (0001) is already as large as I(calc.) for the much stronger line (0002). The parameter z is thus narrowed to 0.250 ± 0.005, and this value is used for I(calc.) in the complete x-ray powder spectrum (Table 1) in which the calculated intensities have been reduced to $I(10\bar{1}1) + I(01\bar{1}1) = 10$. The calculated intensities compare well with the observed values and thus the structure of melonite is confirmed.

In the structure of melonite (Fig. 5) each Ni-atom (smaller circles) is surrounded by six Te-atoms (larger circles) at the corners of a distorted octahedron, with the Ni-Te distance 2.58 kX. Each Te-atom is surrounded by three Ni-atoms at 2.58 kX and one Te-atom at 3.44 kX. This gives a pronounced layer structure, explaining the eminent basal cleavage which, as usual, also follows the lattice planes with the greatest spacing. The observed Ni-Te distance agrees exactly with the sum of the radius of quadrivalent Ni in octahedral co-ordination and the normal (single) covalent radius of Te, according to Pauling (1939, pp. 169, 174): Ni^{iv} (1.21) + Te (1.37) = 2.58. The observed Te-Te distance (3.44 kX) is considerably less than the unbonded Te-Te distance 3.69 kX in tetradymite, Bi_2Te_2S (Harker, 1934, p. 180), or 3.74 in the element.[2]

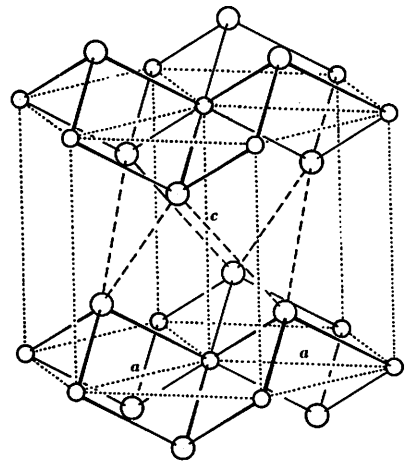


FIG. 5. — Melonite, $NiTe_2$: Crystal structure showing the widely separated layers of close-packed Ni (smaller) and Te (larger) atoms.

[2]Professor Linus Pauling (Pasadena) has been good enough to consider the interatomic distances in melonite and to confirm the propriety of the given comparison of the observed and predicted Ni-Te distance. At the same time he points out that it would not be proper to compare his predicted unbonded Te-Te distance, namely, twice the van der Waals radius less 0.5 or 2 (2.20 — 0.5) = 3.4 (1939, p. 178), with the observed distance 3.44, since the two Te-atoms are not in contact with one and the same Ni-atom.

TABLE 1

MELONITE—$NiTe_2$: *X*-RAY POWDER SPECTRUM

Hexagonal, $C\bar{3}m$; $a = 3.835$, $c = 5.255$ kX; $Z = 1$

Ni: 000; 2Te: $\frac{1}{3}, \frac{2}{3}, 0.25$; $\frac{2}{3}, \frac{1}{3}, \bar{0}.25$

$hk\bar{i}l$	d(calc.)	I(calc.)	d(meas.)	I(obs.)
(0001)	5.255 kX	0.9	5.26 kX	1
(10$\bar{1}$0)	3.321	0.8	3.32	1
(10$\bar{1}$1)	2.808	2.3	2.81	10
(01$\bar{1}$1)	2.808	7.7		
(0002)	2.628	1.4	2.63	3
(10$\bar{1}$2)	2.061	2.0	2.05	5
(01$\bar{1}$2)	2.061	2.0		
(11$\bar{2}$0)	1.918	4.3	1.912	5
(11$\bar{2}$1)	1.801	0.3	....	..
(0003)	1.752	0.0	....	..
(20$\bar{2}$0)	1.661	0.1	....	..
(20$\bar{2}$1)	1.584	1.9	1.586	2
(02$\bar{2}$1)	1.584	0.6		
(11$\bar{2}$2)	1.549	1.6	1.544	6
(10$\bar{1}$3)	1.549	1.7		
(01$\bar{1}$3)	1.549	0.5		
(20$\bar{2}$2)	1.404	0.6	1.404	1
(02$\bar{2}$2)	1.404	0.6		
(0004)	1.314	0.4	1.311	1
(11$\bar{2}$3)	1.293	0.1	....	..
(21$\bar{3}$0)	1.255	0.1	....	..
(10$\bar{1}$4)	1.222	0.0	1.224	2
(01$\bar{1}$4)	1.222	0.1		
(21$\bar{3}$1)	1.221	0.5		
(12$\bar{3}$1)	1.221	1.6		
(20$\bar{2}$3)	1.205	0.2	1.201	1
(02$\bar{2}$3)	1.205	0.8		
(21$\bar{3}$2)	1.133	0.5	1.136	$\frac{1}{2}$
(12$\bar{3}$2)	1.133	0.5		
(30$\bar{3}$0)	1.107	0.7	1.109	$\frac{1}{2}$
(11$\bar{2}$4)	1.084	1.4	1.081	2
(30$\bar{3}$1)	1.083	0.0		
(03$\bar{3}$1)	1.083	0.1		
(0005)	1.051	0.0	....	..
(20$\bar{2}$4)	1.030	0.0	....	..
(02$\bar{2}$4)	1.030	0.0		
(21$\bar{3}$3)	1.020	1.0	1.022	1
(12$\bar{3}$3)	1.020	0.3		
(30$\bar{3}$2)	1.020	0.2		
(03$\bar{3}$2)	1.020	0.2		
(10$\bar{1}$5)	1.002	0.2	1.001	1
(01$\bar{1}$5)	1.002	0.5		

MELONITE FROM COLORADO

Harcourt's *x*-ray powder data for melonite from Boulder County, Colorado (Cu/Ni), are given below for comparison with Table 1.

d	*I*	*d*	*I*	*d*	*I*	*d*	*I*
3.33	1.0	2.075	3.0	1.555	3.0	1.228	2.0
2.82	8.0	*2.030	0.5	*1.442	0.3	1.135	0.2
2.63	1.0	1.930	4.0	1.410	0.3	1.086	0.2
*2.35	2.0	1.592	2.0	1.318	0.3	1.024	0.2

There is substantial agreement between the two sets of readings; at the same time there are significant differences. The most important is the presence of three lines in Harcourt's pattern which do not correspond to possible sets of planes in melonite. These extraneous lines, which we have marked with asterisks, must have originated from foreign material, and Harcourt's useful tables show at once that the impurity was gold or silver, for which the following spacings and intensities are given:

Gold (Cu/Ni): 2.36 (9), 2.04 (6), 1.44 (4), 1.23 (5), . . .
Silver (Cu/Ni): 2.35 (9), 2.04 (5), 1.44 (4), 1.228 (6), . . .

Our specimen of melonite (M 15765) from the Cresson Mine, Cripple Creek, Colorado, proves to be an intimate intergrowth of melonite with calaverite and gold. A relatively clean sample gave the melonite pattern with a strong superimposed pattern of gold; perhaps Harcourt was obliged to use similar unfavourable material.

CLASSIFICATION

Finally a word regarding the systematic position of melonite in the light of the confirmed structure. In the first volume of the new *Dana*, by Palache, Berman, & Frondel (1944), the mineral species are grouped into mineralogical classes, chemical types, and finally crystallographic groups or series based on known or inferred structural relations. Melonite is appended to the Krennerite Group, no doubt because it was a ditelluride of undetermined structure. In view of the fact that melonite, with its hexagonal layer structure and foliated character, proves to be structurally unrelated to the Krennerite Group, but instead shows close structural and physical relations to molybdenite, MoS_2, the principles of the new Dana

classification would be better maintained by transferring the nickel telluride to the neighbouring Molybdenite Group.

SUMMARY

Melonite is associated with tellurides, sulphides, and gold, in rich ore from the Robb-Montbray Mines, Montbray Township, Abitibi County, Quebec. The mineral is structurally identical with $NiTe_2$ obtained by fusing the elements in vacuum, and x-ray powder photographs lead to the following structure (C6-type): hexagonal; space-group D_{3d}^3—$C\bar{3}m$ (ditrigonal scalenohedral class—$\bar{3}$ $2/m$); $a = 3.835$, $c = 5.255$ kX; cell content $NiTe_2$, giving the calculated specific gravity 7.73, measured 7.72 (Hillebrand); Ni at 000, 2Te at $\frac{1}{3}\ \frac{2}{3}\ z$, $\frac{2}{3}\ \frac{1}{3}\ \bar{z}$, with $z = 0.250 \pm 0.005$. The distances Ni-Te = 2.58, Te-Te = 3.44 kX agree with the sums of the appropriate predicted radii of Pauling. The previously published x-ray powder data for melonite include lines due to free gold. Melonite would be appropriately attached to the Molybdenite Group in systematic mineralogy.

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MINERALOGICAL NOTES

BISMUTH TELLURIDES FROM THE WHITE ELEPHANT CLAIM, BRITISH COLUMBIA

The White Elephant claim, later named the Pre-Cambrian Mine, lies two miles west of Okanagan Lake and 15 south-west of Vernon, in the Vernon Mining Division. The discovery of this quartz body containing "free gold and bismuth" was reported in 1922 (*Minist. Mines B.C.*, Ann. Rep. **1921**, 192, 1922) and the deposit was described in detail by Cairnes (*Geol. Surv. Canada*, Summ. Rep. **1931***A*, 86, 1932). According to Cairnes the ore-body was a mass of white quartz, about 60 × 50 feet, in granite. The largely barren quartz body contained irregular masses of pyrrhotite, some chalcopyrite, a foliated bismuth telluride (tetradymite), and perhaps free gold which was reported as interleaved with plates of the telluride. This association of gold and bismuth telluride, which the author has noted in the Hedley district (*Univ. Toronto Studies*, Geol. Ser., **49**, 56, 1944), may explain the generally high gold values obtained from ores containing bismuth tellurides in British Columbia.

A specimen of the so-called "auriferous tetradymite," or "gold bismuth telluride," from this deposit was examined by Peacock (*Univ. Toronto Studies*, Geol. Ser., **46**, 83, 1941), who noted visible spongy gold on a mass of inhomogeneous bismuth telluride, a sample of which gave the specific gravity 8.2. A powder pattern resembled that of joseite, but basal diffractions revealed the presence of two or more distinct phases in parallel layers.[1]

Through the kindness of Dr. J. S. Stevenson of the British Columbia Department of Mines and Dr. H. M. A. Rice of the Geological Survey of Canada, two specimens from the White Elephant claims were obtained for further study of the bismuth tellurides. These specimens offered the opportunity of preparing samples for chemical analyses by measuring the specific gravities

[1]At that time the main component of that particular specimen of bismuth telluride from Vernon, B.C., was thought to be a variety of joseite with a larger than normal cell. Now it proves that the powder pattern is almost identical with that given by wehrlite which has essentially the composition BiTe (*Univ. Toronto Studies*, Geol. Ser., **49**, 60, 1945). A thorough study of the artificial system Bi-Te-S is required to clear up the complicated relations in these minerals.—Ed.

of many small plates on the Berman balance and collecting those which gave fairly consistent values. *X*-ray powder photographs were made on typical fragments by Mr. R. M. Thompson in the University of Toronto, and the samples were analysed by Professor F. A. Forward of the University of British Columbia and Mr. J. R. Williams of Vancouver. The author is indebted to these men for their valuable assistance and also to Professor M. A. Peacock for arranging this note in its present form.

The specific gravities of numerous flakes from Dr. Stevenson's sample gave 7.22—7.52, average 7.37; four fragments gave 7.50± 0.02. The analysis (1) compares well with the calculated composition of Bi_2Te_2S (A), showing that the mineral is tetradymite, as suggested by Cairnes (1932). An explanation for the specific gravity 7.50 is not apparent in the analysis.

Specific gravity measurements were made on thirty-six apparently clean fragments detached from Dr. Rice's specimen. Two of these gave 8.26 and 8.35, suggesting joseite or wehrlite, and an *x*-ray powder photograph gave Harcourt's pattern for wehrlite from Hungary (*Am. Min.*, **27**, 103, 1942). A specimen examined in Toronto also showed small quantities of a soft massive mineral with a bronze coloured tarnish; this also proved to be wehrlite, although it lacked the typical platy habit. The amounts of wehrlite were too small for chemical analysis, but a spectrographic test for Ag indicated perhaps 0.1—0.5 per cent.

The remaining fragments gave specific gravities ranging from 6.96 to 7.55 with a tendency to fall into three groups: 6.96—7.06 (average 7.03); 7.16—7.35 (average 7.27); 7.42—7.55 (average 7.48). Fragments from the first and second of these groups gave only the tetradymite pattern while a fragment from the third group showed a combination of the patterns of tetradymite and wehrlite. The chemical analyses of these three groups of fragment (2, 3, 4) also agree fairly closely with the composition of tetradymite and therefore the variation of specific gravity seems to be due in part to experimental error. The low S value and high specific gravity in analysis 4 is in keeping with admixed wehrlite whose specific gravity is about 8.4.

In the course of analyses 2, 3, 4, traces of Se were detected. This is of interest in view of the selenium poisoning that has been reported

from several areas in southern British Columbia. The only other occurrence of a selenium bearing mineral in British Columbia known to the writer is the boulangerite with a chemical trace of Se recently described from the Vernon area (*Univ. Toronto Studies*, Geol. Ser., **49**, 80, 1945).

These notes show that two bismuth tellurides, tetradymite and wehrlite, occur in intimate association at the White Elephant claims. Elsewhere in British Columbia the foliated bismuth telluride called tetradymite has usually proved to be some other species. Here tetradymite is for the first time confirmed as the dominant bismuth telluride.

	1	2	3	4	A
Bi	59.10	60.72	60.88	61.05	59.27
Te	35.90	34.71	34.47	35.10	36.19
S	4.85	4.29	4.29	3.65	4.54
	99.85	99.72	99.64	99.80	100.00
Aver. sp. grav.	7.37	7.03	7.27	7.48	7.09-7.39

Analyses of tetradymite from the White Elephant claims, Okanagan Lake, B.C.; 1, by F. A. Forward; 2, 3, 4 by J. R. Williams. A.—Calculated composition of Bi_2Te_2S and range of measured specific gravities.

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University of British Columbia

GOLDFIELDITE = TELLURIAN TETRAHEDRITE

Sharwood (*Min. Sci. Press*, **94**, 731, 1907) first mentioned a "sulphotelluride" from the Mohawk Mine, Goldfield, Nevada, which gave strong reactions for S, Te, Cu, Fe, also As, Sb, Au, Ag, corresponding to a mixture of tetrahedrite and calaverite, but seemingly representing an homogeneous substance. This material was further described by Ransome (*U.S. Geol. Surv.*, Prof. Pap. **66**, 116, 1909), with an analysis by Palmer, and provisionally regarded as a new species named *goldfieldite*. Palmer's analysis has been variously interpreted, most recently (*Dana*, **1**, 384, 1944) as $Cu_{12}Sb_4Te_3S_{16}$. Later, Sharwood (*Econ. Geol.*, **6**, 32, 1911) regarded goldfieldite as a tellurian variety or species of enargite or famatinite type, but Witt, in Shannon (*Am. J. Sci.*, **44**, 469, 1917), remarks "I do not believe that the mineral goldfieldite exists but is probably a mixture of famatinite, bismuthinite, and calaverite or sylvanite, with possibly some tetrahedrite." Tolman & Ambrose (*Econ. Geol.*, **29**, 270,

1934) again considered goldfieldite as a valid species resembling tetrahedrite in polished section and having the composition $6CuS.Sb_2(S, Te)_3$, which was obtained by withdrawing famatinite, sylvanite, petzite, and bismuthinite from Palmer's analysis; but in *Dana* (1944) the validity of the species is once more considered doubtful.

Through the kindness of Dr. V. B. Meen of the Royal Ontario Museum a specimen (M13007) labelled "goldfieldite, Claremont Mine, Goldfield, Nevada," was obtained for study. About two-thirds of a polished section consists of a mineral resembling tetrahedrite which is cut by thin (50 microns) laths of a soft white moderately anisotropic mineral. One small area of a soft pinkish gray anisotropic mineral was found; the remainder of the section consists of gangue in which a few small grains of gold are embedded. The etch reactions of the main mineral correspond to those given by Tolman & Ambrose for goldfieldite. KCN produces scratches and marked zonal growth, exactly like that shown in Fig. 10 of Tolman & Ambrose, showing that we were dealing with typical material. Each of the three minerals was sampled by scraping homogeneous areas with a steel needle, and each sample obtained in this way was divided in two and used for an x-ray powder photograph and microchemical tests.

The main mineral gave the tetrahedrite pattern which was completely indexed on a cubic lattice with $a = 10.35$ kX; positive microchemical tests were obtained for Fe, Cu, Sb, Te, and a positive test for Te was also obtained with sulphuric acid on the portion used for the x-ray photographs. The mineral occurring in thin laths gave the bismuthinite pattern and a positive microchemical test for Bi; the sulphuric acid test for Te in this case was negative. The small area of a pinkish gray mineral gave the famatinite pattern and positive microchemical tests for Fe, Cu, Sb, As; the sulphuric acid test for Te was negative.

These observations show that the Te in the specimen resides in the tetrahedrite and that "goldfieldite," as resurrected by Tolman & Ambrose, is in fact a tellurian tetrahedrite, and that the name "goldfieldite" should be finally dropped.

R. M. THOMPSON
University of Toronto

ANTAMOKITE DISCREDITED

Antamokite is the name given by Alvir (*Philippine Jour. Sc.*, **41**, 137, 1930) to a supposed new gold telluride in ore from the Benguet Consolidated Mining Company mine at Antamok, Mountain Province, Philippine Islands. In polished sections the mineral was grayish white with a slight bluish tinge; it occurred intimately associated with calaverite, together with tetrahedrite, chalcopyrite, pyrite, and quartz. Microsamples gave only Au, Te, and traces of Ag. The described etch-reactions correspond to those of petzite (*Dana*, **1**, 187, 1944). Stillwell (*Proc. Australasian Inst. Mining Met.*, **84**, 118, 1931) found altaite, petzite, free gold, and sphalerite in a rich specimen of ore from this locality.

A specimen labelled "antamokite" (USNM, 95812) from the Benguet Mine, kindly lent by Dr. E. P. Henderson of the United States National Museum, was found to consist of free gold with sulphides and tellurides disseminated through somewhat vuggy quartz. The following minerals, in decreasing order of abundance, were found in polished sections: chalcopyrite, gold, sphalerite, tetrahedrite, galena, calaverite, pyrite, and petzite. Petzite was found in small quantity closely associated with calaverite, with colour, hardness, and etch tests similar to those described by Short. The identification of chalcopyrite, sphalerite, tetrahedrite, galena, and calaverite were confirmed by *x*-ray powder photographs. The sulphuric acid test for Te was applied to each of the above minerals, except petzite, which was too sparse to be separated from the associated minerals; only calaverite gave a positive test.

These observations support the suggestion that the supposed new telluride was in fact petzite intimately associated with calaverite.

R. M. THOMPSON
University of Toronto

HYDROSYNTHESIS OF SMITHITE ($Ag_2S.As_2S_3$)

Sommerlad (*Zeits. anorg. Chem.*, **18**, 420, 1898) obtained cryptocrystalline $Ag_2S.As_2S_3$ and a sublimate of $AsCl_3$ by heating AgCl with As_2S_3. Silver meta-thioarsenite (smithite) may also be synthesized by melting together the sulphides of silver and arsenic. Thus Jaeger & van Klooster (*Zeits. anorg. Chem.*, **78**, 242, 1912) obtained

vitreous orange crystals which they called "arsenomiargyrite," and Gaudin & McGlashan (*Econ. Geol.*, **33**, 143, 1938) obtained skeletal crystals supposed to be identical with smithite from similar melts. In aqueous solutions silver thioarsenites are easily precipitated at room temperature by adding silver ions to thioarsenite solutions, but such precipitates are mixtures of several thioarsenites, even when their overall composition approximates $Ag_2S.As_2S_3$. It thus appears that distinct crystals identical with the mineral smithite have not as yet been prepared in the laboratory.

Calculations and experiments show that metallic sulphides are highly soluble in strongly alkaline solutions at about 400°C. Thus microscopic crystals of $3Ag_2S.As_2S_3$ (proustite) and $3Ag_2S.Sb_2S_3$ (pyrargyrite) were obtained from hot alkaline sulphide solutions by de Sénarmont (*Ann. Chim. Phys.*, **32**, 409, 1851); Jaeger & van Klooster (1912) made good crystals of artificial pyrargyrite in strong alkali sulphide solutions; and Ditte (*Ann. Phys. Chim.*, **12**, 229, 1907) made the double sulphide of silver and sodium.

Some years ago Dr. F. G. Smith (Toronto) designed a steel bomb in which experiments with alkali sulphide solutions could be carried on without excessive contamination due to corrosion of the container. In this way he succeeded in crystallizing from such solutions galena and sphalerite (*Econ. Geol.*, **35**, 645, 1940), and metallic gold, electrum, and calaverite (*Econ. Geol.*, **38**, 561, 1943), and he also did some preliminary work on the ruby silvers. The present hydrosynthesis of smithite is a continuation of Dr. Smith's work and it was accomplished in his laboratory and under his direction.

The experimental technique has been described elsewhere (Smith, 1940). Briefly, a concentrated solution of sodium polysulphide in contact with a piece of silver wire and some arsenic metal is heated in the steel bomb to about 400°C. The volume of the solution is kept such that, if the charge were pure water, the pressure would rise to 1000 bars at 400°C.

Charge No.	1	2	3
Silver wire	0.3 gm.	0.2 gm.	0.3 gm.
Arsenic metal	5.0 gm.	1.0 gm.	2.4 gm.
$Na_2S.9H_2O$ crystals	9.5 gm.	5.3 gm.	7.9 gm.
Sulphur (flowers)	8.3 gm.	7.9 gm.	9.8 gm.

Distilled water	5.5 cc.	10.0 cc.	6.0 cc.
Time of heating from room to maximum temp.	2½ hrs.	2 hrs.	1½ hrs.
Maximum temp. (°C.)	390°	385°	350°
Time during which charge remained at 360°-390°	65 min.	45 min.	at 350°—30 min. at 230°-250°—4½ hrs.
Time of cooling from 360° to room temp.	13 hrs.	15 hrs.	from 230°—8 hrs.

Charges from which smithite crystals were obtained are given in the table. The largest crystals of smithite were obtained from charge no. 1. Charge no. 2 yielded an abundant crop of smaller crystals. In both these charges, all the silver went into smithite. The excess arsenic formed orpiment (As_2S_3), and some sulphur was left over. In thioarsenites of silver the ratio $Ag_2S : As_2S_3$ cannot be smaller than 1. In charge no. 3, dissolution of silver did not proceed at a high enough rate and few flakes of smithite were produced. The silver wire was transformed into brittle red cylinders with black cores.

On opening the bomb, the smithite crystals are coated with or embedded in a crust of colloform orpiment, realgar (AsS), and sulphur. They must be washed with carbon disulphide and ammonia before study. The identification and description of the crystals of artificial smithite are given elsewhere in this issue by Professor M. A. Peacock.

RENÉ BÉLAND
University of Toronto

CRYSTALLOGRAPHY OF ARTIFICIAL AND NATURAL SMITHITE

Smithite is a rare sulpharsenite of silver known only from Binn, Switzerland. The morphology of the equant monoclinic crystals has been well described by Smith & Prior (*Min. Mag.*, **14**, 293, 1907), but as yet the unit cell has not been determined. As there seemed to be little chance of obtaining a crystal of smithite for *x*-ray measurements, Dr. F. G. Smith kindly undertook to guide Mr. R. Béland in an attempt to make measurable crystals of $Ag_2S.As_2S_3$, using a method of hydrosynthesis which had previously served to make good crystals of several of the ore minerals. The experiments, which were

notably successful, are described by Mr. Béland elsewhere in this issue.

The synthetic crystals (Figs. 1, 2) are brownish orange plates up to 1.3 mm. long, recalling the crystals of lepidocrocite from Siegen and showing no close resemblance to the described colour and habit of smithite. However, on the reflecting goniometer it was soon apparent that the plane of platy development is $a(100)$ of smithite while the elongated eight-sided outlines are due to intersections of this plane with $c(001)$, $p(111)$, $P(\bar{1}11)$, and an undeterminable form

FIG. 1

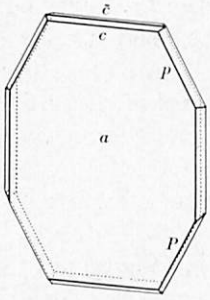

FIG. 2

$(hk0)$. The edge-faces are extremely narrow and fairly good reflections were obtained only from $c(001)$, which gave $ac = 78°\,20'$—$79°\,20'$ (6 measurements), average $78°\,48'$, in agreement with the calculated value $ac = 78°48'$ of Smith & Prior (1907). Single feeble reflections were obtained from p and P: $ap = 63°\,30'$, $63°\,55'$, calculated $63°\,29'$: $aP = 106°\,57'$, calculated $107°\,40\frac{1}{2}'$.

The tip of one of the thickest plates was adjusted to rotate about the symmetry axis for x-ray measurements. On the reflecting goniometer it was found to be twinned by reflection in (100), giving weak reflections, $ac = 78°20'$, $\overline{ac} = 79°12'$. Good rotation and Weissenberg photographs were obtained with Cu radiation. When projected the Weissenberg resolutions of the layers $(h0l)$ and $(h1l)$ showed the reciprocal lattices of the two individuals twinned by reflection in the plane (100). Measurement of the films gave the lattice constants: $p[010] = 7.76$ kX, $d(001) = 14.87$ kX, $d(100) =$

16.87 kX, (001) : (100) = 78.9°. Using the more accurate geometrical angle (001) : (100) = 78° 48′, the cell dimensions are:

$$a = 17.20,\ b = 7.76,\ c = 15.16 \text{ kX};\ \beta = 101°12'$$

giving the comparison:

$a : b : c = 2.216 : 1 : 1.953;\ \beta = 101°12'$ (*x*-ray)
$a : b : c = 2.2206 : 1 : 1.9570;\ \beta = 101°12'$ (gon., Smith, 1907)

With $Ag_{24}As_{24}S_{48} = 12[Ag_2S.As_2S_3]$ in the unit cell the calculated specific gravity is 4.93 as compared to 4.88 measured by Prior (1907).

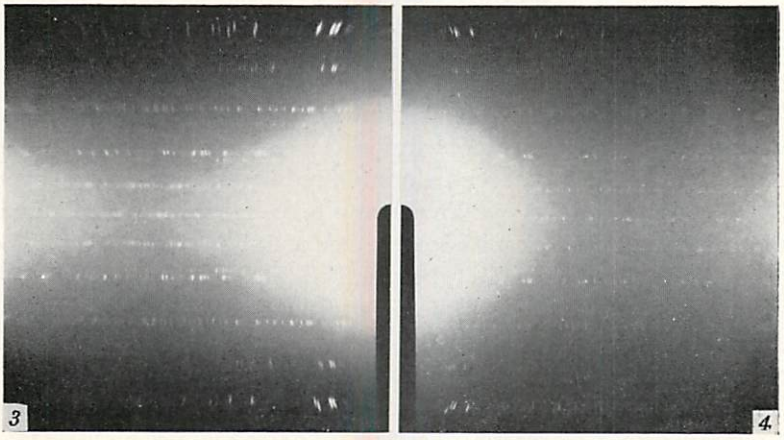

FIG. 3 FIG. 4

The systematically missing spectra conform to the conditions: (*hkl*) present only with $(k + l)$ even; (*h*0*l*) present only with *h* even and *l* even. These conditions are characteristic of the space-groups C_{2h}^6—$A2/a$ (prismatic class) and C_s^4—Aa (domatic class). A one-face-centred monoclinic cell is usually set so that the centred face is (001), but in the present case it seems better to retain the (100)-centred setting thereby keeping the twin plane vertical. Thus the *x*-ray measurements wholly confirm the crystallographic setting originally chosen by Solly (*Min. Mag.*, **14**, 74, 1905).

Twinning is not known in natural smithite; on the other hand all the measurable blades of artificial smithite examined prove to be twins on (100) showing basal planes symmetrical to (100). In

terms of Friedel's geometrical treatment of twinning the twin is pervaded by a common lattice whose periods are [501], [010], [001]. A cell in this twin lattice has five times the volume of a cell of the crystal lattice and the angle [501] : [001] is 91°03′. The twinning is thus an example of twinning by reticular pseudo-merohedry with index 5 and obliquity 1°03′. Many of the plates of artificial smithite also show herringbone striations on (100) symmetrical to the trace of (010). This suggests twinning by reflection in (010) which is possible only in the sphenoidal class of the monoclinic system. However, the systematic extinctions are incompatible with the sphenoidal class and therefore this appearance of twinning is probably due to vicinals with the proper symmetry of the crystal.

In an effort to obtain further information on trechmannite, an imperfectly known rhombohedral silver sulpharsenite from Binn, Dr. E. W. Nuffield detached a minute red crystal from a specimen (ROM, M 12114) labelled "Trechmannite, Lengenbach quarry," and took a rotation photograph about an axis of two-fold symmetry. The photograph (Fig. 4) proved to be exactly like the rotation photograph of artificial smithite (Fig. 3) both as to the positions and the intensities of the spots, showing at once that the supposed crystal of trechmannite was in fact a crystal of smithite, and that the lattice constants of artificial smithite are equally applicable to the natural mineral.

Mr. R. M. Thompson assisted in this short study by projecting and measuring the x-ray films.

M. A. PEACOCK
University of Toronto

THE WALKER MINERALOGICAL CLUB[1]

BY-LAWS[2]

1. The Club shall be known as the Walker Mineralogical Club (of the University of Toronto).

2. For purposes of administration the Club shall be affiliated with the Department of Geological Sciences, University of Toronto, through the Senior Professor of Mineralogy in that Department.

3. The object of the Club shall be to encourage mineralogical, crystallographical, and petrographical study of the minerals and rocks of Canada and to provide a means of presenting the results of such research in a collected form.

Members

4. The Council may elect Honorary Members from those who have rendered conspicuous service to mineralogy, crystallography, or petrography in Canada.

5. Ordinary membership is open to all interested persons and institutions.

6. Student membership is open to students during the period of undergraduate study.

Officers and Council

7. The Officers of the Club shall be an Honorary President, a President, a Secretary-Treasurer, an Editor of the annual publication (who shall be a member of the Department of Geological Sciences, University of Toronto), three Councillors to represent Ordinary Members, one Councillor to represent the Department of Geological Sciences, and one Councillor to represent Student Members.

8. These Officers, together with the Past President, shall be authorized to fill vacancies in the Council during the year and to perform such duties as ordinarily fall to a council. Only the Presi-

[1]Founded in 1938 and named in honour of the late Professor T. L. Walker [1867-1942], then Professor Emeritus of Mineralogy and Petrography in the University of Toronto and Director of the Royal Ontario Museum of Mineralogy.

[2]As amended up to December 31, 1945.

dent and the Secretary-Treasurer shall be authorized to draw cheques on the bank account of the Club for the payment of bills.

9. The Honorary President shall be elected by Council. The remaining Officers shall be elected annually by Members.

MEETINGS

10. The meetings of the Club shall be held in the months of February, April, October, and December, on the second Thursday, or at more convenient dates specified by Council.

PUBLICATION

11. There shall be an annual publication, *Contributions to Canadian Mineralogy* from the Department of Geological Sciences of the University of Toronto and the Walker Mineralogical Club, a copy of which shall be sent to each subscribing member and subscriber.

12. The financial responsibility for the publication of *Contributions to Canadian Mineralogy* shall rest with the Walker Mineralogical Club, University of Toronto.

DUES

13. The annual membership fee with the subscription to the annual publication shall be $2.00. An annual fee of $1.00 may be applied either to membership (without subscription) or to subscription (without membership). The fees for undergraduate students shall be one-half of the ordinary fees. Fees are payable on January 1. Members who are two years or more in arrears in payment of dues shall be dropped from the roll of members.

AMENDMENTS

14. This Constitution may be amended by a two-thirds majority of those voting on such an amendment by means of a letter ballot sent to all members and subscribing members.

OFFICERS FOR 1945

Honorary President.....Professor A. L. PARSONS
President.....Mr. FRANK EBBUTT
Secretary-Treasurer.....Professor V. B. MEEN

Editor.....Professor M. A. PEACOCK
Councillors for Ordinary Members
1945-47.....Dr. L. G. BERRY
1944-46.....Dr. JACK SATTERLY
1943-45.....Mr. G. G. WAITE
Councillor for Department of Mineralogy.....Dr. E. W. NUFFIELD
Councillor for Student Members.....Mr. R. M. THOMPSON
Past President.....Mr. PERCY E. HOPKINS

NEW MEMBERS AND SUBSCRIBERS[3]

M BUTTERFIELD, John, O.L.S. *Room 707, Northern Ontario Building, Toronto 1, Ontario.*
SM EDWARDS, John. *305 Avenue Road, Toronto 5, Ontario.*
SM FULMER, E. A. Student, *29 Classic Avenue, Toronto 5, Ontario.*
SM HUTCHINSON, R. D. Student, *103 Devonshire Road, London, Ontario.*
S JOUBIN, Francis R(enault), M.A. Geologist, *Pioneer Mine, British Columbia.*
SM MOORE, J(ohn) C(arman) G(ailey), M.A. Geologist, with *W. F. James, 67 Yonge Street, Toronto 1, Ontario.*
SM SCOTT, H(arry) S(tuart), M.A. Graduate Student, *Department of Geological Sciences, University of Toronto, Toronto 5, Ontario.*
SM SNOW, William E. *McKenzie Island, Ontario.*
SM STINSON, Erle H(arold). Student, *Brandon College, Brandon, Manitoba.*
SM TAYLOR, R. B. Student, *Department of Mining Geology, University of Toronto, Toronto 5, Ontario.*
SM WOLFE, C(aleb) W(roe), B.E., M.A., Ph.D. Assistant Professor of Geology, *Boston University, Boston, Massachusetts.*

PROCEEDINGS, 1945

MEETING OF FEBRUARY 15, 1945

Held at 5.00 P.M. in Room 64, Royal Ontario Museum. The new president, Mr. Frank Ebbutt, was introduced by the retiring president, Mr. Percy Hopkins.

The Secretary read the names of the following new members who were welcomed to the Club by the President: Messrs. John Butterfield, John Edwards, E. A. Fulmer, R. D. Hutchinson, and R. B. Taylor.

[3]Supplementing the lists in *Univ. Toronto Studies*, Geol. Ser., no. 48, pp. 105-117, 1943, and no. 49, pp. 87-8, 1944. *SM*—Subscribing Member; *S*—Subscriber; *M*—Member.

deposit with particular reference to the minerals which have been deposited since the workings were abandoned in 1868. Mr. G. E. Steel described his activities during the summer in the search for Canadian semi-precious gem material in Eastern Ontario and the Niagara Peninsula. Dr. M. H. Frohberg told of hunting for tellurides in general, and in particular, for additional specimens of montbrayite and melonite at the Robb-Montbray Mine, Quebec, to aid Professor M. A. Peacock and Mr. R. M. Thompson in their

Dr. M. H. Frohberg, Field Geologist, Macassa Mines Ltd., addressed the Club on "The Deposits of Gold and Tellurides of Transylvania, Southern Carpathians." After briefly outlining the mining history of the district, he described the mineralogy of the ore bodies in the red volcanic plugs of the area. His address was illustrated by lantern slides and specimens from his private collection, augmented by specimens kindly loaned by the Royal Ontario Museum of Mineralogy. Following the subsequent discussion, the thanks of the audience was expressed by Mr. Robert A. Bryce.

No. 23: Champsosaurus Albertensis, a new species of rhynchocephalian from the Edmonton formation of Alberta, by W. A. PARKS	$1.00
No. 24: Contributions to Canadian Mineralogy, 1927	1.00
No. 25: Albertosaurus arctunguis, a new species of therapodous dinosaur from the Edmonton formation of Alberta, by W. A. PARKS	1.00
No. 26: Struthiomimus Samueli, a new species of ornithomimidae from the Belly River formation of Alberta, by W. A. PARKS	0.50
No. 27: Contributions to Canadian Mineralogy, 1928	o. p.
No. 28: Contributions to Canadian Mineralogy, 1929	o. p.
No. 29: Contributions to Canadian Mineralogy, 1930	1.00
No. 30: Contributions to Canadian Mineralogy, 1931	1.00
No. 31: A new genus and two new species of trachodont dinosaurs from the Belly River formation of Alberta, by W. A. PARKS	0.50
No. 32: Contributions to Canadian Mineralogy, 1932	0.50
No. 33: New species of stromatoporoids, sponges, and corals from the Silurian strata of Baie des Chaleurs, by W. A. PARKS	0.50
No. 34: New species of dinosaurs and turtles from the Upper Cretaceous formations of Alberta, by W. A. PARKS	0.50
No. 35: Contributions to Canadian Mineralogy, 1933	0.50
No. 36: Contributions to Canadian Mineralogy, 1934	0.50
No. 37: New Species of Trachodont Dinosaurs from the Cretaceous Formations of Alberta with Notes on Other Species, by W. A. PARKS	0.50
No. 38: Contributions to Canadian Mineralogy, 1935	0.50
No. 39: Devonian Stromatoporoids of North America. Part I, by W. A. PARKS	1.00
No. 40: Contributions to Canadian Mineralogy, 1936-1937	1.25
No. 41: Contributions to Canadian Mineralogy, 1938	1.25
No. 42: Contributions to Canadian Mineralogy, 1939	1.25
No. 43: Edmontonia rugosidens (Gilmore), an armoured dinosaur from the Belly River series of Alberta, by LORIS S. RUSSELL	0.50
No. 44: Contributions to Canadian Mineralogy, 1940	1.25
No. 45: Cranial Morphology of the Devonian Crossopterygian Eusthenopteron, by R. M. STERNBERG	1.00
No. 46: Contributions to Canadian Mineralogy, 1941	1.25

all Members and Subscribing Members, had been passed. These Amendments were as follows:

For paragraph 2, *read:* For purposes of administration the Club shall be affiliated with the Department of Geological Sciences, University of Toronto, through the Senior Professor of Mineralogy in that department.

In paragraphs 7, 11: *For* Mineralogy and Petrography *read* Geological Sciences.

For paragraph 12, *read:* The financial responsibility for the publication of *Contributions to Canadian Mineralogy* shall rest with the Walker Mineralogical Club, University of Toronto.

Professor Meen reported that there had been a few responses to the appeal for mineral specimens to rebuild the collections of the Liége Museum.

The President welcomed the large number of guests who were in attendance at this meeting.

Professor Peacock introduced the speaker, Dr. Clifford Frondel, Research Associate in Mineralogy, Harvard University, who then addressed the Club on the subject "Wartime Applications of Crystallography," with special reference to the mass production of quartz oscillator plates. This address was to have been illustrated with lantern slides and a sound motion picture of the cutting of quartz. Unfortunately, a short circuit interrupted the showing of the slides and prevented the use of the film. Despite this, Dr. Frondel carried on, answered questions, and discussed many phases of the subject that could not have been dealt with otherwise. Professor L. S. Russell, until recently Major in the Royal Canadian Corps of Signals, expressed the appreciation of the audience for this most interesting address.

The membership of the Club as on December 31, 1945, is as follows:

Honorary Members	3
Subscribing Members	218
Members	25
Subscribers	41
Student Subscribing Members	7
Total	294

At the beginning of the year, thirty-two members were known to be on Active Service. Some of these have recently returned to civilian life, but the number will not be known until early in the new year. Since the last report, twenty-four members have resigned or been written off for non-payment of dues. These are: F. E. Beamish, Miss H. R. Belyea, J. W. Britton, W. L. Brown, R. A. Bryce, John E. Dawson, W. Foster, Miss M. A. Fritz, A. W. Howard, G. S. Hume, S. F. Kelly, John Knox, A. Montgomery, R. P. Morrison, H. S. Munroe, R. Murphy, D. A. Nichols, F. F. Osborne, W. T. Pecora, G. M. Robson, J. Sanderson, H. G. Savage, M. W. Summerhayes, C. Tolman. As detailed earlier in this report, five of our members died during the year. Eleven new members were enrolled during the year.

The year 1945 has been financially successful. The surplus of $11.05 at December 31, 1944, has been increased to $98.96 at December 31, 1945.

We are indebted to the Royal Ontario Museum for permission to hold our meetings in Room 64 of that building without charge.

FINANCIAL STATEMENT

PROFIT AND LOSS

January 1, 1945, to December 31, 1945

REVENUE			
Members' dues	$170.50		
Subscriptions	265.50		
Back dues	48.00		
Sale of back numbers	14.00		
Bank interest	.84		
Premium on United States funds	5.47		
Unaccounted for	.10		
		$504.41	
DISBURSEMENTS			
Share of cost of printing *Contributions to Canadian Mineralogy*, 1944	$340.20		
Stationery	22.50		
Postage	40.00		
Bank charges	3.30		
Assistance at meetings	2.50		
Hotal accommodation, C. Frondel	8.00		
		$416.50	
Surplus for period		$87.91	
Plus surplus at December 31, 1944		11.05	
Surplus at December 31, 1945			$98.96

BALANCE SHEET

December 31, 1945

ASSETS			
Cash on hand and in bank			$160.96
LIABILITIES			
Accounts Receivable			
Prepaid dues and subscriptions		$62.00	
Surplus at December 31, 1945		98.96	
			$160.96

Examined and found correct.

J. G. DICKENSON,
GEO. E. STEEL,
Auditing Committee

V. BEN MEEN,
Secretary-Treasurer

January 9, 1946.

PERSONAL NOTES[1]

DR. T. F. W. BARTH, Professor of Mineralogy, the University, Oslo, Norway, has accepted a Visiting Professorship in the University of Chicago, Chicago, Illinois.

DR. L. G. BERRY (Ph.D., Toronto, 1941) is now Lecturer in Mineralogy, Queen's University, Kingston, Ontario.

DR. G. M. BROWNELL is now Professor of Geology and Head of the Department, University of Manitoba, Winnipeg, Manitoba.

DR. J. D. H. DONNAY has accepted a Visiting Professorship in Chemical Crystallography and Mineralogy, the Johns Hopkins University, Baltimore, Maryland.

DR. V. B. MEEN (Ph.D., Toronto, 1936) is now Assistant Professor of Mineralogy in the Department of Geological Sciences, University of Toronto, and Associate Director of the Royal Ontario Museum of Geology and Mineralogy.

D. A. MODDLE (M.A., Toronto, 1941) is now Provincial Assayer, Queen's Park, Toronto, Ontario.

DR. E. S. MOORE, Professor of Geology, is now Head of the Department of Geological Sciences, University of Toronto, Director of the Royal Ontario Museum of Geology and Mineralogy, and President of the Royal Society of Canada.

DR. W. W. MOORHOUSE (M.A., Toronto, 1936; Ph.D. Columbia, 1941) is now Assistant Professor in the Department of Geological Sciences, University of Toronto.

DR. E. W. NUFFIELD (Ph.D., Toronto, 1944) is now Lecturer in Mineralogy in the Department of Geological Sciences, University of Toronto.

DR. M. A. PEACOCK is now Professor of Crystallography and Mineralogy in the Department of Geological Sciences, University of Toronto.

DR. A. T. PRINCE (M.A., Toronto, 1938; Ph.D., Chicago, 1941) is now Lecturer in Petrology, University of Manitoba, Winnipeg, Manitoba.

DR. W. T. SCHALLER is now Chief Chemist of the United States Geological Survey, Washington, D.C.

DR. F. G. SMITH (Ph.D., Toronto, 1942) is now Lecturer in the Department of Geological Sciences, University of Toronto.

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[1]Information for these notes on appointments and promotions of members of the Walker Mineralogical Club should be sent to the Secretary.

NOTICE

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