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UNIVERSITY OF TORONTO STUDIES

GEOLOGICAL SERIES, No. 49

CONTRIBUTIONS TO CANADIAN
MINERALOGY, 1944

From the
DEPARTMENT OF MINERALOGY AND PETROGRAPHY
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FORM BIREFRINGENCE OF NEMALITE

By J. D. H. DONNAY
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NEMALITE, a fibrous iron-bearing (ferroan) variety of brucite, has been described from Asbestos, Quebec, by Berman (1932) and its structure has been studied by West (1932, 1934) and in greater detail by Garrido (1936). According to these authors the fibre direction of nemalite is perpendicular to the *c*-axis of brucite and consequently the index of refraction in the fibre direction corresponds to ω . As observed by Berman the index in the fibre direction is 1.585 which is much higher than ω in brucite, and the birefringence in the fibres is much lower than in brucite. Berman states that this high value of ω in nemalite is consistent with the iron content of the material. As shown below this explanation seems insufficient. The purpose of this paper is to offer an alternative explanation for the high refraction and low birefringence of nemalite.

LAW OF GLADSTONE & DALE APPLIED TO NEMALITE

As shown by Larsen & Berman (1934, p. 30) the law of Gladstone & Dale for liquids is approximately true for crystals:

$$K = k_1 p_1 / 100 + k_2 p_2 / 100 + \dots; n = dK + 1;$$

where K is the specific refractive energy of the substance, k_1, k_2, \dots p_1, p_2, \dots are the specific refractive energies and percentage weights of the components, n is the mean refractive index, and d the density.

For pure brucite $\text{MgO} \cdot \text{H}_2\text{O}$, with $k_1 = 0.200$, $k_2 = 0.340$ (Larsen & Berman), $p_1 = 69.2$, $p_2 = 30.8$, for MgO and H_2O , respectively, and $d = 2.40$, the equations give $K = 0.2431$ and $n = 1.583$. From the measured indices of brucite, $\omega = 1.566$, $\epsilon = 1.585$ (Westphal) the mean observed index is $n = (2\omega + \epsilon) / 3 = 1.572$. The good agreement shows that the law gives a fair estimate of the mean refractive index of brucite.

Gonyer's analysis of nemalite from Asbestos, Quebec (Berman, 1932) is as follows:

¹Present address: Hercules Powder Company Experiment Station, Wilmington, Delaware, U.S.A.

	Anal.	Mol.	Brucite	Magnetite
Fe ₂ O ₃	1.95	0.012	.....	0.012
FeO.....	9.57	0.133	0.121 } 1.618	0.012
MgO.....	60.33	1.497	1.497 } 1.588	.....
H ₂ O.....	28.60	1.588	.....	.....
	<u>100.45</u>			

From this analysis the composition of the ferroan brucite contained in the fibres is approximately $(1 - x)\text{MgO} \cdot x\text{FeO} \cdot \text{H}_2\text{O}$, with $x = 0.075$. Taking $k = 0.187$ for FeO (Larsen & Berman) and $d = 2.44$ for nemalite (Dana, 1892, p. 252), the law of Gladstone & Dale gives $n = 1.587$. For pure brucite a correction of -0.011 gives agreement between the calculated and observed mean index. Applying this correction to nemalite the calculated value of n is 1.576. With this value and the birefringence of brucite (0.019) the calculated value of ω for nemalite is about 1.570, which does not agree closely with the observed 1.585. An explanation of the high refraction of nemalite must therefore be sought elsewhere.

MEASUREMENT OF REFRACTIVE INDICES

The refractive indices of nemalite show considerable variation and therefore it is necessary to make all the measurements on material from a single fibre. This can easily be done, as the fibres are long and easily cut with scissors into as many small rods as are needed for index determinations by immersion. The indices were measured in sodium light, by means of mixtures of liquids, and the index of each mixture was determined at the same temperature on an Abbe refractometer.

A fibre was first found with the index n_o (vibration direction parallel to the fibre) = 1.585 ± 0.001 , the value given by Berman. This offered some guarantee that Gonyer's analysis on Berman's material could be taken to represent the composition of the fibre studied. The fibre being considered as a uniaxial entity, the index n_e (vibration direction transverse to the fibre) was then measured and found to be 1.589 ± 0.001 .

The birefringence of the fibre $(n_o - n_e) = \Delta/t$, was calculated from the path-difference or retardation Δ , determined with a Berek compensator, and the thickness t , measured with the calibrated focussing screw of the microscope. Three sets of readings were made:

$\Delta(m\mu)$	$l(\mu)$	$(n_o - n_e)1000$
112	24	4.7
445	98	4.5
445	100	4.4

The average value is 0.0045 as compared to $n_o - n_e = 1.589 - 1.585 = 0.004$, from the measured indices.

MINERALOGICAL COMPOSITION OF THE FIBRES

A number of powder patterns were taken of the nemalite, both in Ni-filtered Cu-radiation and in unfiltered Fe-radiation. Besides dominant brucite $Mg(OH)_2$, they showed the presence of a substance which at first sight could be either magnetite Fe_3O_4 or magnesioferrite $MgFe_2O_4$. Some fibre bundles were locally enriched in interstitial material, appearing as dark streaks. One of those provided the material for a precision powder pattern in Fe-radiation.

The x-ray powder pattern showed, rather weakly, the strongest lines of brucite and, quite distinctly, a great many lines of magnetite. The cell edge of the latter was determined as $a = 8.392 \pm 0.005 \text{ \AA}$.² The usual precautions were taken to ensure accuracy: the film was punched according to the Straumanis scheme, the camera radius was calibrated by means of a tungsten wire, the sample had the form of a very thin rod, and a was obtained by the extrapolation method of Bradley and Jay ($\sin^2\theta$). The observed spacings are listed in Table 1, together with data taken from Hanawalt's catalog (1938) for magnesioferrite and magnetite, and also the calculated spacings for magnetite with $a = 8.392 \text{ \AA}$. The comparison indicates that the accuracy of the results is sufficient to discriminate between magnetite and magnesioferrite. The interstitial substance in the nemalite fibres is thus identified as magnetite.

The same film also showed the presence of periclase MgO in the nemalite fibres. It was important to ascertain this point since Gonyer's chemical analysis can be recalculated in terms of minerals in two different ways, as magnetite and brucite, with either MgO or FeO in excess. Table 2 shows the lines other than those of brucite observed on the film, as well as the lines to be expected from

²With the wave-lengths: $FeK\beta = 1753.013 \text{ X.U.}$, $FeK\alpha_1 = 1932.076 \text{ X.U.}$, $FeK\alpha_2 = 1936.012 \text{ X.U.}$ The measured dimensions are strictly in $\text{X.U.} \times 1000$ or kX , rather than in \AA .

TABLE 1
IDENTIFICATION OF MAGNETITE IN NEMALITE

<i>hkl</i>	Hanawalt (Mo)				Observed (Fe)*				Calculated <i>a</i> = 8.392 Å <i>d</i>
	MgFe ₂ O ₄		Fe ₃ O ₄		α -lines		β -lines		
	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	
111			4.85	0.06	4.85	<i>w</i>	—		4.85
022	2.95	0.27	2.97	0.28	2.97	<i>vs</i>	2.97	<i>m</i>	2.97
113	2.51	1.00	2.53	1.00	2.53	<i>vs</i>	2.54	<i>s</i>	2.53
222			2.42	0.11	2.44	<i>vw</i>	—		2.42
004	2.08	0.13	2.10	0.32	2.10	<i>s</i>	2.11	<i>w</i>	2.10
133					—		—		1.925
224	1.70	0.12	1.71	0.16	1.712	<i>m</i>	1.715	<i>w</i>	1.713
333-115	1.60	0.27	1.61	0.64	1.615	<i>s</i>	—		1.615
044	1.476	0.40	1.483	0.80	1.483	<i>vs</i>	1.483	<i>m</i>	1.483
135					1.414	<i>vw</i>	—		1.418
244					—		—		1.399
026	1.320	0.03	1.326	0.06	1.321	<i>vwv?</i>	—		1.327
335	1.273	0.07	1.279	0.20	1.278	<i>s</i>	1.283	<i>vw</i>	1.280
226					1.263	<i>w</i>	—		1.265
444			1.210	0.05	1.210	<i>w</i>	—		1.211
117-155					—		—		1.175
246	1.114	0.03	1.121	0.10	1.121	<i>m</i>	—		1.121
137-355	1.085	0.07	1.092	0.32	1.093	<i>vs</i>	1.093	<i>vw</i>	1.093
008	1.042	0.01	1.049	0.10	1.049	<i>s</i>	1.050	<i>vw</i>	1.049
337					—		—		1.025
446					—		—		1.018
066-228					0.989	<i>s</i>	0.990	<i>w</i>	0.989
555-157	0.963	0.03	0.970	0.16	—		0.969	<i>w</i>	0.969
266			0.966	0.08	—		—		0.963
048			0.940	0.06	—		0.938	<i>w</i>	0.938

*Only the lines belonging to magnetite are listed.

magnetite Fe₃O₄ (*a* = 8.392Å), periclase MgO, and FeO. The identification of periclase rests on the following observations: the lines *d* 2.47, *d* 2.14, *d* 1.51 are missing on the film; the strong intensity of *d* 2.10 cannot be accounted by the magnetite only, but is explained by the added contribution of the strongest periclase line; likewise, the very strong *d* 1.483 is due to the superposition of two lines.

The identification of brucite in the usual fibres (that is to say, those which do not show local enrichment in magnetite) offered no difficulty. Since this result confirms previous findings by others,

TABLE 2
IDENTIFICATION OF PERICLASE IN NEMALITE

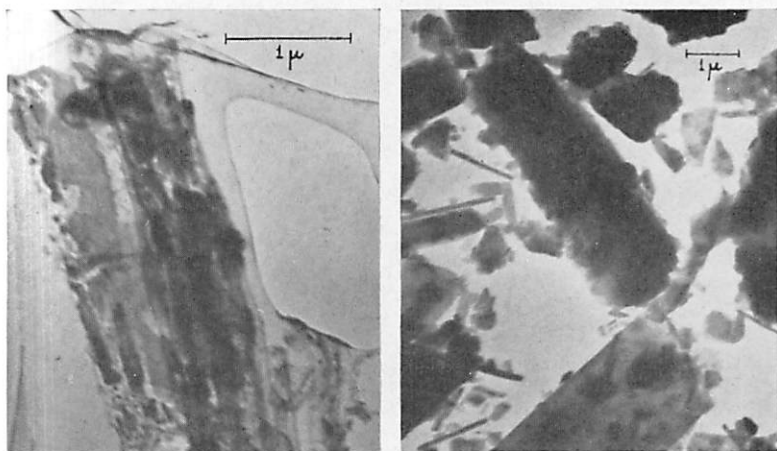
Observed (Fe)		Fe ₃ O ₄		MgO		FeO	
<i>d</i>	<i>I</i>	From Table 1 <i>d</i>	<i>I</i>	Hanawalt (Mo) <i>d</i>	<i>I</i>	Hanawalt (Mo) <i>d</i>	<i>I</i>
4.85	<i>w</i>	4.85	0.06				
2.97	<i>vs</i>	2.97	0.28				
2.53	<i>vs</i>	2.53	1.00				
.....						2.47	0.50
2.44	<i>vw</i>	2.42	0.11	2.42	0.06	.....
.....						2.14	1.00
2.10 _s	<i>s</i>	2.10	0.32	2.10	1.00		
1.714	<i>m</i>	1.713	0.16				
1.615	<i>s</i>	1.615	0.64				
.....						1.51	0.63
1.483	<i>vs</i>	1.483	0.80	1.485	0.75	.....
.....						1.293	0.15
1.280	<i>s</i>	1.280	0.20				
1.263	<i>w</i>	1.265	...	1.266	0.06		
.....						1.238	0.08
1.210	<i>w</i>	1.211	0.05	1.213	0.15		
1.121	<i>m</i>	1.121	0.10				
1.093	<i>vs</i>	1.093	0.32				
.....						1.072	0.03
1.049	<i>s</i>	1.049	0.10	1.050	0.04		
0.989	<i>s</i>	0.989	...			0.984	0.03
0.969	<i>w(β)</i>	0.969	0.16				
.....		0.963	0.08	0.963	0.01		
.....						0.959	0.05
0.938	<i>w(β)</i>			0.940	0.10		

the *x*-ray powder data need not be presented here. Some of the powder patterns obtained, however, showed a number of weak lines which could not be identified with certainty, but have tentatively been assigned to minor amounts of olivine and chrysotile.

STRUCTURE OF THE FIBRES

The fibre, rotated about its elongation axis in a Weissenberg camera, gave a standard rotation diagram. Both the zero and the first layer-line Weissenberg patterns showed reflections drawn out into lines over the whole length of the film. This indicates that the

structural arrangement of the fibre possesses a symmetry of revolution around the fibre axis. This fact was again checked when the pattern obtained in the cylindrical powder camera was found to be the same whether the fibre was rotated about its elongation axis or not. The translation period along the axis was found to be 3.15\AA ., a value already reported by Garrido (1936), in close agreement with that of 3.16\AA . given by Berman (1932). It is known to correspond to the period of brucite along the a -axis (3.13\AA .). It can, therefore, be predicted that the fibre will behave optically as a uniaxial entity and that the constituting brucite particles will be oriented with ω in the direction of the fibre axis.



*Electron Micrographs by W. G. Kinsinger
Courtesy, Hercules Powder Company*

FIGS. 1, 2.—Electron micrographs of ground nemalite. FIG. 1 (left) shows dark streaks of magnetite in brucite. FIG. 2 (right) shows the size of the smallest fibres.

Carefully ground fibres observed in the electron microscope showed tiny lath-shaped hexagons of brucite intergrown with magnetite. The magnetite is less transparent to the electron beam than the brucite; it therefore appears darker on the photograph (Fig. 1). This suggests a case of mutual orientation of crystals. The known prerequisite for such a mutual orientation is the near-coincidence,

in shape and size, of two cells which need not be unit-cells. Assuming the octahedral plane of magnetite to lie on the basal plane of brucite, we note the following near-coincidences: the period $[\bar{1}10]$ in the plane (111) of magnetite is 5.94\AA ., close to $2a$ of brucite (6.25\AA .), and $d(111)$ of magnetite is 4.85\AA ., almost equal to c of brucite (4.75\AA .). Whether or not we are concerned with mutual orientation,³ the electron microscope at any rate establishes the fact that the elementary particles constituting the nemalite fibres are smaller than the wave-length of light (Fig. 2). This condition is a prerequisite to the application of Wiener's formulae of form birefringence, which is the object of the next section.

FORM BIREFRINGENCE OF NEMALITE

The formulae of form birefringence in "mixed bodies" are due to Wiener (1912). So far as I know only three examples have been reported in mineralogy: spherulitic calcite (vaterite A), in which the interstitial medium is water (Donnay, 1936*a*), chalcedony, a mixed substance composed of quartz and interstitial opal (Correns & Nagelschmidt, 1933; Donnay, 1936*b*), and ishkyldite (Syromyatnikov, 1936). The formulae to be applied to nemalite fibres are those of rod-birefringence (positive form birefringence); they can be written as follows (Ambronn & Frey, 1926):

$$n_e^2 = \delta_1 n_1'^2 + \delta_2 n_2^2, \quad n_o^2 = n_2^2 \frac{(\delta_1 + 1)n_1''^2 + \delta_2 n_2^2}{(\delta_1 + 1)n_2^2 + \delta_2 n_1''^2}$$

where n_e and n_o are the principal indices of the fibre, considered as a uniaxial entity with its optic axis in the direction of elongation; n_1' and n_1'' , the indices of the brucite particles in the direction of the fibre axis and in the direction perpendicular to the fibre axis, respectively; n_2 , the index of the interstitial magnetite; δ_1 and δ_2 , the proportions by volume of brucite and magnetite, respectively, so that

³At the suggestion of Dr. C. D. West (Polaroid Corporation, Cambridge, Mass.) magnetite reflections were sought on rotation patterns of nemalite fibres. The usual fibres, low in magnetite, show no magnetite reflections. Fibres with a higher magnetite content show the powder pattern of magnetite superimposed on the rotation diagram of nemalite. Fibres particularly enriched in magnetite showed the same phenomenon even more clearly. The magnetite powder reflections are finely dotted continuous lines, indicating that a number of magnetite crystals exceed 10 microns in size.

$\delta_1 + \delta_2 = 1$. In a first approximation the interstitial medium may be taken to be all magnetite (neglecting periclase).

Westphal's values for the refractive indices of brucite are $\epsilon = 1.585$, $\omega = 1.566$. The index $n_1' = \omega$, and the index $n_1'' = (\epsilon + \omega)/2 = 1.5755$. The index of magnetite is $n_2 = 2.42$ (Na). From these data the values of the fibre indices n_e and n_o can be calculated in terms of the volume percentage of interstitial magnetite ($100 \delta_2$). The curves are almost linear for small values of δ_2 (Fig. 3). The total birefringence of the fibre is negative and

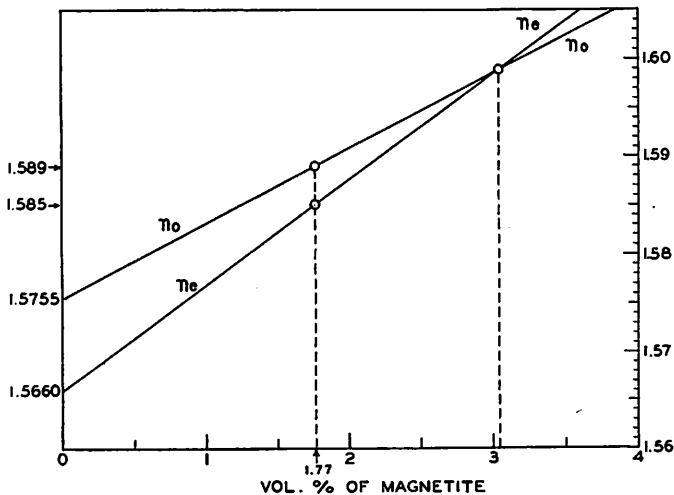


FIG. 3.—Form birefringence in nemalite fibres.

decreases in absolute value as δ_2 increases. For 3.04 vol. per cent of magnetite the theory predicts that the nemalite fibres should be isotropic.

The measured values of the fibre indices ($n_e = 1.585$, $n_o = 1.589$) are seen to lie on a vertical line corresponding to 1.77 vol. per cent of interstitial magnetite. Let us calculate the percentage composition of nemalite by volume from the chemical analysis.

Gonyer's chemical analysis of nemalite is recalculated in terms of minerals as follows: first apportion enough FeO to Fe₂O₃ to form magnetite and use the balance of FeO to make the molecule

FeO.H₂O; then combine the remaining H₂O with MgO to form MgO.H₂O, and there will be an excess of MgO to account for the periclase.⁴ The following specific gravity values were used in the calculations: Fe₃O₄ (4.65), MgO.H₂O (2.40), FeO.H₂O (3.398), MgO (3.571). The mineralogical composition of the nemalite was found to be (percentages by volume):

FeO.Fe ₂ O ₃	1.53	magnetite
MgO.H ₂ O	89.59	} ferroan brucite
FeO.H ₂ O	8.03	
MgO	0.85	periclase
	100.00	

The agreement with the theory is satisfactory, even in this approximative treatment which does not take the periclase into account. In fact 1.53 vol. per cent of interstitial magnetite would only bring the indices of fibrous brucite to $n_e = 1.5825$, $n_o = 1.5872$. Similar calculations show, however, that 0.85 vol. per cent of interstitial periclase (index 1.735, average value for artificial MgO) will further increase n_e by 0.0015 and n_o by 0.0014, thus bringing them to 1.584 and 1.588₆ respectively, in close agreement with the theory, the measured values being 1.585 and 1.589.

The specific gravity of the nemalite should be 2.52, calculated from the above composition. It was determined experimentally, by means of the Berman balance, on several samples. The value obtained varied with the size of the sample: 2.42 for a sample of 3 mg., 2.47 for samples of 5 and 6 mg., 2.48 for a sample of 13 mg. This is probably to be explained by the fact that the fibres spread out at both ends of the bundle, so that air is trapped in the samples. All the experimental values are thus too low. The highest value obtained is nevertheless within 2 per cent of the calculated figure.

DISCUSSION

It is realized that the present study falls short of being as comprehensive as it should be. It would have been desirable to locate more experimental points on the theoretical curves of nemalite

⁴After forming magnetite, H₂O could first be assigned to all the MgO, then the balance of H₂O would go to FeO, and there would be an excess of FeO. This alternative has been ruled out by x-ray results.

indices. Particularly, it was hoped to find examples of isotropic, and possibly of positive, fibres, but efforts in that direction proved fruitless. The amount of interstitial magnetite in the specimens investigated was always below, rather than above, the value found in Gonyer's material. The indices should have been measured on various chemically analysed samples. A preliminary investigation of ordinary homogeneous brucite crystals would also have been required to ascertain the variation of the principal indices ϵ and ω in terms of iron content, so that the indices of the ferroan brucite encountered in the nemalite fibres could have been obtained by interpolation and used in the calculation of Wiener's formulae. The results obtained so far, however, are sufficient to prove the existence of form birefringence in nemalite.

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See also references in Donnay (1936a).

STUDIES OF MINERAL SULPHO-SALTS:
VIII—PLAGIONITE AND SEMSEYITE¹

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THE purpose of these studies is primarily to examine some of the less well-known mineral sulpho-salts by *x*-ray methods in order to obtain the symmetry and dimensions of their unit cells and to establish their diagnostic powder patterns. The cell data are used as the basis of a critical review of the morphological crystallography and the chemical formula, and both of these are re-cast, if necessary, to conform to the structural data. The powder pattern is used to test the identity of the available materials, including related minerals whose individuality may be open to question. Incidentally, other determinable properties, notably the specific gravity and the characters in polished sections, are observed and compared with the existing data. In this way an effort is made to bring the available information on each of the species studied to a uniform level of accuracy and completeness. The work stops short of an attempt to determine the atomic arrangements; but in providing much of the data used in structural analysis the work may open the way to such an undertaking.

PLAGIONITE

Plagionite is a rare sulphantimonite of lead occurring in conspicuously monoclinic crystals with the generally accepted composition $5\text{PbS}\cdot 4\text{Sb}_2\text{S}_3$. The thick tabular lozenge-shaped crystals are rarely of good quality and consequently the existing geometrical elements may not be very accurate. Also the several analyses of the mineral vary somewhat, and they have suggested other more complex chemical formulae.

APPEARANCE AND PHYSICAL PROPERTIES

The observations given in this paper were obtained from crystals on a typical specimen (Royal Ontario Museum of Mineralogy,

¹The titles of the preceding papers of this series appear in Berry (1943, pp. 28-29).

M/4060) from Wolfsberg, Harz, kindly made available by Professor A. L. Parsons. On this specimen the mineral occurs in aggregates of rough crystals associated with quartz crystals and feather ore. These crystals show the typical tabular habit and lozenge-shaped outline, with deep striations parallel to the edges of the (*hhl*) zones. The colour is lead-grey with a bluish-yellow tarnish and the fresh fracture shows bright metallic lustre. These crystals offered no opportunity of adding to the geometrical data for the species but, as described later, they afforded a fragment suitable for accurate x-ray measurements.

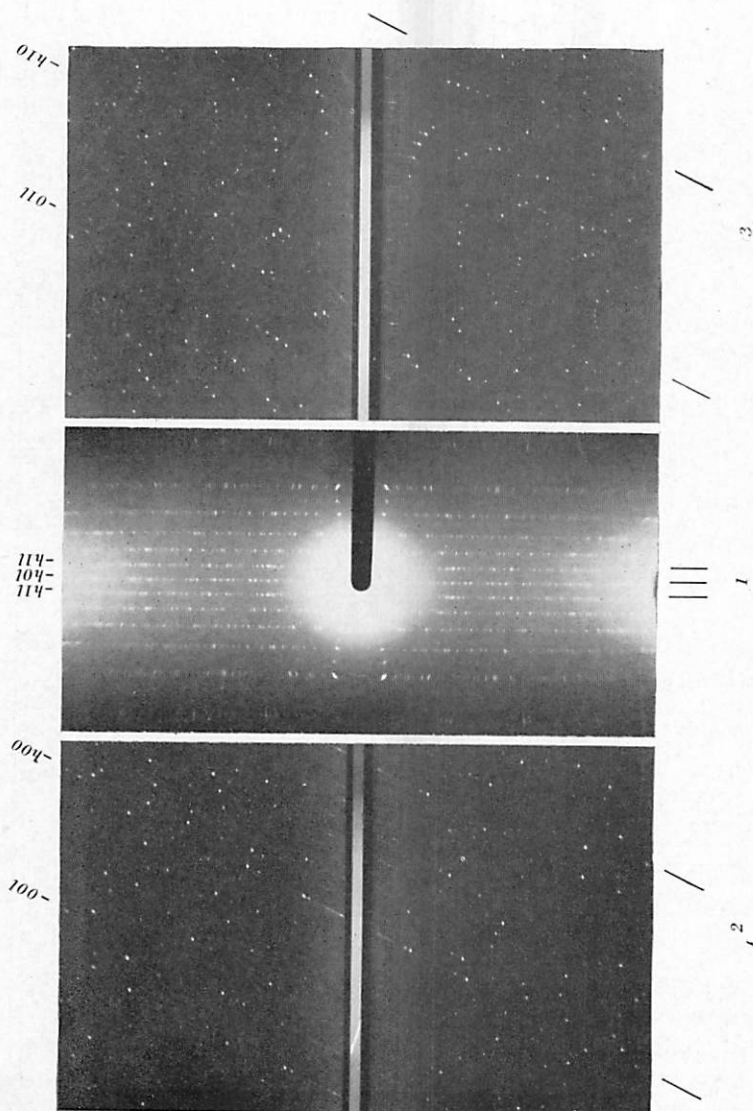
The best of several measurements on the specific gravity, made with the Berman balance on a clean fragment of 23 mg., gave 5.54, as compared with 5.4 (Zincken, 1831), 5.47—5.57 (Spencer, 1897, 1899), all on crystals from the Harz, and 5.54 (Zambonini, 1912) on crystals from Bolivia.

In reflected light a polished section of a group of pligionite crystals is white, showing very slight reflection pleochroism and moderate anisotropism with polarization colours light grey to dark grey. The Talmadge hardness is C, estimated with a needle. Etch-tests gave the following reactions: HNO_3 quickly stains brown without noticeable effervescence; HCl negative; KCN negative; FeCl_3 negative; KOH , slight brown stain; HgCl_2 negative. The mineral is not perfectly opaque, as shown by minute fragments mounted in oil which transmit cherry-red light in thinnest edges. These characters agree substantially with those given by Schneiderhöhn and Ramdohr (1931, p. 397) and Short (1940, p. 116), but they would hardly serve to distinguish pligionite from several other sulphantimonites of lead.

STRUCTURAL CRYSTALLOGRAPHY

A small (0.4 mm.) crystal of pligionite suitable for rotation and Weissenberg photographs was obtained from a larger (2 mm.) crystal with good faces of the base and the front pinakoid, by breaking down the larger crystal while preserving parts of the basal and front pinakoidal planes. This crystal was adjusted on the reflecting goniometer to rotate about the symmetry axis, and the angle $ca = 72^\circ 49'$ was obtained from good signals.

A rotation photograph and Weissenberg resolutions of the zero



FIGS. 1-3.—Plagiomite: single crystal x-ray photographs with unfiltered Cu-radiation; camera radius $360/4\pi$ mm. FIG. 1.—Rotation about [010]. FIG. 2.—Weissenberg resolution of the layer ($h0l$). FIG. 3.—Weissenberg resolution of the layer ($h1l$). One-half actual size.

and first layer lines (Figs. 1-3) gave the following constants for the least oblique unit cell:

$$b = 11.81, d_{(001)} = 19.05, d_{(100)} = 12.85 \text{ \AA}$$

The angle ca was also obtained directly from the zero Weissenberg film, by two methods. Measurement of the distances between the rows $(00l)$, $(h00)$, $(00\bar{l})$, gave $ca = 72^\circ 49'$. Measurement of high order $(h0l)$ spacings, namely $d_{(14.0.6)} = 0.8189 \text{ \AA}$, and $d_{(16.0.\bar{10})} = 0.8323 \text{ \AA}$, and combination of these values with $d_{(001)}$ and $d_{(100)}$, gave $ca = 72^\circ 37\frac{1}{2}'$, $73^\circ 00\frac{1}{2}'$, respectively, average $72^\circ 49'$. Using this well-established axial angle, the dimensions of the unit cell are:

$$a = 13.45, b = 11.81, c = 19.94 \text{ \AA}; \beta = 107^\circ 11'$$

A good check on these cell dimensions was obtained from another crystal which had been rotated about the edge of the (hhl) zone. This crystal had given the period $[\frac{1}{2}10] = 8.95 \text{ \AA}$, as compared with 8.95 \AA calculated from the above values for a and b .

The systematically missing spectra conform to the conditions:

$$\begin{aligned} (hkl) \text{ present only with } (h+k) \text{ even} & \dots\dots\dots (C) \\ (h0l) \text{ present only with } h \text{ even and } l \text{ even} & \dots\dots\dots (c) \end{aligned}$$

which are characteristic of the space groups $C_{2h}^6 = C2/c$ (prismatic class) and $C_s^4 = Cc$ (domatic class).

This determination of the cell dimensions of pligionite from Wolfsberg, Harz agrees tolerably with results obtained on a crystal from Oruro, Bolivia, by Wolfe, in Palache, Berman, and Frondel (1944, p. 464):

$$a = 13.4, b = 11.9, c = 19.77 \text{ \AA}, [\beta = 107^\circ 13']$$

Cell dimensions of pligionite were obtained by Hiller (1939, p. 148) from the powder pattern of material from Wolfsberg, Harz:

$$a = 18.44, b = 16.84, c = 13.52 \text{ \AA}$$

with the geometrical angle $\beta = 107^\circ 15'$, taken from the literature. The above value of b agreed with the period 16.86 \AA given by a rotation photograph of a crystal from the same material, which was "adjusted by the (100) faces and turned about the b -axis" (*trans.*). Hiller's c compares roughly with our a , but there is no further correspondence. As shown later our powder patterns for pligionite agree with Hiller's and thus it is evident that Hiller again obtained erroneous results in attempting to find the dimensions of a large

monoclinic cell from powder spacings.² Hiller's rotation period, 16.86 Å, does not agree with any period in the lattices of pligionite or semseyite, and one must conclude that the crystal used represented some other substance.

GEOMETRICAL CRYSTALLOGRAPHY

The new cell dimensions of pligionite give geometrical ratios:

$$a : b : c = 1.1389 : 1 : 1.6884; \beta = 107^\circ 11'$$

which compare directly with those derived by Zambonini (1912) from measurements on crystals from Oruro, Bolivia, and thus confirm the new setting which was proposed by Zambonini. Previous settings of pligionite are those of Rose (1833), adopted by Luedecke (1883) and Dana (1892); Goldschmidt (1890), used by Spencer (1899); and Fedorov (1903). These earlier settings are transformed to the correct setting of Zambonini by the formulae:

Rose to Zambonini:	100/010/004
Goldschmidt to Zambonini:	100/010/002
Fedorov to Zambonini:	110/110/002

In the correct setting the prismatic cleavage receives the indices (112), whereas in the settings of Rose, Goldschmidt, and Fedorov, the cleavage is denoted by (221), (111), and (011), respectively. Fedorov's setting, which purported to bring out a sub-cubic character in pligionite, is not acceptable by present conventions since the symmetry axis was not taken as a crystallographic axis.

Transformed in this way the available independent axial ratios for pligionite compare as follows:

$a : b : c$	β	
1.1389 : 1 : 1.6884	107° 11'	Wolfsberg (E. W. N. & M. A. P., x-ray)
1.126 : 1 : 1.661	[107 13]	Oruro (Wolfe, x-ray)
1.1305 : 1 : 1.6844	107 15	Oruro (Zambonini)
1.1331 : 1 : 1.6912	107 10½	Wolfsberg (Luedecke)
1.1364 : 1 : 1.6820	107 32	Wolfsberg (Rose)

In the revision of Dana's System, Palache has adopted geometrical elements obtained by averaging those of Zambonini and Luedecke:

$$a : b : c = 1.1318 : 1 : 1.6878; \beta = 107^\circ 13'$$

The foregoing geometrical elements for pligionite do not show

²See Berry (1943, p. 19).

the agreement which is usually obtained between good x -ray and goniometric measurements on sharply crystallized material of constant composition. The ratio $b : c$ and the angle β are tolerably constant but the ratio $a : b$ fluctuates considerably. It may be that there is a measurable difference between crystals from the Harz and from Bolivia but it seems more probable that the variation is due to the habitual imperfection of plagionite crystals which are always striated parallel to the edge of the (hhl) zone and are further defective in a lack of exact parallelism between the upper and lower basal planes. Furthermore, the vertical prism $m(110)$ is not a prominent form on most crystals and consequently good interfacial angles $m : m$, which directly give the ratio $a : b$, cannot be obtained. Minute crystals used for Weissenberg photographs suffer negligibly from such imperfections and therefore sharp Weissenberg photographs on imperfect crystals give better axial ratios than measurements on the reflecting goniometer.³ It seems reasonable, therefore, to propose the geometrical elements derived from the new x -ray measurements as the best elements for plagionite from the Harz. Table 1 gives an angle-table for the forms of plagionite reported by Zambonini (1912) on the preferred geometrical ratios.

FORM IN RELATION TO STRUCTURE

Progress in the work of determining crystal lattices and space-groups by means of x -rays gives repeated opportunities of testing Donnay's important generalization of the Law of Bravais in special cases (Donnay, 1942; Peacock and Ferguson, 1943). This generalization states that the relative importance of forms of a crystal species are proportional to the spacings of the corresponding structural planes in the simplest notation that conforms to the space-group conditions. The law recognizes the fundamental influence of the crystal lattice in determining form importance, and thus far it is equivalent to the Law of Bravais; in addition, it states that the further virtual subdivision of planar spacings caused by additional symmetry elements of the space-group (glide-planes and screw-axes) are expressed by further reduction in the relative importance of the corresponding crystal forms.

In a given special case the approximate truth of Donnay's law

³See Berry (1940, p. 601).

TABLE I

PLAGIONITE—5PBs.4SP₂S₃

Monoclinic—C/2c

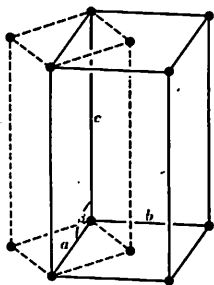
$a : b : c = 1.1389 : 1 : 1.6884$; $\beta = 107^{\circ} 11'$

$\rho_0 : q_0 : r_0 = 0.9191 : 1 : 0.6198$; $\mu = 72^{\circ} 49'$

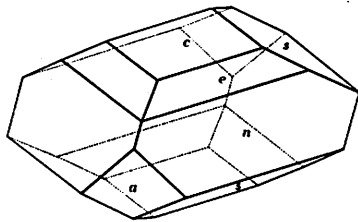
$\rho' = 1.5518$, $q_0' = 1.6884$, $x_0' = 0.3092$

Forms	ϕ	ρ	ϕ_2	$\rho_2 = B$	C	A
c(001)	90°00'	17°11'	72°49'	90°00'	0°00'	72°49'
b(010)	0 00	90 00	—	0 00	90 00	90 00
a(100)	90 00	90 00	0 00	90 00	72 49	0 00
m(110)	42 35	90 00	0 00	42 35	78 28	47 25
r(310)	70 04	90 00	0 00	70 04	73 52	19 56
ξ(013)	28 47½	32 42½	72 49	61 44	28 16	74 55
ζ(025)	24 36	36 36½	72 49	57 10	32 50	75 37½
Ω(012)	20 07	41 57½	72 49	51 06½	38 53½	76 42½
η(023)	15 22	49 25	72 49	42 55½	47 05	78 23½
d(021)	5 14	73 34	72 49	17 13½	72 46½	84 59
n(102)	90 00	47 20	42 40	90 00	30 09	42 40
f(102)	-90 00	25 01	115 01	90 00	42 12	115 01
g(101)	-90 00	51 10½	141 10½	90 00	68 21½	141 10½
p(118)	67 15	28 36½	68 17½	79 19½	14 16½	63 47
L(116)	63 38½	32 22	60 24½	76 15	18 26½	61 20½
L ₁ (2.2.11)	62 34	33 40½	59 24	75 12	19 52½	60 31
f(115)	61 24½	35 12½	58 13	73 59	21 32½	59 35
e(114)	58 48½	39 11	55 07	70 54	25 48½	57 17
l(113)	55 45	45 00	50 25½	66 33	31 59	54 14
n(112)	52 07	53 58	42 40	60 13½	41 22	50 20
x(111)	47 47	68 18	28 15	51 22	56 11	46 31
y(332)	46 09½	74 42	20 46	48 04½	62 46	45 55
s(114)	-10 34	23 14½	94 30	67 10½	31 04½	94 09
h(113)	-20 17	30 58	101 45	61 09	39 57½	100 16½
l(225)	-24 45½	36 38½	107 18	57 49	46 09	104 28½
k(112)	-28 56	43 58	115 01	52 35	53 57½	109 37½
N(223)	-32 47½	53 15	125 57	47 39½	63 40½	115 43
V(137)	36 16½	41 54½	62 02	57 25	34 08	66 43½
a(314)	74 00½	56 52½	34 10	76 40	40 32½	36 23
β(313)	73 10½	62 47	28 15	75 05	46 29½	31 39½
ψ(311)	71 13	79 12	11 23½	71 33½	63 01	21 34
v(421)	62 36½	82 14½	8 43½	62 52½	67 07	28 23½
S(10.1.2)	84 01½	82 58½	7 04	84 04½	65 53½	9 13
w(423)	-57 24	64 25½	150 23½	60 55½	79 10	139 27
σ(312)	-67 18	65 26	153 38½	69 27½	81 25	147 02½
r(512)	-76 42	74 45	164 21	77 10½	91 30	159 52
Σ(311)	-68 46	77 53½	167 02½	69 16	93 57	155 42
ε(511)	-77 14	82 32½	172 21½	77 20½	99 18	165 14½

can be tested in two ways: by attempting to determine the geometrical form of the structural lattice and the space-group from geometrical data, before these have been established by *x*-ray measurements; or by preparing the theoretical list of form importance according to Donnay's law, and comparing it with a list compiled from morphological observations. In recent years both methods have been frequently applied in the Toronto laboratory and the morphological choice of lattice and space-group has been made and written down before the *x*-ray work was begun. These predictions have been uniformly successful, and such was also the case in the present instance.



4



5

FIG. 4.—Plagionite: crystal lattice.

FIG. 5.—Plagionite: crystal of typical habit (redrawn after Rose, 1933), with $c(001)$, $a(100)$, $e(114)$, $n(112)$, $s(\bar{1}14)$.

Without attempting to give the full description of the procedure, it can be said that the method involves preparing a gnomonic projection of all the known forms of the species (in this case on the symmetry plane) and making a list of the commoner forms in approximate order of decreasing importance. The choice of lattice and space-group is then guided by the "rule of simplest structural indices" (Peacock and Moddle, 1941, p. 111), keeping in mind the possible types of lattice centring and the possible space-group conditions.

In the present case the base-centred mode of the monoclinic lattice (Fig. 4) was clearly shown by the lozenge-shaped habit (Fig. 5)

due to the predominant development of the (hhl) and $\bar{h}hl$ zones. The space-group condition $(h0l)$ present only with h even and l even is shown by the presence of $g(\bar{2}02)$ as a common form whereas the simpler planes $(\bar{2}01)$ and (201) are unknown as crystal forms. These must, therefore, have doubled indices and halved spacings to reduce their theoretical importance in conformity with the morphological facts.

TABLE 2
PLAGIONITE: THEORETICAL AND ACTUAL FORM DEVELOPMENT

Form	(hkl)	$d(\text{\AA})$	Form	(hkl)	$d(\text{\AA})$	Form	(hkl)	$d(\text{\AA})$	Form	(hkl)	$d(\text{\AA})$
* <i>c</i>	(002)	9.53	σ	$(\bar{3}12)$	4.15	<i>A</i>	(223)	3.29	<i>L</i>	(116)	2.81
* <i>m</i>	(110)	8.69	<i>B</i>	(221)	4.07	* <i>j</i>	(115)	3.26	—	$(\bar{1}35)$	2.80
—	$(\bar{1}11)$	8.58	* γ	(310)	4.03	—	$(\bar{3}15)$	3.26	—	(402)	2.80
* <i>x</i>	(111)	7.37	<i>N</i>	$(\bar{2}23)$	3.98	—	$(\bar{2}06)$	3.25	ξ	(026)	2.80
* <i>k</i>	$(\bar{1}12)$	7.18	—	$(\bar{3}13)$	3.93	ζ	(025)	3.20	<i>C</i>	(331)	2.78
<i>a</i>	(200)	6.43	* <i>c</i>	(114)	3.86	<i>t</i>	$(\bar{2}25)$	3.20	—	$(\bar{4}24)$	2.76
* <i>g</i>	$(\bar{2}02)$	6.25	<i>G</i>	$(\bar{1}15)$	3.79	<i>F</i>	$(\bar{1}16)$	3.20	—	$(\bar{1}17)$	2.76
<i>b</i>	(020)	5.91	<i>q</i>	(130)	3.76	—	(133)	3.12	—	$(\bar{3}34)$	2.73
* <i>n</i>	(112)	5.86	—	$(\bar{1}31)$	3.75	—	$(\bar{1}34)$	3.09	<i>a</i>	(314)	2.72
<i>h</i>	$(\bar{1}13)$	5.70	Ψ	(311)	3.74	β	(313)	3.04	—	$(\bar{2}41)$	2.70
* <i>d</i>	(021)	5.64	Ω	(024)	3.71	—	$(\bar{3}31)$	2.95	<i>v</i>	(421)	2.69
ρ	(022)	5.02	—	(131)	3.63	—	$(\bar{3}32)$	2.94	—	(240)	2.68
—	(202)	4.72	—	$(\bar{3}14)$	3.61	—	$(\bar{4}22)$	2.92	—	(043)	2.68
* <i>l</i>	(113)	4.70	—	$(\bar{1}32)$	3.60	—	$(\bar{3}16)$	2.92	—	$(\bar{2}42)$	2.67
<i>s</i>	$(\bar{1}14)$	4.58	—	(132)	3.40	—	(041)	2.92	<i>y</i>	(332)	2.63
<i>f</i>	$(\bar{2}04)$	4.52	—	(312)	3.39	—	$(\bar{4}21)$	2.90	τ	$(\bar{5}12)$	2.62
—	$(\bar{2}21)$	4.44	—	(204)	3.38	<i>w</i>	$(\bar{4}23)$	2.87	—	(225)	2.62
η	(023)	4.32	—	$(\bar{1}33)$	3.37	—	(134)	2.84	—	$(\bar{4}25)$	2.62
Ξ	$(\bar{3}11)$	4.18	—	$(\bar{4}02)$	3.36	—	(420)	2.82			

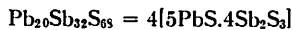
*Common form.

The result of the second method of testing the law is shown in Table 2 which shows the twenty-five known forms, including all the common forms except one, in the first thirty places of the theoretical list. In the present instance there are several striking anomalies: for example, the absence of $(\bar{1}11)$ (3rd place) as a known form; the small importance of (200) and (020) (6th and 8th places); the weakness of $(\bar{1}13)$ (10th place); the absence of (202) and $(\bar{2}21)$ (13th and 17th places), and so on; but the interesting thing is that even these numerous anomalies do not vitiate the general picture, as shown by

the fact that, in spite of them, the lattice and space-group were correctly inferred. The reason for this is, of course, that no choice of lattice would explain the absence of $(\bar{1}11)$, for example. This is clearly an anomaly which does not affect the inspective method; it must, like the other anomalies mentioned, be caused by some further and as yet not understood influence of structure on morphological development.

COMPOSITION AND CELL CONTENT

The measured cell dimensions of pligionite together with the new measured specific gravity give the molecular weight of the cell contents, $M = 10,166$. In Table 3 this value has been used to obtain the atomic contents from the six available analyses of the mineral. It will be observed that the average of the analyses and the empirical cell contents (A) agree excellently with the theoretical composition and cell content (B), namely



This cell content gives the calculated specific gravity 5.57, in exact

TABLE 3
PLACIONITE: ANALYSES AND CELL CONTENTS
 $M = 10,166$

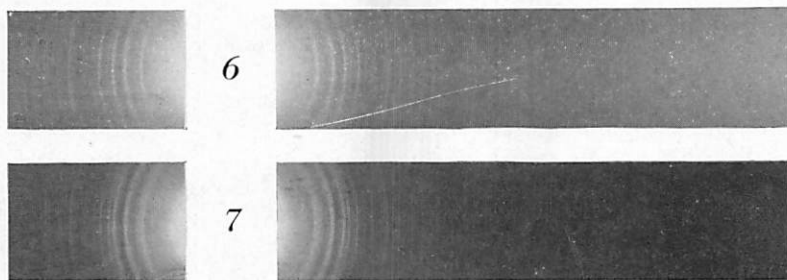
	1	2	3	4	5	6	A	B	
Analyses	Cu	...	...	1.27	...	...	...	...
	Ag	...	...	...	...	0.18	...	...
	Pb	40.52	40.62	40.98	39.36	41.24	40.28	40.50	40.55
	Sb	37.94	[37.49]	[37.53]	37.84	37.35	38.30	37.86	38.12
	S	21.53	21.89	21.49	21.10	21.10	21.43	21.42	21.33
		99.99	[100.00]	[100.00]	99.57	99.69	100.19	99.78	100.00
Atoms in unit cell	Cu	...	...	2.04	...	...	...	...
	Ag	...	...	...	...	0.17	...	...
	Pb	19.88	19.93	20.11	19.39	20.30	19.72	19.89	20
	Sb	31.68	[31.30]	[31.34]	31.73	31.28	31.92	31.54	32
	S	68.28	69.42	68.15	67.20	67.12	67.83	68.00	68

1, 2. Wolfsberg, Harz; anal. H. Rose (1833, in Hintze, 1904, p. 1019). 3. Wolfsberg, Harz; anal. Kudernatsch (1836, in Hintze, 1904). 4. Wolfsberg, Harz; anal. Schultz (1860, in Hintze, 1904). 5. Wolfsberg, Harz; anal. Prior (in Spencer, 1899). 6. Oruro, Bolivia; anal. Zambonini (1912). A. Average composition and cell content. B. Calculated for $5\text{PbS}.4\text{Sb}_2\text{S}_3$.

agreement with the highest value measured by Spencer (1897) on material from the Harz. This affords complete confirmation of the simplest generally accepted chemical formula, and thus excludes the less simple alternative formulae suggested by Spencer (1899, p. 65) to account for slight variation among the available analyses.

X-RAY POWDER PATTERN

Figs. 6 and 7 give the x-ray powder patterns (Cu radiation, Ni filter) of pligionite from the Harz and from a specimen from the Yukon territory. Table 4 gives the observed relative intensities and the measured spacings for the Harz material which was used



FIGS. 6, 7.—Pligionite: x-ray powder photographs with Cu-radiation (Ni-filter); camera radius $360/4\pi$ mm. FIG. 6.—Wolfsberg, Harz. FIG. 7.—Carbon Hill, Wheaton district, Yukon Territory. Actual size.

for single crystal measurements. The pattern has been indexed as far as $\theta = 27^\circ$; the measured spacings agree satisfactorily with one or more spacings calculated from the lattice dimensions and thus the pattern is adequately verified.

Table 5 gives a comparison of the intensities and measured spacings obtained on the Harz and Yukon materials together with the previously published data for Harz material by Hiller (1939). There is substantial agreement between the two new sets of measurements and those of Hiller, although a close comparison shows some slight differences between the Yukon and the Harz patterns. These are presumably due to slight chemical variation within the established chemical formula. Harcourt (1942, p. 93) apparently obtained a weak pattern for pligionite. Nearly all his spacings can be

TABLE 4

PLAGIONITE: $5\text{PbS}_4\text{Sb}_2\text{S}_3$ Monoclinic, $C2/c$; $a = 13.45$, $b = 11.81$, $c = 19.94\text{\AA}$, $\beta = 107^\circ 11'$; $Z = 4$

$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	(hkl)	$d(\text{calc.})$	$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	(hkl)	$d(\text{calc.})$
2	7.55°	5.85Å	(112)	5.86 Å				(606)	2.08 Å
6	11.55	3.84	(114)	3.86	$\frac{1}{2}$	21.85°	2.07 Å	(245)	2.08
$\frac{1}{2}$	11.75	3.78	$\left\{ \begin{array}{l} (\bar{1}15) \\ (130) \\ (\bar{1}31) \end{array} \right.$	$\left\{ \begin{array}{l} 3.78 \\ 3.76 \\ 3.75 \end{array} \right.$				(445)	2.08
1	12.25	3.63	$\left\{ \begin{array}{l} (131) \\ (\bar{3}14) \\ (\bar{1}32) \end{array} \right.$	$\left\{ \begin{array}{l} 3.63 \\ 3.61 \\ 3.60 \end{array} \right.$	1	22.2	2.03	(229)	2.07
$\frac{1}{2}$	13.2	3.37	$\left\{ \begin{array}{l} (132) \\ (312) \\ (204) \\ (\bar{1}33) \\ (402) \end{array} \right.$	$\left\{ \begin{array}{l} 3.40 \\ 3.39 \\ 3.38 \\ 3.37 \\ 3.36 \end{array} \right.$				(624)	2.07
(1) 10	$\left\{ \begin{array}{l} 13.55 \\ 13.8 \end{array} \right.$	$\left\{ \begin{array}{l} 3.28 \\ 3.22 \end{array} \right.$	$\left\{ \begin{array}{l} (223) \\ (400) \end{array} \right.$	$\left\{ \begin{array}{l} 3.29 \\ 3.21 \end{array} \right.$	1	22.2	2.03	(350)	2.07
(2) 9	15.3	2.91	$\left\{ \begin{array}{l} (\bar{4}22) \\ (\bar{3}16) \\ (041) \\ (\bar{4}21) \end{array} \right.$	$\left\{ \begin{array}{l} 2.92 \\ 2.92 \\ 2.92 \\ 2.90 \end{array} \right.$	3	22.7	1.992	(338)	2.05
3	16.05	2.78	$\left\{ \begin{array}{l} (402) \\ (026) \\ (331) \end{array} \right.$	$\left\{ \begin{array}{l} 2.80 \\ 2.80 \\ 2.78 \end{array} \right.$	3	23.4	1.936	(208)	2.04
$\frac{1}{2}$	16.8	2.66	$\left\{ \begin{array}{l} (043) \\ (\bar{2}42) \end{array} \right.$	$\left\{ \begin{array}{l} 2.68 \\ 2.67 \end{array} \right.$	3	22.7	1.992	(247)	2.04
(3) 8	17.05	2.62	$\left\{ \begin{array}{l} (332) \\ (225) \\ (\bar{4}25) \\ (241) \end{array} \right.$	$\left\{ \begin{array}{l} 2.63 \\ 2.62 \\ 2.62 \\ 2.61 \end{array} \right.$	3	24.0	1.890	(442)	2.03
2	18.05	2.48	($\bar{2}44$)	2.47	3	22.7	1.992	(155)	2.03
								(514)	1.996
								(532)	1.996
								(2.0.10)	1.994
								(029)	1.993
								(446)	1.989
								(155)	1.938
								(138)	1.938
								(355)	1.937
								(246)	1.935
								(353)	1.889
								(261)	1.889
								(515)	1.864
								(356)	1.859
								(711)	1.858
								(261)	1.858
								(157)	1.815
								(0.2.10)	1.813
								(249)	1.771
								(644)	1.771
								(265)	1.749
								(065)	1.749

TABLE 4—(Continued)

$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	(hkl)	$d(\text{calc.})$	$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	(hkl)	$d(\text{calc.})$		
1	18.9	2.37	{(008) (243)}	2.38 2.37	3	27.0	1.693	{(646) (718)	1.702 1.702		
1	19.1	2.35	{(423) (404) (318) (226)}	2.36 2.36 2.36 2.35				{(535) (735) (462) (712)}	1.702 1.701 1.698 1.693		
1	20.35	2.22	{(152) (244) (153) (442)}	2.23 2.22 2.22 2.22							
6	21.1	2.14	{(444) (153) (600) (154)}	2.15 2.15 2.14 2.13							

$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$
3	30.65°	1.508 Å	1	36.05°	1.307 Å	1	40.8°	1.176 Å
2	31.75	1.461	½	36.75	1.288	½	41.25	1.166
1	32.8	1.419	½	37.6	1.260	½	42.75	1.133
½	33.8	1.382	½	38.0	1.249	2	43.95	1.108
½	34.7	1.350	1	38.9	1.224	1	47.7	1.040
½	35.15	1.336	1	39.6	1.206			

closely matched by spacings in our patterns; but the comparison of relative intensities, especially in regard to the three strongest lines which are used for identification, is not good and therefore it might be well to disregard this pattern in favour of the now confirmed powder spectrum of pligionite.⁴

SEMSEYITE

Semseyite is a sulphantimonite of lead closely resembling pligionite in appearance. The lozenge-shaped, tabular crystals originally found at Felsöbánya, Hungary, apparently gave poor measurements and consequently the monoclinic elements obtained by

⁴In a private communication Dr. Harcourt agreed that the material he used may not have been pligionite.

TABLE 5
 PLAGIONITE: COMPARISON OF X-RAY POWDER DATA

Harz (E.W.N.)		Harz (Hiller)		Yukon (E.W.N.)	
<i>I</i> (Cu)	<i>d</i> (meas.)	<i>I</i> * <i>(Fe)</i>	<i>d</i> (meas.)	<i>I</i> (Cu)	<i>d</i> (meas.)
2	5.85 Å	...	...	1	5.93 Å
	...	vw	4.36 Å	1	4.38
	...	...	...	½	4.16
6	3.84	w	3.90	4	3.92
½	3.78	w	3.77	4	3.77
1	3.63	w	3.64	3	3.66
½	3.37	...	...	½	3.44
(1) 10	{ 3.28	vs	3.30	(1) 10	{ 3.28
	{ 3.22	vs	3.22		{ 3.22
	...	...	...	½	3.00
(2) 9	2.91	vs	2.92	(2) 7	2.91
3	2.78	w	2.80	4	2.81
½	2.66	...	...	½	2.68
(3) 8	2.62	s	2.62	(3) 5	2.63
	...	...	...	½	2.57
2	2.48	w	2.48	2	2.51
1	2.37	m	2.36	1	2.37
1	2.35	...	...	1	2.34
1	2.22	m-w	2.20	1	2.22
6	2.14	s	2.14	3	2.14
½	2.07	...	...	½	2.07
1	2.03	w	2.04	2	2.04
3	1.992	w	1.998	2	1.996
3	1.936	m	1.950	1	1.955
3	1.890	m	1.899	2	1.901
3	1.854	m	1.865	2	1.865
2	1.809	w	1.814	...	...
2	1.770	dw	1.775	1	1.776
½	1.751	...	...	...	...
3	1.693	s	1.698	...	...
	...	...	...	½	1.669
	...	m	1.675	...	...
	...	dw	1.614	...	...
2	1.508	w	1.516	1	1.526
	...	vw	1.494	...	...
3	1.461	s	1.470	1	1.465
1	1.419	m-s	1.432	...	...
	...	m-s	1.405	...	...
½	1.382	vw	1.384	...	...
½	1.350	s	1.354	...	...

TABLE 5—(Continued)

Harz (E.W.N.)		Harz (Hiller)		Yukon (E.W.N.)	
<i>I</i> (Cu)	<i>d</i> (meas.)	<i>I</i> * <i>(Fe)</i>	<i>d</i> (meas.)	<i>I</i> (Cu)	<i>d</i> (meas.)
$\frac{1}{2}$	1.336	s	1.341	1	1.342
1	1.307	m-s	1.313		...
$\frac{1}{2}$	1.288	m-s	1.292		...
$\frac{1}{2}$	1.260	dw	1.260		...
$\frac{1}{2}$	1.249		...		...
1	1.224	vs	1.227		...
1	1.206	s	1.213		...
1	1.176	w	1.183		...
$\frac{1}{2}$	1.166		...		...
$\frac{1}{2}$	1.133	w	1.139		...
2	1.108	s	1.113		...
	...	vw	1.086		...
	...	m	1.065		...
1	1.040	m	1.043		...
	...	m	1.028		...
	...	m	1.019		...

*vw, very weak (ganz schwach); w, weak (schwach); m, medium (mittlere); s, strong (stark); vs, very strong (sehr stark); d, diffuse (verschwommen).

Krenner (1884), given in Dana (1892, p. 123), were inaccurate. Exact measurements were later obtained by Smith (1919) on better crystals from Dumfriesshire, Scotland. The varying earlier analyses also led to a variety of chemical formulae, including $7\text{PbS} \cdot 3\text{Sb}_2\text{S}_3$, given in Dana (1892); but the later analyses, in Smith (1919), pointed clearly to the formula $9\text{PbS} \cdot 4\text{Sb}_2\text{S}_3$ which is now generally accepted.

PHYSICAL PROPERTIES

The observations given in this paper were made on two specimens from Kisbánya, Romania (HMM 82443, 82446) kindly loaned for study by the late Professor Berman, Harvard University. On these specimens semseyite occurs in radiating clusters of rough plates up to 5 mm. wide associated with some feather ore and quartz crystals. The colour is somewhat lighter than that of pligionite, especially on a freshly broken surface which is nearly tin white with a good metallic lustre. Unbroken surfaces show occasional bluish-yellow tarnish. The specific gravity measured on two crystals was 6.03 in both cases.

A polished section of a crystal group is white in reflected light and moderately anisotropic, the colours ranging from grey blue to grey with a pink tinge. The hardness is C (Talmadge). The standard etch-tests gave: HNO_3 , quickly stains black without effervescence; HCl , stains slightly in places; KCN , negative; FeCl_3 , negative; KOH , stains slightly in places; HgCl_2 , light brown stain in places. These observations substantially agree with those given for semseyite by Short (1940, p. 116) but it should be noted that the characters of semseyite and pligionite in polished sections are so similar that it would be difficult to distinguish these species by microscopic means.

STRUCTURAL CRYSTALLOGRAPHY

In semseyite the prismatic cleavage, which receives the symbol (112) in structural notation, is better than the corresponding cleavage in pligionite. It was therefore possible to reduce a platy crystal showing opposite faces of the base (001), with the help of the cleavage, to obtain a small crystal suitable for x -ray measurements. This crystal was rotated about the symmetry axis by adjusting it so that the angle (010):(112) read $57^\circ 02'$ as calculated from Smith's geometrical elements. The corresponding angle subsequently calculated from the cell dimensions is $57^\circ 03'$.

The x -ray photographs, a rotation about [010] and Weissenberg resolutions of the ($h0l$) and ($h1l$) layer-lines, were similar to those of pligionite in quality, and gave the lattice constants:

$$d_{(100)} = 13.09, d_{(010)} = 11.99, d_{(001)} = 23.59 \text{ \AA}, \beta = 105^\circ 49'$$

These gave the cell dimensions:

$$a = 13.61, b = 11.99, c = 24.52 \text{ \AA}, \beta = 105^\circ 49'$$

as compared to the measurements by Wolfe, in Palache, Berman, and Frondel (1944, p. 467):

$$a = 13.48, b = 11.87, c = 24.48 \text{ \AA}, \beta = 105^\circ 45'$$

When Smith's (1919) geometrical elements are transformed according to the formula:

$$\text{Smith to Wolfe: } 100/010/002$$

the x -ray ratios compare with the geometrical values as follows:

$$\begin{aligned} a : b : c &= 1.1356 : 1 : 2.0436; \beta = 105^\circ 46' \text{ (Smith)} \\ &1.1356 : 1 : 2.0623; \beta = 105^\circ 45' \text{ (Wolfe)} \\ &1.1347 : 1 : 2.0449; \beta = 105^\circ 49' \text{ (E.W.N. \& M.A.P.)} \end{aligned}$$

In the same setting the original elements of Krenner give:

$$a : b : c = 1.1442 : 1 : 2.2102; \beta = 108^\circ 56'$$

These are evidently faulty in view of the good agreement shown above. The agreement between the new structural ratios and the geometrical ratios of Smith is very close and therefore Smith's ratios are properly retained, as in Palache, Berman, and Frondel (*loc. cit.*), to define the morphology of semseyite.

Like pligionite, semseyite shows the extinctions of the space-group $C_{2h}^6 - C2/c$ which is also the space-group reported by Wolfe; and as in the case of pligionite the lattice and space-group were inferred from the morphology of the species before the x -ray measurements were made.

From the previous descriptions of the morphology of semseyite the actual form development of this species was compared with the theoretical development according to Donnay's law, as shown in Table 6. Again there are notable anomalies, such as the absence of (110), ($\bar{1}13$), (020), among the known forms whereas several common forms with smaller spacings are present; but these did not prevent the lattice and space-group being correctly predicted from the morphological development.

TABLE 6
SEMSEYITE: THEORETICAL AND ACTUAL FORM-DEVELOPMENT

Form (<i>hkl</i>)	<i>d</i> (Å)	Form (<i>hkl</i>)	<i>d</i> (Å)	Form (<i>hkl</i>)	<i>d</i> (Å)	Form (<i>hkl</i>)	<i>d</i> (Å)
* <i>c</i> (002)	11.80	<i>S</i> ($\bar{1}14$)	5.39	— ($\bar{2}23$)	4.20	— ($\bar{1}32$)	3.72
— (110)	8.84	* ρ (022)	5.34	* γ (310)	4.10	— (025)	3.71
* <i>X</i> ($\bar{1}11$)	8.83	* <i>g</i> (202)	5.16	— ($\bar{3}13$)	4.09	— (312)	3.60
* <i>x</i> (111)	7.82	<i>f</i> ($\bar{2}04$)	5.13	— (204)	3.89	— ($\bar{3}15$)	3.58
* <i>k</i> ($\bar{1}12$)	7.79	— (023)	4.77	— (115)	3.88	— (223)	3.58
* <i>a</i> (200)	6.55	* <i>e</i> (114)	4.54	— (311)	3.88	— ($\bar{2}25$)	3.57
* <i>n</i> (112)	6.52	— ($\bar{1}15$)	4.52	— ($\bar{2}06$)	3.87	— (132)	3.55
— ($\bar{1}13$)	6.50	— ($\bar{2}21$)	4.50	<i>t</i> ($\bar{1}16$)	3.87	— ($\bar{1}33$)	3.55
* <i>G</i> ($\bar{2}02$)	6.47	— ($\bar{3}11$)	4.23	— ($\bar{3}14$)	3.86	— ($\bar{4}02$)	3.40
— (020)	6.00	* σ ($\bar{3}12$)	4.22	— (130)	3.82	<i>s</i> (116)	3.37
<i>d</i> (021)	5.81	— ($\bar{2}21$)	4.21	— ($\bar{1}31$)	3.82	— ($\bar{1}17$)	3.36
<i>l</i> (113)	5.40	— (024)	4.20	— (131)	3.73	— ($\bar{1}34$)	3.33

S($\bar{1}14$) (observed by Smith, 1919, but without a form letter), is given as *s*($\bar{1}14$) in Palache, Berman, and Frondel (1944, p. 467), and *t*($\bar{1}16$), *s*(116) (reported by Krenner, 1883) are omitted.

*Common form.

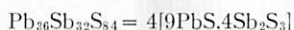
TABLE 7
SEMSEVITE: ANALYSES AND CELL CONTENTS
M = 14,078

		1	2	3	4	5	6	7	8	A	B
Analyses	Cu.....	...	...	...	...	0.06	0.11	...	...	...	...
	Ag.....	...	...	1.6	...	0.13	0.56	0.25	...	...	...
	Fe.....	0.10	...	...	0.67	0.06	trace	...	...	...	...
	Pb.....	53.16	51.84	52.9	52.37	52.49	51.88	54.27	53.21	52.77	53.10
	Sb.....	26.90	28.62	24.8	25.49	28.34	27.20	26.17	26.95	26.81	27.73
	S.....	19.42	19.42	18.7	18.81	18.93	19.73	18.99	19.90	19.24	19.17
		99.58	99.88	98.0	99.81 ⁵	100.22 ⁵	100.63 ⁷	99.69 ⁸	100.14 ⁹	99.52	100.00
Atoms in unit cell	Cu.....	...	...	...	...	0.01	0.02	...	...	...	...
	Ag.....	...	...	2.13	...	0.02	0.74	0.33	...	...	...
	Fe.....	0.25	...	...	0.69	0.02	...	...	...	...	...
	Pb.....	36.27	35.26	36.67	36.55	35.66	35.47	36.99	36.13	36.13	36
	Sb.....	31.23	33.13	29.26	30.28	32.76	31.65	30.36	31.14	31.23	32
	S.....	85.64	85.38	83.79	84.86	83.12	87.19	83.66	87.33	85.12	84

1. Felsöbánya, Romania; anal. Sipöcz (1886). 2. Wolfsberg, Harz; anal. Prior (in Spencer, 1899). 3. Oruro, Bolivia; anal. Prior (in Spencer, 1907). 4. Glendinning, Dumfriesshire; anal. Prior (in Smith, 1919). ⁵Incl. Zn trace, MgCO₃ trace, CaCO₃ 1.66, insol. 0.81. 5. Kisbánya, Romania; anal. Loczka, 1926 (*Min. Abs.* 3-8). ⁶Incl. insol. 0.21. 6. Kisbánya, Romania; anal. Endrédy, in Koch, 1932 (*Min. Abs.* 5-190). ⁷Incl. insol. 1.15. 7. Kisbánya, Romania; anal. Finály, in Koch, 1932 (*Min. Abs.* 5-190). ⁸Incl. insol. 0.01. 8. Ó-Radna, Romania; anal. Endrédy, in Koch, 1932 (*Min. Abs.* 5-190). ⁹Incl. insol. 0.08. A. Average composition and cell content. B. Calculated for 4[9PbS.4Sb₂S₃].

COMPOSITION AND CELL CONTENT

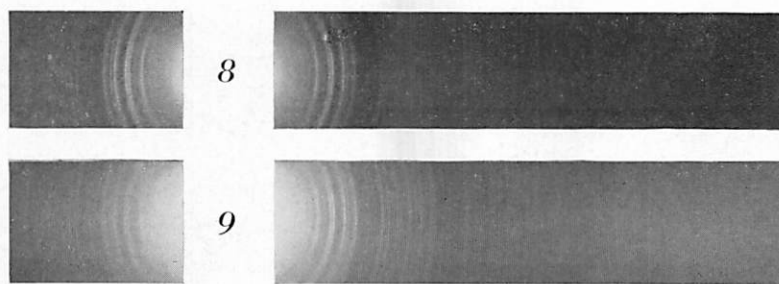
The new cell dimensions and measured specific gravity of semseyite give the molecular weight, $M = 14,078$. This has been used to compute the atomic cell contents from the available analyses in Table 7. The average composition and cell content (A) closely approaches the calculated values (B) indicating the cell content:



This shows that the generally accepted composition is correct and that the slight variations in the analyses are due to occasional replacement of lead by small amounts of silver or iron and slight mutual substitution between antimony and sulphur.

X-RAY POWDER PATTERN

The x-ray powder pattern (Fig. 8) given by a crystal fragment from the specimen studied in this paper is reproduced together with the identical pattern (Fig. 9) from a well-formed crystal from an unknown locality. The measured spacings and estimated intensities for Cu-radiation are listed in Table 8 with the indices and calculated spacings of the reflecting planes. Harcourt (1942, p. 98) gives a list of 15 spacings and intensities for semseyite from Rez-bánya, Hungary; these agree substantially with the data in our table.



FIGS. 8, 9.—Semseyite: x-ray powder photographs with Cu-radiation (Ni-filter). Camera radius $360/4\pi$ mm. FIG. 8.—Kisbánya, Romania. FIG. 9.—Crystal from unknown locality. Actual size.

TABLE 8

SEMSEYITE: $9\text{PbS}_4\text{Sb}_2\text{S}_3$ Monoclinic, $C2/c$; $a = 13.61$, $b = 11.99$, $c = 24.52 \text{ \AA}$, $\beta = 105^\circ 49'$; $Z = 4$

$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	(hkl)	$d(\text{calc.})$	$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	(hkl)	$d(\text{calc.})$
$\frac{1}{2}$	6.7°	6.59 Å	(200)	6.55 Å				(441)	2.16 Å
$\frac{1}{2}$	8.1	5.46	(113)	5.40	3	20.9°	2.15 Å	($\bar{4}$ 45)	2.16
$\frac{1}{2}$	9.7	4.56	{(114) ($\bar{1}$ 15)}	{4.54 4.52}				($\bar{1}$ 55)	2.15
$\frac{1}{2}$	10.5	4.20	{(221) ($\bar{2}$ 23) (024)}	{4.21 4.20 4.20}	$\frac{1}{2}$	21.4	2.11	(514)	2.15
5	11.55	3.84	{($\bar{3}$ 14) (130)}	{3.86 3.82}				(318)	2.15
$\frac{1}{2}$	11.85	3.75	{(131) ($\bar{1}$ 32)}	{3.73 3.72}	$\frac{1}{2}$	21.4	2.11	($\bar{3}$ 51)	2.12
2	12.4	3.59	{($\bar{3}$ 15) ($\bar{2}$ 25)}	{3.58 3.57}	1	22.0	2.05	(623)	2.12
(3)	8	3.37	{(116) ($\bar{1}$ 17)}	{3.36 3.36}				($\bar{6}$ 22)	2.11
(1)	10	3.26	{(026) ($\bar{3}$ 16) (400) ($\bar{2}$ 26) ($\bar{4}$ 04)}	{3.29 3.29 3.27 3.25 3.23}	1	22.0	2.05	(048)	2.10
(2)	9	2.97	{(040) ($\bar{3}$ 31) ($\bar{1}$ 18) (041) (225) (117) ($\bar{2}$ 27) (008)}	{3.00 2.99 2.97 2.97 2.97 2.97 2.96 2.95}	$\frac{1}{2}$	22.6	2.00	(532)	2.07
								($\bar{6}$ 26)	2.05
								(2.0.10)	2.05
								($\bar{2}$.0.12)	2.04
					$\frac{1}{2}$	22.6	2.00	(060)	2.00
								(1.1.11)	2.00
								($\bar{1}$.1.12)	2.00
					$\frac{1}{2}$	22.9	1.975	(156)	1.980
								($\bar{1}$ 57)	1.979
								(049)	1.973
								(062)	1.970
					2	23.65	1.916	($\bar{7}$ 14)	1.917
								($\bar{2}$ 61)	1.917
								(338)	1.916
								($\bar{5}$.1.11)	1.914
					$\frac{1}{2}$	23.9	1.897	($\bar{3}$ 57)	1.899
								(248)	1.897
								(262)	1.863
					1	24.45	1.858	($\bar{2}$ 64)	1.862
								(0.4.10)	1.854

TABLE 8—(Continued)

$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	(hkl)	$d(\text{calc.})$	$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	(hkl)	$d(\text{calc.})$
4	15.6°	2.86	{	(420) 2.87 Å	1	25.25°	1.802	{	(711) 1.805 Å
				(424) 2.86					(2.2.11) 1.804
				(331) 2.86					(321) 1.804
				(135) 2.86					(322) 1.803
1	16.1	2.77	{	(425) 2.77				{	(339) 1.801
				(421) 2.77					(158) 1.799
				(318) 2.75					(2.2.13) 1.799
4	16.55	2.70	{	(226) 2.70	½	25.85	1.763	{	(555) 1.766
				(228) 2.69					(646) 1.761
1	18.05	2.48	{	(243) 2.49	1	26.55	1.720	{	(267) 1.722
				(516) 2.47					(3.1.14) 1.721
				(227) 2.47					(737) 1.691
				(229) 2.46					(2.4.10) 1.691
½	18.9	2.37	{	(424) 2.37	1	27.1	1.687	{	(642) 1.691
				(244) 2.37					(3.3.13) 1.691
				(246) 2.37					(172) 1.690
				(428) 2.36					(171) 1.690
				(0.0.10) 2.36					(2.4.12) 1.688
3	20.0	2.25	{	(2.2.10) 2.26				{	(648) 1.687
				(602) 2.26					(2.2.12) 1.685
				(604) 2.26					(0.0.14) 1.685
				(513) 2.26					
				(245) 2.25					
				(139) 2.25					
				(518) 2.25					
				(442) 2.25					
(247) 2.25									
$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	$I(\text{Cu})$	$\theta(\text{Cu})$	$d(\text{meas.})$	
1	31.35°	1.478 Å	½	37.6°	1.260 Å	½	40.7°	1.179 Å	
½	35.1	1.337	½	38.55	1.234				
½	36.9	1.280	½	39.4	1.211				

THE PLAGIONITE GROUP

Plagionite, heteromorphite, and semseyite were regarded by Spencer (1899, p. 55) as members of a natural group of minerals with progressive properties. When fülöppite was described by de Finály and Koch (1929), it was found that this mineral could also be fitted into the group. Our efforts to obtain authentic fülöppite and heteromorphite have not yet succeeded and therefore we cannot offer structural data for these minerals. However, it will be seen in Table 9 that the grouping of these minerals is supported by the cell dimensions of plagionite and semseyite which show similar values for a , b , and β , while c in semseyite is substantially larger than in plagionite in keeping with the larger content of PbS. The specific gravities of the four minerals also increase in a roughly linear manner in keeping with the regular increment of PbS.

TABLE 9
PLAGIONITE GROUP

	a	b	c	β	Sp. grav.
Fülöppite..... $3\text{PbS.4Sb}_2\text{S}_3$	...	...	...	...	5.23
Plagionite..... $5\text{PbS.4Sb}_2\text{S}_3$	13.45 Å	11.81 Å	19.94 Å	107°11'	5.54
Heteromorphite.. $7\text{PbS.4Sb}_2\text{S}_3$	5.73
Semseyite..... $9\text{PbS.4Sb}_2\text{S}_3$	13.61	11.99	24.52	105°49'	6.03

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FLUORESCENCE AS RELATED TO MINERALS

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THE term *fluorescence* is usually used to mean the emission of visible or near-visible light by a solid, liquid, or gas during the time of absorption of another kind of energy. *Phosphorescence* is the term used for the emission of visible light after the cessation of the exciting energy. This discussion will be limited to the fluorescence and phosphorescence of solids. The colour of the fluorescence and phosphorescence is usually, but need not be, the same. It is sometimes quite dissimilar, although in such cases the fluorescent light is composite and contains the phosphorescent component in addition to the fluorescent component. That is, the fluorescence may be a pale yellow colour to the eye, the yellow being actually a mixture of red and green, and the phosphorescence may be green due to the red component not persisting after the excitation ceases. Solid crystalline fluorescent and phosphorescent materials are also termed *phosphors*.

The means commonly used for exciting fluorescent materials are: (1) ultra-violet radiation, (2) electron bombardment, (3) ion bombardment, (4) *x*-ray radiation.

Any one phosphor may be excited by one or more of the above excitation methods, but it is usually excited to a greater extent by one means than the others. In addition, the intensity factor of the excitation source for any one method of excitation shows an optimum for any one fluorescent material. That is, if the phosphor is excited by ultra-violet radiation, there is one wave-length which allows a higher conversion to visible light than wave-lengths shorter and longer than the optimum, and if the material is excited by electrons then the voltage, or velocity, of the electrons is the control over the efficiency of energy conversion. Historically, fluorescence of gases was observed first, with ion bombardment, and of crystalline materials, with *x*-ray excitation and also in gas discharge tubes. In recent years the large-scale commercial application of fluorescent materials involves either ultra-violet radiation or electron bombardment as the excitation medium.

The transfer of energy in fluorescence, to obey the laws of thermodynamics, is always in a downhill direction and the efficiency of the transfer may approach but not exceed 100 per cent although some fluorescent materials have surprisingly high conversion efficiencies. The conversion of absorbed energy into re-emitted energy is also downhill in the sense that even though the conversion may approach 100 per cent, the intensity factor is lower on the re-emitted side. That is, a higher intensity excitation (e.g., short wave-length light) is converted into a lower intensity (e.g. long wave-length light re-emission), similar to the relations in heat transfer.

CRYSTAL BOND TYPES

All crystalline compounds can be divided into groups according to the type of inter-atomic, inter-ionic, or inter-molecular forces. At one extreme is the metallic bond type. In metallic crystals, the outer electron shell of the atoms making up the crystal can be thought to be present in the interstices of the structure, being common to the structure as a whole, and not fixed in position near any one atom. The free electrons may migrate through the structure under the influence of an electrical potential gradient. Such crystals are opaque to visible radiations, good conductors of heat and electricity, and have mechanical properties characteristic of metals, such as malleability, ductility, and softness. Another extreme type of bonding is ionic, wherein the outer shell of the electrons is complete around each of the atoms, giving a resultant positive or negative charge to atoms of different type. The electrons are thus fixed in position and do not migrate under the influence of an electrical potential gradient. Such crystals are transparent, soluble in water, poor conductors of heat and electricity, and have the mechanical properties associated with compounds such as common salt. That is, they are brittle and soft. Another extreme type of bonding in crystals is the homopolar bond type, wherein the outer electron shells are shared between adjacent atoms making up the crystal, but the electrons are fixed in position and do not migrate under an electrical potential gradient. Such crystals are transparent, insoluble in water, poor conductors of heat and electricity, and are hard and brittle. There are all gradations in bond type between the metallic and the homopolar types, and there are all

gradations between the ionic and homopolar types. That is, the homopolar bond type is transitional between the strictly metallic and the strictly ionic. The gradation of bond type from homopolar to metallic is followed by the principal optical absorption edge (i.e., the wave-length limit of transparency) moving from far in the ultra-violet region, through the ultra-violet, through the visible spectrum, and into the infra-red region. As the absorption edge approaches and moves through the visible region, the colour changes in compounds are: white, yellow, orange, red, dark red, black, metallic. In addition, the electronic conductivity increases progressively, the hardness decreases, and the malleability increases. The transition from the ionic to the homopolar bond type is accompanied by a decrease in solubility and an increase in hardness. The inorganic fluorescent crystals have bond types between the purely ionic to homopolar. Most phosphors nearer the ionic bond extreme type may be excited by ultra-violet radiation easier than by electronic excitation, the reverse being true for those nearer the homopolar bond extreme type.

THEORY OF FLUORESCENCE

The theory of energy absorption and emission by a phosphor is exceedingly complex and not thoroughly understood at the present time, but certain empirical methods of representing the energy transfers have been devised which aid in understanding the progressive changes in emission due to variations in the composition of the phosphor. A convenient method is to represent on a diagram the various energy levels in a crystal structure situated above the main energy levels of the crystal in an unexcited state. No attempt will be made to discuss this phase of the problem fully, but in a general way the highest level above the ground state is the level of conducting electrons. That is, if enough energy is absorbed by the crystal then some of the bound electrons may be thrown into an excited state which allows them to migrate through the structure under the influence of an electrical potential gradient. Such excited electrons may immediately return to the ground state or may fall to various levels progressively on their way back to the ground state. The energy levels between the ground state and the free electron level are provided by various types of crystal lattice imper-

fections. The fall of excited electrons into the energy levels provided by such imperfections provides the energy for the emission of the visible fluorescent light. The lower the energy level provided by the imperfection, the greater is the energy difference between it and the free electron, or conducting level, so that the intensity factor of the emitted light is greater. This corresponds to the wave-length of the fluorescent light being nearer the violet end of the spectrum. The excited electrons may be free to fall to lower energy levels, and finally back to the ground state, or they may reach partly-bound unstable positions in the conduction band from which they are gradually dislodged by thermal agitation and fall to the ground state. Such unstable energy levels near the conducting electron level are called *electron traps*. A useful picture of fluorescence is as follows: A crystal absorbs radiant energy and some of the bound electrons take on higher energy sufficient to displace them from the stable arrangement. The excited electrons find new positions of rest in unstable positions in the structure, but soon fall back to the ground state, the loss of energy taking the form of radiant energy. During excitation, electrons are moving into the conduction band and falling back; some are caught in unstable positions and held for a short time before falling back. After the excitation ceases, the electrons still held in the unstable positions fall back gradually to the ground state. The emission of radiant energy during the fall from the conduction level back to the ground state is thus composed of three types: (1) emission due to excited electrons falling back to the ground state before being trapped, during the time of absorption of outside energy, (2) emission due to excited electrons falling back to the ground state after being trapped, but during the time of absorption of outside energy, and (3) emission due to excited electrons falling back to the ground state after being trapped, but after the cessation of absorption of outside energy. The emission due to the first two effects is the fluorescence, and due to the last effect, the phosphorescence.

A schematic representation of the relationship between the various energy levels is shown in Fig. 1. In the diagram some of the possible electron energy paths are shown. On the left-hand side, the energy of some of the electrons increases sufficiently so that they enter the conduction band or the unstable traps. In the centre of

the diagram, the electrons in the conduction band return to the ground state, emitting their excess energy as visible light on falling into and being momentarily trapped by the imperfection levels I, II, and III. The energy emitted on falling from the conduction band to level III may be as red light, to level II, as green light, and to level I, as blue light. Very pure crystals which have presumably no levels II and III, however, have level I, which may be thought of as the imperfection left by the electron as it moves to the conduction band. Such crystals emit blue, violet, or ultra-violet light.

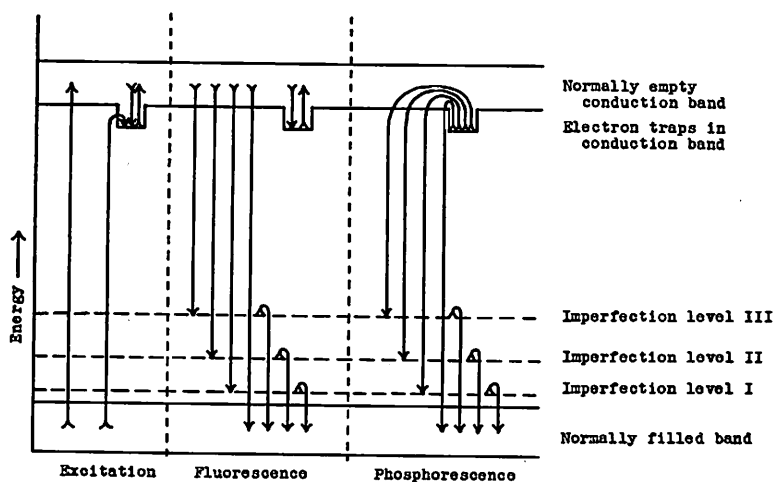


FIG. 1.—Schematic diagram of electron energy changes in a phosphor during excitation, fluorescence, and phosphorescence.

Other types of phosphors have levels II and I, level II being due to a minor amount of a contaminating element, or excess of one component. In such crystals the light emitted may be, say, green. If the impurity is present in a very small amount, the colour emitted may be a mixture of blue (level I) and green (level II). If another impurity is incorporated into the crystal structure, a new level III may be formed, which allows, say, red emission. Thus a phosphor could be prepared such that the emission colour is blue, green, red, blue-green, purple (blue plus red), yellow (green plus red), or white (blue plus green plus red). The emission colour will depend upon

the ratio of the trapping effect of level II to level III, and on the ratio of the trapping effect of levels II plus III to level I.

The crystalline compounds in which electron energy changes may go with accompanying light emission are called phosphor *bases*. A good example of a phosphor base is zinc orthosilicate, crystallized in the rhombohedral class of the hexagonal system. Prepared synthetically it is identical to the mineral *willemite*. When precautions are taken to prepare willemite in very pure form, it is found to have a pale blue fluorescence with ultra-violet and electron excitation. When a trace of manganese is present in solid solution in the willemite crystals, the emission is bright yellowish green. As the manganese content is increased, the yellowish green emission displaces all the blue emission, and the optimum manganese content for highest conversion of the exciting energy into visible light is approximately 1 per cent replacement of the zinc atoms by divalent manganese atoms. Other well-known phosphor bases are zinc sulfide (sphalerite and wurtzite), calcium sulfide, calcium tungstate (scheelite), magnesium tungstate, zinc orthophosphate, zinc aluminate (gahnite), zinc sulphate, and calcium silicates. From the results of several exploratory searches for new phosphors by the author, it would appear that any crystalline compound with a bond type between ionic and homopolar can be considered to be a phosphor base. A phosphor base is defined by its composition and also its crystal structure. For instance, zinc orthosilicate ($2\text{ZnO} \cdot \text{SiO}_2$) can be prepared in three modifications: α (willemite), β , and γ . The β form is hexagonal, but in a different class than willemite, and the γ form has a platy habit. Each of the crystal modifications is a distinct phosphor base with different fluorescent characteristics.

The crystal imperfections responsible for the energy levels between the conduction band and the lower, normally filled, band, which act as agents in the conversion of excess electron energy into visible light, are of several types. In a phosphor base AB where A and B are elements, impurity levels may be established in the following ways: (1) excess A in the compound, (2) excess B in the compound, (3) replacement of a trace of C for A, (4) replacement

of a trace of D for B, (5) combinations of (1) or (2) and (3) and (4), (6) frozen Schottky defects,¹ (7) frozen Frenkel defects.²

The commonest method of providing a phosphor base with a crystal defect is to synthesize it with a very small amount of a distinctly different element replacing one of the essential elements of the base. In the case of willemite, manganese is made to replace zinc. Many elements can be used, each providing different impurity levels, but usually only one or two are useful. Such elements added to a phosphor base to confer special fluorescent properties are known as *activators*. The choice of activators for any one phosphor base is controlled by the efficiency of energy transformation when the optimum amount of activator is present and the emission colour. In special cases phosphors are made to contain two or more activators to provide a broad emission band. There appears to be no available method of predicting either the conversion efficiency of any activator-base pair or the emission colour. New phosphors are developed by observing the effect of different amounts of various activators in any given base. The following table shows some of the activators known to be effective in the limited number of phosphor systems that have been studied.

TABLE 1

VALENCY OF ATOM IN BASE	POSSIBLE ACTIVATORS
1	Cu, Ag, Au, Mn, Pb, Tl, U
2	Cu, Ag, Au, Mn, Pb, Ni, Sb, Bi, V, R.E., U
3	Mn, Cr, Ni, Bi, V, Ce, R.E., U
4	Mn, Ce, Ti, Sn, Th, Hf, Mo, W, U

The fluorescent colour of any one activator-base pair can be altered by simply replacing one of the essential components of the

¹Defects of the Schottky type are holes in the structure, equally distributed between A and B positions in the above example, which are developed in significant amount as a crystal is heated to a temperature approaching its melting point. If cooling is rapid some of such defects may be preserved and the consequent distortion of the electronic structure near the holes provides centres of electron trapping at higher levels than the ground state.

²Defects of the Frenkel type are holes in the structure due to ions which have moved into interstitial positions at an elevated temperature and which may be preserved in such metastable condition by rapid cooling.

base with a substantial amount of a similar atom, so that the unit cell of the modified phosphor crystal is larger or smaller than the original. Thus if manganese-activated willemite crystals are prepared containing say a 15 per cent replacement of beryllium for zinc, the emission colour is yellow. The shifting of the emission colour in this way is proportional to the amount of replacement. Elements added to a phosphor to shift the emission colour by this means are called *modifiers*. The choice of modifiers is considerably more restricted than the choice of activators, and usually only one, two, or three modifiers can be used. The limits of solid solution determine the limits of substitution of a modifier element.

Certain elements present in solid solution in phosphors have the property of trapping the excited electrons falling back to the ground state but the energy released is, for the most part, in the form of heat motion instead of visible radiation. Such elements are termed fluorescent *poisons*. In the preparation of phosphors, such poisons must be eliminated very carefully. In general the purification of phosphor components is carried beyond the limits of spectrographic detection. Iron is a poison for several phosphors and must be kept in as small an amount as possible. In addition, the presence of an activator in an amount considerably more than the optimum is often found to very greatly decrease the fluorescent efficiency. Thus activator elements present above a certain amount function as poisons.

Phosphors, which exhibit phosphorescence at, say, room temperature, when excited at an elevated temperature, have no phosphorescence. Also, when very cold, the rate of decrease of the brightness of phosphorescence is slower than at room temperature. This is believed to represent the dependence of the rate of dislodgement of excited electrons in traps on the temperature: the higher the temperature, the more rapidly are the trapped electrons released by thermal agitation, and *vice versa*. The rate of decrease of the phosphorescence brightness, otherwise known as the *decay rate*, is often of a composite nature. Immediately after the cessation of the exciting energy, the free electrons fall back to the ground state. This takes a very short time, in the order of 10^{-6} seconds. This very rapid fall in brightness is followed by a slower decay rate thought to represent the falling of a large proportion of the trapped electrons

to the ground state. This merges into and is followed by an even slower decay rate which is thought to represent the falling of the trapped electrons to the ground state whenever an available hole in that band approaches near enough for the transfer to take place. Mathematical analyses of the slow decay rates of this type show that the brightness of the first part of the phosphorescence is what would be expected from a monomolecular reaction, and that of the second part, from a bimolecular reaction. That is, in the first part of the phosphorescence, the rate of falling of the trapped electrons is a function of the number trapped and the temperature, but in the last part of the phosphorescence, the rate of falling of the trapped electrons is a function of the number of trapped electrons, the number of available positions in which to fall, and the temperature. The decay rate can be accelerated in some cases by irradiating the excited phosphor with infra-red rays of definite wave-length. The absorption of the infra-red rays apparently is sufficient to increase the rate of dislodgment of the trapped electrons, thus increasing the decay rate of the phosphorescence.

FLUORESCENT SYSTEMS

Two of the most important and useful fluorescent systems are the zinc sulphide and zinc silicate systems. The importance of each system is that fluorescent colours can be obtained from one end of the spectrum to the other, along with an efficient conversion of the exciting source to visible light.

The base compounds of the sulphide system are sphalerite and wurtzite. These are prepared synthetically by heating precipitated zinc sulphide to a high temperature. The fluorescent and phosphorescent properties of the two forms of zinc sulfide are similar and they can be discussed as if they were composed of sphalerite alone. Synthetic sphalerite prepared by heating pure precipitated zinc sulphide to say 1000°C for one hour in the presence of fluxes such as sodium chloride has a bright light blue fluorescence and phosphorescence with electron or ultra-violet excitation. When the precipitated zinc sulphide before firing is made to contain about 0.01 atomic per cent replacement of copper for zinc, the fluorescence and phosphorescence is very bright yellowish green. If the fluorescence of synthetic sphalerite prepared with amounts of copper from zero

up to 0.01 atomic per cent is examined by means of a spectroscope, it is seen that the light blue peak of fluorescence decreases in intensity along with a gradual rise in the intensity of the yellowish-green peak due to the copper. By substituting silver for copper in a similar series, a new peak in the blue-violet appears and takes the place of the blue peak of the unactivated zinc sulphide. If the activator is gold a new peak rises in the blue-green region, and if the activator is manganese there is a sharp peak in the yellow region. In a similar way the fluorescence of zinc sulphide activated with both silver and copper depends upon the ratio of the two elements and also upon the ratio of the copper plus the silver to the zinc. In addition to the variation in emission colour due to the type and amount of activator, variations are obtained by the use of two kinds of modifiers. One is substitution of cadmium for zinc. The peak of the fluorescent colour is thereby shifted progressively toward the red end of the spectrum, and colours from bluish violet to very deep red can be obtained. In addition, the sulphur in the sphalerite crystals may be progressively replaced by selenium and such replacement also shifts the peak of the emission colour toward the red end of the spectrum. Crystals of sphalerite containing zinc, cadmium, sulphur, and selenium with a variety of emission colours are on the market. The duration and intensity of the phosphorescence in the zinc sulphide series of fluorescent compounds are functions of the type of activator and the amount of cadmium and selenium replacement for zinc and sulphur, and applications exist for phosphors with a specified emission colour and a specified decay rate of phosphorescence. Mixture of sulphide phosphors with different emission colours can be devised such that the resultant light to the eye appears white. The emission colour is spread in each case far enough from the peak wave-length so that a mixture of two, such as yellow and blue, appears to be a good white colour to the eye. Sometimes violet-blue is mixed with orange, and the resultant purplish white is corrected by a small addition of phosphor with a yellowish green emission.

The other important fluorescent system is the willemite system. Pure synthetic willemite may be prepared by firing an intimate mixture of zinc oxide and silica at a high temperature until the two components have combined to form small crystals of willemite.

The fluorescence of such willemite is pale blue. If the willemite is prepared such that it contains about a 1 per cent atomic replacement of manganese for zinc, the fluorescence is bright yellowish green. Manganese appears to be the only element which functions as activator in willemite to any marked degree. However, the peak of the emission colour can be moved toward the red end of the spectrum by progressive substitution of beryllium for zinc and cadmium for zinc, or both. Another method of shifting the colour is to heat-treat the willemite suitably so that metastable modifications are preserved at room temperature. The stable modification (α zinc orthosilicate or willemite) has a green emission, the first unstable form (β zinc orthosilicate) has a canary yellow fluorescence, and the second unstable modification (γ zinc orthosilicate) has an orange fluorescence, when the activator is manganese. By starting with a variety of willemite containing some substitution of beryllium for zinc, fluorescent colours from yellowish green to red may be obtained by choosing α , β , or γ phase. Thus by choosing a composition and a phase one can select an emission colour between green and red. The pale blue fluorescence of unactivated willemite is not very bright so that it is not possible to obtain a good white fluorescent colour by mixing varieties of willemite but it is the practice in certain applications to mix zinc sulphide having a blue fluorescence with zinc silicate having a yellow fluorescence in order to obtain a resultant white fluorescence.

FLUORESCENT MINERALS

There are a great number of fluorescent minerals recorded in the literature. The excitation methods include: (1) short wave-length ultra-violet rays, (2) long wave-length ultra-violet rays, (3) visible light, (4) x -rays, (5) gas discharge, (6) cathode rays, (7) canal rays, (8) electron beam, (9) thermal changes, (10) mechanical distortion.

Some contradictions of data exist because of non-equivalent excitation. For instance, a description of an ultra-violet source should include a statement of the wave-length distribution of the radiant energy. However, even with the excitation constant, the fluorescence and phosphorescence of a mineral vary considerably according to the deposit from which it was obtained, its position in the deposit, and the zones within any one crystal. As mentioned

above, it is conceivable that all the transparent minerals are possible phosphor bases, so that any such mineral would be fluorescent provided that all three of the following requirements are met simultaneously: (1) presence of elements in solid solution which function as activators, (2) amounts of the activators close to the optimum for highest efficiency of fluorescence, and (3) absence of appreciable amounts of elements in solid solution which function as poisons.

It will be evident that such an order of coincidence will be rarely attained, especially since iron is both ubiquitous and a poison for fluorescence. Any one mineral may have many fluorescent colours corresponding to all the possible activators, or fluorescent colours which are the complementary effects of several activators. The activators may be determined by noting an association between the spectrographic record and the fluorescent colour of a number of different samples of the mineral. It is suggested that a systematic study of fluorescence in minerals should include the following data: (1) fluorescent and phosphorescent effects, (a) with ultra-violet excitation, (b) with cathode ray excitation; (2) spectrographic analyses, (a) of fluorescent varieties, (b) of non-fluorescent varieties; (3) determination of (a) activators, (b) modifiers, (c) poisons; (4) syntheses, (a) testing effect of the activators, (b) testing effect of the modifiers, (c) testing effect of the poisons.

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HEDLEYITE, A NEW BISMUTH TELLURIDE FROM BRITISH COLUMBIA, WITH NOTES ON WEHRLITE AND SOME BISMUTH-TELLURIUM ALLOYS

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and

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THE mineral described in this paper is a foliated bismuth telluride, resembling joseite, which was first noted on two small specimens showing visible gold, from the Good Hope mineral claim, about four miles south-east of the town of Hedley, Osoyoos mining division, B.C. These two specimens were received by one of us (H.V.W.) from Mr. W. R. Wheeler in the spring of 1943, about the time when gold was found on the Good Hope claim. Later in the year Mr. Wheeler kindly furnished further specimens of the telluride; these, together with a sample contributed by Dr. W. E. Cockfield, provided the material for the present work.

A preliminary study of the bismuth telluride was made in Vancouver with the assistance of Mr. R. M. Thompson, who made the many specific gravity measurements needed to prepare material for analysis, and Mr. G. S. Eldridge, who kindly undertook the analyses. The mineral was further examined in Toronto with the assistance of Dr. E. W. Nuffield, who determined the specific gravity and etch-reactions of typical material. When the work in Toronto finally showed that the mineral cannot be properly identified with any described bismuth telluride, we named it hedleyite after the mining town near which it was found.

OCCURRENCE AND GENERAL DESCRIPTION

(H.V.W.)

The geology and ore deposits of the Hedley district (Osoyoos mining division) have been described and mapped by Camsell (1910), Bostock (1930), Bostock & McNaughton (1940), and others. Dr. V. Dolmage, now in charge of development on the Good Hope claim, kindly furnished further geological information. From these sources it may be briefly stated that the region is occupied by inclined sedimentary rocks of Triassic age, intruded by granitic bodies of

late Mesozoic or Tertiary age. At the Good Hope claim the country rock is a skarn composed mainly of garnet, epidote, and pyroxene cut by irregular veins and stringers of quartz. Most of the hedleyite samples were obtained from these quartz bodies, but the mineral was also noted in the skarn. Some of the best samples were got by panning disintegrated rock in the vicinity of the mineral showing.

Hedleyite is associated with native bismuth, joseite, pyrrhotite, arsenopyrite, calcite, and gold. Bismuth is conspicuous in some samples but joseite cannot be distinguished from hedleyite by inspection. Pyrrhotite and arsenopyrite in small amounts occur in the skarn near the quartz veins. Calcite is sporadically scattered through the veins and stringers. Visible gold occurs close to the bismuth minerals, sometimes as films in the foliated tellurides. The ore minerals are notably poor in sulphur and thus it is evident that the mineralizing solution was deficient in sulphur. The presence of occasional quartz crystals projecting into cavities in the gangue indicate that the temperature of mineralization was low to moderate.

The presence of two bismuth tellurides on the material from Hedley was first suggested by the large variation shown by specific gravity measurements. A few plates gave 8.1, a normal value for joseite (Peacock, 1941, p. 87); but many others gave much higher and somewhat variable values, for example 8.68—8.89 (on 8 plates), 8.76—8.93 (on another 8 plates), measured on the Berman balance.

To obtain samples of the heavy telluride for analysis clean flakes were broken from the hand specimens or selected from pan concentrates. These were trimmed and cleaved if necessary to a weight of about 50 mg. The specific gravity of each flake was then determined and the flake was retained if it came within the range of the higher specific gravities. In this process a black film was frequently revealed in the cleavage planes. This was considered to be an alteration product since it appeared mainly in material obtained by panning disintegrated rock. Much of the mineral obtained directly from the veins appeared to be free from this film.

Two samples of the heavy bismuth telluride were analysed by Mr. G. S. Eldridge, with the results shown under 1 and 2. A spectrographic analysis of the material represented by analysis 1 gave the additional approximate percentages: Sb 0.05, Pb 0.01, Cu 0.01.

The simple rational formula which best fits the analyses is Bi_5Te_2 which has the calculated composition under A.

	1	2	A
Bi.....	80.60	81.55	80.4
Te.....	18.52	17.60	19.6
S.....	0.12	0.04	....
	<u>99.24</u>	<u>99.19</u>	<u>100.0</u>

Joseite from Glacier Gulch, B.C., has the composition Bi_4TeS_2 (Warren & Davis, 1940; Peacock, 1941), and thus hedleyite might be considered to be a sulphur-free joseite, related to joseite somewhat as tellurbismuth (Bi_2Te_3) is to tetradyrite ($\text{Bi}_2\text{Te}_2\text{S}$). However, the x-ray work described in the following pages does not support this idea; it appears rather that hedleyite is a bismuth-tellurium alloy whose composition may vary and cannot, therefore, be properly expressed by a simple rational formula.

FURTHER OBSERVATIONS

(M.A.P.)

HEDLEYITE

The material received for study consisted of several clean plates of the new mineral, up to 6 mm. wide and 1 mm. thick, showing no straight edges or bevelling planes. These plates have the usual tin-white colour and heavy metallic lustre of bismuth tellurides and easy cleavage parallel to the plane of the plates. A single plate is readily separated into thin, somewhat flexible leaves by means of a fine needle, giving cleavage surfaces which are always more or less warped and frequently filmed with an iron black tarnish. The hardness is 2, and the specific gravity is 8.91 (Nuffield).

In a polished section of the largest plate, cut nearly parallel to the plate surface, the white colour in reflected light is between that of silver and that of galena. The anisotropism is slight (light grey to dark grey). The hardness is B (galena), and the reactions to the standard etch-reagents are as follows: HNO_3 , effervesces vigorously and quickly turns grey; the fumes give a brown iridescent tarnish. HCl , negative. KCN , negative. FeCl_3 , stains brown, in places iridescent. KOH , negative. HgCl_2 , negative. As compared to other bismuth tellurides hedleyite is clearly distinguished by only

one of its physical properties, namely the specific gravity which is substantially higher than that of any of the species in question.

X-ray powder photographs of hedleyite gave a rather simple pattern (Fig. 4) which resembles the patterns of josite (Peacock, 1941) and first suggested that hedleyite is a sulphur-free josite. However, an attempt to index the pattern with reference to a josite lattice did not succeed. On the other hand, it was found that all the lines, except two weak ones, correspond to a rhombohedral lattice with the dimensions:¹

$$a_{\text{hex}} = 4.46 \text{ \AA}, c = 5.94 \text{ \AA}; a_{\text{rh}} = 3.248 \text{ \AA}, \alpha = 86^\circ 42\frac{1}{2}'$$

Table 1 gives the observed powder intensities, glancing angles, measured spacings, hexagonal and rhombohedral indices, and calculated spacings.

TABLE 1
HEDLEYITE: X-RAY POWDER SPECTRUM
Hexagonal, *R*

$$a_{\text{hex}} = 4.46 \text{ \AA}, c = 5.94 \text{ \AA}; a_{\text{rh}} = 3.248 \text{ \AA}, \alpha = 86^\circ 42\frac{1}{2}'$$

<i>l</i>	$\vartheta(\text{Cu})$	<i>d</i> (mcas.)	(<i>hkl</i>) (<i>hkl</i>)	<i>d</i> (calc.)
1	10.1°	4.38 Å	.....
$\frac{1}{2}$	12.3 β	3.26 } 3.25 }	(10 $\bar{1}$) (100)	3.238 Å
10	13.7 α			
5	19.0	2.36	(01 $\bar{1}$ 2) (110)	2.354
4	20.15	2.23	(11 $\bar{2}$ 0) (10 $\bar{1}$)	2.230
1	21.4	2.11	.....
3	22.8	1.984	(0003) (111)	1.980
3	24.7	1.840	(02 $\bar{2}$ 1) (11 $\bar{1}$)	1.836
4	28.3	1.621	(20 $\bar{2}$ 2) (200)	1.619
4	31.3	1.480	(11 $\bar{2}$ 3) (210)	1.481
3	32.8	1.419	(21 $\bar{3}$ 1) (20 $\bar{1}$)	1.418
2	33.6	1.389	(10 $\bar{1}$ 4) (211)	1.386
2	36.0	1.308	(12 $\bar{3}$ 2) (21 $\bar{1}$)	1.310
1	36.65	1.288	(30 $\bar{3}$ 0) (2 $\bar{1}$ 1)	1.287

To explain the two lines which are not referable to the above rhombohedral lattice, basal diffractions were recorded by prolonged zero-Weissenberg resolutions on small practically plane cleavage plates rotated about random axes in the cleavage plane.

¹All the conjugate hexagonal and rhombohedral cell dimensions given in this paper rest on measured dimensions of the hexagonal cells, from which the rhombohedral dimensions have been calculated and checked by verifying the fact that the rhombohedral cell volume is one-third of the hexagonal cell volume.

The result was a complicated series of spots indicating a hexagonal superlattice with $c' = 20c/3 = 39.60 \text{ \AA}$, or a rhombohedral superlattice with $c'' = 20c = 118.8 \text{ \AA}$. Assuming that these superlattices have the same value of a_{hex} as the principal lattice, the alternative superlattice elements are:

$$a_{\text{hex}} = 4.46 \text{ \AA}, c' = 39.60 \text{ \AA};$$

$$a_{\text{hex}} = 4.46 \text{ \AA}, c'' = 118.8 \text{ \AA}; a_{\text{rh}} = 39.68 \text{ \AA}, \alpha = 6^\circ 26\frac{1}{2}'$$

The two extra lines in the powder spectrum can then be indexed as follows:

<i>I</i>	$\vartheta(\text{Cu})$	<i>d</i> (meas.)	$(hkl)c'$	$(hkl)c''$	<i>d</i> (calc.)
1	10.1°	4.38 Å	(0009)	(0.0.0.27) (999)	4.400 Å
1	21.4	2.11	(11 $\bar{2}$ 6)	(1.1. $\bar{2}$.18) (765)	2.113

The volumes of the alternative superlattice cells are both twenty times the volume of the small rhombohedral cell. There is nothing to determine a choice between the two superlattices, and therefore we may arbitrarily choose the rhombohedral cell corresponding to c'' to account for all the observed diffractions.

Using the measured specific gravity 8.91 the molecular weights of the two rhombohedral cell contents are 184.2 and 3684 respectively. With these values the two analyses of hedleyite give the following atomic cell contents:

	Anal. 1	Atoms in		Anal. 2	Atoms in	
		small cell	large cell		small cell	large cell
Bi.....	80.60	0.716	14.32	81.55	0.725	14.49
Te.....	18.52	0.270	5.39	17.60	0.257	5.13
S.....	0.12	0.008	0.15	0.04	0.003	0.05
	99.24	0.994	19.86	99.19	0.985	19.67

The two cells contain nearly 1 atom and 20 atoms, respectively; and in view of the alloy-character of the mineral we need not expect integral numbers of atoms of Bi and Te in the larger cell. The empirical content of the larger cell is roughly $\text{Bi}_{14}\text{Te}_6$, which gives the calculated specific gravity 8.93, in good agreement with the measured value 8.91. If the composition of the mineral is to be expressed by a rational formula, Bi_7Te_3 (79.3 per cent Bi) is pre-

ferable to Bi_5Te_2 even though the analyses come closer to the latter formula.

Comparing hedleyite and joseite, which has a rhombohedral unit cell containing 7 atoms— Bi_4TeS_2 , or more generally $\text{Bi}_{4+x}(\text{Te}, \text{S})_{3-x}$ (Peacock, 1941)—we note a similarity in the hexagonal lattice dimensions:

Hedleyite:	$a_{\text{hex}} = 4.46 \text{ \AA}$,	$c'' = 3(39.60) \text{ \AA}$
Joseite:	$a_{\text{hex}} = 4.24$	$c = 39.69$
	4.33	40.75

However, if hedleyite has the character of a 3-storey joseite structure, the larger cell of hedleyite would contain 21 atoms, not 20. For this reason, and the fact that S is an essential constituent of joseite, amounting to 1 or 2 atoms in the 7-atom cell, hedleyite does not appear to be a variety of joseite.

This leaves one described bismuth telluride to which we might compare hedleyite, namely the mineral from Deutsch-Pilsen, Hungary, called wehrlite. Although we have not been able to obtain a specimen of this mineral either in Canada or the United States, a consideration of its described properties permits some useful conclusions regarding its character and its relation to hedleyite.

WEHRLITE

A bismuth telluride was known from Deutsch-Pilsen, Hungary, already in the eighteenth century. Originally supposed to be a compound of silver and molybdenum (*argent molybdique* de Born) the mineral was soon found to be a compound of bismuth (*Wismuthglanz* Klaproth). The approximate quantitative composition of the mineral was first established by an incomplete analysis by Wehrle in 1831 (Table 3), and the mineral was therefore named wehrlite²

²The name wehrlite has fallen into some confusion. It was originally given by von Kobell in 1838 to a silicate which was soon identified with ilvaite, or a mixture, and subsequently the name was used to denote an ultrabasic rock-type. In spite of the recommendation of the Committee on British Petrographic Nomenclature (1921) that wehrlite be dropped as an unnecessary petrological term *Mineralogical Abstracts*, vols. 1-8 (1920-1943), show that wehrlite continues to be used both as a rock-name and as the name of the Hungarian ore mineral. One is tempted to recommend the revival of Kenngott's *pilsenite* for the ore mineral; but since pilsenite has long been dismissed as a synonym of wehrlite it will be more practical to urge again that wehrlite be restricted to the bismuth telluride from Deutsch-Pilsen.

by Huot in 1841. Later Sipöcz (1885) added two analyses the first of which was made on excellent material. These analyses suggest that more than one species of bismuth telluride occur at Deutsch-Pilsen, as is the case in other localities. Analysis 2, made on excellent material, seems to be the most reliable, and it may best represent the original silver-bearing mineral.

TABLE 2
WEHRLITE FROM DEUTSCH-PILSEN: ANALYSES

	1	2	3
Ag.....	2.07	4.37	0.48
Bi.....	61.15	59.47	70.02
Te.....	29.74	35.47	28.52
S.....	2.33	.....	1.33
	<u>95.29</u>	<u>99.31</u>	<u>100.35</u>

1. Anal. Wehrle (1831, in Dana, 1892, p. 41); sp. grav. 8.44.

2. Anal. Sipöcz (1885), on very clean, thin, broad, flexible and elastic plates, with hardness 2, sp. grav. 8.368 (mean of three pykometric measurements), from a collection in Budapest. Composition, AgBi_7Te_7 .

3. Anal. Sipöcz (1885), on scanty material from a collection in Vienna. Composition Bi_7Te_8 , excluding Ag_2S and Bi_2S_3 as assumed impurities.

A valuable addition to the knowledge of wehrlite is the *x*-ray powder pattern obtained by Harcourt (1942, p. 103) on a specimen from Deutsch-Pilsen, the type locality.³ Harcourt's observed spacings and intensities for wehrlite resemble our observed data for hedleyite and consequently the wehrlite pattern leads to rhombohedral elements similar to those of the smaller cell of hedleyite, namely:

$$a_{\text{hex}} = 4.42 \text{ \AA}, c = 5.97 \text{ \AA}; a_{\text{rh}} = 3.236 \text{ \AA}, \alpha = 86^\circ 08\frac{1}{2}'$$

Table 3 gives the observed spacings and those calculated from the above elements. The agreement is unusually good, and the two

³Dr. G. A. Harcourt (Copper Cliff, Ontario) has kindly sent us further details of his observations on this mineral. The *x*-ray sample was taken from a thin sheet of the specimen, and all the powder lines beyond $d = 1.140 \text{ \AA}$ were very weak. A semi-quantitative spectrographic analysis was made on a sample from the polished section of the same material. Only Bi, Ag, Te, were noted, with intensities 12, 10, 1, respectively. This shows that the mineral contained a substantial amount of Ag, in keeping with analysis 2 in Table 2, which we considered to be the most reliable.

very faint lines which cannot be indexed can perhaps be neglected as extraneous.

Assuming that Harcourt's pattern corresponds to the specific gravity and preferred analysis by Sipöcz, the cell content of wehrlite is Ag 0.07, Bi 0.49, Te 0.48 = 1.04 atoms, or roughly one atom in the unit cell. Conversely the specific gravity of wehrlite calculated from the analysis and a cell containing one atom, is 8.05, in rather poor agreement with the measured value 8.368. However, a cell containing $\frac{1}{2}[\text{BiTe}]$ has the calculated specific gravity 8.245 and silver has the specific gravity 10.50. Assuming that Ag is present in wehrlite as uncombined silver, and using the empirical formula AgBi_7Te_7 appropriate to the analysis, the calculated specific gravity is $14(8.245)/15 + (10.50)/15 = 8.40$, which agrees well with the

TABLE 3
WEHRLITE: X-RAY POWDER SPECTRUM
Hexagonal, *R*

<i>l</i>	$\vartheta(\text{Cu})$	<i>d</i> (meas.)	(<i>hkl</i>) (<i>hkl</i>)	<i>d</i> (calc.)
	$a_{\text{hex}} = 4.42 \text{ \AA}, c = 5.97 \text{ \AA}; a_{\text{rh}} = 3.236 \text{ \AA}, \alpha = 86^\circ 08\frac{1}{2}'$			
6.0	13.8°	3.22 Å	(10 $\bar{1}$ 1) (100)	3.222 Å
3.0	19.1	2.35	(01 $\bar{1}$ 2) (110)	2.354
3.0	20.35	2.21	(11 $\bar{2}$ 0) (101)	2.210
1.0	22.7	1.99	(0003) (111)	1.990
1.0	25.0	1.82	(02 $\bar{2}$ 1) (11 $\bar{1}$)	1.823
1.0	28.5	1.61	(20 $\bar{2}$ 2) (200)	1.611
1.0	31.35	1.478	(11 $\bar{2}$ 3) (210)	1.479
1.0	33.3	1.40	{ (21 $\bar{3}$ 1) (20 $\bar{1}$)	1.406
			{ (10 $\bar{1}$ 4) (211)	1.391
0.5	36.2	1.302	(12 $\bar{3}$ 2) (21 $\bar{1}$)	1.302
0.3	37.05	1.275	(30 $\bar{3}$ 0) (21 $\bar{1}$)	1.276
0.3	40.65	1.180	(02 $\bar{2}$ 4) (220)	1.177
0.3	42.4	1.140	(01 $\bar{1}$ 5) (221)	1.140
0.2	44.1	1.105	(22 $\bar{4}$ 0) (20 $\bar{2}$)	1.105
0.2	45.25	1.082	.....	.....
0.2	45.65	1.075	(30 $\bar{3}$ 3) (300)	1.074
0.2	47.65	1.040	(21 $\bar{3}$ 4) (310)	1.039
0.2	50.4	0.998	{ (3142) (301)	1.000
			{ (0006) (222)	0.995
0.2	51.45	0.983	.....	.....
0.2	54.7	0.942	(4041) (31 $\bar{1}$)	0.945
0.2	56.5	0.922	(12 $\bar{3}$ 5) (320)	0.921

measured value. Ag may therefore be present in wehrlite as uncombined silver, and wehrlite may then have substantially the composition BiTe.

From the foregoing it is clear that there is an underlying structural similarity between hedleyite and wehrlite. However, the two minerals differ so greatly in composition and specific gravity (hedleyite, Bi_7Te_3 , $G = 8.9$; wehrlite, BiTe , $G = 8.4$) that they cannot be usefully referred to a single name. As shown in the next section some consideration of the artificial system Bi-Te, and the preparation and examination of several alloys in the appropriate range, also tend to support the decision to distinguish these minerals by separate names.

SYNTHESES

The results of studies of the bismuth-tellurium system are summarized in Hansen (1936, p. 339) and represented in his phase diagram (Fig. 1), in which we are concerned only with the region extending from Bi to Bi_2Te_3 . The previous workers are agreed that there is only one compound in this system, namely Bi_2Te_3 (52.2 per cent Bi by weight), which corresponds to the now well-

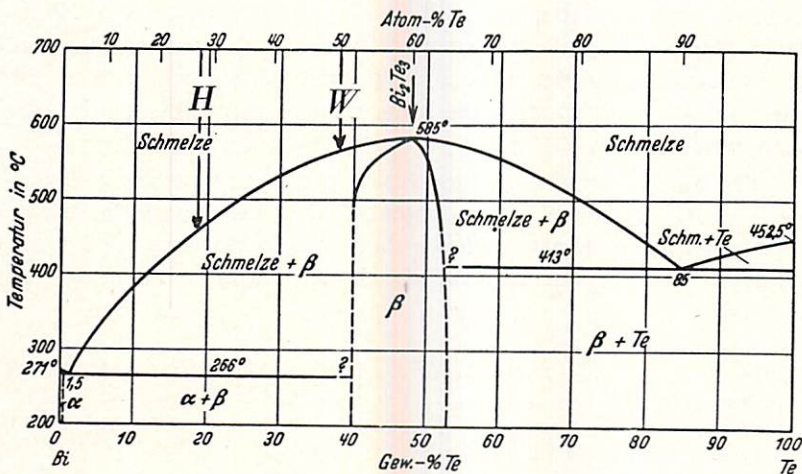


FIG. 1.—Bismuth-tellurium system: phase diagram from Hansen (1936, p. 340, fig. 160), showing the relations of hedleyite (*H*), wehrlite (*W*), and telluribismuth (Bi_2Te_3).

known mineral tellurbismuth (Warren, 1940, p. 109; Peacock & Berry, 1940, p. 67; Frondel, 1940). This compound takes Bi or Te into solid solution giving the β -phase with the approximate range, 60-47 per cent Bi. Bismuth will hold only about 1 per cent Te in solid solution (α -phase), and thus stable alloys with 99 to 60 per cent Bi are mixtures of the α - and β -phases. X-ray powder photographs were made of some of the Bi-Te alloys by Körber & Haschimoto (1930), but these were used only in a qualitative way.

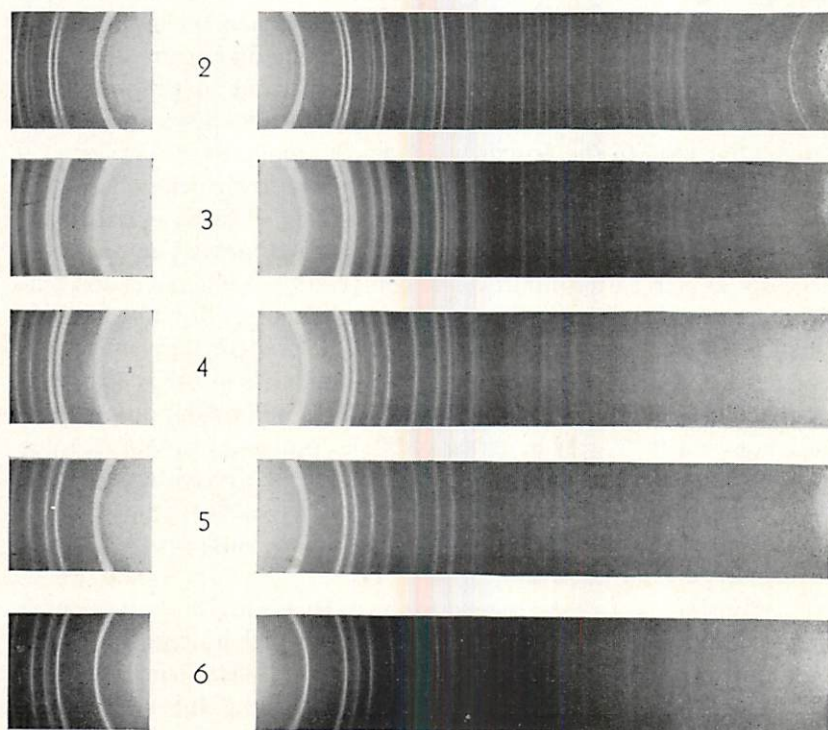
From the foregoing it seemed unlikely that hedleyite could be reproduced by fusing the elements. However, the attempt was made by fusing a charge of 1 gm. of powdered Bi and Te with the same composition as the mineral (81.2 per cent Bi) in an evacuated pyrex tube, and cooling in air. A polished section of the product showed white moderately anisotropic crystal plates in a ground that rapidly took on the familiar brown tarnish of bismuth and showed minute inclusions of the white platy crystals. According to the phase diagram this intergrowth consists of crystals of the β -phase at the limiting Bi-content (60 per cent) in a eutectic of the α -phase (99 per cent Bi) and the β -phase. The x-ray powder photograph (Fig. 3) showed a pattern which has the appearance of the hedleyite pattern (Fig. 4) with some of the hedleyite lines replaced by doublets. A plate of hedleyite was then fused and allowed to crystallize in an evacuated pyrex tube. The powder photograph showed the same double pattern with the same relative intensities of the two components.

The double pattern of these fusion products was completely indexed with reference to two rhombohedral lattices (α -phase and β -phase) which compare with the rhombohedral lattices of bismuth, hedleyite, and tellurbismuth, as shown below with hexagonal elements:

	a_{hex}	c
*Bismuth.....	4.55 Å	2(5.925) Å
α -phase in fused hedleyite.....	4.52	2(5.90)
Hedleyite.....	4.46	20(5.94)
β -phase in fused hedleyite.....	4.42	5.93
*Tellurbismuth.....	4.375	5(6.08)

**Strukturbericht*, vol. 1, p. 58.

*Peacock, in Peacock & Berry (1940, p. 67).



FIGS. 2-6.—Bismuth-tellurium alloys: x -ray powder photographs with Cu-radiation (Ni-filter); camera radius $90/\pi$ mm. (1 mm. on film = $1^\circ\vartheta$); full-size reproductions of contact prints.

FIG. 2.—Pure bismuth; α -phase.

FIG. 3.—Bi 81.2-Te 18.8 wt. per cent; two-phase alloy showing the patterns of the α -phase (Bi) and the β -phase (Bi_2Te_3 , Bi). Fused hedleyite gives the same double pattern.

FIG. 4.—Hedleyite; essentially an unstable single phase with the same composition as the above. Only one faint line ($\vartheta = 21.4^\circ$) from the superstructure is visible in the print.

FIG. 5.—Bi 62.1-Te 37.9 (Bi : Te = 1 : 1); β -phase (Bi_2Te_3 , Bi). Wehrlite gives the same pattern.

FIG. 6.—Bi 52.2-Te 47.8 (compound Bi_2Te_3). Tellurbismuth gives the same pattern.

In keeping with the slight solid solubility of Te in Bi the lattice of the α -phase in fused hedleyite is a slightly contracted Bi-lattice. Owing to the greater solid solubility of Bi in Bi_2Te_3 the lattice of the β -phase shows more distortion as compared to the lattice of Bi_2Te_3 ; furthermore it is relatively simple since it shows none of the lines that require the $5c$ -axis which is characteristic of Bi_2Te_3 .

From these results, which are in agreement with the phase diagram of the Bi-Te system, it is clear that hedleyite is essentially an unstable solid solution of Bi in Bi_2Te_3 with Bi greatly in excess of the stable saturation limit. The composition of the analysed material may therefore be expressed approximately by the formula $\text{Bi}_2\text{Te}_3.\text{Bi}_5$; but the name hedleyite will be properly applied to any bismuth telluride, free from significant amounts of other elements, particularly sulphur, which is essentially a solid solution of Bi in Bi_2Te_3 with Bi largely in excess of 60 per cent by weight. At some undetermined composition between that of hedleyite and bismuth we may expect natural alloys which will give the Bi-pattern (α -phase); these would be properly regarded as varieties of bismuth and named tellurian bismuth.

Wehrlite, as we have seen, appears to be essentially an alloy with the composition BiTe (62.1 per cent Bi) which is practically the Bi-limit of the β -phase in the artificial system. It seemed possible, therefore, that the mineral might be reproduced by fusion of the elements, and an alloy of this composition was accordingly prepared. It proved to be a nearly homogeneous aggregate of warped crystal plates (β -phase) with sparse inclusions of a tarnished phase (α -phase). The x -ray powder photograph (Fig. 5) gave a simple pattern which agrees exactly with Harcourt's pattern for wehrlite, except for the absence of the two very faint lines which could not be indexed in Harcourt's pattern. The pattern of the alloy was fully indexed with reference to a rhombohedral lattice whose hexagonal dimensions compare with those of wehrlite and tellurbismuth as shown below:

	a_{hex}	c
Wehrlite.....	4.42 Å	5.97 Å
β -phase in Bi : Te = 1 : 1.....	4.42	5.99
Tellurbismuth.....	4.375	5(6.08)

The structural identity of wehrlite and the alloy Bi : Te = 1 : 1

confirms the essential composition of the mineral and shows that it is a solid solution of Bi in Bi_2Te_3 corresponding to the β -phase at about the Bi-limit in the artificial system. This can be expressed by writing the composition of wehrlite as $\text{Bi}_2\text{Te}_3\cdot\text{Bi}$. This might suggest that wehrlite is merely a variety of tellurbismuth; however, the fact is that there are now ten analyses of tellurbismuth (Doelter, 1926, p. 858, 1-9; Warren, 1940, p. 110) which agree closely with Bi_2Te_3 , and none in the range between tellurbismuth and wehrlite. This shows that there is a marked tendency for this compound to form in nature without excess Bi.

At one stage in this work it seemed that the evidence was pointing to the existence of a distinct compound BiTe which had been overlooked in the artificial system. This was suggested by the simple composition of wehrlite and the fact that the patterns of wehrlite and the alloy $\text{Bi} : \text{Te} = 1 : 1$ lack the lines of tellurbismuth that require the $5c$ -axis and consequently differ in appearance from the pattern of the pure compound. However, this idea was finally dispelled by a resolution of the basal diffractions from a nearly flat plate picked from the crushed alloy. These diffractions agreed exactly with those given by a plate of the pure compound and showed that the true c -axis of the alloy is five times the value given by the powder pattern. A similar multiplication of the c -axis of wehrlite might be revealed by a resolution of the basal diffractions.

SUMMARY

Hedleyite is a bismuth-tellurium alloy which is essentially a solid solution of Bi in Bi_2Te_3 , with Bi greatly in excess of the saturation limit (about 60 per cent Bi) found in the artificial system. The specific properties of the type material are as follows: Rhombohedral; $a_{\text{rh}} = 39.68 \text{ \AA}$, $\alpha = 6^\circ 26\frac{1}{2}'$ (from $a_{\text{hex}} = 4.46 \text{ \AA}$, $c = 118.8 \text{ \AA}$); the rhombohedral unit cell contains 20 atoms or approximately $\text{Bi}_{14}\text{Te}_6$; substructure rhombohedral; $a_{\text{rh}} = 3.248 \text{ \AA}$, $\alpha = 86^\circ 42\frac{1}{2}'$ (from $a_{\text{hex}} = 4.46 \text{ \AA}$, $c = 5.94 \text{ \AA}$); this rhombohedral cell contains 1 atom. In plates with easy cleavage (111) giving flexible and slightly elastic folia. Hardness 2; specific gravity 8.68—8.93, 8.91 (meas.), 8.93 (calc.); lustre metallic; colour tin-white with iron-black tarnish; opaque. Polished section white, slightly anisotropic on section near

(111). Strongest x -ray powder lines: (10) 3.25, (5) 2.36, (4) 2.23 Å. Composition near $\text{Bi}_2\text{Te}_3\text{Bi}_5$. Analyses: Bi 80.60, 81.55; Te 18.52, 17.60; S 0.12, 0.04; totals 99.24, 99.19. Occurs with native bismuth, joseite, and gold, in quartz and skarn at Good Hope mineral claim, Hedley, B.C. Breaks down to Bi and a solid solution of Bi in Bi_2Te_3 (wehrlite) on fusion and recrystallization.

Wehrlite is a bismuth-tellurium alloy, with added silver, which is essentially a solid solution of Bi in Bi_2Te_3 with Bi approximately at the saturation limit (about 60 per cent Bi) found in the artificial system. Rhombohedral; $a_{\text{rh}} = 3.236$ Å, $a = 86^\circ 08\frac{1}{2}'$ (from $a_{\text{hex}} = 4.42$ Å, $c = 5.97$ Å); the rhombohedral unit cell contains 1 atom or $\frac{1}{2}[\text{BiTe}]$. Basal diffractions may reveal a multiple c -axis. In foliated masses with perfect cleavage (111) giving flexible and slightly elastic folia. Hardness 1-2; specific gravity 8.37—8.44 (meas.), 8.40 (calc. for BiTe with Ag as intercalated silver); lustre bright metallic; colour tin-white to light steel-grey; opaque. Strongest x -ray powder lines (Harcourt): (6) 3.22, (3) 2.35, (3) 2.21 Å. Composition: $\text{Bi}_2\text{Te}_3\text{Bi} + \text{Ag}$. Analysis (Sipöcz): Bi 59.47, Te 35.47, Ag 4.37 = 99.31. Definitely known only from Deutsch-Pilsen, Hungary. The nearly homogeneous artificial alloy Bi : Te = 1 : 1 gives the x -ray powder pattern of wehrlite.

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MINERALOGICAL NOTES

MERCURIAN SILVER FROM BRITISH COLUMBIA

The specimen, a rounded and flattened light-grey nugget 8 mm. in greatest dimension, was found in a gold placer near Germansen Landing, Omenico district, B.C. On a freshly cut surface the mineral is compact and silver-white. Two measurements of the specific gravity gave 10.37 and 10.39. An x-ray powder photograph showed a slightly contracted silver pattern with no extra lines. The cube-edge is 4.10 Å, as compared to 4.077 Å for pure silver, 4.107 Å for the homogeneous α -phase with Ag 80, Hg 20 per cent by weight, in the Ag-Hg system (Preston, in Murphy, *Strukturbericht*, **2**, 704, 1937). A qualitative test confirmed Hg in the mineral and a determination of Ag, kindly made by Dr. V. B. Meen, gave Ag 80.2 per cent. The mineral is thus a mercury-bearing variety of silver appropriately called mercurian silver.

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ON POTARITE

Through the kindness of Dr. S. Bracewell and Mr. C. L. C. Bourne of the Geological Survey of British Guiana, and Mr. S. V. Burr, a former student who visited the colony in 1943, I received in the same year a specimen of potarite, the rare palladium mercuride or palladium amalgam from the Potaro River region of British Guiana. This material gave the opportunity of making some observations confirming and supplementing the description of the mineral by Spencer (*Min. Mag.*, **21**, 397, 1928)—which includes the substance of the original reports by Harrison and Bourne—and the notes on a polished section by Cissarz (*Zeits. Krist.*, **74**, 501, 1930).

The specimen was a rough flat nugget, about 10 mm. wide, creamy white in colour and indistinctly columnar in structure, but lacking the "octahedral points" which permitted Spencer to assign the mineral to the cubic system. A polished section of about half of the specimen showed a pure white, highly reflecting mineral, entirely isotropic and free from inclusions. On this section Mr. R. M. Thompson noted the following etch reactions: HNO₃ slowly stains brown, in part blue; HCl negative; KCN negative; FeCl₃ quickly

etches brown; KOH negative; HgCl_2 negative. Hardness C+. Our specimen thus appears to represent a homogeneous cubic mineral.

The composition attributed to potarite, PdHg or, in the case of some samples, perhaps Pd_3Hg_2 , apparently rests on qualitative tests for Pd and Hg together with the results of heating experiments in which the loss of weight was taken as a measure of Hg. A spectrographic examination of the material in hand, kindly made under the direction of Professor F. E. Beamish in the Department of Chemistry, gave Pd, Hg, and also Au, but no other metals. Pd was then estimated on a sample of 46 mg. by dimethylglyoxime, using details of procedure also furnished by Professor Beamish. This gave Pd 33.7 per cent, as compared to Pd 34.7 per cent required by the formula PdHg. A few minute particles of gold were seen in the HNO_3 solution but an effort to collect and weigh them did not succeed. The composition PdHg with a trace of Au may then be accepted for the homogeneous mineral.

The doubtful composition Pd_3Hg_2 was suggested by the loss of weight on heating two samples of potarite (Harrison, in Spencer). These samples may perhaps have been similar to that examined in polished section by Cissarz, who noted anisotropic inclusions in an isotropic ground. It is now clear that potarite is the isotropic compound PdHg. The inclusions may be some other compound of Pd and Hg, as suggested by Cissarz. If this were Pd_2Hg , the only compound of Pd and Hg mentioned by Mellor (15, 649, 1936), the composition Pd_3Hg_2 would be explained as that of a mixture of PdHg and Pd_2Hg .

An attempt to synthesize PdHg was not successful. Palladium filings and mercury, in equal atomic proportions, were strongly heated in an evacuated silica glass tube in the hope of obtaining a melt. However the charge did not fuse even at white heat, when the tube exploded. Equal proportions of palladium black and mercury were then rubbed together in an agate mortar. The resulting black powder gave an x-ray pattern different from those of Pd, PdHg, and Hg; the product may have been Pd_2Hg .

An x-ray powder photograph of potarite, with filtered copper radiation, gave a rather weak pattern which was completely indexed on a simple cubic lattice with $a = 5.21 \text{ \AA}$. With Pd_4Hg_4 in the unit cell the calculated specific gravity is 14.33, as compared to Spencer's average value of 14.8, from eleven determinations ranging from

13.48 to 16.11. Thus the cubic symmetry of potarite is confirmed, and also the specific gravity, which is much higher than that of palladium (calculated 12.04) and nearly equal to that of crystallized mercury at -46°C (calculated 14.26). From the high specific gravity Spencer concluded that potarite is a definite compound of Pd and Hg rather than an amalgam; this is now borne out by the unit cell of potarite which is unrelated to those of the component elements.

Only one reasonable atomic arrangement has suggested itself for potarite, that is the structure attributed to FeSi by Wever and Möller (*Zeits. Krist.*, **75**, 362, 1930. *Strukturbericht*, **2**, 13; **3**, 13). This structure has the symmetry of the space-group T^4-P2_13 , and both sets of four atoms are placed at (a):

$$x, x, x; \frac{1}{2} + x, \frac{1}{2} - x, \bar{x}; \frac{1}{2} - x, \bar{x}, \frac{1}{2} + x; \bar{x}, \frac{1}{2} + x, \frac{1}{2} - x$$

With x (Pd) = \bar{x} (Hg) = 0.155, the ideal case in which all the Pd-Hg distances are alike and equal to the reasonable value 2.79 Å, the calculated intensities show some resemblance to those observed. Good agreement, however, has not yet been obtained by varying the two parameters, and the structure is not considered proved.

In conclusion, the described specimen of potarite is a homogeneous cubic compound containing 33.7 per cent Pd and a trace of Au, as compared to 34.7 per cent Pd calculated for PdHg. The unit cell with $a = 5.21$ Å contains Pd₄Hg₄. Potarite is thus a well-defined mineral, entitled to be raised from its dubious standing in the new Dana's *System* (1, 105, 1944) to the full rank of a mineral species.

M. A. PEACOCK
University of Toronto

RECROSSING AXIAL PLANE DISPERSION IN GOETHITE—AN ERROR

In a recent number of these *Contributions (Univ. Toronto Studies, Geol. Ser., 47, 53, 1942)* Nuffield & Peacock described a novel optical effect in goethite, namely crossing of the optic axial plane from (100) in the red to (001) in the yellow, strong absorption in the blue, and finally good transmission in the violet with the optic axial plane recrossed to (100), as in the red. The observations claimed only approximate accuracy since the light source was a mercury lamp with single Wratten filters and the optical axial angles in air were measured with a graduated eyepiece.

On reading of this hitherto unknown optical behaviour, Dr. W. M. D. Bryant, who has specialized in the study of optic axial dispersion, requested the opportunity to examine the material. Fragments from the Cornish crystals which we had used were accordingly sent to Dr. Bryant who reported his observations in the following letter:

Silverside Road, R. D. 3
Wilmington, Delaware
December 10, 1944

Dear Professor Peacock:

I have examined the goethite sample you sent me but I have had no success in obtaining light transmission at wave-lengths below the yellow green, either with a carbon arc and monochromator or with an H-4 mercury lamp and filter combination. The following measurements were made at $24 \pm 3^\circ\text{C}$ on a thin cleavage plate whose transmission color is amber yellow in white light:

λ	$2H$	E
6908 Å	48.0°	38°
6438	35.0	27
6130 \pm 10	0	0
5780	40.0	31
5461	68.5	58.5
5410	78.5	73
5300	87.0	90
5085	not transmitted	
4358	not transmitted	
4047	not transmitted	

By visual inspection of the preparation 5250 Å was the shortest wavelength that could be detected; with sources of shorter wavelengths only traces of residual long wavelength radiation were observed.

The following transmission measurements, obtained with our small photocell assembly, give some quantitative indication of the effect and also of the pleochroism of the section:

λ	Percentage transmission			Relative intensity of radiation
	No Nicols	Analyser at		
		0°	90°	
6908 Å	47	43	43	4.22
5780	48.4	52.0	42.7	56.0
5461	12.8	16.5	7.6	61.0
*5085	6	....	....	....
*4800	2	....	....	....
4358	2.4	2.0	1.6	42.0
4047	0	0	0	6.5
3650	1	1	1	97.0

*Improvised apparatus using monochromator with mercury-cadmium lamp.

I do not believe that any of the transmissions at wavelengths below 5461 Å are real. They appear to be due to traces of residual red and yellow radiation and to small amounts of light reflected around the specimen. I shall check this with an Ehringhaus eyepiece microspectroscope and also measure the thickness of the crystal.

In view of the above results I doubt that this particular sample of goethite shows recrossing of the axial planes. If you have other specimens that could differ in this respect I would be glad to test them for you.

With best regards, I am

Yours very truly,

W. M. D. BRYANT

In view of Dr. Bryant's experience and the excellence of his equipment, his observations and conclusions are accepted without question. Furthermore, the material submitted was typical and there is no reason to believe that its optical properties would vary greatly from one crystal to another. From red to yellow-green our rough measurements of the optic axial half-angle at room temperature agree reasonably with Dr. Bryant's accurate measurements. But in view of Dr. Bryant's finding that goethite is practically opaque to wave-lengths shorter than 5461 Å it is certain that the apparent "recrossing" of the axial plane which we observed with single violet filters was a false effect due to residual red light transmitted by our ineffective filters.

M. A. PEACOCK
University of Toronto

NOTES ON CANADIAN GEMS AND ORNAMENTAL STONES

The available information on gems and ornamental stones from Canadian localities is contained mainly in two papers by Professor A. L. Parsons (*Univ. Toronto Studies*, Geol. Ser., **36**, 13, 1934; **41**, 45, 1938). In addition, references to gem-minerals are scattered through official Canadian geological reports, but these give little indication of the probable usefulness of the materials for cutting purposes.

In pursuing his hobby of collecting and cutting gem material and ornamental stones, the writer has made a collection of cut stones which represent known localities and also some which are little known or previously unreported. The following notes on selected stones are therefore given to add to the existing information on Canadian gem material. The selection is intended only to repre-

sent the gem possibilities of Canadian minerals; it should not be inferred that the list exhausts the known resources, let alone the unknown possibilities. Some of the described stones are single examples, others are typical of a number of similar stones.

The size of cabochons is given as length \times breadth \times depth. The weights of facet-cut stones are given in metric carats (200 mg.). It will be noted that several examples are flawed, but in such cases the flaws are not serious enough to render the stone unattractive. The occurrences which are new or little known are marked with an asterisk.

Agate, W. end of Michipicoten Is., Lake Superior; tallow-cut cabochon, 27 \times 20 \times 6 mm., red and white, showing a fine pattern. This known locality yields plentiful, colourful material of highest quality. *Agate*, Simpson Is., Lake Superior; cabochon, 21 \times 11 \times 5 mm., malachite green; plentiful in small sizes on certain beaches.

Amethyst, Thunder Bay, Lake Superior; mixed cut, 3.0 ct., deep amethyst colour with crimson shades.

Andalusite, Great Slave Lake, N.W.T.; polished slab, 38 \times 36 \times 5 mm., brown and black with a fine chiastolite pattern.

Apatite, Wilberforce, Monmouth Tp., Haliburton Co., Ont.; green, round brilliant, 2.1 ct. Gem material is obtained from fragments of large crystals.

Aquamarine, Butt Tp. (near Kearney*), Nipissing District, Ont.; blue, round brilliant, 2.1 ct., flawed but with fine colour. *Aquamarine* from near Quadville, Renfrew Co., Ont., blue, mixed cut, 3.1 ct. The colour and clarity of these stones matches the best from Brazil.

Aventurine feldspar, Drag Lake,* Dudley Tp., Haliburton Co., Ont.; taupe cabochon, 15 mm. diam. \times 7 mm., with minute spangles and a blue moonstone flame.

Carnelian, W. end of Michipicoten Is., Lake Superior, red cabochon, 11 \times 9 \times 5 mm., with good translucency. The material varies widely in depth of colour and translucency.

Diopside, Bird's Creek, Herschel Tp., Hastings Co., Ont.; light green, step cut, 0.67 ct., with fine colour. *Diopside*, Laurel, Argen-teuil Co., Que.; a smoky sherry cabochon, 9 \times 6 \times 4½ mm., with white flame moonstone; and a sherry marquise brilliant, 1.55 ct.

The stones from Laurel were obtained from fragments of large crystals.

Idocrase, Laurel, Argenteuil Co., Que.; a golden brown aventurine cabochon, $14 \times 12 \times 8$ mm., and a fine golden brown oblong brilliant, 1.75 ct. These were got from fragments of large crystals.

Iolite, Great Slave Lake, N.W.T.; blue, mixed cut, 0.7 ct., flawed.

Peridot, Timothy Mt.,* near Lake LaHache, B.C.; grass-green, stepped triangular cut, 0.72 ct., with good colour.

Peristerite, Sundridge,* Strong Tp., Parry Sound District, Ont.; yellow white cabochon, $13 \times 7 \times 5$ mm., less transparent than Ceylon moonstone, but with more brilliant flame.

Prehnite, Simpson Is., Lake Superior; cabochon, $22 \times 15 \times 6$ mm., showing inclusions of native copper; often associated with the green agate.

Rose quartz, Lyndoch Tp., Renfrew Co., Ont.; pale pink cabochon, 25 diam. \times 8 mm. The material is plentiful.

Sapphire, York River, north-east of Bancroft, Dungannon Tp., Hastings Co., Ont.; grey-blue cabochon, 4.6 ct., shows asterism but with a poor star.

Scapolite, Khartum,* Griffith Tp., Renfrew Co., Ont.; uneven pale green, flawed, step cut, 1.75 ct., from a large single crystal found at "Old Spain" mine. Scapolite, Drag Lake,* Dudley Tp., Haliburton Co., Ont.; very clear, pale yellow, triangular mixed cut, 0.25 ct.

Sodalite, York River, north-east of Bancroft, Dungannon Tp., Hastings Co., Ont.; double cabochon, $17 \times 13 \times 8$, deep blue, translucent and flawless. Found as "nuggets" in nepheline syenite.

Sphalerite, near Wiarton, Bruce Co., Ont.; round brilliant, 6.0 ct., resinous golden brown, but not uniform; shows twinning.

Thomsonite, Michipicoten Is., Lake Superior; red brown cabochon, $31 \times 16 \times 10$ mm.; shows typical pattern but lacks contrasting colours; not plentiful.

Tourmaline, Wilberforce,* Monmouth Tp., Haliburton Co., Ont.; mixed cut, 0.82 ct.; very dark green and crimson, quite similar to the andalusite type of tourmaline from Ceylon. Tourmaline, Wakefield, Que.; mixed triangular cut, 1.15 ct., good green, matching good Brazilian colour.

Tremolite, Wilberforce,* Monmouth Tp., Haliburton Co., Ont.; marquis brilliant, 0.70 ct., with deep blue colour; this material is usually cat's eye. Also a step-cut, 0.50 ct., brilliant emerald green; this material occurs with diopside of the same colour, and both types of tremolite have been mistaken for diopside. Tremolite, Haliburton, Haliburton Co., Ont.; cabochon, 17 × 13 × 5 mm., grey-green with good cat's eye; this material is plentiful.

Zircon, Brudenell Tp., Renfrew Co., Ont.; marquis brilliant, 0.8 ct., fine orange and red; fragment of a large crystal.

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ANTIMONY MINERALS FROM BRITISH COLUMBIA AND YUKON
TERRITORY: BOULANGERITE, CHALCOSTIBITE, JAMESONITE,
ZINCKENITE

Antimony is a relatively abundant element in some parts of British Columbia and the Yukon. Stibnite, tetrahedrite, freibergite, pyargyrite, polybasite, stephanite, and allemontite have all been reported, and the present notes show that several other antimony minerals have been overlooked or mistaken, usually for stibnite, jamesonite, or tetrahedrite. No authenticated occurrence of jamesonite was hitherto known in British Columbia or the Yukon, although this mineral has often been erroneously reported.

In the present work the usual methods of identifying ore minerals have been supplemented by numerous determinations of specific gravity with the Berman micro-balance, and many spectrographic analyses. Most of the identifications were also confirmed by Professor M. A. Peacock and Dr. E. W. Nuffield in the Department of Mineralogy, University of Toronto, by means of *x*-ray photographs compared with standard patterns. The five chemical analyses were made by J. R. Williams & Son of Vancouver, B.C. The authors also wish to express their thanks to the many mining companies and individuals who made available many of the samples, particularly to Mr. J. M. McLay of the Consolidated Mining and Smelting Company, Mr. F. R. Joubin of Pioneer Gold Mines Limited, the B. C. and Yukon Chamber of Mines, and Mr. W. E. McArthur of Greenwood. Credit for drawing attention to zinkenite on the Robson group, and doing preliminary work on this mineral, must be given to Mr. A. A. Almstrom and Mr. J. Currie of Bralorne.

BOULANGERITE— $5\text{PbS}\cdot 2\text{Sb}_2\text{S}_3$

This mineral has recently been described in detail by Berry (*Univ. Toronto Studies, Geol. Ser.*, **44**, 5, 1940) who found that all the Canadian specimens labelled "jamesonite" that he examined, including several from British Columbia, are boulangerite. As shown by the following notes, fibrous sulphantimonites from British Columbia, usually referred to jamesonite, generally prove to be boulangerite.

Sullivan Mine. Boulangerite is erratically distributed throughout the Sullivan Mine, near Kimberley, south-east British Columbia, as a soft fibrous mineral associated with galena, sphalerite, and pyrrhotite, and minor amounts of pyrite, arsenopyrite, and quartz. Occasionally it may be found in vugs, as projecting hair-like crystals up to 2 cm. long, with one cleavage parallel to the elongation; these are flexible, whereas similar crystals of jamesonite are brittle owing to the transverse cleavage, illustrated by Berry (*Min. Mag.*, **20**, pl. xxvi, 1940). The average specific gravity of 30 fragments is 6.18. A spectrographic analysis showed traces of Ag, Cu, Sn, As, Cd, Mn, V, Ti. The mineral was originally reported as jamesonite, but a specimen of the present material, like those x-rayed by Berry, gave the powder pattern of boulangerite. A chemical analysis on picked material with the average specific gravity 6.18, by J. R. Williams & Son, gave the results under 1, in the table of analyses of boulangerite.

Babine Bonanza. This property, also known as the Cronin, lies near the head of Cronin Creek, thirty-two miles from Telkwa, in the Omineca Mining Division, B.C. The massive, locally abundant boulangerite, formerly confused with tetrahedrite, is associated with sphalerite, galena, tetrahedrite, and minor amounts of pyrite and chalcopyrite, in quartz gangue. Several fragments gave the average specific gravity 6.08. A spectrographic analysis showed traces of Cu, Sn, Mn, and the x-ray powder photograph gave the pattern of boulangerite. A chemical analysis of this material, by J. R. Williams & Son, is given under 2 in the table.

Comet Group. These claims are on the south slope of Four-Mile Mountain, about five miles from Hazelton, Omineca Mining Division, B.C. The fibrous mineral associated with galena, sphalerite, and arsenopyrite, in quartz, has been referred to jamesonite. Impure fragments give the average specific gravity 5.97 and a spectro-

graphic analysis shows essential Pb, Sb, about 1 per cent Fe, and traces of Cu, Ag, Zn, Mn, Ti. The mineral may be boulangerite.

Lamarr Mine. A sample from this showing near the head of Driftwood Creek, nineteen miles east of Smithers, Omineca Mining Division, consisted of boulangerite intimately intergrown with barite. The average specific gravity, 5.83, is probably low owing to this impurity. The spectrographic analysis showed Pb, Sb, Ba, and traces of Ag, Cu, As, Fe, Zn, V, Ti. The *x*-ray photograph showed a weak boulangerite pattern with extra unidentified lines.

Lightning Peak Group. These claims are situated at the headwaters of Granby River and Rendell Creek, in the Vernon Mining Division, B.C. The specimen submitted to us for identification contains only quartz and boulangerite, but galena, sphalerite, and minor amounts of pyrite, chalcopyrite, and high-grade silver minerals have been reported from the locality by C. E. Cairnes (*Geol. Surv. Canada*, Summ. Rep. 1930 A, 113, 1931). The boulangerite has a fibrous habit and the average specific gravity is 6.08. A spectrographic analysis revealed traces of Cu, Ag, Sn, Bi, Te, Au, Mn, V, Ti, in addition to the main constituents, and an *x*-ray powder photograph gave the pattern of boulangerite. In the course of a chemical analysis, by J. R. Williams & Son, under 3 in the table, the presence of Se was detected.

Amandy Property. This claim is on the south slope of Roderic Dhu Mountain, north-west of Jewel Lake, Greenwood Mining District, B.C. In this locality Freeland (*Minister of Mines, B.C.*, Ann. Rep., 1934 D, 6, 1935) reported pyrite, galena, sphalerite, and probably gold telluride, in a quartz vein. In the sample submitted to us boulangerite was recognized by the fibrous habit, average specific gravity 6.02, and a spectrographic analysis which gave essential Pb, Sb, and traces of Cu, Ag, As, Zn, Fe. The identification was confirmed by the *x*-ray powder pattern.

Red Paddy. So far as we know there is no official description of this property, which is situated near the headwaters of the Kettle River, Greenwood Mining Division. The specimen studied consisted of boulangerite and quartz. The boulangerite has a fibrous habit and the average specific gravity 6.12. A spectrographic analysis showed essential Pb, Sb, and traces of Fe, As, Sn, Cu, Ag, Bi, Au.

Kismet Group. This group of claims, situated on the north side

of Trap Creek, a tributary of the Kettle River, Greenwood Mining Division, is briefly described by Pearson (*Minist. Mines, B.C., Ann. Rep., 1933*, 156, 1934). The mineralization consists of galena, pyrite, and boulangerite; the specimen submitted to us consisted of clean fibres of boulangerite in quartz. A number of specific gravity measurements gave the average value 6.00. A spectroscopic analysis showed essential Sb, Pb, and traces of Ag, Cu, Fe, Bi, Te, Sn, As, Mn, Cd, Zn, Ti.

Big Five Group. These claims are at the extreme head of Ferguson Creek, Lardeau Mining Division. Here Gunning (*Geol. Surv. Canada, Mem. 161*, 99, 1929) identified boulangerite, by microchemical tests, associated with tetrahedrite, galena, and sphalerite. The average specific gravity of several fragments of the fibrous mineral is 6.05. A spectrographic analysis shows essential Pb, Sb, and traces of Cu, Ag, Sn, As, Fe. The identification of boulangerite is confirmed by an x-ray powder photograph.

Lily May. The Richmond-Lily May group of claims, located south of Rossland on the Dewdney trail, is described by Langley (*Minist. Mines B.C., Ann. Rep., 1921*, 151, 1922). The mineralization consists of galena, pyrite, pyrrhotite, sphalerite, and occasionally boulangerite, which was formerly confused with stibnite, in a quartz gangue. Several fragments gave the average specific gravity 6.02. A spectroscopic analysis showed essential Sb, Pb, and traces of Fe, Sn, Cu, As, Zn, Cd, Ti, Mn. Etch reactions on a polished section were identical with those given for boulangerite by Short (*loc. cit.*). The x-ray powder photograph gave the pattern of boulangerite.

Arctic Group. These properties are at the head of Star Creek, high on the north-west slope of Galena Hill, twenty-seven miles north-east of Mayo, Yukon Territory. The reported mineral association is galena, freibergite, cerussite, siderite, manganese, and iron oxides, with some quartz and pyrite. The specimen studied, kindly supplied by Dr. H. S. Bostock, consists of a mass of fibrous boulangerite and cellular limonite. A polished section showed boulangerite intimately intergrown with sphalerite and gangue. The highest specific gravity obtained, 5.80, may be low due to impurities. Cleaner material, obtained by crushing, screening, and superpanning, gave the x-ray powder pattern of boulangerite.

	1	2	3	A
Pb.....	55.35	55.45	55.40	55.24
Ag.....	...	0.06	...	...
Fe.....	0.51	0.13	0.25	...
Sb.....	24.95	25.40	25.50	25.96
As.....	0.71	0.36	0.24	...
S.....	18.40	18.45	18.50	18.80
	99.92	99.85	99.89	100.00

Analyses of boulangerite from British Columbia, by J. R. Williams & Son. 1—Sullivan mine; 2—Babine Bonanza; 3—Lightning Peak group; A—Calculated for $5\text{PbS}\cdot 2\text{Sb}_2\text{S}_3$.

CHALCOSTIBITE— $\text{Cu}_2\text{S}\cdot\text{Sb}_2\text{S}_3$

This rare mineral occurs intergrown with stibnite in quartz gangue, in a small vein in granodiorite, at the Porter Property, Carbon Hill, Wheaton District, Yukon Territory. In a description of the antimony-silver veins of the Wheaton District, D. D. Cairnes (*Geol. Surv. Canada*, Mem. **31**, 120, 1912) noted stibnite as the main ore mineral in some of the veins on the Porter claim. In a hand specimen chalcostibite can hardly be distinguished from stibnite, but by painting a fairly smooth surface of the specimen with KOH, whereby stibnite is coated orange-red while chalcostibite is unaffected, the latter appears in laths rarely exceeding 3 mm. in length. Several small fragments gave the average specific gravity 4.86. In a polished section the anisotropism and etch reactions agree with those given by Short (*op. cit.*, 138). Spectrographic analyses show Cu, Sb, and traces of Pb, Ag, Sn, As, Fe, Zn, Mn. The x-ray powder pattern is identical with that given by chalcostibite from Chocaya la vieja mine, prov. Sud-Chichas, dep. Potosi, Bolivia.

JAMESONITE— $4\text{PbS}\cdot\text{FeS}\cdot 3\text{Sb}_2\text{S}_3$

A sulphantimonite resembling jamesonite, associated with arsenopyrite, pyrite, pyrrhotite, very small amounts of galena, sphalerite, chalcopyrite, and microscopic specks of native silver, has been reported by C. E. Cairnes (*Geol. Surv. Canada*, Summ. Rep. **1930 A**, 120, 1931) from the St. Paul mine, Monashee Mountain, Vernon Mining Division. Two small specimens available to us from this locality showed a similar association of minerals. The cleanest available fragments of the fibrous mineral resembling

jamesonite gave the average specific gravity 5.59. In polished sections the cleavage across the elongation of the fibres was not observed, but KOH gave an iridescent tarnish and a microchemical test for Fe gave a strong positive reaction, as noted for jamesonite by Berry (*Min. Mag.*, **25**, 597, 1940). An x-ray powder photograph showed the pattern of typical jamesonite from Cornwall, with a few faint extra lines attributed to some impurity. A spectrographic analysis showed essential Sb, Pb, Fe, together with traces of Cu, Sn, In, As, Mn, Zn, Cd, of which the last four may have been due to admixed arsenopyrite and sphalerite. A chemical analysis on a sample, apparently containing some arsenopyrite and sphalerite, was made by J. R. Williams & Son (4). The recalculated values obtained by withdrawing As as FeAsS and Zn as ZnS (B) compare tolerably with the calculated composition of $4\text{PbS}\cdot\text{FeS}\cdot 3\text{Sb}_2\text{S}_3$ (C).

	4	B	C
Pb.....	35.77	40.73	40.32
Sb.....	31.25	35.58	35.10
S.....	19.45	19.15	21.86
Fe.....	7.51	4.54	2.72
Cu.....	trace	...	...
Zn.....	1.25	...	...
As.....	4.73	...	...
Insol.....	trace	...	...
	<u>99.96</u>	<u>100.00</u>	<u>100.00</u>

This verification of the occurrence of jamesonite in British Columbia is of interest in view of the fact that the mineral reported as jamesonite in other occurrences in this province and elsewhere in Canada has so far proved to be some other species.

ZINCKENITE— $\text{PbS}\cdot\text{Sb}_2\text{S}_3$ or $6\text{PbS}\cdot 7\text{Sb}_2\text{S}_3$

This uncommon mineral occurs in the principal vein on the Robson Group, near Bonanza Creek, Tyaughton Lake area, Bridge River district, where it is intergrown with calcite and associated with sphalerite and tetrahedrite, also arsenopyrite and some pyrrhotite, chalcopyrite, and gold. The zinckenite is soft and fibrous or hair-like and it gives the etch-reactions described by Short (*op. cit.*, 116). Material apparently containing some calcite gave the specific gravity 5.15 and a preliminary analysis by J. P. Beley yielded: Pb 33.3,

Sb 40.8, S 20.9, As trace, total 95.0. From these properties we concluded that the mineral is zinckenite and this was later confirmed by an x-ray powder photograph which gave the pattern of typical zinckenite from Wolfsberg, Harz, Germany. A picked sample was then crushed, screened, and concentrated on Haultain's "super-panner." A spectrographic analysis of this material showed traces of Cu, Ag, Au, Zn, Cd, Mn, V, Ti, in addition to the main constituents; a chemical analysis by J. R. Williams & Son (5) is compared to the percentage compositions of $PbS.Sb_2S_3$ (D) and $6PbS.7Sb_2S_3$ (E), which are respectively the older accepted composition of zinckenite and the composition recently inferred by Vaux & Bannister (*Min. Mag.*, **25**, 221, 1938).

	5	D	E
Pb.	34.58	35.79	32.60
Sb.	42.30	42.06	44.70
S.	21.84	22.15	22.70
Fe.	0.50	...	...
As.	0.48	...	...
	<hr/> 99.70	<hr/> 100.00	<hr/> 100.00

H. V. WARREN and R. M. THOMPSON
University of British Columbia

THE WALKER MINERALOGICAL CLUB¹

BY-LAWS²

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 Mineralogy and Petrography, University of Toronto.
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 Mineralogy and Petrography, University of Toronto), three Councillors to represent Ordinary Members, one Councillor to represent the Department of Mineralogy and Petrography, 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

¹Founded 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.

²A re-arrangement of the original constitution of the Club (*Univ. Toronto Studies*, Geol. Ser., no. 41, p. 83, 1938) and subsequent amendments, prepared by a Committee of Council appointed March 2, 1944.

perform such duties as ordinarily fall to a council. Only the President 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 Mineralogy and Petrography 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 Head of the Department of Mineralogy and Petrography, University of Toronto.

DUES

13. The annual membership fee with 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 1944

Honorary President Professor A. L. PARSONS
President Mr. PERCY E. HOPKINS

<i>Secretary-Treasurer</i>	Dr. V. B. MEEN
<i>Editor and Past President</i>	Professor M. A. PEACOCK
<i>Councillors for Ordinary Members</i>	
1944-46.....	Dr. JACK SATTERLY
1943-45.....	Mr. G. G. WAITE
1942-44.....	Mr. W. C. RINGSLEBEN
<i>Councillor for Department of Mineralogy</i>	
	Professor ELLIS THOMSON (<i>ob.</i>)
<i>Councillor for Student Members</i>	
	Dr. E. W. NUFFIELD

NEW MEMBERS AND SUBSCRIBERS³

- SM BEATON, Neil S(tewart), M.Sc., Ph.D. Geologist, *Northern Canada Mines Ltd., 44 Victoria Street, Toronto 1, Ontario.*
- S DEPUTY MINISTER OF MINES, *Ontario Department of Mines, Toronto 2, Ontario.*
- SM ELSON, John A(lbert). Student, *Department of Geology, University of Western Ontario, London, Ontario.*
- SM FROHBERG, M(ax) H(ans), M.E., Dr. Eng. Field Geologist, *Macassa Mines Ltd., 85 Richmond Street West, Toronto 1, Ontario.*
- SM HAMILTON, R(obert) J. Student, *University of Toronto, 67 Bushey Avenue, Toronto 9, Ontario.*
- SM HILL, H. Stanton, M.A. Instructor in Mineralogy and Geology, *Pasadena Junior College, Pasadena 4, California.*
- KERR, H. L. *202 Inglewood Drive, Toronto, Ontario.*
- S KILLER, F(rederick) A(nderson), B.A. Field Geologist, *Imperial Oil Exploration Department, Moose Jaw, Saskatchewan.*
- S LAMONT, George Lewis, B.A. Junior Geologist, *McIntyre Porcupine Gold Mines Ltd., Schumacher, Ontario.*
- S LIBRARY, *Department of Mines, Victoria, British Columbia.*
- SM MOYD, Louis. Mineralogist, *c/o Union Mines Development Corporation, 50 East 42nd Street, New York, New York.*
- S PEACOCK, Katharine West, B.S. (Mrs. M. A.). *81 Moore Avenue, Toronto, Ontario.*
- S SULLIVAN, D. W., B.Sc. *Canadian Refractories Ltd., Kilmar, Quebec.*
- SM THOMPSON, Robert M(itchell), M.A.Sc. Demonstrator, *Department of Mineralogy, University of Toronto, Toronto 5, Ontario.*
- SM THORVALDSON, T(horbergur), B.A., Ph.D., F.R.S.C. Head, *Department of Chemistry, University of Saskatchewan, Saskatoon, Saskatchewan.*
- SM TREVOR, Edward A(usten), Chief Assistant, *Strategic Minerals Division, Department of Mines and Resources, Ottawa, Ontario.*

³Supplementing the list in *Univ. Toronto Studies*, Geol. Ser., no. 48, pp. 105-117, 1943. SM—Subscribing Member; S—Subscriber.

- S WEST, Cutler DeLong, B.A., Ph.D. Research Chemist, *Polaroid Corporation, Cambridge, Massachusetts.*
- S.M WINSTALL, Paul A. R. President, *Winstall Diamond Corporation Ltd., 25 King Street West, Toronto 1, Ontario.*
- S.M WRIGHT, J. F., Ph.D. Consulting Geologist, *11 King Street West, Toronto 1, Ontario.*

PROCEEDINGS, 1943

MEETING OF OCTOBER 28, 1943

Held at 5 P.M. in Room 64, Royal Ontario Museum, with the President, Professor M. A. Peacock, in the chair. The announcement that the Council had elected Professor A. L. Parsons as an Honorary Member and Honorary President of the Club was received with approval.

The Secretary read a notice of proposed Amendments to the Constitution:

1. That the three paragraphs under "*Members*" (1938, p. 84) be replaced by the following:

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

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

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

2. That the paragraph under "*Dues*" (1938, p. 84) be replaced by the following:

"The annual membership fee with 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. All fees are payable on January 1st."

3. That the word "member" in the paragraph under "*Publications*" (1938, p. 85) be replaced by "subscribing member and subscriber."

4. That the Amendment to the Constitution regarding the Office of Editor (1940, p. 114) be replaced by the following:

"The financial responsibility for the publication of *Contributions to Canadian Mineralogy* shall rest with the Head of the Department of Mineralogy and Petrography, University of Toronto.

The Editor shall be a member of that Department and a member of Council."

5. That the paragraph under "*Meetings*" (1938, p. 84; 1939, p. 158) be replaced by the following:

"The meetings of the Club shall be on the fourth Thursday of February, April, and October, and the second Thursday of December."

The Secretary then reported that the Nominating Committee had recommended the following gentlemen for office in 1944:

<i>President</i>	Mr. PERCY E. HOPKINS
<i>Secretary-Treasurer</i>	Dr. V. B. MEEN
<i>Editor</i>	Professor M. A. PEACOCK
<i>Councillor for Ordinary Members, 1944-46</i>	Dr. JACK SATTERLY
<i>Councillor for Department of Mineralogy</i>	Professor ELLIS THOMSON
<i>Councillor for Student Members</i>	Mr. E. W. NUFFIELD

It was moved by Dr. V. J. Okulitch, seconded by Dr. L. G. Berry, that this report be accepted and instructions be given the Secretary to send out ballots to all members; that the poll close December 7 at 5 P.M.; and that Council canvass the ballot and report to the December meeting. Carried.

The President called attention to the new section in *Contributions to Canadian Mineralogy, 1943*, entitled "Mineralogical Notes" in which short communications may be published. He also suggested that members having interesting specimens might bring them to future meetings for exhibition.

Professor Ellis Thomson gave a comprehensive "Review of the Origin and Synthesis of Diamond" with special reference to the recent work of Bannister & Lonsdale on Hannay's artificial diamonds. Following a number of questions, the President extended the thanks of the Club to the speaker.

MEETING OF DECEMBER 9, 1943

Held at 5 P.M., in Room 64, Royal Ontario Museum, with the President, Professor M. A. Peacock, in the chair.

After second reading of the Amendments to the Constitution proposed at the October meeting, it was moved by Professor R. J. Montgomery, seconded by Dr. Jack Satterly, that these amendments be adopted. Carried.

It was moved by Professor Ellis Thomson, seconded by Mr. H. L. Banting, that the Council consider framing an Amendment to provide that future Amendments to the Constitution be handled by letter ballot. Carried.

The Secretary read the names of the following new members who were welcomed to the Club by the President:

Mr. G. L. Lamont, Mr. Louis Moyd, Mrs. M. A. Peacock, Professor T. Thorvaldson, Dr. C. D. West, Dr. J. F. Wright.

The Secretary announced that the ballot had been canvassed and the officers for 1944 were elected as nominated. A number of interesting specimens were exhibited by members, and Professor Peacock called attention to new reports and books of interest to mineralogists.

Dr. A. E. R. Westman, Ontario Research Foundation, addressed the Club on "Mineralogy in Ceramics." Beginning with a brief history of the development of ceramics from the Stone Age to the present, from the use of local products to the production of artificial minerals, he discussed some problems which arise in glazing china-ware. Following the address and the subsequent discussion, the President extended the thanks of the Club to the speaker.

The membership of the Club on December 31, 1943, was as follows:

Honorary Members.....	3
Ordinary Members.....	323
Student Members.....	<u>12</u>
	338

Of the Ordinary Members there are four with whom we cannot correspond at present. Thirty-one members are known to be on Active Service and, in addition, a number of members in civilian positions are attached to a branch of the Armed Services. The following members have resigned: J. A. Dawson, S. A. Ferguson, J. T. King, T. D. Lance.

We regret to report the death of one member, George Frederick Kay, M.A., Ph.D., Sc.D., LL.D., Dean and Professor of Geology, the State University of Iowa, who died on July 19, 1943.

We are indebted to the Royal Ontario Museum for permission to hold our meetings in that building.

CHANGE OF FISCAL YEAR

Since its organization in 1938 the Walker Mineralogical Club has operated on a fiscal year corresponding to that of the University of Toronto, that is from July 1 to the following June 30. Annual dues were collected in October and the journal, *Contributions to Canadian Mineralogy*, also published in October, was mailed to all members whose dues for the previous year were paid. It is easy to see that this brought about uncertainties to members, and difficulties to the Secretary-Treasurer. In addition, at the expiry of a fiscal year, the Club was always in debt for the issue of *Contributions to Canadian Mineralogy* to be published in the following October.

With the passage of the Amendments to the Constitution at the December meeting it became possible to change the fiscal year to the calendar year, January 1 to December 31. In this way, dues collected in January apply to the year in which *Contributions to Canadian Mineralogy* is published. The increase in fees permitted by these Amendments was necessary. Last year the cost of publishing the journal exceeded the income from fees and other sources, and we were gradually encroaching on the money collected in advance. With the increase in fees and the change of the fiscal year this condition should be remedied. We have foregone a period of six months' revenue, from July 1 to December 31, 1943, but it is felt that the change will justify this loss.

FINANCIAL STATEMENT

PROFIT AND LOSS

June 18, 1943, to December 31, 1943

REVENUE

Back dues.....	\$ 24.00
Sale of back numbers.....	4.50
Bank interest, premium, less charges....	0.58
Redemption of postage on unused cards..	2.25
Donation from John T. Scott, Esq.....	50.00
	————— \$ 81.33

DISBURSEMENTS

Stationery.....	\$ 14.17
Share of cost of printing <i>Contributions to Canadian Mineralogy, 1943</i>	353.30
Postage.....	24.75
	————— \$392.31

Deficit for period.....	\$310.98
Less surplus, June 18, 1943.....	146.01
Deficit at December 31, 1943.....	\$164.97

BALANCE SHEET

December 31, 1943

ASSETS

Cash on hand and in the bank.....	\$248.13
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LIABILITIES

Accounts Receivable	
Prepaid dues at June 18, 1943.....	\$ 30.00
Prepaid dues, June 18-December 31....	22.00
	<u>\$ 52.00</u>
Accounts Payable	
Share of cost of <i>Contributions to Canadian Mineralogy, 1943</i>	\$353.39
Stationery.....	7.71
	<u>\$361.10</u>
	\$413.10
Less Deficit at December 31, 1943.....	164.97
	<u>\$248.13</u>

Examined and found correct,

J. G. DICKENSON,

GEO. E. STEEL,

Auditing Committee

V. BEN MEEN,

Secretary-Treasurer

July 4, 1944.

PROCEEDINGS, 1944

MEETING OF MARCH 2, 1944

Held in Room 64, Royal Ontario Museum, at 5.00 p.m. The retiring President, Professor M. A. Peacock, introduced the new President, Mr. Percy Hopkins, who took the chair.

The Secretary read a recommendation of the Council that the constitution be amended as follows:

1. The wording of the paragraph under "*Meetings*" (1938, p. 84; 1939, p. 158), and amended December 9, 1943, be worded to read:

"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."

2. That the paragraph under "*Amendments*" (1938, p. 85) be worded to read:

"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."

Dr. L. G. Berry moved, seconded by Mr. Frank Ebbutt, that a committee consisting of the President, the Secretary, the Editor, Dr. Jack Satterly, and Professor Ellis Thomson, be appointed to prepare a co-ordinated statement of the Constitution and Amendments for publication in the next issue of *Contributions to Canadian Mineralogy*. Carried.

The President read an invitation from the Department of Mineralogy to attend a lecture on the "Synthesis of Gems" by Dean Edward H. Kraus of the University of Michigan, at 11.00 A.M., March 25, in the Mining Building, University of Toronto. Professor Peacock called attention to the recent literature.

Mr. Frank Ebbutt, Howe Sound Company, New York, gave an address on "Weathered Outcrops of Ore-Bodies," illustrated by Kodachrome slides. He pointed out the characteristics of the weathered outcrops of a number of different ore minerals, and stressed the fact that often there is none of the ore mineral remaining in the exposed region. Mr. Ebbutt was accorded the unanimous thanks of the meeting.

MEETING OF APRIL 27, 1944

Held at 5.00 P.M. in Room 64, Royal Ontario Museum, with the President in the chair.

Second reading was given to the two proposed amendments to the Constitution read at the first meeting. These were passed by the meeting.

It was moved by Dr. J. E. Thomson, seconded by Dr. Jack Satterly, that an Auditing Committee composed of Messrs. George E. Steel and J. G. Dickenson be appointed to audit the books of the Club. Carried.

The Secretary announced the death on March 23 of Benjamin Leonard Thorne, Department of National Resources, Canadian Pacific Railway, Calgary, Alberta. The names of new members and subscribers were then read:

Dr. N. S. Beaton; Deputy Minister of Mines, Ontario; Dr. M. H. Frohberg; Mr. R. J. Hamilton; Mr. H. S. Hill; Mr. F. A.

Killer; Library, Dept. of Mines, B.C.; Mr. R. M. Thompson; Mr. P. A. R. Winstall; Mr. E. A. Trevor.

Professor M. A. Peacock addressed the meeting on the subject "Three Years of Mineralogy: A Review based on *Mineralogical Abstracts*." He gave an analysis of the abstracts (1938-40) of papers proposing new mineral names, to show the distribution of research in descriptive mineralogy, by countries and periodicals, in a typical pre-war period. Professor Ellis Thomson expressed the thanks of the Club to the speaker.

MEETING OF OCTOBER 26, 1944

Held at 5.00 P.M., in Room 64, Royal Ontario Museum, with the President in the chair.

The Secretary announced the deaths of four members since the previous meeting:

William Foster Green, M.A., Provincial Assayer, Province of Ontario, died August 16.

Mathew Fraser Fairlie, B.Sc., Consulting Mining Engineer, died August 19.

Joseph Ellis Thomson, B.A.Sc., Ph.D., F.R.S.C., Head of the Department of Mineralogy, University of Toronto, died September 26.

Wilbert E. Johnston, M.A.Sc., Ph.D., Mill Superintendent, Macassa Mines, Limited, Kirkland Lake, Ontario, died October 12.

Professor A. L. Parsons moved, seconded by Dr. J. Satterly, that the Club adopt the following resolution:

"With the sudden death on September 26, 1944, of Professor Joseph Ellis Thomson, B.A.Sc., Ph.D., F.R.S.C., the Walker Mineralogical Club has lost a Charter Member, a Councillor, and a Past-President who worked unceasingly to promote the welfare of the Club. Suitable memorials will be published in the transactions of national and international societies of which he was a member, but at this time the members of the Walker Mineralogical Club wish to give expression to their feeling of sadness and a sense of personal loss in the passing of Professor Thomson. His counsel, his lucid discussion of papers, and over all his cordial greeting, will be sadly missed at our meetings. The Club extends to Mrs. Thomson their most heartfelt sympathy in her bereavement and

directs that a copy of this resolution be inscribed in the minutes and that the Secretary be instructed to send a copy of the same to Mrs. Thomson." Carried.

The Secretary reported that the Council proposed the following candidates for office in 1945:

<i>President</i>	Mr. FRANK EBBUTT
<i>Secretary-Treasurer</i>	Professor V. B. MEEN
<i>Editor</i>	Professor M. A. PEACOCK
<i>Councillor for Ordinary Members, 1945-7</i>	Dr. L. G. BERRY
<i>Councillor for Department of Mineralogy</i>	Dr. E. W. NUFFIELD
<i>Councillor for Student Members</i>	Mr. R. M. THOMPSON
<i>Auditing Committee</i>	Mr. J. G. DICKENSON
	Mr. G. E. STEEL

As there were no further nominations, it was moved by Professor Peacock and seconded by Mr. J. G. Dickenson, that this proposal be accepted and that the Secretary be instructed to send out ballots to all Members and Subscribing Members; that the poll should close December 12 at 5.00 P.M.; and that the Council be instructed to canvass the ballot and report the results at the December meeting.

The Secretary read the name of one new member: Mr. J. A. Elson. Professor Peacock called attention to new reports and books, with special reference to the first volume of the seventh edition of Dana's *System of Mineralogy*, by Palache, Berman, and Frondel. The President called attention to the appointment of Professor A. L. Parsons as Director Emeritus of the Royal Ontario Museum of Mineralogy.

The Editor, Professor Peacock, reported that the Department of Mineralogy and the Council had decided to change the time of publication of *Contributions to Canadian Mineralogy* from October to a generally more suitable time, namely March, and that therefore there would be no issue until March 1945.

Short addresses were given by four of our members under the title "Short Reports on the Past Field Season."

Mr. A. K. Watt discussed the apatite occurrence known as the MacLaren Mine in Bedford Township, Ontario. He sketched the history of its interrupted operations from about 1890 to the present,

and gave a brief description of the geological relationships. The apatite, usually green and granular, occurs in lenses and occasional crystals, associated with crystals of pyroxene, pink calcite, and hornblende. Specimens were exhibited.

Mr. R. M. Thompson described his work with a party of the Geological Survey of Canada along the 600 mile route of the Canol pipe-line, from Whitehorse, Yukon, to Fort Norman, North West Territories. He described the difficulties of the route and the sparse mineral occurrences which are confined to the west end of the line. He mentioned a number of veins of solid barite in limestone, exposed up to 700 feet in length and 1,500 feet in height. A few small quartz veins containing galena were also seen.

Dr. Jack Satterly reported a few curiosities in an otherwise normal Precambrian area in the Beatty-Munro area, near Matheson, Ontario. He described and showed examples of quartz veins containing axinite, and quartz, epidote and chlorite veins. He described a differentiated sill in which the following rocks were identified from bottom to top: serpentized peridotite, pyroxenite, gabbro. These points are dealt with in greater detail in Dr. Satterly's published report on the area (*Ont. Dept. Mines*, 1944).

Mr. Ebbutt had spent considerable time in northern Manitoba. He commented on the rarity of specimens suitable for museum display. He exhibited some groups of selenite crystals from Lac Dubonnet, Manitoba, which fluoresce with a green colour. In a staurolite schist near Snow Lake he noted that the staurolite crystals are largest and best developed where the metamorphism is least.

Unexpectedly prolonged field work prevented two other members, Dr. M. H. Frohberg and Mr. H. S. Robinson, from contributing their reports. Dr. E. S. Moore expressed the thanks of the meeting to the speakers.

MEETING OF DECEMBER 14, 1944

Held at 8.00 P.M. in Room 26, Mining Building, University of Toronto, with the President in the chair. At this, the Anniversary Meeting, reports were received from the President, the Secretary-Treasurer, and the Editor.

Mr. Percy Hopkins remarked on the pleasure he had had as

President of the Club and expressed the hope that the new President would receive the same co-operation from the Council.

In the absence of the Secretary-Treasurer, Dr. Meen, his reports were kindly read by Dr. E. W. Nuffield. The activities of the year were briefly reviewed, a statement of membership was given, and the financial position of the Club was outlined. It was moved by Dr. Jack Satterly, seconded by Dr. Nuffield, that these reports be accepted. Carried.

The Editor, Professor Peacock, reported that he expected that the next issue of *Contributions to Canadian Mineralogy* would be published in March, 1945. He called attention to the circulation of our journal; in addition to approximately 300 copies sent to subscribing Members and Subscribers, a similar number is purchased by the University of Toronto for the Library and exchanged with similar institutions all over the world.

It was reported that the ballot for officers for 1945 (p. 95) had been canvassed and that all the candidates had been elected.

Dr. Nuffield read a letter from Mrs. Ellis Thomson thanking the Club for its sympathy expressed in the form of a resolution at the third meeting. The name of a new subscriber was read: Mr. D. W. Sullivan. Professor Peacock called attention to the recent literature and mentioned the anticipated second printing of the recently published first volume of the seventh edition of Dana's *System of Mineralogy*.

Professor Peacock then read a letter from our member, Dr. J. D. H. Donnay, Hercules Powder Company, Wilmington, Delaware, in which he reported the complete destruction of the Mineralogical Museum of the University of Liège by the enemy. In this letter Dr. Donnay put the following motion:

"That a Canadian Committee be appointed by the Club, for the restoration of the Liège Mineralogy Museum, and that close contact be maintained with the similar U.S. committees." Professor Peacock mentioned that Dr. V. B. Meen, Director of the Royal Ontario Museum of Mineralogy, had already indicated that he would co-operate, and he appealed to other members who had specimens to save them for this worthy cause. The motion was seconded by Dr. Jack Satterly. Carried.

Dr. F. Gordon Smith, Special Lecturer, Department of Geology,

University of Toronto, then gave a lecture-demonstration on "Fluorescence in Minerals" (p. 41), illustrated by some striking examples of natural and artificial phosphors. Mr. Hopkins expressed the thanks of the audience to the speaker for his excellent address.

All members were advised by letter in January of the amendments to the Constitution passed at the December meeting (1943) and were requested to indicate their choice of category, as Subscribing Member, Member, or Subscriber. Some of our members have not yet furnished this information.

The membership of the Club as on December 31, 1944, is as follows:

Honorary Members.....	3
Subscribing Members.....	170
Members.....	19
Subscribers.....	35
Student Subscribing Members.....	3
Category not yet chosen.....	82
	312

At present, thirty-two members are known to be on Active Service and in addition a number of our members in civilian positions are attached to a branch of the Armed Services. Thirty members have resigned during the year. These are: P. E. Auger, M. W. Bartley, F. J. Bowley, A. F. Brigham, A. M. Campbell, F. M. Chace, P. A. Chubb, W. E. Clark, L. H. Cole, T. C. Denis, J. S. DeLury, V. L. Eardley-Wilmot, V. H. Emery, A. G. Fleming, O. B. J. Fraser, G. E. Goodspeed, M. C. Haller, W. A. M. Hewer, I. W. Jones, N. B. Keevil, M. Kerr, S. Laing, H. C. McCloskey, J. G. MacMillan, B. Neilly, V. J. Okulitch, T. H. Rea, C. D. Stevenson, C. H. Stockwell, W. T. Turrall. As detailed earlier in this report, five of our members have died during the year.

The year 1944 has been financially successful. The loss of \$164.97 at December 31, 1943, has been made up and at December 31, 1944, we have a surplus of \$11.05, with all accounts paid. We can ascribe our better position directly to the increased dues. Subscriptions for 1944 have been carried forward to 1945, since there was no issue of the journal in 1944.

We are indebted to the Royal Ontario Museum for permission to hold our meetings in that building.

FINANCIAL STATEMENT

PROFIT AND LOSS

January 1, 1944, to December 31, 1944

REVENUE

Members' dues.....	\$166.50
Back dues.....	46.00
Sale of back numbers.....	18.50
Bank premium, interest, less charges....	3.33
Unaccounted for.....	.50
	\$234.83

DISBURSEMENTS

Stationery.....	\$ 27.21
Postage.....	28.75
Bank charges.....	.35
Room rent, December 14, University of Toronto.....	2.50
	\$ 58.81

Surplus for period.....	\$176.02
Less Deficit at December 31, 1943.....	164.97
Surplus at December 31, 1944.....	\$ 11.05

BALANCE SHEET

December 31, 1944

ASSETS

Cash on hand and in bank.....	\$258.55
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LIABILITIES

Accounts Receivable	
Prepaid subscriptions	
1944 transferred to 1945.....	\$182.50
1946, etc.....	30.00
Prepaid dues.....	23.00
Money on account.....	12.00
Surplus at December 31, 1944.....	11.05
	\$258.55

Examined and found correct,

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

V. BEN MEEN,
Secretary-Treasurer

January 12, 1945.

NOTICE

The annual *Contributions to Canadian Mineralogy* from the Department of Mineralogy and Petrography, University of Toronto, and the Walker Mineralogical Club, are non-consecutive numbers of the *Geological Series of the University of Toronto Studies*. The *Contributions* are published about the end of March and sent to Subscribing Members of the Walker Mineralogical Club (\$2.00 per annum payable to the Secretary-Treasurer, Professor V. B. Meen, Department of Mineralogy and Petrography, University of Toronto, Toronto 5, Canada) and to Subscribers (\$1.00 per annum payable to the Secretary-Treasurer). Back numbers (see back cover), with a few exceptions, may be obtained from the Secretary-Treasurer.

The previously published numbers of *Contributions to Canadian Mineralogy* may be conveniently bound in three volumes:

Volume 1: 1921 (No. 12), 1922 (No. 14), 1923 (No. 16), 1924 (No. 17), 1925 (No. 20), 1926 (No. 22), 1927 (No. 24), 1928 (No. 27), 1929 (No. 28), 1930 (No. 29) with Index, 1921-1930.

Volume 2: 1931 (No. 30), 1932 (No. 32), 1933 (No. 35), 1934 (No. 36), 1935 (No. 38), 1936-1937 (No. 40) with Index, 1921-1937.

Volume 3: 1938 (No. 41), 1939 (No. 42), 1940 (No. 44), 1941 (No. 46), 1942 (No. 47), 1943 (No. 48) with Index, 1938-1943.

The conduct of *Contributions to Canadian Mineralogy* is in the hands of the Editor, Professor M. A. Peacock, Department of Mineralogy and Petrography, University of Toronto, Toronto 5, Canada, in consultation with the Council of the Walker Mineralogical Club. There is a general invitation for manuscripts on topics relating to Canadian Mineralogy, to be published as regular articles or mineralogical notes. Authors may find recent issues of the *Contributions* helpful as a guide in preparing text, illustrations, and references. Material for publication in March should reach the Editor not later than November 30 of the preceding year. Fifty reprints with covers of each paper are provided free. Extra reprints normally cost about 50 cents per page per hundred.

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