University of Toronto Studies

Geological Series, No. 44

CONTRIBUTIONS TO CANADIAN MINERALOGY, 1940

From the
DEPARTMENT OF MINERALOGY AND PETROGRAPHY
UNIVERSITY OF TORONTO
and the
WALKER MINERALOGICAL CLUB

THE UNIVERSITY OF TORONTO PRESS
TORONTO, CANADA
1940

London:
HUMPHREY MILFORD
Oxford University Press

TABLE OF CONTENTS

STUDIES OF MINERAL SULPHO-SALTS: III—BOULANGERITE AND "EPIBOULANGERITE"

By L. G. Berry
University of Toronto

Boulangerite (Thaulow, 1837) is described in Dana (1892, p. 129) as a metallic, bluish lead-grey mineral with the composition $3PbS.Sb_2S_3$, occurring in plumose, granular, and compact aggregates; specific gravity 5.75-6.0. Lacking crystallographic data this characterization of boulangerite is incomplete and hardly sufficient to distinguish the mineral from several other naturally occurring sulphides of lead and antimony.

The formula $3PbS.Sb_2S_3$ was obtained by Boulanger (1835) and apparently confirmed in the earlier descriptions by Thaulow (1837), Hausmann (1839), Rammelsberg (1839, 1846, 1875), and others. However, Sjögren (1897) analysed boulangerite from Sala, Sweden, and derived the formula $5PbS.2Sb_2S_3$ which, he showed, satisfied many of the earlier analyses better than the earlier formula. Shannon (1918) proposed the name *mullanite* for a presumably new mineral with the composition $5PbS.2Sb_2S_3$, from Mullan, Idaho. Later Shannon (1921a) realized that this composition was actually the most recently established composition of boulangerite, which he confirmed by several new analyses.

The existing morphological data on boulangerite, given by Sjögren (1897) and Shannon (1918, 1921b), were obtained on striated needles with poor terminations. Both observers gave orthorhombic elements which show no simple relations:

$$a : b : c = 0.5527 : 1 : 0.7478 \text{ (Sjögren, 1897)}$$
$$a : b : c = 0.5038 : 1 : 0.6862 \text{ (Shannon, 1921b)}$$

Hiller (1938) likewise proposed an orthorhombic lattice cell from x-ray powder photographs together with a rotation about the needle axis:

$$a_0 : b_0 : c_0 = 4.4478 : 1 : 3.6890 \text{ (Hiller, 1938)}$$

Although certain partial relations can be found between these ratios and the monoclinic ratio obtained by the single crystal x-ray measurements described in this paper, complete correspondence cannot be found in any of the three cases. This appears to be due to the poor development of the crystals on which the geometrical ratios were obtained and the inadequacy of the *x*-ray methods by which the structural cell was determined.

In the course of a study of jamesonite (1940), many specimens bearing this name were found to be boulangerite. A study of the latter species was therefore undertaken with a view to improving the description of this mineral and establishing the essential differences with jamesonite.

MATERIALS AND ACKNOWLEDGMENTS

The following materials, which include several previously analysed specimens, all gave the characteristic *x*-ray powder pattern of boulangerite, which is easily distinguishable from that of jamesonite. The original name, as given on the label, is retained for each specimen.

1. Boulangerite (United States National Museum, 93760), Gold Hunter Mine, Mullan, Idaho; fine needles and prisms with sphalerite, siderite, and quartz. This is the mineral described as "mullanite" by Shannon (1918) and later identified as boulangerite (1921a, b).

2. Boulangerite (U.S.N.M., 93895), Iron Mountain Mine, Superior, Montana; curved needles and fibrous aggregates in quartz. Described by Shannon (1918, 1921a, b).

3. Boulangerite (U.S.N.M., 96040), Independence Mine, Wood River District, Idaho; curved fibrous aggregate with pyrite in quartz. Analysed by Shannon (1921a).

4. Boulangerite (U.S.N.M., 83983), Príbram, Bohemia; compact and granular material. Analysed by Shannon (1921a).

5. Boulangerite (U.S.N.M., 47005), Oberlahr, Germany; powdered mineral, part of sample analysed by Shannon (1921a).

6. Boulangerite (Harvard Mineralogical Museum, 11443), Oruro, Bolivia; long, very fine, brilliant, metallic needles.

7. "Jamesonite," Sullivan Mine, Kimberley, British Columbia; long, very fine needles.

8. "Jamesonite" (University of Toronto, Department of Geology, Pb 1-2), Sullivan Mine, Kimberley, British Columbia; curved fibrous aggregate with galena in schist.

9. "Epiboulangerite" (Royal Ontario Museum of Mineralogy, M/11623), Altenberg, Silesia; fine needles in calcite gangue.

10. "Geocronite" (R.O.M.O.M., M/19055), Rocker Gulch Placer Claim, near Deer Lodge, Montana; fine needles and fibrous aggregate with a black cleavable mineral.

11. Boulangerite, Cleveland Mine, Stevens Co., Washington; fine needles and prisms and fibrous aggregates.

12. "Jamesonite" (University of Toronto, Department of Mineralogy, A/2204 and polished section B.3.7.6), Silver Cup, New Hazelton, British Columbia; fine fibrous aggregate.

13. "Jamesonite" (U.T., Dept. Min., A/1196), Příbram, Bohemia; fine hair-like crystals with calcite.

14. "Jamesonite" (U.T., Dept. Min., A/1467), Silver City, South Dakota; fibrous aggregate with quartz.

15. "Jamesonite" (U.T., Dept. Min., E/1345), Hungary; fine hair-like crystals with calcite.

16. "Jamesonite" (U.T., Dept. Min., polished section B.3.3.4), Portland Canal, British Columbia; fine needles in dark brown sphalerite.

17. "Jamesonite" (U.T., Dept. Min., polished section B.3.3.3) Deadwood, South Dakota; compact fibrous aggregate with quartz.

18. "Jamesonite" (U.T., Dept. Min., polished section A.2.1.4), Glacier Creek, British Columbia; compact fibrous aggregate.

19. Boulangerite (U.T., Dept. Min., A/1779), Oberlahr, Prussia; very fine fibrous aggregate.

20. "Jamesonite" (U.T., Dept. Min., E/530), New South Wales; fibrous aggregate.

21. Boulangerite, lot 12, concession VIII, Barrie Township, Frontenac Co., Ontario; curved fibrous aggregate in quartz. Recorded as jamesonite by Hoffmann (1892, p. 30).

22. "Stibnite" (U.T., Dept. Min., E/334), New South Wales; fibrous aggregate.

23. "Jamesonite" (U.T., Dept. Min., E/531), East Kootenay, Vermont Creek, British Columbia; granular material with galena.

For the use of the majority of these materials my cordial thanks are due to Professor A. L. Parsons, Royal Ontario Museum of Mineralogy, and Professor Ellis Thomson. Dr. Harry Berman kindly provided the material from the Harvard Mineralogical Museum together with some samples from specimens lent to him by Dr. W. F. Foshag, United States National Museum. The material from British Columbia was contributed by Professor H. V. Warren, University of British Columbia. I am also indebted to Professor M. A. Peacock for many helpful suggestions in the course of this work and in the preparation of this paper.

PHYSICAL PROPERTIES

Boulangerite occurs in fine needle-like crystals in vugs, curved fibrous aggregates in quartz, flexible hair-like crystals, plumose masses, and compact aggregates. The mineral is lead-grey in colour, somewhat lighter than most specimens of jamesonite, with a dull to brilliant metallic lustre.

The following table gives some of the published specific gravity measurements, together with three new measurements on the material used for *x*-ray work and the value calculated from the cell data.

TABLE 1.—BOULANGERITE: SPECIFIC GRAVITY

Locality	Sp. gr.	Observer
Molières, France	5.97	Boulanger (1835)
Nertschinsk, Siberia	5.688 5.726 5.941	Hausmann (1839)
Oberlahr, Germany	5.813	Rammelsberg (1839)
Sala, Sweden	6.182 6.185 6.188	Sjögren (1897)
Superior, Montana	6.274	Shannon (1921a)
Mullan, Idaho	6.407	Shannon (1921a)
	6.14 6.23 6.32	Berry
	6.21	Calculated

On the whole the measured values are fairly consistent and agree well with the calculated value. The low measured values may well be due to the fibrous character of the measured material. Shannon's relatively high values are difficult to explain; they are not confirmed by the new measurements. The specific gravity of boulangerite is sufficiently higher than that of jamesonite (5.67, calc.) to serve as a means of distinguishing between the two minerals.

The appearance and etch-reactions of boulangerite were studied in polished sections of materials 1, 3, 9, 12, 16, 17, 18. The mineral occurs in long needles or in granular aggregates. It is galena-white and strongly anisotropic with polarization colours: light tan, brown, light blue. Identical etch-reactions were obtained on all the sections: HNO_3, effervesces, etches, and stains dark grey, and is tarnished iridescent by the fumes; HCl, stains faintly grey and is tarnished slightly iridescent by the fumes; KCN, $FeCl_3$, KOH, $HgCl_2$, negative. Positive microchemical tests were obtained for lead, antimony, and sulphur, but not for iron. Thus in polished sections boulangerite may be distinguished from jamesonite by the lack of cross cleavage, the absence of iron, and the negative reaction to KOH.

STRUCTURAL CRYSTALLOGRAPHY

The structural lattice, space group, and cell content of boulangerite were obtained from single crystal *x*-ray measurements on an unterminated needle-like crystal, about 1 mm. long and 0.05 mm. thick from material 1 (Mullan, Idaho). *X*-ray measurements on the other materials were confined to powder photographs which were compared with the pattern of the fully studied specimen.

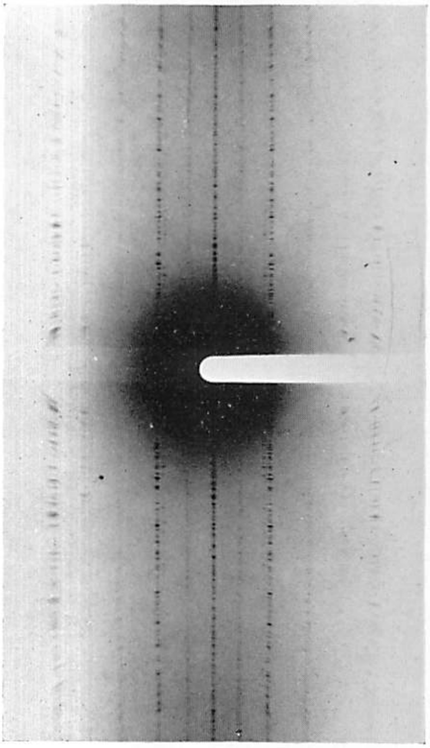
The rotation photograph about the needle axis (Fig. 1) shows the equator and four layer-lines, the even lines being strong, the odd lines very weak. The strong lines alone lead to a lattice period of nearly 4 Å, as in jamesonite. Taking the weak layers into account, and using both the α- and the β-diffractions, eleven values for the period in the needle axis were obtained, giving:

$$c_0 = 8.07 \pm 0.02 \text{ Å}$$

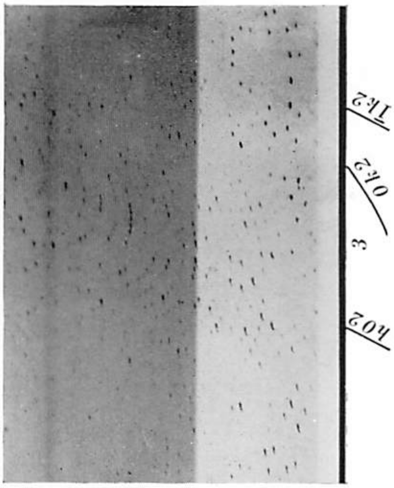
The zero-layer Weissenberg photograph (Fig. 2) about the rotation axis showed orthorhombic symmetry. Reflections were present up to 26 orders of $h00$ and 24 orders of $0k0$, including the orders extinguished by the space-group symmetry and the structure. Eight values for the spacing d_{100} and five for the spacing d_{010} were obtained, giving:

$$d_{100} = 21.14 \pm 0.03 \text{ Å}$$
$$d_{010} = 23.46 \pm 0.03 \text{ Å}$$

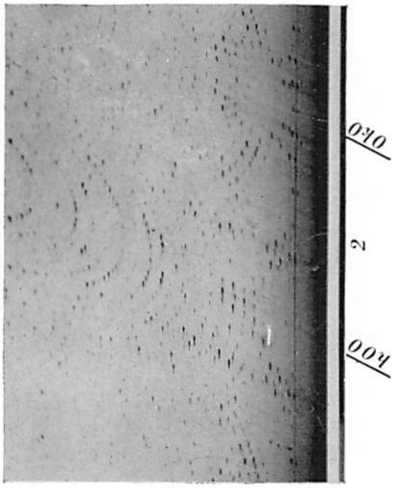
A long exposure (33.2 KWH) Weissenberg photograph of the first (weak) layer line $/hk1/$ gave a weak but distinct pattern showing monoclinic symmetry and an offset sensibly equal to one-half of the reciprocal lattice period a^*. A Weissenberg photograph (Fig. 3) of the second (strong) layer line $/hk2/$ gave a pattern of orthorhombic appearance, the constructed position of the point $(\bar{1}02)$ lying sen-



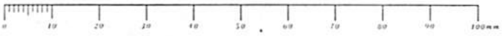
1



3



2



FIGS. 1-3.—Boulangerite; x-ray photographs with unfiltered copper radiation. Radius of camera $= 360/4\pi$mm.

FIG. 1.—Mullan, Idaho (material 1). Rotation photograph about the needle axis $c[001]$; 2.3 KWH.

FIG. 2.—The same. Weissenberg photograph of the zero layer line $/hk0/$; 20.6 KWH.

FIG. 3.—The same. Weissenberg photograph of the second layer line $/hk2/$; 19.5 KWH.

sibly at the centre of the projection. Accepting the offset of the second layer line /*hk*2/ as exactly equal to a^* the monoclinic axial angle β is 100°48′±30′ and the cell dimensions are:

$$a_0 = 21.52 \pm 0.03,\ b_0 = 23.46 \pm 0.03,\ c_0 = 8.07 \pm 0.02\ \text{Å}$$
$$\beta = 100°48' \pm 30'$$

The systematically missing spectra conform to the conditions:

*h*0*l* present only with *h* even
0*k*0 present only with *k* even

These conditions are characteristic for the space group:

$$C_{2h}^{5}\text{—}P2_1/a$$

If the weak first layer /*hk*1/ were neglected the lattice of boulangerite would appear to be orthorhombic—*P* (Fig. 4) with:

$$a_0 = 21.14,\ b_0 = 23.46,\ c_0 = 4.035\ \text{Å}$$

Again, the lattice might be taken as orthorhombic—*B* (Fig. 4) with:

$$a_0 = 42.28,\ b_0 = 23.46,\ c_0 = 8.07\ \text{Å}$$

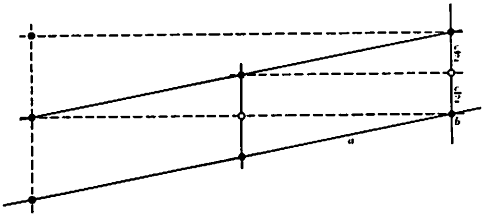


FIG. 4.—Boulangerite; structural lattice. Two simple monoclinic lattice cells are shown in full lines. If the weak layer line /*hk*1/ is neglected the small (simple) rectangular pseudo-cell is obtained. If the lack of orthorhombic symmetry is overlooked the large (side face centred) rectangular pseudo-cell is given. Note: the blank points are not lattice points.

But this interpretation is excluded by the absence of a symmetry plane (100) in the first layer /*hk*1/, and the monoclinic extinction condition, *h*0*l* present only with *h* even.

The structural lattice ratio:

$$a_0 : b_0 : c_0 = 0.917 : 1 : 0.344;\ \beta = 100°48'$$

shows only partial correspondence with the existing geometrical ratios, as already stated. On the other hand, unpublished monoclinic elements, obtained by Professor Charles Palache, Harvard University, on good crystals of boulangerite from a specimen labelled "geocronite" (corresponding to material 10):

$$a : b : c = 0.9158 : 1 : 0.3456;\ \beta = 100°39\tfrac{1}{2}'$$

agree well with the structural ratio.

POWDER PHOTOGRAPHS

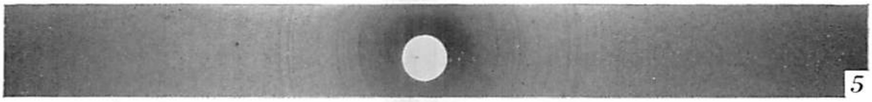
An *x*-ray powder photograph of boulangerite, material 1, yielded the complex pattern shown in Figure 5; powder photographs of all the materials listed gave the same pattern, which is clearly characteristic of the species.

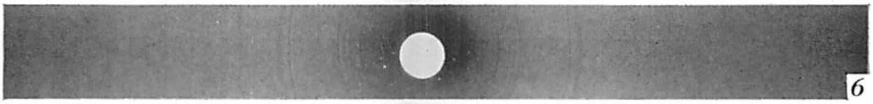
Table 2 gives the *x*-ray powder spectrum of boulangerite indexed as far as $\theta = 33°$ with reference to the cell dimensions given by the single crystal measurements.

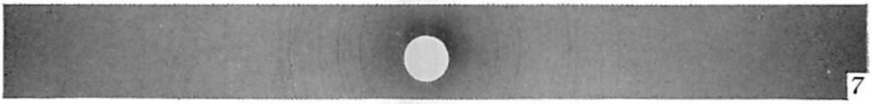
Hiller's orthorhombic cell edges (1938), $a_0 = 17.88$, $b_0 = 4.02$, $c_0 = 14.83$ Å, show no similarity to ours except that his b_0 (needle axis) is about half our c_0 (8.07 Å). It was desirable, therefore, to ascertain whether Hiller's powder photographs with iron radiation were actually made on boulangerite. For this purpose Hiller's θ-values for copper radiation (θ_{Cu}) have been calculated and listed for comparison with our θ-values (Table 2). The obvious agreement shows that Hiller's material, which included the original material analysed by Thaulow (1837) and Rammelsberg (1846), is structurally the same as ours. The lack of agreement in the cell edges is undoubtedly due to the inadequacy of the powder method as a means of finding large cell dimensions.

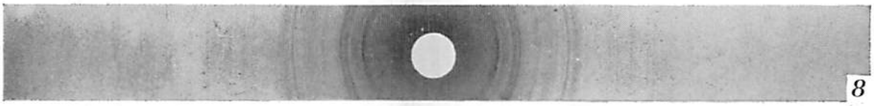
FIGS. 5-14.—Boulangerite; *x*-ray powder photographs with copper radiation, nickel filter. Radius of camera $= 360/4\pi$ mm.

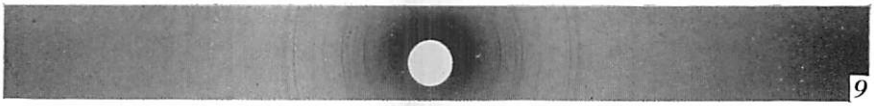
FIG. 5.—Idaho (boulangerite, material 1); 4.8 KWH.
FIG. 6.—Idaho (boulangerite, material 3); 6.5 KWH.
FIG. 7.—Germany (boulangerite, material 5); 5.7 KWH.
FIG. 8.—Silesia ("epiboulangerite," material 9); 4.5. KWH.
FIG. 9.—Montana ("geocronite," material 10); 3.8. KWH.
FIG. 10.—British Columbia ("jamesonite," material 12); 6.4 KWH.
FIG. 11.—Bohemia ("jamesonite," material 13); 6.1 KWH.
FIG. 12.—South Dakota ("jamesonite," material 17); 3.8 KWH.
FIG. 13.—British Columbia ("jamesonite," material 18); 3.4 KWH.
FIG. 14.—Ontario (boulangerite, material 21); 9.9. KWH.


5

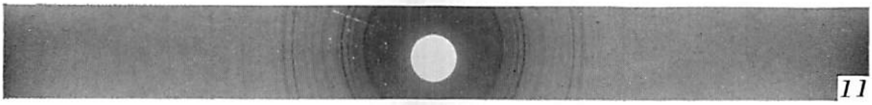

6

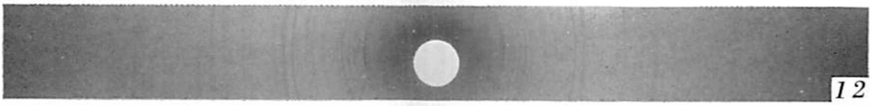

7

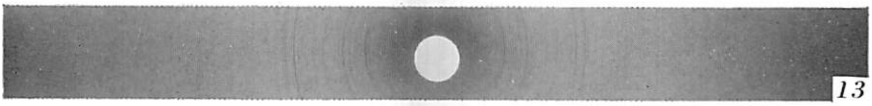

8

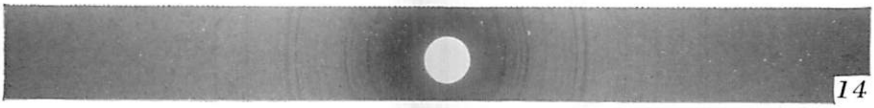

9

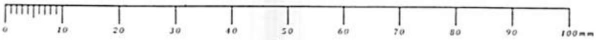

10


11


12


13


14



FIGS. 5-14

TABLE 2.—BOULANGERITE: *X*-RAY POWDER SPECTRUM

						Hiller	
θ_{Cu}	I_P	$d_{meas.}$	*hkl*	$d_{calc.}$	I_W	θ_{Cu}	$I_{P(Fe)}$
..	..	..	..	..	..	10.8	vvw
11.3	vw	3.92	012	3.91	..	11.4	vw
			$\bar{2}12$	3.91	..		
			350	3.91	vs		
11.9	vvs	3.73	022	3.75	..	12.0	s
			$\bar{2}22$	3.75	..		
			112	3.72	vs		
			$\bar{3}12$	3.72	vs		
			530	3.72	vvs		
			260	3.67	vvs		
12.9	vvw	3.44	540	3.43	s	..	..
13.4	vw	3.32	170	3.31	vvs	..	..
13.8	m	3.22	630	3.21	vvs	..	..
			132	3.20	..		
			$\bar{3}32$	3.20	..		
14.8	m	3.01	052	3.03	vs	14.9	m
			$\bar{2}52$	3.03	vs		
			242	3.01	vs		
			$\bar{4}42$	3.01	vs		
15.85	vvs	2.81	$\bar{1}62$	2.81	vvs	15.9	s
			342	2.81	vs		
			$\bar{5}42$	2.81	vs		
			062	2.79	vvs		
			$\bar{2}62$	2.79	vvs		
16.8	w	2.66	352	2.65	m	16.7	m
			$\bar{5}52$	2.65	m		
17.3	vvw	2.58	532	2.51	m	17.3	vw
			$\bar{7}32$	2.51	m		
19.0	vvw	2.36	622	2.37	s	..	..
			$\bar{8}22$	2.37	s		
			490	2.34	vs		
19.3	vw	2.33	182	2.31	s	19.2	m
			$\bar{3}82$	2.31	s		
..	..	..	..	..	..	20.2	m
21.1	w	2.14	722	2.17	s	21.1	m
			$\bar{9}22$	2.17	s		
			4.10.0	2.14	vs		
22.1	w	2.04	802	2.08	vs	22.1	s
			$\overline{10}.0.2$	2.08	vs		
			5.10.0	2.05	s		
			752	2.00	m		
			$\bar{9}52$	2.00	m		
23.1	vvw	1.959	024	1.954	..	23.2	vw
			$\bar{4}24$	1.954	..		

TABLE 2.—*Continued*

						Hiller	
θ_{Cu}	I_P	$d_{meas.}$	*hkl*	$d_{calc.}$	I_W	θ_{Cu}	$I_{P(Fe)}$
23.6	m	1.920	762	1.924	s	23.7	m
			$\bar{9}62$	1.924	s		
			034	1.921	..		
			$\bar{4}34$	1.921	..		
			842	1.918	s		
			$\overline{10}.4.2$	1.918	s		
24.3	vvs	1.868	592	1.860	vs	24.5	vs
			$\bar{7}92$	1.860	vs		
			10.6.0	1.860	vs		
			1.11.2	1.856	s		
			$\bar{3}.11.2$	1.856	s		
..	..	..	..	..	..	25.0	vw
26.0	s	1.753	$\bar{1}.12.2$	1.759	s	26.0	s
			5.10.2	1.758	m		
			$\bar{7}.10.2$	1.758	m		
			8.10.0	1.754	vs		
			0.12.2	1.753	s		
			$\bar{2}.12.2$	1.753	s		
			3.13.0	1.748	vs		
26.4	m	1.729	10.1.2	1.730	vs	..	..
			$\overline{12}.1.2$	1.730	vs		
			11.6.0	1.725	vs		
..	..	..	..	..	..	27.6	vvw
..	..	..	..	..	..	29.1	vvw
..	..	..	..	..	..	30.3	vvw
31.4	w	1.475	12.2.2	1.496	m	31.6	m
			$\overline{14}.2.2$	1.496	m		
..	..	..	..	..	..	32.5	vw
33.0	s	1.411	13.1.2	1.413	vs	33.2	s
			$\overline{15}.1.2$	1.413	vs		
..	..	..	..	..	..	33.9	vw
..	..	..	..	..	..	35.4	vw
36.1	m	1.305	..	..	..	36.4	m
38.1	m	1.246	..	..	..	38.4	s
..	..	..	..	..	..	39.8	vw
..	..	..	..	..	..	41.6	vw
..	..	..	..	..	..	43.3	vw
45.6	m	1.076	..	..	..	46.0	s

θ_{Cu}—Corrected value of the glancing angle, obtained by subtracting 0.2 mm. from the semi-diameter *s*. I_P—Intensity estimated visually. $d_{meas.}$—Planar spacing (Å). *hkl*—Indices of the powder ring. $d_{calc.}$—Planar spacing (Å). I_W—Intensity of the corresponding Weissenberg spot, if in the range of the photographs taken. Hiller, θ_{Cu}—Calculated from Hiller's data. Hiller, $I_{P(Fe)}$—Intensity given by Hiller.

COMPOSITION AND CELL CONTENT

Boulangerite from Mullan, Idaho, corresponding to the material on which the cell dimensions were obtained, was analysed by Shannon (Table 3, column 1). The cell volume and the measured specific gravity (6.23, Berry) give the molecular weight of the cell contents, $M_0=15048$. Combining this number with the analysis we obtain the cell content shown in column 4. Considering the fact that odd numbers of equivalent atoms are excluded by the space group symmetry, the cell content $Pb_{40}Sb_{32}S_{88}=8[5PbS.2Sb_2S_3]$ is rather clearly indicated, confirming the empirical formula first derived by Sjögren and re-established by Shannon. For this cell content the calculated specific gravity is 6.21, in good agreement with the measured value.

TABLE 3.—BOULANGERITE, GOLD HUNTER MINE, MULLAN, IDAHO: ATOMIC CONTENT OF THE UNIT CELL

	1	2	3	4		5
Pb...........	53.33	0.5512	0.002660	40.03		40
Fe...........	1.47	...	...	...		
Sb...........	24.67	0.2550	0.002094	31.51	32.84	32
As...........	0.64	0.0066	0.000088	1.33		
S............	18.11	0.1872	0.005839	87.86		88
	98.22	1.0000				

1. Analysis by Shannon (1921a), including iron as siderite. 2. Analysis reduced to the sum of unity. 3. Atomic proportions. 4. Numbers of atoms in the unit cell, obtained by multiplying the values under 3 by the molecular weight, 15048. 5. Ideal cell content of boulangerite.

A similar discussion of several of the better analyses of materials with measured specific gravity leads to the same formula; and therefore it is permissible to reduce all the better analyses to 88 atoms of sulphur (Table 4) in order to verify the chemical formula.

The average numbers of equivalent atoms again indicate the cell content $Pb_{40}Sb_{32}S_{88}$. The number of Pb atoms is unquestionably 40; the choice for Sb lies between 30 and 32 atoms, the latter being more probable since it is divisible by 8, and gives a formula of the usual double sulphide type.

TABLE 4.—BOULANGERITE: ANALYSES REDUCED TO 88 ATOMS OF SULPHUR

	1	2	3	4	5	6	7
Pb	40.0	42.0	39.5	39.6	39.6	37.4	41.2
Fe	..	..	1.6	..	..	..	0.2
Cu	..	..	..	..	..	..	0.5
Ag	..	..	..	..	..	..	1.2
Sb	29.6	31.2	29.4	30.2	31.2	28.7	31.4
S	88.0	88.0	88.0	88.0	88.0	88.0	88.0

	8	9	10	11	12	13	14
Pb	40.2	43.5	41.6	40.8	41.3	39.8	39.0
Fe	3.9	3.7	1.2	..	..	..	..
Sb	30.2	29.6	34.8	28.5	32.1	31.4	30.0
S	88.0	88.0	88.0	88.0	88.0	88.0	88.0

	15	16	17	18	19	20	21	Average
Pb	40.2	40.0	39.0	40.5	40.2	39.4	40.1	40.2
Fe	..	..	1.2	1.1	..	..	..	..
Sb	30.2	31.6	28.2	30.5	32.0	31.4	31.6	30.9
As	..	..	2.0	0.2	0.5	0.5	1.3	
S	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0

1. Nasafjeld, Lapland; anal. Thaulow (1837). 2. Nertschinsk, Siberia; anal. Bromeis, in Hausmann (1839). 3, 4. Oberlahr, Germany; anal. Abendroth, in Rammelsberg (1839). 5. Wolfsberg, Harz; anal. Rammelsberg (1846, p. 509). 6,7,8,9. Příbram, Bohemia; anal. Bořický, in Zepharovich (1867, p. 32). 10. Echo District, Nevada; anal. Genth (1868, p. 320). 11, 12. Silbersand, Germany; anal. vom Rath (1869, p. 431). 13. Sala, Sweden; anal. Mauzelius, in Sjögren (1897, p. 155). 14. Oberlahr, Germany; anal. Shannon (1921a, p. 597). 15. Příbram, Bohemia; anal. Shannon (1921a, p. 598). 16. Peru; anal. Shannon (1921a, p. 597). 17. North Star Mine, Idaho; anal. Shannon (1921a, p. 595). 18. Independence Mine, Idaho; anal. Shannon (1921a, p. 595). 19, 20. Iron Mountain Mine, Montana; anal. Shannon (1921a, p. 594). 21. Gold Hunter Mine, Mullan, Idaho; anal. Shannon (1921a, p. 593).

"EPIBOULANGERITE"

Websky (1869) proposed the name epiboulangerite for a mineral from Altenberg, Silesia, resembling boulangerite but containing somewhat more sulphur and correspondingly less antimony. Dana (1892, p. 149) accepted epiboulangerite as an independent species with the composition $Pb_3Sb_2S_8$; Guillemain (1898), however, observed that a specimen from the original locality consisted of boulangerite with intergrown galena, and suggested that Websky's epiboulangerite is a similar mixture. Hintze (1904, p. 1041) adopted this view and recorded epiboulangerite under the occurrences of boulangerite.

A polished section of a specimen labelled "epiboulangerite, Altenberg, Silesia" (material 9) was found to consist of needles of a mineral resembling boulangerite, associated with arsenopyrite in calcite. A sample from the needles gave the powder pattern of boulangerite (Fig. 8). This tends to confirm the identity of "epiboulangerite" and boulangerite.

SUMMARY

Unterminated needles of boulangerite, from the Gold Hunter Mine, Mullan, Idaho, are monoclinic; space group, $C_{2h}^5—P2_1/a$; cell edges, $a_0=21.52\pm0.03$, $b_0=23.46\pm0.03$, c_0 (needle axis) $=8.07\pm0.02$ Å; $\beta=100°48'\pm30'$. The unit cell contains $Pb_{40}Sb_{32}S_{88}=8[5PbS.2Sb_2S_3]$. Specific gravity, 6.23 (meas.), 6.21 (calc.).

The structural elements show little correspondence to the existing orthorhombic ratios which appear to have been obtained from poorly developed crystals; they agree well, however, with unpublished monoclinic elements by Palache. Hiller's structural lattice and cell content is not confirmed.

"Epiboulangerite" from Altenberg, Silesia (type locality) and many specimens labelled jamesonite, including all the Canadian examples available, prove to be boulangerite.

REFERENCES

Berry, L. G. (1940): Studies of mineral sulpho-salts: II—Jamesonite from Cornwall and Bolivia—(in press).

Boulanger, C. (1835): Sur un sulphure double d'antimoine et de plomb de Molières, départment du Gard—*Ann. Mines*, vol. 7, pp. 575-582.

Dana, E. S. (1892): *System of mineralogy*, ed. 6—New York.

Genth, F. A. (1868): Contributions to mineralogy—*Am. Jour. Sci.*, vol. 45, pp. 305-321.

Guillemain, C. (1898): Beiträge zur Kenntnis der natürlichen Sulphosalze—Abs. in *Zeits. Kryst.*, vol. 33, pp. 72-78.

HAUSMANN, J. F. L. (1839): Ueber den sogenannten Boulangerit—*Pogg. Ann.*, vol. 46, pp. 281-283.

HILLER, J. E. (1938): Röntgenographische Bestimmungsmethoden und Untersuchung der Bleispiessglanze—*Zeits. Krist.* (A), vol. 100, pp. 128-156.

HINTZE, C. (1904): *Handbuch der Mineralogie*, vol. 1, pt. 1—Leipzig.

HOFFMAN, G. C. (1892): Mineralogical notes—*Geol. Surv. Canada*, Ann. Rep. 1892, vol. 6, pt. R, pp. 24-31.

RAMMELSBERG, C. (1839): Ueber den Boulangerit—*Pogg. Ann.*, vol. 47, pp. 493-496.

——————(1846): Mineralanalysen—*Pogg. Ann.*, vol. 68, pp. 505-518.

——————(1875): *Handbuch der Mineralchemie*, ed. 2—Leipzig.

RATH, G. vom (1869): Mineralogische Mittheilungen—*Pogg. Ann.*, vol. 136, pp. 405-437.

SHANNON, E. V. (1918): On mullanite, a new member of the jamesonite group, from two localities—*Am. Jour. Sci.*, vol. 45, pp. 66-70.

——————(1921a): Boulangerite, bismutoplagionite, naumannite and a silver-bearing variety of jamesonite—*Proc. U. S. Nat. Mus.*, vol. 58, pp. 589-607.

——————(1921b): Additional notes on the crystallography and composition of boulangerite—*Am. Jour. Sci.*, vol. 1, pp. 423-426.

SJÖGREN, Hj. (1897): Om boulangeritens kristallform och kemiska sammansättning—*Geol. För, Förh.*, vol. 19, pp. 153-167.

THAULOW, M. C. J. (1837): Analyse eines Antimonerzes vom Nasafjeld, Lapland—*Pogg. Ann.*, vol. 41, pp. 216-221.

WEBSKY, M. (1869): Ueber Epiboulangerit, ein neues Erz—*Zeits. deutsch. geol. Ges.*, vol. 21, pp. 747-752.

ZEPHAROVICH, V. R. v. (1867): Mineralogische Mittheilungen—*Sitzber. Ak. Wien.*, vol. 56, pp. 19-47.

THE NEW SCHOOL OF MINES IN QUEBEC

By J. D. H. Donnay
Université Laval, Québec, P.Q.

Introduction

Laval University has recently completed a large building to be devoted mainly to mining and geology. This is part of a programme of expansion of its Faculty of Science.

Except for the Faculty of Medicine, which dates back to the foundation of the University, sciences as a whole have been rather neglected in the past. In recent years, however, French Canada has become more and more aware of the importance of scientific studies and research. The School of Surveying and Forestry was founded in 1910, then a School of Chemistry was established in 1920, the rapid and successful development of which is certainly due, in large part, to the vision and efforts of the present Archbishop of Ottawa, His Excellency Mgr Alexandre Vachon. An excellent chemist himself, he not only founded the School of Chemistry, but gradually expanded its scope, so that it became the nucleus of the Faculty of Science, formally established in 1937. Mgr Vachon, after serving as Professor and Director of the School of Chemistry, was made the Dean of the new Faculty and had been the Rector of the University for a few months only, when he was called to his present high position.

Although the loss of a man of his calibre is a severe blow to the institution, the development of scientific studies at Laval University was well under way when he left. Like a tree which, once planted, will continue to grow by itself, the Faculty of Science is proceeding with its organization.

At the present time, in addition to surveying and forestry, the Faculty comprises six departments: mathematics, physics, chemistry, biology, geology and mineralogy, mining and metallurgy. The expansion of the Geology Department and the creation of the School of Mines are recent (1937) and were made possible thanks to the support granted by the provincial Government.

The new building is a large construction, with five main floors and a basement (Fig. 1). A new power plant has also been added. Part of the basement and the first two floors are occupied by mining and metallurgical laboratories. The office of the dean and the administration are also on the second floor, which is the ground floor. The third floor is reserved for the auditorium, general lecture-rooms, drafting-rooms, and library. The fourth floor is the domain of geology and mineralogy. The fifth floor provides for future expansion, one large room being already used for storage of rock and mineral specimens, in ten large steel cabinets with three sets of drawers each. The staircase and a passenger elevator (E_1) are located in the centre of the building; a freight elevator (E_2), in one of the wings, facilitates the handling of rock concentrates in the ore-dressing laboratories and of heavy shipments of minerals or rocks for the Geology Department.

FIG. 1.—The School of Mines, Laval University, Quebec.

The creation of a new centre of teaching and research in which geological and mineralogical sciences have been given a prominent place, may well be considered a contribution to Canadian mineralogy. This is the reason why, at the suggestion of the editor, Professor A. L. Parsons, I am giving this short description of the new school, with special regard to mineralogy.

THE GEOLOGY AND MINERALOGY FLOOR

The principles underlying the design of the floor were the following: (1) To concentrate mineralogy and petrography in one wing, general geology and economic geology in the other, with a common large museum in the centre. (2) To arrange the laboratories in such a manner that they can be used as lecture-rooms as well. (3) To provide each professor with a private research laboratory adjoining his office. The resulting lay-out has proved to be very compact and convenient (see Fig. 2).

The detail of the mineralogy-petrography wing is as follows: Room 1, the office of the mineralogy professor leads to his private laboratory (2); Room 2 has only one window, which is sufficient since most of the work is to be done in darkness or semi-darkness. The professor of petrography has his office in Room 3, next to his private laboratory (4). Across the hall, Room 5 is the graduate students' research laboratory. Room 6 is the combined laboratory and lecture-room for mineralogy, equipped for blowpipe and other chemical work; it communicates with Room 8, the petrography laboratory, reserved for microscope work. At the corner of the L formed by this duplex-arrangement, the thin-section grinding room 7, duly sound-proofed of course, is accessible from both laboratories.

The centre of the building is occupied by the main museum (9), and alcove (9A). Twelve floor show-cases, in the main museum, are arranged in four groups of three, devoted, respectively, to mineralogy, petrography, general geology and paleontology, economic geology. The alcove will be used to house the special collection of Canadian minerals and rocks.

In the geology section (right wing), the two main corners are occupied by the combined laboratory-lecture rooms: general geology (14) and economic geology (10). The office of the general geology professor (12) communicates with his private laboratory (13) and also with the typist's office (11). The two rooms of the economic geology professor are located near the freight elevator (E_2): office (16) and laboratory (15). The central rooms (17 and 18) are used as photographic dark rooms. The wash-room is located in 19. Finally, Room 20 is a spare office, intended for guest scientists or

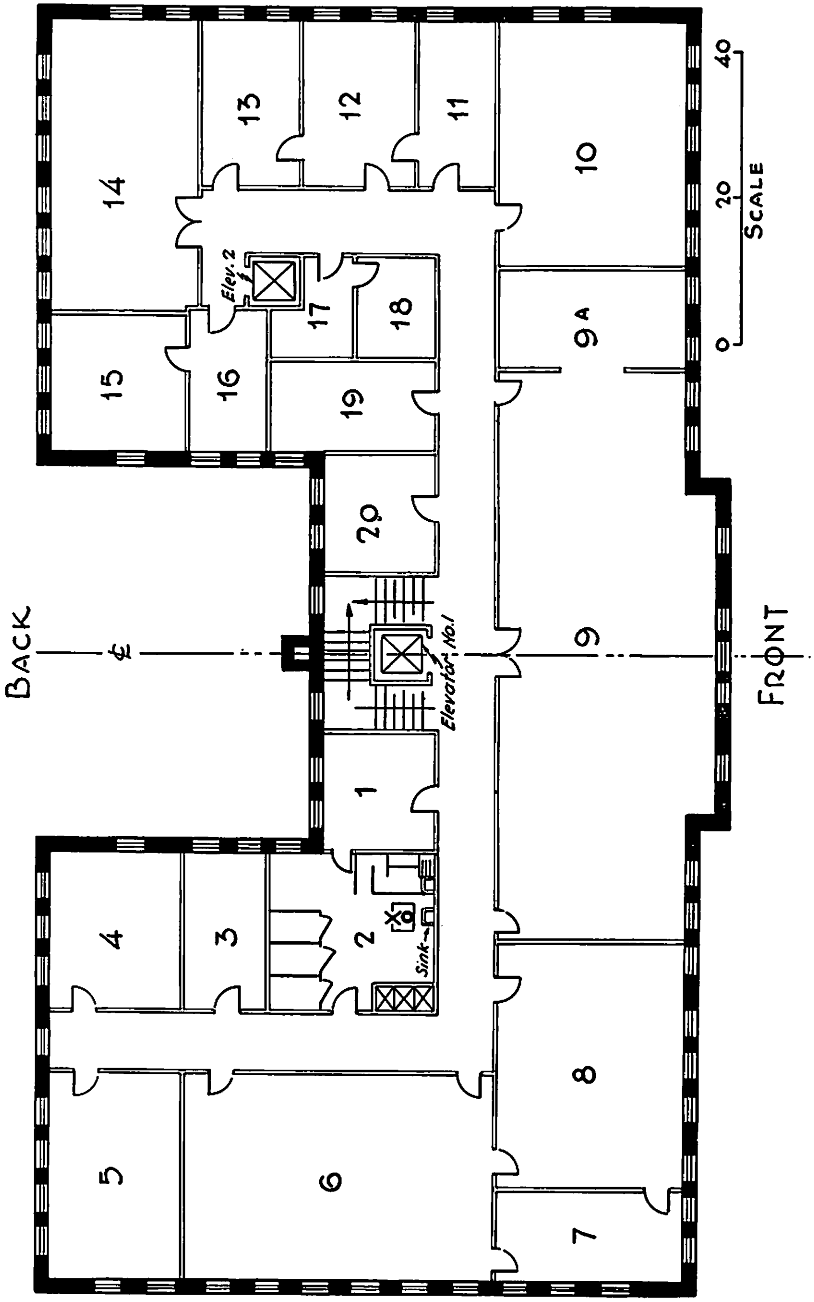


FIG. 2.—Plan of Geology and Mineralogy Floor, School of Mines, Laval University, Quebec.

visiting lecturers, when and if money can be found to establish an annual research fellowship.

In addition to the facilities provided on the fourth floor, the department has also the use of the polished section laboratories, on the second floor. The reason for this is that it was deemed advisable, in a School of Mines, to house chalcography and metallography together. A suite of five rooms is provided for teaching: one for chalcography, one for metallography, with the polishing room in between; a dark-room and a small store-room, next to the metallography room. The research suite comprises a small laboratory, housing the Panphot microscope, with adjoining dark-room, on one side, and small office on the other.

The general lecture-rooms, drafting-rooms, and library, on the third floor, are shared by all departments concerned (mining, geology, and mathematics).

So much for the lay-out. As to equipment, we were fortunate in having it practically complete when the war broke out. A shipment of Leitz microscopes, ordered several months before, was on the last boat that came in from Germany—and nearly escaped with its cargo. Much of our equipment had been ordered in Canada and in the United States.

As to books, the main library of the University gave the Faculty of Science a large number of periodicals, many valuable, complete or nearly complete, sets. The scientific publication of the University, *Le Naturaliste Canadien*, now in its 67th year of existence, also contributes, through its exchanges, to supply the needs of the library.

TEACHING

The geological sciences are part of the mining curriculum. The mathematical background of engineering students anywhere is, of course, better than that of geology students. This facilitates the teaching of crystallography, which is given in the second year to students already acquainted, for instance, with spherical trigonometry and some vector calculus. Of the 25 lectures and 36 hours of laboratory work, about one-half is devoted to crystal morphology and the other half to crystal optics.

Mineralogy and petrography are given in the third year, in the first and second term, respectively. Each subject is covered in 25 lectures and 75 hours of laboratory. General geology (including paleontology) is also a third year subject, given through the year, with 75 lectures and 48 hours of laboratory, exclusive of field trips.

Economic geology is given in the fourth year, through the year, with a total of 75 lectures and 40 hours of laboratory.

After the four years of mining are completed, a fifth year may be devoted to specialization, either in metallurgy or in geology. For geologists, the main requirement besides their advanced courses is geological mapping.

Summer work is compulsory. Surveying courses in the field are given after the first year. The summers following the next two (or three) years are spent in mines, in mills, or in the field, according to the specialty chosen by the student.

In addition to the regular programme of studies outlined above, research facilities are also provided for advanced students.

One point may perhaps be emphasized, regarding the teaching of mineralogy. When our students enter their third year, they have had their course in crystallography, including crystal optics, and they know how to handle a microscope. The teaching of systematic mineralogy can thus be unified, instead of being split into two courses: one on the physical and chemical properties; another on the optical properties, as it is still commonly done, probably for historical reasons, in many universities. The laboratory is conducted in the two adjoining rooms (6 and 8) used simultaneously. Simple physical characters are determined in the mineralogy room (6), where blowpipe and other chemical tests are also carried out; then slides, prepared with fragments of the mineral, are examined in the microscope room (8), away from the grit and fumes of the blowpipe laboratory. This method avoids considerable duplication in teaching and is found to give a satisfactory preparation for the petrography course, which follows in the second term. Twenty individual students' collections of minerals are housed in the blowpipe laboratory. All the drawers are interchangeable and fit a drawer space provided in each student's desk. For each lecture, the student takes the proper drawer and can thus examine the specimens while their description is being given by the professor. In the petrography room, a section cut in the top of the table may be lifted on its hinges, disclosing a lower board with electric outlet, on which the microscope is placed. In this manner, the student sits comfortably with the ocular at a convenient height, on one side, and a writing desk at the correct level, on the other side.

RESEARCH

I shall describe briefly one research laboratory only (room 2), concerned with mineralogy (Fig. 2).

Next to the window there is a table where a Berman specific gravity balance is installed. There also is a Bausch and Lomb binocular microscope, used mainly for preliminary examination and mounting of crystals. Three semi-dark rooms, duly ventilated, are located against the same wall. They are reserved for optical work. One contains a Fuess one-circle goniometer; the second is destined to a two-circle goniometer, now being built for us by Baird Associates in Cambridge, Mass.; the third is equipped with hot and cold water circulation and a mixer to control the temperature of a water cell and of our Zeiss Abbe refractometer; a Leitz research microscope and a sodium vapour lamp complete this installation.

An x-ray unit, built by Baird Associates, occupies part of the opposite wall of the room (Fig. 3). This unit is very compact and simple and has proved very satisfactory. An argon bulb is near the x-ray unit; another is placed in the office (room 1) to permit remote control. A Weissenberg equi-inclination x-ray goniometer, with special attachment for Laue photos, and a Baird powder camera, are used. The crystal carrier fits the Weissenberg and all optical goniometers.

Next to the diffraction unit, a small dark-room for developing x-ray films has been built. It is very compact, yet has a maze-entrance, so that the double door of a light-lock was avoided. In the office, a Marchand calculating machine is available.

The kind help of Messrs. M. A. Peacock, D. Harker, M. J. Buerger, and Baird Associates in installing this laboratory is gratefully acknowledged.

The equipment available makes it possible to investigate most mineralogical problems. Chemical analyses, of course, are made in separate chemistry laboratories.

Mineralogical research in progress deals mainly with problems in crystal morphology, and particularly the relationships between crystal habit and internal structure. A collection of about 3,000 crystals, all measured on the one-circle goniometer, with 36 accompanying note-books of sketches and measurements, was bequeathed to the author by Henri Ungemach, the French mineralogist who died a few years ago. These crystals are now being investigated on the Weissenberg x-ray goniometer, in order to test the reticular constants and the space-group determined by the morphological method.

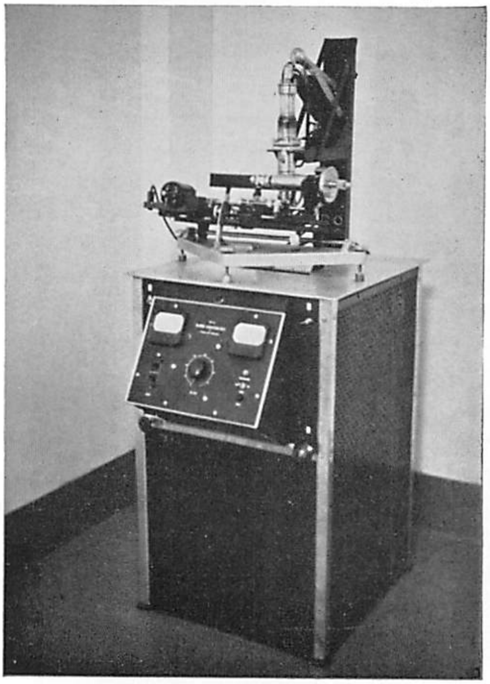


FIG. 3.—The Baird x-ray diffraction unit, with Weissenberg goniometer

Other problems, recently completed or well under way, include the chemical analysis and description of an augite found near Cape

Tourmente; the study of the optical properties of cleavage flakes, mostly in convergent light, as an aid in mineral identification; a new presentation of general extinction tables for the 230 space-groups; the investigation of two crystalline modifications of certain nitrates and the determination of the inversion point.

MUSEUM

The collection of the Quebec Seminary constitutes the nucleus of the new museum. This collection is interesting in many ways, especially in that it contains specimens of old, famous localities, now exhausted. The Department of Geology and Mineralogy deeply appreciate the helpful co-operation of the Quebec Seminary. It has also contracted a debt of gratitude toward the Royal Ontario Museum of Mineralogy and its Director, Professor A. L. Parsons. The latter, keenly interested in fostering the advance of mineralogy in Canada, has kindly granted us exchange privileges at a time when the budding Quebec museum truly had little to offer in return. His help in building up our special Canadian collection cannot be over-estimated. The Royal Ontario Museum can be assured of the grateful support of our department in years to come.

All the members of the mineralogy and petrography staff at Harvard University are also to be listed among our benefactors. We were proud and happy to accept the many beautiful specimens which they generously contributed.

Donations have also been received from other gentlemen, too numerous to mention individually, mainly from the Johns Hopkins University and Stanford University.

It may not be out of place, in closing this description, to say that gifts or exchanges of specimens will always be gratefully considered. Canadian mineralogists, in particular, might put their duplicate specimens to useful work by sending them to the new French outpost of mineralogy in Canada.

ON DYSCRASITE AND ANTIMONIAL SILVER

By M. A. Peacock
University of Toronto

A crystallized mineral composed essentially of silver and antimony was known already to Romé de l'Isle and Werner in the eighteenth century. Early named *antimonial silver* (*argent antimonial*, Haüy, 1801, p. 391; *Silberantimon*, Breithaupt, 1823, p. 119), this mineral received the specific name *dyscrasite* (*discrase*, Beudant, 1832, p. 613, from *δυσκρᾶσις, a bad alloy*), which has been applied to crystallized and massive materials composed of silver with varying proportions of antimony. Andreasberg in the Harz, one of the earliest known localities for dyscrasite, is the source of most of the distinctly crystallized material described in the past and has thus become the type locality for dyscrasite in the sense of the early mineralogists.

The existing analyses of materials referred to dyscrasite (Doelter, 1926, p. 234) range from about Ag 73, Sb 27 per cent, corresponding to Ag_3Sb, to about Ag 84, Sb 16 per cent, giving Ag_6Sb. Dana (1892, p. 42) gives both these formulas without a stated preference, lending some authority for the loose application of the name dyscrasite. However, even the early analyses point to the composition Ag_3Sb for the crystallized mineral from Andreasberg, while seven later analyses, by Liebisch (1910), made on fragments from orthorhombic crystals from Andreasberg, completely establish this composition. The compound Ag_3Sb is, furthermore, the only compound known in the artificial system Ag—Sb (Doelter, 1926, p. 237). The name dyscrasite thus applies to the mineral with the composition Ag_3Sb and is consequently not applicable to materials substantially richer in silver.

The composition Ag_6Sb is actually indicated by only two acceptable analyses, one of which, by Liebisch (1910), represents a "cubic" antimonial silver. Other analyses departing significantly from the composition Ag_3Sb refer to materials which have not been examined in polished sections, or have been clearly recognized as intergrowths of two constituents.

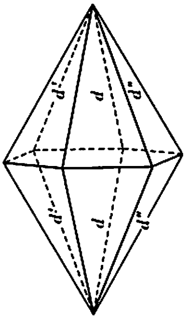
An opportunity to improve the specific description of dyscrasite presented itself in the form of a small specimen (81632) in the Harvard Mineralogical Museum, consisting mainly of a single crystal of dyscrasite from Andreasberg. Although a chemical analysis could not be made on this unique specimen its identity as dyscrasite—Ag_3Sb was indicated by its physical properties and confirmed by an *x*-ray powder photograph which agreed exactly with the powder data given by Machatschki (1928) for dyscrasite from Andreasberg and artificial Ag_3Sb. The specimen from Andreasberg was kindly placed at my disposal by Professor Charles Palache. Further information on some of the materials named dyscrasite from Cobalt, Ontario, was obtained on specimens made available by Professors A. L. Parsons and Ellis Thomson.

DYSCRASITE

Crystal Form and Physical Properties. Dyscrasite commonly occurs in massive, granular or foliated form; distinct crystals are rare and poorly developed. The generally accepted description of the crystal form rests on observations by Hausmann (1847, p. 57), who gave orthorhombic elements which appear to have been derived from the minimum number of measurements, namely two, on crystals from Andreasberg. In a previous attempt to verify these elements the writer found measurable crystals corresponding to Hausmann's description on only one specimen labelled "dyscrasite, Andreasberg." These eventually proved to be crystals of stephanite—Ag_5SbS_4 (1940) which were emplanted on granular dyscrasite or antimonial silver and might well have been taken to represent that mineral. Since there is no correspondence between Hausmann's morphology and the structural results obtained by Machatschki (1928) on dyscrasite and artificial Ag_3Sb, and essentially confirmed in the present work, it seems certain that Hausmann's crystallography was obtained on stephanite associated with dyscrasite.

There is, however, a still earlier crystallographic description of dyscrasite from Andreasberg, by Haidinger (1827, p. 284), which has been neglected in later work. Scanty though it is, this description is interesting since it agrees well with the geometrical and structural observations given later: "The antimonial silver of the

Hartz sometimes occurs in acute six-sided pyramids, Fig. 20, imbedded in, or rather enveloped by, coats of arsenic. These are compound groups. . . . There is a distinct, though not very bright cleavage perpendicular to the axis of the supposed pyramid; but there are also two directions of cleavage, which produce a prism, parallel to the one, whose faces are *d* and *d*, with an angle of about 95½°, contiguous to the apex of that pyramid."



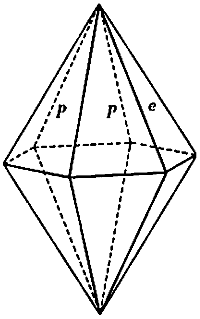


FIG. 1 (left).—Dyscrasite, Andreasberg; reproduction of Haidinger's drawing in the adopted setting.

FIG. 2 (right).—Dyscrasite, Andreasberg; habit of the crystal studied.

Haidinger's Fig. 20 is reproduced in our Fig. 1, with the axis of the "six-sided pyramid" set vertical instead of horizontal, for comparison with Fig. 2 representing the habit of the crystal studied in the present work. In this position Haidinger's description indicates a pseudo-hexagonal orthorhombic crystal formed by the prism *d* twinned on (110) and $(1\bar{1}0)$; cleavages *c* and *d*, with $cd = \frac{1}{2}(180° - 95\frac{1}{2}°) = 42\frac{1}{4}°$.

The crystal on which the present observations were made has the appearance of a rough incomplete hexagonal dipyramid 6 mm. in greatest dimension. One end is attached to a matrix of indistinctly crystallized dyscrasite; the other is blunted by poor end-faces. The crystal is unsuited for goniometric measurements, but the nature of the form and cleavages which it displays could be determined with the help of the orthorhombic axial ratio obtained from *x*-ray measurements on cleavage fragments:

$$a_0 : b_0 : c_0 = 0.5722 : 1 : 0.9225$$

These elements give the following calculated angles which are useful in the present connection:

(010) : (110) = 60°13′
(001) : (011) = 42 41½
(001) : (112) = 42 53
(001) : (021) = 61 32½
(001) : (111) = 61 42
(111) : (1$\bar{1}$1) = 51 52
(111) : (021) = 52 23

The angles show that dyscrasite approaches hexagonal symmetry very closely. The possible forms (011) and (112) together make a pseudo-hexagonal dipyramid; the same is true of (021) and (111). Since the crystal is twinned on (110), as shown by the *x*-ray photographs, refined measurements on excellent material would be necessary to distinguish the quasi-equivalent planes. Our rough crystal offers no opportunity for such measurements. Contact measurements over the edge between the best two adjoining faces gave 49°—53°. The crystal is thus formed by *e* (021) or *p* (111), or a combination of both forms.

As noted by Haidinger there is a basal cleavage, which is easy but rather imperfect, giving an uneven surface interrupted by triangular markings. These are due to the second cleavage observed by Haidinger, which is excellent but somewhat difficult, giving brilliant though slightly warped surfaces owing to the fact that the mineral tends to bend before breaking. This cleavage is in zone with the basal cleavage and an external plane but less steeply inclined to the vertical axis. A good measurement on the reflecting goniometer gave the angle 42°50′ between the basal and the inclined cleavages. This angle agrees with Haidinger's corresponding angle, namely 42¼°, and shows that the second cleavage is either (011) or (112), or a combination of both. Attempts to settle this question by direct observation were inconclusive; the crystal structure given later seems to favour the prismatic cleavage (011), repeated by twinning, as noted by Haidinger, rather than the dipyramidal cleavage (112).[1]

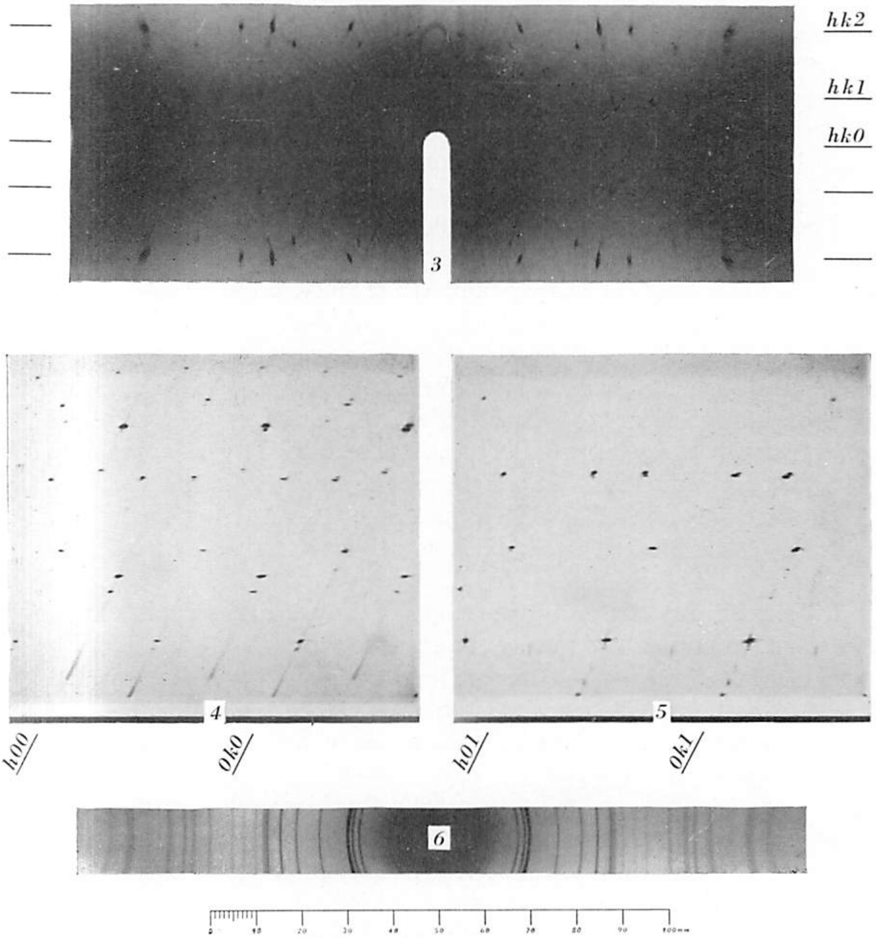
---

[1] The fact that Haidinger found the prismatic cleavage to be parallel to the external form, (011) in our notation, whereas the form of his crystal corresponds to (021) repeated by twinning, cannot be explained.

On freshly broken surfaces dyscrasite is pure silver-white with brilliant metallic lustre. Tarnished surfaces are tin-white to lead-grey. The hardness is $3\frac{1}{2}$. The mineral is scarcely sectile since it deforms slightly and crumbles under a sharp knife. Four measurements of the specific gravity of crystal fragments gave 9.74 ± 0.07 (Berman balance). Seven measurements on crystal fragments from Andreasberg, by Liebisch (1910), gave 9.63—9.82, mean 9.76; Berman (1939, p. 439) obtained 9.82 for Andreasberg.

A polished section of a fragment from the single crystal is pure white under vertical illumination, with no inclusions or visible structure. Crossed nicols reveal faint but distinct anisotropism, light grey to dark grey, and a barely visible jig-saw pattern due to interlocking parts in different optical orientations. This is probably an expression of twinning with irregular twin junctions which might be expected in a crystal whose lattice deviates by only a few minutes from hexagonal form. In one part of the section a few distinct twin lamellae are also visible. Etch reactions: HNO_3, no effervescence; slowly stains grey to black. HCl, negative. KCN, negative. $FeCl_3$, slowly stains iridescent. KOH, negative. $HgCl_2$, slowly stains iridescent. No structure is developed by any of the reagents. These etch reactions are practically the same as those given for dyscrasite blades in an antimonial silver ore from Cobalt, Ontario, by Schwartz (1928, p. 498). The reactions in Short (1934) are less definite, since they refer to a variety of substances composed of silver and antimony.

Crystal Structure. From practically identical x-ray powder photographs on foliated dyscrasite from Andreasberg and artificial Ag_3Sb, Machatschki (1928) derived an hexagonal cell with $a_0 = 2.985$, $c_0 = 4.816$ Å, containing two atoms, or $\frac{1}{2}[Ag_3Sb]$. The systematic extinctions, $(h.h.\overline{2h}.l)$ present only with l even, indicated a structure consisting of equivalent atoms of Ag and Sb (3 : 1) in hexagonal closest packing. This structure was verified by generally good agreement between the observed and calculated intensities of the powder lines. It was concluded that dyscrasite is not a true compound but an alloy Ag_xSb_y similar to the close packed hexagonal phases in artificial systems such as Ag—Zn. In an effort to reconcile this structure with the orthorhombic form and cleavages given for dyscrasite—an effort which could not succeed for the reason already



FIGS. 3-6.—Dyscrasite, Andreasberg; x-ray photographs with copper radiation. Radius of cameras, $360/4\pi$ mm.

FIG. 3.—Rotation photograph about [001] (unfiltered).

FIG. 4.—Weissenberg photograph of the zero-layer /$hk0$/ (unfiltered).

FIG. 5.—Weissenberg photograph of the first-layer /$hk1$/ (unfiltered).

FIG. 6.—Powder photograph (nickel filter); the two rings nearest the centre are due to the mounting wax.

given—Machatschki admitted that the structure might deviate slightly from the proposed hexagonal arrangement but not sufficiently to show in *x*-ray photographs. In this connection it is noteworthy that Machatschki obtained wide outer powder rings which reappeared unchanged in a photograph of material which had been subjected to an annealing treatment.

The first *x*-ray photographs obtained in the present work appeared to confirm Machatschki's findings. The powder photographs, which showed the same diffusion of the outer rings, conformed exactly with the published results. Rotation and zero-layer Weissenberg photographs about the edge between the basal and prismatic cleavages (hexagonal *A*-axis) gave cell dimensions very close to those given.

Rotation and Weissenberg photographs about the normal to the basal cleavage (Figs. 3—5) showed, however, that the structure of dyscrasite does in fact deviate slightly but definitely from the hexagonal arrangement, thereby assuming orthorhombic symmetry. The evidence for this symmetry appears in a number of weak spots (*hk*0) and (*hk*1) which are incompatible with an hexagonal lattice; in easily measurable differences in the θ-values of higher order diffractions such as (060) and (330) which are equivalent in an hexagonal lattice; and in double spots due to near-superposition of such quasi-equivalent diffractions by twinning on (110). The single crystal photographs led to a simple orthorhombic cell with:

$$a_0=2.990,\ b_0=5.225,\ c_0=4.820,\ \text{all} \pm 0.005\ \text{Å}$$

This cell is very nearly the orthohexagonal equivalent of Machatschki's lattice; it contains four atoms, Ag_3Sb, giving the calculated specific gravity 9.75 in good agreement with the observed values (9.76 Liebisch; 9.74, Peacock). Thus dyscrasite is after all a normal compound with a definite composition and an integral cell content.

The observed diffractions in (*hk*0), (*hk*1), and (00*l*), are given below, the weak spots incompatible with hexagonal symmetry being indicated in italics:

—	—	020	—	040	*050*	060
—	110	*120*	130	*140*	150	
200	—	220	—	240	*250*	
—	310	—	330			

—	—	021	031	041	—	061
—	111	121	—	*141*	151	
—	—	221	*231*	241		
—	311					
—	—	002	—	004	—	006

Neglecting the diffractions in italics the systematic omissions conform to the conditions: (hkl) present only with $(h+k)$ even, $(h0l)$ present only with h even and l even; these are the orthohexagonal criteria for hexagonal closest packing. The weak diffractions not conforming to these criteria are evidently due to the non-equivalence of Ag and Sb atoms, which are sufficiently alike in effective radius and scattering power to give essentially a close-packed hexagonal arrangement.

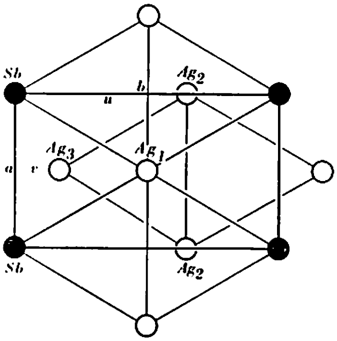


FIG. 7

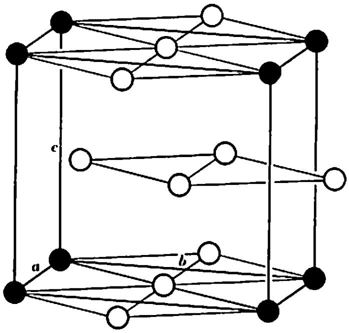


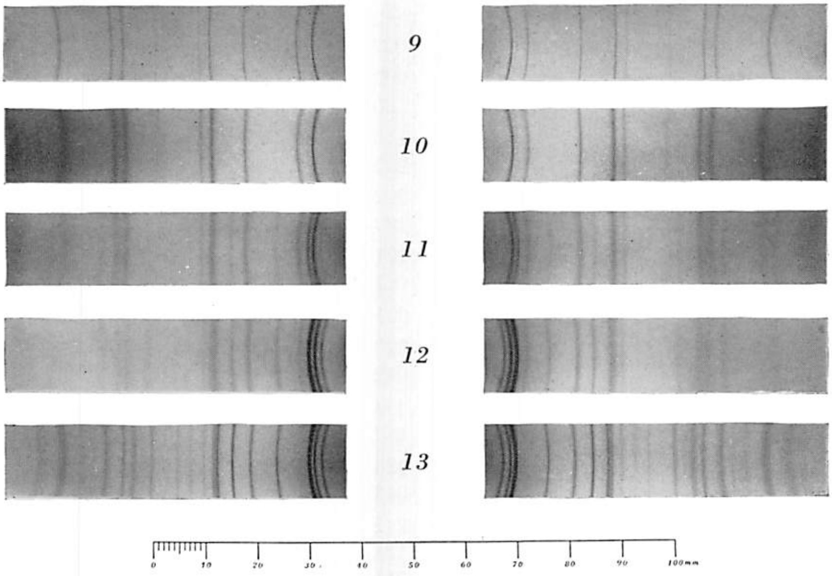
FIG. 8

FIGS. 7, 8.—Dyscrasite; plan and inclined view of the crystal structure.

In an orthohexagonal cell containing four atoms in hexagonal closest packing there is only one way of replacing one atom by a non-equivalent atom, giving the arrangement shown in Figs. 7, 8. Taking an antimony atom as the origin the atomic positions are:

$$\mathrm{Sb}(000);\ \mathrm{Ag}_1(\tfrac{1}{2}\tfrac{1}{2}0),\ \mathrm{Ag}_2(0u\tfrac{1}{2}),\ \mathrm{Ag}_3(\tfrac{1}{2}v\tfrac{1}{2})$$

with $u=\frac{2}{3}$, $v=\frac{1}{6}$. This arrangement gives a simple orthorhombic lattice; (100) and (001) remain mirror planes; but (010), which is a c-glide plane in the hexagonal structure, ceases to be a symmetry plane. Thus the symmetry changes from *Cmcm* to *Pm*2*m*, in which the *b*-axis is polar and consequently there is no centre of symmetry. Owing to the similarity in the scattering powers of Ag and Sb the odd orders of ($h00$) and ($00l$) give very small calculated intensities, explaining the absence of these diffractions.



FIGS. 9-13.—*X*-ray powder photographs with copper radiation (nickel filter); camera radius $360/4\pi$ mm.

FIG. 9.—Pure silver.

FIG. 10.—Antimonial silver with $6\frac{1}{2}$ per cent Sb, Temiskaming Mine, Cobalt, Ontario (polished section in Fig. 14).

FIG. 11.—Intergrowth of antimonial silver with subordinate dyscrasite, Kerr Lake Mine, Cobalt, Ontario (polished section in Fig. 15).

FIG. 12.—Intergrowth of silver-rich dyscrasite with subordinate antimonial silver, Buffalo Mine, Cobalt, Ontario (polished section in Fig. 16).

FIG. 13.—Dyscrasite, Andreasberg.

TABLE 1.—DYSCRASITE: X-RAY POWDER SPECTRUM

s	I_P	$d_{\text{meas.}}$	hkl	$d_{\text{calc.}}$	I_W	$hk\bar{i}l$
17.35 mm.	m	2.61 Å	110	2.60 Å	m	$10\bar{1}0$
			020	2.61	m	
18.7	m	2.43	002	2.41	s	0002
19.8	vs	2.30	111	2.29	s	$10\bar{1}1$
			021	2.30	s	
26.0	m	1.769	112	1.766	s	$10\bar{1}2$
			022	1.771	-	
31.0	m	1.053	200	1.495	s	$11\bar{2}0$
			130	1.505	s	
34.5	s	1.366	113	1.366	s	$10\bar{1}3$
			023	1.369	-	
37.3	m	1.276	202	1.270	-	$11\bar{2}2$
			132	1.277	-	
38.15	w	1.251	221	1.253	s	$20\bar{2}1$
			041	1.261	s	
39.9	vw	1.205	004	1.205	vvw	0004
42.5	vw	1.143	222	1.143	m	$20\bar{2}2$
			042	1.149	-	
44.9	vw	1.094	114	1.093	m	$10\bar{1}4$
			024	1.094	-	
49.75	m	1.011	223	1.009	s	$20\bar{2}3$
			043	1.014	-	
53.0	m	0.966	241	0.964	s	$12\bar{3}1$
			151	0.966	s	
53.6		0.958	311	0.959	s	
55.0	m	0.941	134	0.941	-	$11\bar{2}4$
55.3		0.938	204	0.938	-	
58.5	m	0.904	115	0.904	s	$10\bar{1}5$
			025	0.904	-	
61.0	vw	0.884	224	0.883	m	$20\bar{2}4$
			044	0.886	-	
63.0	vw	0.865	330	0.865	s	$30\bar{3}0$
			060	0.871	s	

Radiation—CuK_α; camera radius—360/4 π mm.; s—semi-diameter of powder ring; I_P—intensity of powder ring; $d_{\text{meas.}}$—spacing given by $\theta = s - 0.25$; hkl—orthorhombic indices; $d_{\text{calc.}}$—orthorhombic spacing; I_W—intensity of the Weissenberg spot, if in the range of the photographs taken; $hk\bar{i}l$—pseudo-hexagonal indices.

Trial calculations showed that u and v are not exactly $\frac{2}{3}$ and $\frac{1}{6}$ respectively, as was expected from the fact that $a : b$ is not exactly $1 : \sqrt{3}$, and Sb is normally larger than Ag. The best agreement was obtained with $u = 0.65$, $v = 0.17$. With these parameters the interatomic distances are:

	Å		Å
Sb—Sb	= 2.99	Ag$_2$—Ag$_2$	= 2.99
Sb—Ag$_1$	= 3.01	Ag$_2$—Ag$_3$	= 2.92
Sb—Ag$_2$	= 3.03	Ag$_1$—Ag$_2$	= 2.94
Sb—Ag$_3$	= 2.97	Ag$_1$—Ag$_3$	= 2.96

In silver the Ag—Ag distance is 2.89 Å; in antimony the Sb—Sb distances are 2.87 Å and 3.37 Å. In dyscrasite the silver atoms are slightly farther apart while the antimony atoms are less crowded than the closer atoms of the element.

Powder Photograph. Although the x-ray powder pattern of dyscrasite (Fig. 6) was not used to find the crystal lattice, a re-interpretation of this pattern will be useful in explaining the generally diffuse nature of the powder lines and in providing a properly indexed pattern for identification purposes. In Table 1 it will be noted that most of the lines correspond to pairs of orthorhombic forms (hkl) with nearly equal calculated spacings; these in turn are equivalent to a single pseudo-hexagonal form ($hk\bar{i}l$). Two of the very diffuse outer lines, corresponding to (12$\bar{3}$1) and (11$\bar{2}$4), separate visibly into pairs on the films. Deformation in grinding may contribute to the diffusion of the lines, but the principal cause appears to lie in the pseudo-hexagonal character of the crystal lattice.

ANTIMONIAL SILVER ORES

Antimonial silver ores, generally called dyscrasite, have been described repeatedly, more recently by Schwartz (1928) who gives references to previous descriptions. Chemically these ores are richer than dyscrasite in silver and in polished sections they are generally inhomogeneous, consisting of two phases: one of these is taken to be dyscrasite—Ag_3Sb, the other silver or a solid solution (mix-crystals) of antimony in silver. From a consideration of the Ag—Sb equilibrium diagram Schwartz gave precision to this interpretation, taking 10 per cent Sb as the limit of solid solution of Sb in Ag. With authentic dyscrasite for comparison it seemed desirable to re-examine a few of these antimonial silver ores, supplementing observations on polished sections by x-ray powder photographs. For this purpose three specimens from Cobalt, Ontario, were used: "dyscrasite" (ROM, M/11132), Temiskaming Mine; "dyscrasite" (B 1.7.2), Kerr Lake Mine; "dyscrasite" (ROM, M/8817), Buffalo Mine. The first two were described by Walker (1921), with analyses by Todd, and notes on polished sections by Thomson; the third evidently does not correspond to the specimen from the Buffalo Mine analysed by Ellsworth (1916, p. 203).

Antimonial Silver. The material from the Temiskaming Mine gave Ag 92.19, Sb 6.78, As 0.45 (Todd). It has a yellowish-bronze colour and is bounded by warped cleavage planes and hackly fracture surfaces. It is harder and tougher than pure silver, bending and breaking with a creaking sound. The x-ray powder photograph (Fig. 10) shows only the pattern of silver (Fig. 9), the lines being somewhat blurred and slightly drawn together. The blurring is not attributed to mechanical deformation in scraping off the test powder, since pure silver gives sharp lines with a similarly prepared sample. The contraction of the pattern is due to an expansion of the silver lattice from $a_0 = 4.076 \pm 0.005$ Å to $a_0 = 4.111 \pm 0.005$ Å, corresponding to the replacement of some of the atoms in the silver structure by the larger atoms of antimony.

The polished section (Fig. 14) is pure white and homogeneous, except for occasional blebs of silver (2 per cent) with enclosed needles of dyscrasite. Under crossed nicols the main mass is distinctly anisotropic, the effect being slightly more evident than that shown by the section of dyscrasite previously described. The whole section (0.5 cm. in diameter) behaves essentially as a single crystal except for a few narrow twin lamellae that mainly follow three directions. Etch tests on the main mass: HNO_3, effervesces slightly, darkens quickly, leaving a white deposit; HCl, negative; KCN, darkens slightly, especially toward the periphery of the drop; $FeCl_3$, tarnishes iridescent; KOH, negative; $HgCl_2$, stains brown and iridescent. The groundmass of the enclosed blebs is quite isotropic; it reacts like the main mass of the section but darkens more readily with KCN. The enclosed needles react like dyscrasite.

The anisotropism of the homogeneous main mass, which contains almost the entire antimony content of the material, may be due to deformation of the cubic silver lattice by the partial replacement of silver atoms by atoms of antimony, giving a nearly cubic rhombohedral lattice. Silver has a face-centred cubic lattice, or a face-centred rhombohedral lattice with $\alpha = 90°$; antimony has a face-centred rhombohedral lattice with $\alpha = 92°53'$. If the distortion of the silver lattice is measured by the proportion of the replacing antimony, antimonial silver with $6\frac{1}{2}$ per cent Sb will have a rhombohedral lattice with $\alpha = 90°11'$. A lattice so nearly cubic would give a cubic powder pattern with slightly blurred lines, as shown in Fig. 10.

This essentially homogeneous material with the structure of silver is a variety of silver to which the name *antimonial silver* may be appropriately applied. From the polished section it appears that $6\frac{1}{2}$ per cent Sb is near the limiting antimony content in natural mix-crystals of Ag, Sb; the material described below clearly shows that 13 per cent Sb is well beyond the limiting value. Since limits of this kind can hardly be accurately set we may accept 10 per cent Sb, given by the Ag—Sb equilibrium diagram, as the maximum antimony content in antimonial silver.

Fig. 14.—Antimonial silver with $6\frac{1}{2}$ per cent Sb, Temiskaming Mine, Cobalt, Ontario; polished section with nicols nearly crossed, showing twin lamellae (*x*-ray powder photograph in Fig. 10); ×66.

Intergrowths of Antimonial Silver and Dyscrasite. The specimen from the Kerr Lake Mine is a mounted polished section representing the material for which Todd obtained the composition: Ag 85.47, Sb 12.99, As 1.12. The x-ray powder photograph (Fig. 11) shows a strong pattern of antimonial silver in which the lines are slightly more blurred and drawn together than in Fig. 10 representing the material with 6½ per cent Sb. This indicates that the main constituent is an antimonial silver with a somewhat larger antimony content and consequently a larger cell edge and a more distorted cubic form. The pattern also shows weak lines corresponding to the strongest lines of pure dyscrasite (Fig. 13). These lines are slightly wider apart as compared with the same lines in dyscrasite, showing that the structure of dyscrasite will tolerate some replacement of Sb by Ag with shrinkage of the lattice. The polished section (Fig. 15) shows sparse rods of arsenic and a network of dyscrasite needles in a more abundant groundmass of antimonial silver. The etch reactions of the two constituents are the same as those described above; the contrast is brought out well by etching with KCN.

FIG. 15.—Intergrowth of antimonial silver (black) with subordinate dyscrasite (white), Kerr Lake Mine, Cobalt, Ontario; polished section etched with KCN; vertical illumination (x-ray powder photograph in Fig. 11); ×66.

The specimen from the Buffalo Mine is a rough, rounded and channelled prism 1¾ inches long and ½ inch thick without determinable faces. The outer surface is lead-grey and the material is brittle. The x-ray powder photograph (Fig. 12) shows a strong and distinctly expanded dyscrasite pattern, indicating that the principal constituent is dyscrasite with somewhat reduced lattice dimensions due to partial replacement of Sb by Ag. The film also shows faint indications of the pattern of antimonial silver. The polished section (Fig. 16) is composed mainly of leaf-like and needle-like areas of dyscrasite in a scanty matrix of antimonial silver.

These observations essentially confirm the previous description of antimonial silver ores from Cobalt. In view of the sharper definitions given to the names dyscrasite and antimonial silver inhomogeneous materials like those from Cobalt are better described as intergrowths of dyscrasite and antimonial silver.

FIG. 16.—Intergrowth of dyscrasite (white) with subordinate antimonial silver (black), Buffalo Mine, Cobalt, Ontario; polished section etched with KCN; vertical illumination (*x*-ray powder photograph in Fig. 12); ×66.

SUMMARY

Dyscrasite, the "bad alloy," is a good compound with the composition Ag_3Sb. A rough crystal from Andreasberg in the Harz gave the following data: Symmetry, orthorhombic; C_{2v}^1—$Pm2m$. Cell edges: $a_0=2.990$, $b_0=5.225$, $c_0=4.820$, all ± 0.005 Å. Cell content: Ag_3Sb. Atomic positions: Sb (000), Ag_1 $(\frac{1}{2}\frac{1}{2}0)$, Ag_2 $(0u\frac{1}{2})$, Ag_3 $(\frac{1}{2}v\frac{1}{2})$, with the approximate values, $u=0.65$, $v=0.17$. Form: pseudo-hexagonal dipyramid, (021) and (111), twinned on (110). Cleavages: (001), imperfect; (011), perfect. Hardness: $3\frac{1}{2}$. Specific gravity: 9.74 (meas.), 9.75 (calc.). Colour: silver-white with strong metallic lustre; tin-white to lead-grey when tarnished.

Polished section: pure white, homogeneous; weakly anisotropic, showing twinning.

Antimonial silver (6.78 per cent Sb) from Temiskaming Mine, Cobalt, Ontario, gives a slightly blurred and contracted silver pattern indicating a nearly cubic lattice with $a_0 = 4.111 \pm 0.005$ Å. Polished section: pure white, nearly homogeneous; distinctly anisotropic, showing twinning.

Antimonial silver ores from Kerr Lake Mine and Buffalo Mine, Cobalt, Ontario, are intergrowths of silver-rich dyscrasite and antimonial silver.

REFERENCES

BERMAN, H. (1939): A torsion microbalance for the determination of specific gravities of minerals—*Am. Mineral.*, vol. 24, pp. 434-440.

BEUDANT, F. S. (1832): *Traité élémentaire de minéralogie*, vol. 2—Paris.

BREITHAUPT, A. (1823): *Vollständische Charakteristik des Mineral-Systems*—Dresden.

DANA, E. S. (1892): *System of mineralogy*, ed. 6—New York.

DOELTER, C. (1926): *Handbuch der Mineralchemie*, vol. 4, part 1—Dresden and Leipzig.

ELLSWORTH, H. V. (1916): A study of certain minerals from Cobalt, Ontario—*Rep. Ontario Bur. Mines*, vol. 25, pp. 200-243.

HAIDINGER, W. (1827): On the regular composition of crystallized bodies—*Edinburgh Jour. Sci.*, vol. 6, pp. 278-287.

HAUSMANN, J. F. L. (1847): *Handbuch der Mineralogie*, vol. 2—Göttingen.

HAÜY, R. J. (1801): *Traité de minéralogie*, vol. 3—Paris.

LIEBISCH, Th. (1910): Über Silberantimonide—*Sitz.-Ber. Preuss. Ak. Wiss.*, pp. 365-370.

MACHATSCHKI, F. (1928): Über die Kristallstruktur des blättrigen Dyskrasites von Andreasberg (Harz) und der künstlich dargestellten Legierung Ag_3Sb—*Zeits. Krist.*, vol. 67, pp. 169-176.

PEACOCK, M. A. (1940): Goldschmidtine identical with stephanite—*Am. Mineral.*, vol. 25, pp. 372-373.

SCHWARTZ, G. M. (1928): Dyscrasite and the silver-antimony constitution diagram—*Am. Mineral.*, vol. 13, pp. 495-503.

SHORT, M. N. (1934): Microscopic determination of the ore minerals—*U.S. Geol. Surv.*, Bull. 825, revision of part 3, determinative tables (mimeographed).

WALKER, T. L. (1921): Dyscrasite from Cobalt, Ontario—*Univ. Toronto Studies, Geol. Ser.*, no. 12, pp. 20-22.

RÖNTGENOGRAPHIC OBSERVATIONS ON ORE MINERALS[1]

By M. A. PEACOCK and L. G. BERRY
University of Toronto

The following notes constitute a summary report of mineralogical observations and conclusions based on *x*-ray measurements on ore minerals, made in the Department of Mineralogy during the period December, 1938—May, 1940. An account of the use of *x*-rays in mineralogy and a sketch of the apparatus used for this purpose was given recently (1939). For those who are unfamiliar with the subject, the essential applications of *x*-ray measurements to mineralogy, as illustrated in these notes, may be concisely stated.

Determination of the Symmetry, Dimensions, and Atomic Content of the Unit Cell. A mineral species may be defined as a natural substance occurring as an assemblage of atoms of a particular kind or kinds in a special periodic arrangement. The periodic nature of the arrangement gives crystalline character and crystal form; the special periodic arrangement in a single species is expressed in constancy of crystal form; the fact that the arrangement consists of atoms of a particular kind or kinds results in constancy of chemical composition.

Classical mineralogy recognized constancy of crystal form and constancy of chemical composition as the fundamental attributes of a mineral species, and stated these properties as precisely as was possible for each species. The crystal form was given by a geometrical ratio ($a : b : c, \alpha\ \beta\ \gamma$) defining the geometrical form of a parallelepiped outlined by eight identical points in the periodic arrangement; the chemical composition was given by a chemical ratio (R_mS_n. . .) stating the kinds and numerical proportions of the constituent atoms.

X-ray measurements on single crystals yield, in the first place, the actual array of identical points in the periodic arrangement. In this array we can select a unique parallelepiped, namely the smallest

---

[1] Some of these observations were given in an address by M. A. Peacock, A. S. Dadson, V. B. Meen, L. G. Berry, and J. S. Allen, to the Walker Mineralogical Club, Toronto, April 11, 1940.

that possess the full symmetry of the arrangement; this is called the unit cell which is defined by the cell elements ($a_0\, b_0\, c_0,\ \alpha\ \beta\ \gamma$), where $a_0\, b_0\, c_0$ are in absolute units of length (cm.$\times 10^{-8}$).

The single crystal photographs also indicate the symmetry of the arrangement. They always give the "aspect" (Donnay and Harker, 1940), 97 possibilities; occasionally they give the space group, 230 possibilities, which also defines the class, lattice and system of classical crystallography. The surest determination of the space group rests on morphological and structural considerations.

The volume of the unit cell together with the specific gravity and the chemical analysis of the crystal leads to the content of the unit cell in actual numbers of atoms.

Thus the symmetry, dimensions, and atomic content of the unit cell exactly define the special periodic arrangement of particular atoms proper to a mineral species, expressing in absolute terms what classical mineralogy could express, in favourable cases, only in relative terms. In these cases, where the geometrical form and chemical composition of the unit cell were correctly inferred by the older methods, x-ray measurements give confirmation and precision to the definition of the mineral species. In many others, it is found that the form of the unit cell was incorrectly inferred and the contents unhappily expressed; in such cases, appropriate transformation of the geometrical crystallography and reformulation of the composition is desirable.

The symmetry, dimensions, and atomic content of the unit cell have thus become fundamental data of special mineralogy, and the completion of the work of obtaining these data is believed to be of prime importance in present-day mineralogy. The actual atomic arrangement within the unit cell has been determined for many minerals (Bragg, 1937), and work in this direction is progressing in the hands of specialists in crystal structure. These results will lead to further improvements in descriptive and systematic mineralogy; but at present the completion of such work is a more remote objective.

Identification. Röntgenographic observations find a simpler and very practical application in mineral identification. An unknown mineral may be identified conveniently and usually with great certainty by comparing an x-ray powder photograph of the unknown mineral with similar photographs of known minerals. Most minerals give characteristic *x*-ray powder spectra, and usually one can tell at a glance whether two photographs, and consequently the two minerals represented, are identical or not. Members of an isostructural group or series give very similar spectra, but even in such cases careful measurements reveal definite differences. *X*-ray photographs are particularly helpful in identifying the opaque minerals which are, in general, more difficult to recognize in ordinary specimens than the non-opaque minerals.

Choice of Material Studied. The work of revising the last edition of Dana's great *System of Mineralogy* (1892), which is progressing under the direction of Emeritus Professor Palache at Harvard University, is emphasizing the chief deficiencies in the available mineralogical information. These consist of lack of structural information on species of undoubted individuality, and also lack of information on ill-defined substances whose individuality is in doubt. The present work is directed toward filling a few of these gaps, supplying or improving the data on some of the good species, and re-examining some of the doubtful substances with a view to deciding their standing. In this way, we have turned to the ore minerals which are described in the early part of the *System*. Naturally work of this kind centres on the rarer minerals; at the same time, some of our observations bear on common species.

The minerals examined are listed below in alphabetical order. Under these names, nearly all of which are accepted species, misapplied specific names are given in quotation marks, synonyms and names applied to mixtures in italics, misapplied discredited names in italics and quotation marks.

Nature of the Observations. The reported observations consist of determinations of the unit cell made for the first time or believed to correct or improve previous determinations, similar observations leading to useful confirmation of results obtained by others, and a selection of identifications and other notes of interest. Most of the observations in the first group are the röntgenographic parts of more extended mineralogical studies; a few of these have appeared elsewhere, others are in various stages of progress. With possibly a few exceptions the remaining observations will not reappear. The disadvantage of some eventual duplication is perhaps offset by the convenience of having these notes together and immediately accessible.

In the observations that follow the space groups are written in Schoenflies and International notation. The space group given is the most symmetrical group compatible with the observed systematic general extinctions, unless there is evidence for lower symmetry. The values for the cell edges are in Ångstrom units. The cell contents are based on the best available analyses. Cleavage and twinning are noted only if observed. Measurements of specific gravity, without the observer's name, are new. Papers referred to without the author's name are by the author of the descriptive section in which the reference occurs. The several sections are initialled by the responsible author (M.A.P. or L.G.B.). Further observations made in this laboratory have been contributed by V. B. Meen (V.B.M.) and J. S. Allen (J.S.A.), University of Toronto, and by E. D. Taylor (E.D.T.), Université Laval, Québec.

For access to authentic material, without which work of this kind is valueless, we are particularly indebted to Professor A. L. Parsons, who has made many valuable specimens from the Royal Ontario Museum, Toronto (ROM), available for study. Specimens from the collections in the Department of Mineralogy, University of Toronto (UT), include some polished sections kindly lent by Professor Ellis Thomson. For further material our thanks are likewise due to Professor C. Palache and Doctor H. Berman, Harvard Mineralogical Museum, Cambridge, Massachusetts (HMM), Doctor W. F. Foshag, United States National Museum, Washington, D.C. (USNM), Mr. F. A. Bannister, British Museum of Natural History, London (BM), and Professor G. Aminoff, Naturhistoriska Riksmuseum, Stockholm (NRS).

M.A.P.

REFERENCES

BRAGG, W. L. (1937): *Atomic structure of minerals*—Ithaca, N.Y.

DONNAY, J. D. H., and HARKER, D. (1940): Nouvelles tables d'extinctions pour les 230 groupes de recouvrements cristallographiques—*Naturaliste Can.*, vol. 67, pp. 33-69.

PEACOCK, M. A. (1939): *X*-rays in mineralogy: design of a serviceable apparatus—*Univ. Toronto Studies, Geol. Ser.*, no. 42, pp. 79-93.

ANTIMONIAL SILVER

Ag, Sb

Material. "Dyscrasite" (ROM, M/11132), Temiskaming Mine, Cobalt, Ontario (Sb, 6.78 per cent). "Dyscrasite" (UT, B.1.7.2), Kerr Lake Mine, Cobalt, Ontario (Sb, 12.99 per cent).

Results. The first material, which is almost homogeneous and distinctly anisotropic in polished section, gives only the *x*-ray powder pattern of silver. The lines are slightly blurred and slightly displaced giving the pseudo-cubic cell edge:

$$a_0 = 4.111 \pm 0.005$$

as compared with the cube edge:

$$a_0 = 4.076 \pm 0.005$$

measured on pure silver.

The second material shows an intergrowth of antimonial silver and dyscrasite in polished section. The *x*-ray powder photograph shows the pattern of antimonial silver and a weaker pattern of dyscrasite.

The name *antimonial silver* may be used appropriately as a variety name to describe homogeneous mixed crystals Ag, Sb with the structure of silver.

A description of dyscrasite and antimonial silver is given in the present issue of these *Studies*.

M.A.P.

BAUMHAUERITE

$3PbS.2As_2S_3$

Material. "Dufrenoysite" (ROM, M/12326; UT, E/4682; polished section A.1.8.2.), Binnenthal, Switzerland. *Guitermanite* (ROM, M/12330), Zuni Mine, Silverton, Colorado (type locality).

Results. These materials gave identical *x*-ray powder photographs. Single crystal *x*-ray photographs on a cleavage fragment from the Binnenthal, Switzerland, gave preliminary cell data:

Symmetry:	Monoclinic; space group not determined
Cell elements:	$a_0 = 22.69 \pm 0.03$
	$b_0 = 8.29 \pm 0.02$
	$c_0 = 7.86 \pm 0.1$
	$\beta = 96°45' \pm 30'$
Cell content:	$Pb_{12}As_{16}S_{30} = 4[3PbS.2As_2S_3]$
Cleavage:	(100)
Sp. gravity:	5.330 (Solly), 5.43 (calc.)

The cell elements agree well with unpublished values by Hurlbut (*pers. com.*):

$$\text{Space group } C_{2h}^2 - P2_1/m$$

$$a_0 = 22.68,\ b_0 = 8.32,\ c_0 = 7.92,\ (\beta = 97°17')$$

The structural ratio (Berry) compares closely with the morphological ratio of Solly (*Min. Mag.*, **13**, 151, 1902), as corrected by Palache (*Am. Mineral.*, **23**, 821, 1938):

$a_0 : b_0 : c_0 = 2.737 : 1 : 0.948;\ \beta = 96°45'$ (Berry)
$2a : b : c = 2.7374 : 1 : 0.9472;\ \beta = 97°17'$ (Solly)

The cell content given here seems to be indicated rather than $Pb_{12}As_{18}S_{39} = 3[4PbS.3As_2S_3]$, but a new analysis on pure material is desirable to settle this question.

L.G.B.

BOULANGERITE

$5PbS.2Sb_2S_3$

Material. Boulangerite (USNM, 93760), Gold Hunter Mine, Mullan, Idaho (Shannon's *mullanite* = boulangerite). Boulangerite (USNM, 93895), Iron Mountain Mine, Superior, Montana. Boulangerite (USNM, 96040), Independence Mine, Wood River District, Idaho. Boulangerite (USNM, 83983), Příbram, Bohemia. Boulangerite (USNM, 47005), Oberlahr, Germany. Boulangerite (HMM, 11443), Oruro, Bolivia. Boulangerite, lot 12, concession VIII, Barrie Township, Frontenac County, Ontario. *Epiboulangerite* (ROM, M/11623), Altenberg, Silesia. "Geocronite" (ROM, M/19055), Rocker Gulch Placer Claim, near Deer Lodge, Montana. "Stibnite" (UT, E/334), New South Wales. "Jamesonite" from many localities in Canada.

Results. These minerals gave identical *x*-ray powder patterns. Single crystal *x*-ray photographs (USNM, 93760) gave:

Symmetry:	Monoclinic; $C_{2h}^5 - P2_1/a$
Cell elements:	$a_0 = 21.52 \pm 0.03$
	$b_0 = 23.46 \pm 0.03$
	$c_0 = 8.07 \pm 0.02$ (needle axis)
	$\beta = 100°48' \pm 30'$
Cell content:	$Pb_{40}Sb_{32}S_{88} = 8[5PbS.2Sb_2S_3]$
Sp. gravity:	6.14, 6.23, 6.32 (meas.)
	6.21 (calc.)

The structural ratio (Berry) agrees well with unpublished geometrical elements for boulangerite, by Palache (*pers. com.*):

$a_0 : b_0 : c_0 = 0.917 : 1 : 0.344;\ \beta = 100°48'$ (Berry)
$a : b : c = 0.9158 : 1 : 0.3456;\ \beta = 100°39\tfrac{1}{2}'$ (Palache)

A description of boulangerite is given in the present issue of these *Studies*.

L.G.B.

COBALTITE

(Co, Fe, Ni)AsS

Material. Cobaltite (ROM, M/11824), Hackensboda, Vastmanland, Sweden; crystal with (021). Cobaltite (ROM, M/14048), Tunaberg, Södermanland, Sweden; crystal with (001), (111), (021). Cobaltite (ROM, M/14469), Columbus Claim, Cobalt, Ontario; crystal with (111), (001).

Results. These gave very similar *x*-ray powder patterns, yielding the cube edges:

	a_0
Hackensboda	5.551 ± 0.005
Tunaberg	5.574 ± 0.005
Columbus Claim	5.577 ± 0.005

The new values compare with previous measurements as follows:

	a_0	
Tunaberg	5.65 ± 0.02	(Mechling, 1921—*Strukturber.*, 1, 283)
	5.58	(Ramsdell, 1925—*Strukturber.*, 1, 284)
Modum	5.58 ± 0.02	(Zachariasen, 1927—*Strukturber.*, 1, 284)

Existing analyses representing the measured materials indicate various amounts of Fe and Ni in place of Co, accounting for the variations in the cube edge. Similar powder patterns are given by gersdorffite, corynite, ullmanite, kallilite, and willyamite which form an isostructural group.

V.B.M.

CORYNITE

Ni(As, Sb)S

Corynite (ROM, M/12853), Carinthia, Germany (type locality); massive, with concentric structure. The *x*-ray pattern is similar to that of cobaltite but the lines are weak and broad, indicating inhomogeneous material. The cube edge:

$$a_0 = 5.724 \pm 0.005$$

is close to that of some specimens of gersdorffite.

V.B.M.

COSALITE

$2PbS.Bi_2S_3$

Material. Cosalite (ROM, M/11147), Mondoux Claim, McElroy Township, Timiskaming District, Ontario. Cosalite (ROM, M/19544), Cariboo Gold Quartz Mine, Wells, Cariboo District, British Columbia. Cosalite (ROM, M/19545), Island Mountain Mine, Wells, British Columbia. Cosalite (NRS, yellow 4054), Nordmark Mines, Värmland, Sweden. Cosalite (NRS, Coll. Min. Hj. Sjögren, 129), Nordmark Mines, Värmland, Sweden.

Results. Identical *x*-ray powder patterns were obtained from these materials. *X*-ray photographs on a single crystal (ROM, M/11147) gave:

Symmetry:	Orthorhombic; $D_{2h}^{16}-Pbnm$
Cell elements:	$a_0=19.05\pm0.03$
	$b_0=23.82\pm0.03$
	$c_0=$ 4.047 ± 0.01 (needle axis)
Cell content:	(i) $Pb_{14}Cu_2Bi_{16}S_{40}=8[2(Pb, Cu)S.Bi_2S_3]$
	Other analyses indicate essentially:
	(ii) $Pb_{16}Bi_{16}S_{40}=8[2PbS.Bi_2S_3]$
Sp. gravity:	6.76 (Todd; Mondoux Claim)
	6.88 (calc., i); 7.14 (calc., ii).

The geometrical setting of Flink (*Bihang. K. Svenska Vet.-Akad. Handl.*, **12**-2, no. 2, 1886) is related to the structural setting (Berry) by the transformation:

Flink to Berry : $00\frac{1}{2}/100/0\frac{1}{6}0$

The corresponding ratios agree rather poorly:

$$a_0 : b_0 : c_0 = 0.800 : 1 : 0.170 \text{ (Berry)}$$
$$a : b : c = 0.795 : 1 : 0.181 \text{ (Flink)}$$

Descriptions of cosalite were recently given by Berry in these *Studies* (**42**, 23, 1939) and by Warren, in these *Studies* (**42**, 151, 1939).

L.G.B.

DYSCRASITE

Ag_3Sb

Material. Dyscrasite (HMM, 81632), Andreasberg, Harz, Germany (type locality); single crystal (6 mm.). Dyscrasite (ROM, M/8817), Buffalo Mine, Cobalt, Ontario; rough columnar crystal (45 mm.).

Results. The specimen from Andreasberg gives a distinctive *x*-ray powder pattern; the specimen from Cobalt shows also a weaker pattern of antimonial silver.

Single crystal x-ray photographs (Andreasberg) gave:

Symmetry:	Orthorhombic; $C_{2v}^1 - Pm2m$
Cell elements:	$a_0 = 2.990 \pm 0.005$ $b_0 = 5.225 \pm 0.005$ $c_0 = 4.820 \pm 0.005$
Cell content:	Ag_3Sb
Cleavage:	(001), easy but imperfect (011), difficult but good
Twinning:	on (110)
Sp.gravity:	9.74 (meas.), 9.75 (calc.)

The orthorhombic lattice corresponds very nearly to the hexagonal lattice, with $\frac{1}{2}[Ag_3Sb]$ per unit cell, obtained from powder photographs by Machatschki (*Zeits. Krist.*, **67**, 169, 1928):

$$a_0 = 2.985, \ c_0 = 4.816$$

The structural elements show no simple relation to the morphological elements attributed to dyscrasite (Hausmann, *Handbuch Min.*, 57, 1847); these were probably obtained from associated crystals of stephanite (*Am. Mineral.*, **25**, 372, 1940).

A description of dyscrasite and antimonial silver is given in the present issue of these *Studies*.

M.A.P.

GALENA

PbS

Galena. "Kobellite" (HMM, 82436), Red Mountain, Colorado. *Beegerite* (ROM, M/9636), Old Lout's Mine, near Ouray, Colorado. *Lillianite* (ROM, M/4076), Lillian Mines, Leadville, Colorado (type locality). These materials all gave the x-ray powder pattern of galena.

L.G.B.

GALENOBISMUTITE

$PbS.Bi_2S_3$

Material. Galenobismutite (NRS, yellow 3987), Kogrufvan, Nordmark Mines, Sweden (type material). Galenobismutite (ROM, M/19716), Cariboo Gold Quartz Mine, Wells, Cariboo District, British Columbia. "*Lillianite*" (ROM, M/14076), Mt. Farrell, Tasmania. "*Lillianite*" (ROM, M/11826; UT, A.2.3.2), Gladhammar, Sweden (intergrown with galena).

Results. These gave identical x-ray powder photographs. Single crystal x-ray measurements on the type material gave:

Symmetry:	Orthorhombic; $D_{2h}^{16}-Pnam$
Cell elements:	$a_0=11.72\pm0.03$
	$b_0=14.52\pm0.03$
	$c_0=4.07\pm0.02$ (axis of elongation)
Cell content:	$Pb_4Bi_8S_{16}=4[PbS.Bi_2S_3]$
Cleavage:	In the zone [001]
Sp. gravity:	6.96, 7.01, 7.04 (meas., Kogrufvan)
	7.18 (calc.)

The structural ratio (Berry) agrees with the geometrical elements of Flink (*Ark. Kem. Min. Geol.*, 3-35, 13, 1910) for "*lillianite*" =galenobismutite from Gladhammar, Sweden:

$$a_0 : b_0 : c_0 = 0.807 : 1 : 0.280 \text{ (Berry)}$$
$$a : b : \tfrac{c}{2} = 0.8002 : 1 : 0.2727 \text{ (Flink)}$$

A description of galenobismutite and "lillianite" is in press.

L.G.B.

GERSDORFFITE

(Ni, Co, Fe)AsS

Material. Gersdorffite, Sudbury, Ontario; crystal with (111), (001), received from Dr. G. A. Harcourt. Gersdorffite (ROM, M/15861), Garson Mine, Sudbury; crystal with (111), (001). Gersdorffite (ROM, M/12176), Crean Hill, Sudbury; crystals with (001) and (111).

Results. These gave x-ray powder patterns similar to that of cobaltite, yielding the cube edges:

	a_0
Sudbury	5.593 ± 0.005
Garson Mine, Sudbury	5.645 ± 0.005
Crean Hill	5.655 ± 0.005

Previous measurements:

	a_0	
	5.719	(Oldshausen, 1925—*Strukturber.*, 1, 284)
Germany	5.68	(Ramsdell, 1925—*Strukturber.*, 1, 284)
Lobenstein	5.70 ± 0.02	(Zachariasen, 1927—*Strukturber.*, 1, 284)

Analyses of gersdorffite from Sudbury show large and variable amounts of Co and Fe in place of Ni; these elements appear to reduce the cube edge.

V.B.M.

GUANAJUATITE

$Bi_2(Se, S)_3$

Guanajuatite (ROM, M/3773), Guanajuato, Mexico (type locality), gave an *x*-ray pattern similar to, yet distinct from those of bismuthinite and stibnite, and very different from that of artificial Bi_2Se_3.

L.G.B.

JAMESONITE

$4PbS.FeS.3Sb_2S_3$

Material. Jamesonite (HMM, 11501), Cornwall, England. Jamesonite (UT, A/471), Endellion, Cornwall. Jamesonite (ROM, M/14506), Itos Mine, near San Felipe de Oruro, Bolivia. "Heteromorphite (*plumosite*)" (ROM, M/9164), same locality. Jamesonite (BM), Cerro de Ubina, Huanchaca, Potosi, Bolivia. "Zinckenite" (ROM, M/19694), Santa Cruz Mine, Poopo, Bolivia. Also further specimens from Cornwall and Bolivia.

Results. These gave identical *x*-ray powder photographs. Single crystal *x*-ray photographs on a needle from Bolivia (ROM, M/14506) gave:

Symmetry:	Monoclinic; $C_{2h}^5 - P2_1/a$
Cell elements:	$a_0 = 15.68 \pm 0.05$
	$b_0 = 19.01 \pm 0.05$
	$c_0 = 4.03 \pm 0.01$ (needle axis)
	$\beta = 91°48' \pm 30'$
Cell content:	$Pb_8Fe_2Sb_{12}S_{28} = 2[4PbS.FeS.3Sb_2S_3]$
Cleavage:	(001), good; (120), good
Twinning:	On (100)
Sp. gravity:	5.61 (Cornwall); 5.63 (Bolivia)
	5.67 (calc.).

The cell elements do not confirm the values given by Hiller (*Zeits. Krist.*, A, **100**, 128, 1938). The structural ratio (Berry) compares with the geometrical ratio of Slavík (*Centralbl. Min.*, 7, 1914) as follows:

$a_0 : b_0 : c_0 = 0.8247 : 1 : 0.2120; \beta = 91°48'$ (Berry)

$a : b : \frac{c}{2} = 0.8316 : 1 : 0.2130; \beta = 91°24\frac{1}{2}'$ (Slavík)

The cell content confirms the empirical formula derived by Loczka (Abs. in *Jour. Chem. Soc.*, **96**, 153, 1909) and Schaller (*U.S. Geol. Surv.*, Bull. **490**, 25, 1911).

A description of jamesonite is in press.

L.G.B.

JORDANITE

$27PbS.7As_2S_3$

Material. "Dufrenoysite" (ROM, E/2778), Binnenthal, Switzerland. Jordanite (ROM, M/13004), Beuthen, Upper Silesia. "Boulangerite" (ROM, M/4075), Sala, Sweden.

Results. These materials gave identical *x*-ray powder photographs. Single crystal *x*-ray photographs of a cleavage fragment from the Binnenthal specimen gave:

Symmetry:	Monoclinic; $C_{2h}^2-P2_1/m$
Cell elements:	$a_0=8.89\pm0.03$ $b_0=31.65\pm0.03$ $c_0=8.40\pm0.02$ $\beta=118°21'\pm30'$
Cell content:	$Pb_{27}As_{14}S_{48}=27PbS.7As_2S_3$
Cleavage:	(100). (010) was not developed on the fragment used.
Twinning:	Polysynthetic lamellar twinning was noted in a polished section.
Sp. gravity:	6.44 (meas.), 6.49 (calc.).

The structural lattice with shortest translations (Berry) is related to the morphological lattice of Baumhauer (*Zeits. Kryst.*, **23**, 300, 1894), which was retained by Solly and Jackson (*Min. Mag.*, **12**, 290, 1900), by the transformation:

Baumhauer to Berry: $\frac{\bar{1}}{2}0\frac{\bar{1}}{2}/0\bar{1}0/001$

giving the comparison of elements:

$a_0:b_0:c_0=0.281\ :1:0.265;\ \beta=118°21'$ (Berry)
$a:b:c=0.2795:1:0.2655;\beta=117°49\frac{1}{2}'$ (Baumhauer)

Palache, Richmond, and Winchell (*Am. Mineral.*, **23**, 827, 1938) transformed Baumhauer's elements to a new setting suggested by Peacock from the morphology; this setting is related to our structural setting by the transformation:

Peacock to Berry: $00\bar{2}/010/101$

Richmond's cell dimensions:

$$a'=7.529,\ b'=31.87,\ c'=4.421;\beta=93°59'$$

appeared to confirm Peacock's setting; we find, however, that Richmond's cell edges are $a'=[\frac{1}{2}01]$, $b'=[010]$, $c'=[\frac{\bar{1}}{2}00]$, in the simple structural lattice, defining a half unit cell. Transformed to the adopted setting Richmond's cell dimensions give:

$$a_0=8.84,\ b_0=31.87,\ c_0=8.46;\ \beta=117°26'$$

in fair agreement with the new measurements.

The cell content (Berry) compares with the alternatives derived by Richmond (1938), and that suggested by Fisher (*Am. Mineral.*, **25**, 297, 1940), as follows:

$$
\begin{array}{ll}
Pb_{27}As_{14}S_{48} & \text{(Berry)} \\
\left.\begin{array}{l} Pb_{14}As_{7}S_{24} = \frac{1}{2}(Pb_{28}As_{14}S_{48}) \\ Pb_{13}As_{7}S_{23} = \frac{1}{2}(Pb_{26}As_{14}S_{46}) \end{array}\right\} & \text{(Richmond)} \\
Pb_{14}As_{7}S_{23} = \frac{1}{2}(Pb_{28}As_{14}S_{46}) & \text{(Fisher)}
\end{array}
$$

In terms of the generally accepted formula the cell content is nearly given by:

$$Pb_{28}As_{14}S_{49} = 7[4PbS.As_2S_3]$$

L.G.B.

JOSEITE

Bi_3TeS (?) or Bi_4TeS_3 (?)

Material. Joseite (USNM, R 400), San Jose, Minas Geraes, Brazil (type from coll. A. A. Damour). Grünlingite (USNM, C 277), Carrock Fells, Cumberland, England (type locality). Joseite (ROM, M/19602a), Glacier Gulch, Hudson Bay Mountain, near Smithers, British Columbia.

Results. These materials gave identical *x*-ray powder photographs, the pattern being different from that of tetradymite or of tellurbismuth. These observations are not regarded as sufficient basis for definitely uniting joseite and grünlingite.

Notes on bismuth tellurides, including joseite, are given by Warren and Davis in the present issue of these *Studies.*

M. A. P.

KALLILITE

Ni (Sb, Bi) S

Kallilite (ROM, E/1531), Obersdorf, near Siegen, Germany. The polished section shows a mixture but the *x*-ray powder photograph gives a sharp pattern of the cobaltite type with the cube edge:

$$a_0 = 5.915 \pm 0.005$$

which is almost the same as that of ullmannite.

V. B. M.

LIMONITE

$2Fe_2O_3.3H_2O$

Material. Limonite (UT, E 3556), Easton, Pennsylvania; mammillary mass with fibrous structure and varnish-like exterior. Iron ore, Steeprock Lake, Atikokan, Ontario; compact, liver-brown mass.

Results. These gave identical *x*-ray powder patterns which are distinct from the patterns of hematite and goethite, suggesting that limonite of this kind is a distinct mineral rather than a mineral colloid of indefinite composition.

M. A. P.

MAUCHERITE

$Ni_{11}As_8$

Material. Maucherite (ROM, M/19704), Eisleben, Thuringia, Germany (type locality). Maucherite, Sudbury, Ontario. *Temiskamite* (ROM, M/8518, M/8519, M/9669), Moose Horn Mine, Elk Lake, Ontario (type material). "Rammelsbergite?" (HMM), Orford, Quebec.

Results. These materials gave identical *x*-ray powder patterns. *X*-ray photographs on single crystals from Eisleben gave:

Symmetry:	Tetragonal; D_4^4—$P4_12_1$
Cell elements:	$a_0=6.844\pm0.01$
	$c_0=21.83\pm0.05$
Cell content:	$Ni_{44}As_{32}=4[Ni_{11}As_8]=16[Ni_3As_2]-4Ni$
Cleavage:	Not obtained
Twinning:	On (106)?, common
Sp. gravity:	8.00 (Berman, Sudbury); 8.04 calc.

A well-marked pseudo-cell has $a'=a_0/2$, $c'=c_0$. These cell edges agree with the values:

$$a_0=3.45,\ c_0=21.7$$

obtained by Laves (*Zeits. Krist.*, A, **90**, 279, 1935) on maucherite and artificial "Ni_3As_2."

A description of maucherite appeared recently (*Min. Mag.*, **25**, 557, 1940).

M. A. P.

MENEGHINITE

$Pb_{13}Sb_7S_{23}$[2]

Meneghinite (ROM, M/4096), Bottino, Tuscany (type locality). Unknown lead-grey prismatic mineral with metallic lustre and perfect longitudinal cleavage, in quartz; lot 8, concession II, Anglesea Township, Lennox and Addington County, Ontario. The two minerals gave identical *x*-ray powder photographs.

L. G. B.

---

[2] Richmond (*Am. Mineral.*, **23**, 826, 1938).

PARARAMMELSBERGITE

$NiAs_2$

Materials. "*Temiskamite*" (ROM, M/12411), Moose Horn Mine, Elk Lake, Ontario. "Rammelsbergite" (ROM, M/11772), Hudson Bay Mine, Cobalt, Ontario. "Rammelsbergite" (ROM, M/14242), Keeley Mine, South Lorrain, Ontario.

Results. These gave an x-ray powder pattern quite unlike that of rammelsbergite.

Single crystal photographs on a cleavage fragment from Elk Lake gave:

Symmetry: Pseudo-orthorhombic; $D_{2h}^{11}-Pbma$
Cell elements: $a_0 = 5.74 \pm 0.01$
$b_0 = 5.81 \pm 0.01$
$c_0 = 11.405 \pm 0.03$
Cell content: $Ni_8As_{16} = 8[NiAs_2]$
Cleavage: (001), perfect
Twinning: Not observed
Sp. gravity: 7.12 (meas.), 7.24 (calc.)

These data are not closely comparable to those of any of the members of the Marcasite Group (Buerger, *Am. Mineral.*, **22**, 48, 1937), or to the cube edge of chloanthite—"$NiAs_2$" (Oftedal, *Zeits. Krist.*, **66**, 517, 1928).

The name *pararammelsbergite* was recently proposed (*Am. Mineral.*, **24**, 12(2), 10, 1939) for a mineral previously referred with some doubt to rammelsbergite (these *Studies*, **42**, 95, 1939).

A description of rammelsbergite and pararammelsbergite is in press.

M. A. P.

PYRITE

FeS_2

Material. Pyrite, cubic crystal, Brosso, Piedmont, Italy; on a rectangular block cut parallel to the cube faces the specific resistance was 246 ohms/cm. cube in the directions of a cube edge. Pyrite, pentagonal dodecahedron with small cube faces, Rio Marina, Elba; on a random rectangular block the specific resistance was 0.021 ohms/cm. cube.

Results. X-ray powder photographs of the poor conductor and the good conductor are identical, showing that there is no observable difference in the length of the cube edge ($a_0 = 5.410 \pm 0.005$) or in the sulphur parameter. The variation in the electrical conductivity of pyrite is described by Smith in the present issue of these *Studies*. M. A. P.

RAMMELSBERGITE

$NiAs_2$

Material. Rammelsbergite (ROM, M/4036), Schneeberg, Saxony (type locality). Rammelsbergite (ROM, M/19708), Eisleben, Thuringia. Rammelsbergite (USNM, C-693), Eisleben, Thuringia.

Results. These gave identical *x*-ray powder photographs, the mineral from Schneeberg showing also a few lines due to native bismuth.

Single crystal *x*-ray photographs on cleavage fragments from Eisleben gave:

Symmetry:	Orthorhombic; $D_{2h}^{12}-Pmnn$
Cell elements:	$a_0=3.53\pm0.01$
	$b_0=4.78\pm0.01$
	$c_0=5.78\pm0.01$
Cell content:	$Ni_2As_4=2[NiAs_2]$
Cleavage:	(110), perfect
Twinning:	On (110), common
Sp. gravity:	6.97 (meas.), 7.05 (calc.)

These data place rammelsbergite closer to marcasite—FeS_2 (Buerger, *Am. Mineral.*, **16**, 361, 1931) than to loellingite—$FeAs_2$ (Buerger, *Zeits. Krist.*, A, **32**, 165, 1932).

A description of rammelsbergite and pararammelsbergite is in press. M. A. P.

RATHITE

$13PbS.9As_2S_3$ (?)

Material. Rathite (HMM, 82414), Binnenthal, Switzerland (one small crystal).

Results. Single crystal *x*-ray measurements gave:

Symmetry:	Monoclinic; $C_{2h}^5-P2_1/n$
Cell elements:	$a_0=25.00\pm0.03$
	$b_0=7.91\pm0.03$
	$c_0=8.42\pm0.03$
	$\beta=99°00'\pm30'$
Cell content:	(i) $Pb_{13}As_{18}S_{40}$
	(ii) $Pb_{14}As_{18}S_{40}$
	(iii) $Pb_{14}As_{18}S_{41}$
Cleavage:	(100)
Sp. gravity:	5.45 (Solly), 5.37 (Berman)
	5.31 (i), 5.45 (ii), 5.48 (iii), calc.

The structural lattice with shortest translations (Berry) is related to the morphological elements given for *wiltshireite* = rathite by Lewis (*Min. Mag.*, **16**, 197, 1912) by the transformation:

Lewis to Berry: $\bar{2}0\bar{1}/010/001$

giving the comparison of elements:

$$a_0 : b_0 : c_0 = 3.160 : 1 : 1.064;\ \beta = 99°00' \text{ (Berry)}$$
$$a : b : c = 3.1548 : 1 : 1.0698;\ \beta = 98°44' \text{ (Lewis)}$$

The cell content appears to be best represented by the first of the alternatives given. The content of two cells is well represented by $Pb_{27}As_{36}S_{81} = 9[3PbS.2As_2S_3]$, but well-exposed rotation photographs about [010] and [001] failed to reveal longer periods than those given.

L. G. B.

SARTORITE

$PbS.As_2S_3$

Material. "Dufrenoysite" (ROM, E/3456), Binnenthal, Switzerland.

Results. Single crystal *x*-ray photographs of a fragment of an unterminated striated needle gave:

Symmetry (pseudo-cell):	Pseudo-orthorhombic; $D_2^4-P2_12_12_1$	
Cell elements:	True cell	Pseudo-cell
	$a_0=77.9$	19.48 ± 0.02
	$b_0=83.0$	4.15 ± 0.05
	$c_0=7.86$	7.86 ± 0.03 (needle axis)
Cell content:	$Pb_{320}As_{640}S_{1280}$	$Pb_4As_8S_{16}$
	$=320[PbS.As_2S_3]$	$=4PbS.As_2S_3]$
Sp. gravity:	5.05 (Baumhauer); 4.980 (Solly); 5.04 (calc.)	

The elements of the pseudo-cell agree well with those determined on typical sartorite by Bannister, Pabst, and Vaux (*Min. Mag.*, **25**, 264, 1939), namely:

Space group $P2_12_12_1$; $a_0=19.46$, $b_0=7.79$, $c_0=4.17$

The true cell, as given by these films, differs in that the *a*-period is four times the pseudo-period, whereas the above authors obtained an *a*-period equal to three times the pseudo-period.

L. G. B.

SEMSEYITE

$9PbS.4Sb_2S_3$ [3]

Semseyite (UT, A/1782), Kisbanya, Hungary. "Boulangerite" (UT, A/1780), Montlucon, France. These gave an *x*-ray powder pattern which is distinct from that of any of the other lead antimony sulphides examined.

L. G. B.

SKUTTERUDITE

$(Co, Ni, Fe)(As, S)_{3-1.5}$

Material. Skutterudite (ROM, M/11929), Temiskaming Mine, Cobalt, Ontario (brilliant crystals analysed by Walker, *Am. Mineral.*, **6**, 54, 1921). Smaltite (ROM, M/16104) Castle Tretheway Mine, Gowganda, Ontario. Smaltite (ROM, M/11420), Huevla, Spain. Smaltite (ROM, M/19698), Irtem, Morocco. Smaltite (ROM, M/15714), Hesse, Germany. Smaltite (ROM, E/3870), Schneeberg, Saxony. Smaltite (ROM, M/7444), Riechelsdorf, Hesse, Germany. Chloanthite (ROM, M/3998), Schneeberg, Saxony.

Results. These gave almost identical *x*-ray powder patterns with only very slight variation in the spacing of the lines. Skutterudite (M/11929) gave:

Symmetry: Cubic; $T_h^5 - Im3$
Cell element: $a_0 = 8.18 \pm 0.01$
Cell content: $(Co, Fe, Ni)_{9.1}(As, S)_{22.8} = 8[RAs_3]$ with about 1 R in place of As
Sp. gravity: 6.65 (meas.); 6.84 (calc. for $CoAs_3$)

J. S. A.

These observations confirm the structural identity of skutterudite and smaltite-chloanthite, already found by Oftedal (*Zeits. Krist.*, **66**, 517, 1928). The measured cell edge agrees with Oftedal's value:

$$a_0 = 8.189 \pm 0.002$$

for skutterudite from Skutterud, Norway, with Co:As about 1:2.75. The unit cell contains 32 atoms, with an excess in R and a defect in As as compared with the cell content R_8As_{24} of the structure derived by Oftedal. Analyses of skutterudite give R:As = 1:3 to about 1:2.5; analyses of smaltite-chloanthite give R:As about 1:2.5 to 1:1.5. The wide departures from the structural atomic ratio

---

[3] One of the formulas given for semseyite by Spencer (*Min. Mag.*, **12**, 65, 1900).

R:As = 1:3 are thus due to varying proportions of R-atoms taking the place of As-atoms, and not to extra R-atoms or to vacant As-positions. The structural formula may therefore be written:

$$\mathrm{R}_8 \left| \begin{matrix} \mathrm{R}_p \\ \mathrm{As}_{24-p} \end{matrix} \right|$$

where $p/24$ is the varying proportion of As-positions occupied by R-atoms.

Skutterudite and smaltite-chloanthite may be considered to constitute one species for which the name skutterudite (Haidinger, 1845), with the ideal composition $\mathrm{RAs_3}$, seems preferable to smaltite (Beudant, 1852) or chloanthite (Breithaupt, 1845), which have an average composition of roughly $\mathrm{RAs_2}$. Within the species skutterudite we may recognize varieties in keeping with present usage: skutterudite (*sensu stricto*), $\mathrm{RAs}_{3-2.5}$ with R mainly Co; smaltite $\mathrm{RAs}_{2.5-1.5}$ with R mainly Co; chloanthite, $\mathrm{RAs}_{2.5-1.5}$ with R mainly Ni. Some analyses also give substantial amounts of Fe in place of Co and Ni, and S in place of As.

M. A. P.

STEPHANITE

$\mathrm{Ag_5SbS_4}$

Material. Stephanite (Ungemach coll.), Ste-Croix aux Mines, Alsace; one small crystal.

Results. Single crystal *x*-ray measurements gave:

Symmetry: Orthorhombic; $C_{2v}^{12} - Cmc2$
Cell elements: $a_0 = 7.70 \pm 0.05$
$b_0 = 12.32 \pm 0.05$
$c_0 = 8.48 \pm 0.05$
Cell content: $\mathrm{Ag_{20}Sb_4S_{16}} = 4[\mathrm{Ag_5SbS_4}]$
Twinning: On (110) and (130)
Sp. gravity: 6.27 (Berman), 6.47 (calc.)

The space group, reached independently from the morphology and the missing spectra (Taylor, *Am. Mineral.*, **25**, 327, 1940), improves previous determinations on stephanite (Salvia, 1932—*Strukturber.*, **2**, 348) and on *goldschmidtine* = stephanite (Peacock, *Am. Mineral.*, **24**, 227, 1939; **25**, 372, 1940).

The cell edges compare with previous measurements as follows:

$a_0 = 7.85 \pm 0.02$	$b_0 = 12.48$	$c_0 = 8.58$	(Salvia)
7.75 ± 0.05	12.32 ± 0.05	8.42 ± 0.05	(Peacock)

E. D. T.

TELLURBISMUTH[4]

Bi_2Te_3

Material. Tellurbismuth, Hunter Group Claims, Khutze Inlet, near Swanson Bay, British Columbia. Tellurbismuth, Ashloo mine, near Squamish, Howe Sound, British Columbia. Artificial Bi_2Te_3.

Results. These materials gave identical x-ray powder photographs. The pattern is definitely different from those given by tetradymite and by joseite (grünlingite). Single crystal and powder photographs on artificial Bi_2Te_3 gave the preliminary data:

Symmetry: Rhombohedral; $D_{3d}^5 - R\bar{3}m$
Cell elements: $a_{rh} = 10.44 \pm 0.03$; $\alpha = 24°11\frac{1}{2}'$
$a_0 = 4.375 \pm 0.01$
$c_0 = 30.39 \pm 0.10$
Cell content: Bi_2Te_3 (in rhombohedral cell)
Cleavage: (111) (0003), perfect and easy
Sp. gravity: 7.80 (Ashloo), 7.82 (Hunter)
7.86 (calc.)

The cell elements do not agree with preliminary data given by Ramsdell (*Am. Mineral.*, **15**, 119, 1930) for artificial Bi_2Te_3, or by Frondel (*Am. Mineral.*, **24**, 12(2), 7, 1939) for *tellurobismuthite*—Bi_2Te_3. The new values are close to the cell elements of tetradymite—Bi_2Te_2S, determined by Harker (*Zeits. Krist.*, A, **89**, 175, 1934):

$$a_{rh} = 10.31;\ \alpha = 24°10'$$

Further details are given by Warren and Davis in this issue of these *Studies*.

M. A. P.

TETRADYMITE

Bi_2Te_2S

Tetradymite (ROM, M/15547), Schubkau, Schemnitz, Hungary (type locality), gave an x-ray powder pattern which is distinctly different from those given by tellurbismuth and by joseite (grünlingite).

M. A. P.

---

[4] The name *tellurbismuth* (Balch, 1863), corresponding to Tellurwismuth (Berzelius, 1823), has priority over *tellurobismuthite* (Wherry, *Jour. Wash. Ac. Sci.*, **10**, 490, 1920) or *telluro-bismutite* (Short, *U.S. Geol. Surv.*, Bull. **825**, 73, 1931).

ULLMANNITE

$NiSbS$

Material. Ullmannite (ROM, E/1911), Salchendorf, near Siegen, Germany; massive with good cubic cleavage. Ullmannite (ROM, M/13302), Montenarba, Sardinia; striated cubic crystals.

Results. These gave nearly identical *x*-ray powder patterns of the cobaltite type, yielding the cube edges:

	a_0
Salchendorf	5.899±0.005
Montenarba	5.905±0.005

These values agree well with previous measurements:

	a_0	
	5.91	(Ramsdell, 1925—*Strukturber.*, **1**, 284)
Siegen	5.89±0.02	(Zachariasen, 1927—*Strukturber.*, **1**, 284).

Except for small amounts of As in place of Sb, analyses of ullmannite come close to the ideal composition and consequently the cube edge is nearly constant.

V. B. M.

WEIBULLITE

Mixture with composition near $2PbS.Bi_2S_3.Bi_2Se_3$

Material. "Galenobismutite" (*seleniferous galenobismutite*) (ROM, M/12992), "galenobismutite" (USNM, 84460), *weibullite* (USNM, R/6532), *seleniferous chiviatite* (NRS, 24083, type material), all from Falun, Sweden. Published analyses of similarly named materials from Falun give varying proportions of Pb, Bi, Se, S with small amounts of Cu and Fe.

Results. Polished sections and *x*-ray powder photographs have shown that these materials are all essentially alike, being intimate intergrowths of two undetermined white metallic minerals, with associated chalcopyrite.

One of the undetermined minerals is fibrous to columnar in habit; single crystal *x*-ray photographs gave:

Symmetry: Monoclinic; D_{2h}^1-P2/m
Cell elements: $a_0=18.03\pm0.03$
$b_0= 4.04\pm0.02$
$c_0=17.53\pm0.03$
$\beta=94°29'\pm30'$

The other undetermined mineral has a platy habit with perfect cleavage parallel to the plane of platy development. Single crystal photographs gave:

Symmetry:	Hexagonal; space group not determined
Cell elements:	$a_0 = 4.20 \pm 0.03$
	$c_0 = 13.22 \pm 0.02$
Cleavage:	(0001)

Attempts to isolate either constituent in sufficient amount to determine the physical and chemical properties have not yet succeeded. The fibrous mineral is not cosalite or bismuthinite; the platy mineral is not identical with artificial Bi_2Se_3. Neither mineral is galenobismutite.

L. G. B.

WILLYAMITE

(Co,Ni)SbS

Willyamite (ROM, E/1708), Broken Hill, New South Wales, Australia; massive with cubic cleavage. Gives an x-ray powder pattern of the cobaltite type with the cube edge:

$$a_0 = 5.918 \pm 0.005$$

which is close to the values for kallilite and ullmannite.

V. B. M.

ASTERISM IN SELENITE

By R. L. RUTHERFORD
University of Alberta

Asterism, or the star-like arrangement of rays observed on some minerals in reflected light and on others in transmitted light, is usually attributed to the presence of impurities or cavities arranged in a definite manner. The sapphire variety of corundum is said to show asterism in reflected light and some varieties of mica in transmitted light. Asterism is briefly referred to in text-books and the writer has not seen any discussion of the relationship of asterism to crystal form.

Clear transparent selenite shows well-defined asterism in transmitted light, and the rays of light thus formed have a definite relationship to the crystal forms. It is best observed by using a smooth cleavage piece held close to the eye and in line with a candle flame about four feet away.

Selenite crystals commonly show the following forms: *b* (010), *m* (110), and *l* (111) (Dana's letters and symbols). Cleavage parallel to *b* (010) is highly perfect and in examining for asterism, the crystal is held so that the light is transmitted perpendicular to this face. Cleavage parallel to *n* $(\bar{1}11)$ gives a fibrous fracture and flexibility to thin pieces cleaved parallel to *b* (010). Cleavage parallel to (100) has a conchoidal fracture.

Fig. 1 shows the trace of the predominant crystal forms and cleavage directions on the (010) face, the crystallographic axes *a* and *c*, and the vibration directions X and Z. The directions of the dominant rays in the asterism are indicated as ast. 1, ast. 2, and ast. 3.

Some crystals show a single broad band of light corresponding in position to one of the main directions shown on Fig. 1. Others show two or more bands. When these crystals are split to thinner lamellae, the width of the bands usually decreases and other rays appear. The stronger bands, however, still correspond in position to those shown on Fig. 1.

The position of these ray directions can be marked on the crystal or cleavage face, with a pin point, while it is held up to the light, then measured on a microscope with reference to the Z and X vibration directions and the cleavage lines. This method is somewhat inaccurate, since it is difficult to mark the position of the asterism when viewing the light through the mineral. Variations up to 5° in position with reference to the Z direction were obtained by this method, but it indicated that the main bands in the asterism occurred perpendicular to the trace of the following forms on the (010) cleavage face:

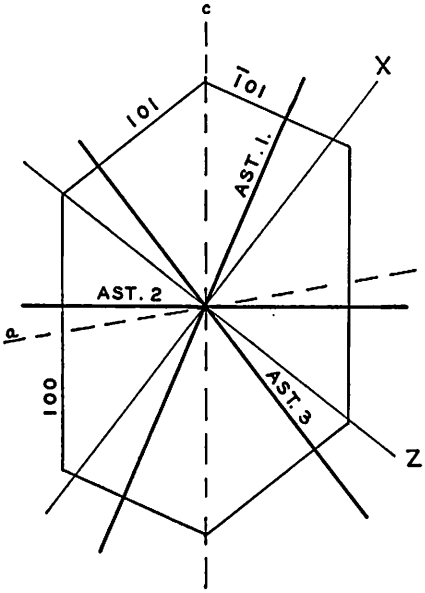


FIG. 1.—Trace of the predominant crystal forms and cleavage directions on the (010) face of selenite. Showing also the direction of the main bands of light in the asterism.

$(\bar{1}01)$..............trace *n* $(\bar{1}11)$ cleavage........(ast. 1)
(100) cleavage..................................(ast. 2)
(101)..............trace *l* (111)................(ast. 3)

By setting cleavage pieces on a drawing similar to Fig. 1 with the $(\bar{1}11)$ cleavage lines orientated to the drawing, it is easy to mark three lines on the selenite perpendicular to the trace of the forms listed above. When these marked pieces are examined in transmitted light, the main bands of asterism coincide with the direction of the markings, confirming the conclusion that the main bands in the asterism lie in planes perpendicular to these three forms.

A few crystals of quartz showing oscillatory combinations on the prism faces were examined in candle light. These show asterism in the form of one strong band parallel to the crystallographic *c*-axis. The strongest effect was noticed when the light passed through perpendicular to faces showing the best development of these oscillatory lines.

Phlogopite from North Burgess, Ontario, shows well-defined asterism. In our specimens, the number of bands or rays in the asterism varies inversely as the thickness of the cleavage piece. When moderately thick lamellae are used there are three main bands which appear to coincide with the directions of the "percussion figure," as shown in Dana's *Textbook of Mineralogy*, p. 658. The rays of minor intensity appearing in thinner pieces appear to coincide with the lines of the "pressure figure" shown on the same illustration. Apparently the asterism in this phlogopite is definitely related to the crystal forms or internal crystal structure.

Asterism is produced by cellulose sheet commonly used as coverings on automobile windows to overcome frosting. This material usually produces one strong band in transmitted light. Celluloid drafting instruments show a similar effect in candle light with a tendency to the development of several intersecting rays in the thinner pieces. These substances have a definite internal structure and show a biaxial figure on a petrographic microscope. R. G. Drummond (*Nature*, vol. 145, p. 67, Jan. 13, 1940), has recently given some of the optical data on cellulose sheet.

In some instances, the stronger bands seen through the selenite and the mica in candle light show interference colours in closely spaced bands. Similar effects on a larger scale occur in celluloid on the car windows.

There is no evidence of any marked polarization of the asterized rays from selenite, mica, or quartz, as might be expected if the asterism is due to reflection from numerous subparallel planes. The rays in the asterism show no change in intensity when viewed through a rotating polarizing prism.

Asterism in mica has been attributed to a regular arrangement of impurities. It would seem from the above observations that if such an arrangement of impurities occurs it is incidental to asterism and not the cause of it.

The regular arrangement of cavities or openings is also said to cause asterism. In the case of selenite, it is possible that such openings exist but they are not evident in the well-formed crystals that show asterism. With one exception all the selenite examined came from occurrences on shale banks in Alberta where the crystals have grown at or near the surface. Such conditions of growth would be favourable to oscillatory development of the different forms.

If small cavities are the cause of asterism in selenite, those parallel to the cleavage ($\bar{1}11$) would produce ast. 1, those parallel to the cleavage (100) would produce ast. 2, whereas ast. 3 would have to be explained as openings related to oscillations between the (111) and (101) forms. The other rays of asterism of minor intensity, however, are probably related to crystal forms not commonly represented by crystal faces.

The writer has not been able to determine the presence of small openings in transparent selenite by ordinary petrographic methods. Obviously if cleavage is observed under the microscope there are openings parallel thereto, but no openings are discernible when the cleavage lines are not seen.

Cellulose sheet is non-cleavable and, since it shows asterism, it would seem that this property is related to the internal structure and not to the arrangement of openings or inclusions.

AN ORBICULAR GABBRO FROM TREMEER LAKE KENORA DISTRICT, ONTARIO[1]

By J. SATTERLY
Ontario Department of Mines

During the field season of 1939 the writer carried out a geological survey of the Dryden-Wabigoon area in the district of Kenora. In the course of this work the writer's assistant, G. L. Colgrove, found an orbicular rock near Tremeer Lake. Time did not permit the writer to visit the locality personally. Orbicular rocks are petrographic curiosities on this continent, and as this orbicular gabbro is believed to be the first observed occurrence in Canada, it is thought a brief description is warranted.

The general geology of the area has been briefly reviewed in a preliminary report (Satterly, 1939) accompanied by a geological sketch map which is reproduced here (Fig. 1). This map will also serve to show the location of the area as the town of Dryden on the Canadian Pacific Railway is half way between Fort William and Winnipeg. For convenience a table of formations from the preliminary report is repeated here in simplified form.

TABLE 1.—GEOLOGICAL SUCCESSION

PLEISTOCENE	Varved clay, boulder clay, silt, sand, gravel, boulders.
	Great Unconformity
PRE-CAMBRIAN	
Keweenawan:	Diabase (dike).
	Intrusive Contact
Algoman:	Granite, diorite, quartz diorite, pegmatite, porphyry, etc.
	Intrusive Contact
Haileyburian:	Gabbro, norite, peridotite, soapstone.
	Intrusive Contact
Keewatin:	
Sedimentary members:	Arkose, greywacke, quartzite, slate, schists, iron formation.
Volcanic members:	Basic to acid lavas, pillow lavas, volcanic breccias, tuff, basic intrusives, metamorphosed equivalents.

---

[1] Published with the permission of the Provincial Geologist of the Ontario Department of Mines.

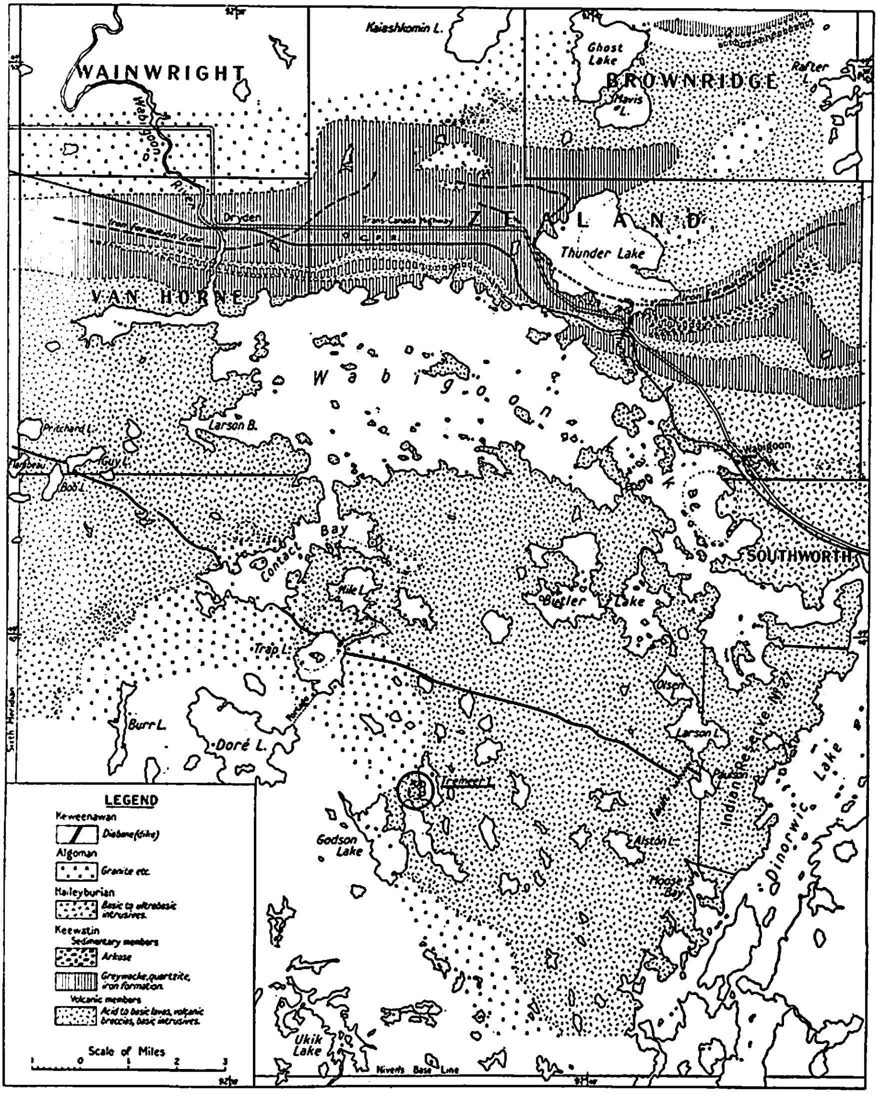


FIG. 1.—Geological map of the Dryden-Wabigoon area, District of Kenora, Ontario, showing the location of the Tremeer Lake orbicular gabbro (in circle).

The orbicular gabbro forms an isolated outcrop west of Tremeer Lake and north of Godson Lake. This outcrop is irregular in shape and approximately 200 by 500 feet in dimensions. Two other outcrops of gabbro, not showing orbicular structure, occur one-quarter of a mile to the north. The three outcrops are believed to form a small stock intrusive into the Keewatin volcanics (Fig. 1). The main granite batholith is exposed one-quarter of a mile west of the outcrop of orbicular gabbro. Larger areas of gabbro are found near the village of Wabigoon and west and south of Contact Bay, Wabigoon Lake (Fig. 1), but no orbicular structures were observed in these, unless the nodular structure in the harzburgite on Trap Lake be considered a kind of orbicular structure. The evidence for the determination of age of the gabbros will be fully described in the final report on the area. They are believed to be of the Haileyburian age.

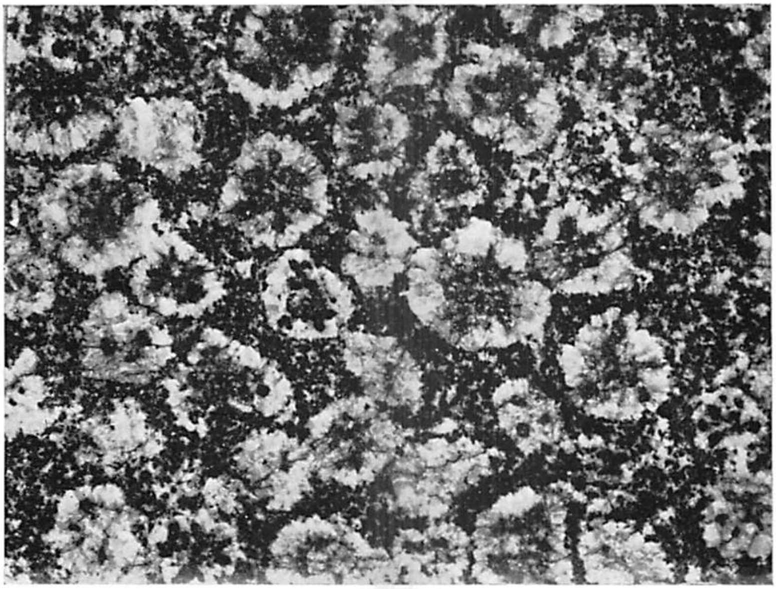


FIG. 2.—Photograph, natural size, of a polished surface of the orbicular gabbro from Tremeer Lake. The light rims of the orbicules consist of bytownite.

Measurements on a polished surface of the orbicular gabbro (Fig. 2) show the orbicules to vary from 7 to 20 mm., with an average of about 13 mm. diameter. The orbicules constitute 53 per cent of the area of the rock as determined by an Ansler planimeter.[2]

Studied in thin section under the microscope the orbicules are found to consist of rings of radially arranged plagioclase crystals showing twinning and, in their outer parts, zoning. The plagioclase is only slightly altered to an aggregate of zoisite-epidote grains mainly confined to the central portions of the crystals. The plagioclase was determined to be bytownite Ab_{20} An_{80} by the use of immersion liquids.[3] The centres of the orbicules consist of felted aggregates of grey-green chlorite and an occasional flake of brown biotite. The chlorite is confined to the centres of the orbicules; it represents the alteration product of some ferromagnesian mineral, but no relicts remain to indicate what it was. Outside the orbicules, that is interstitial to them, the rock consists of shredded hornblende, plagioclase laths, and a little brown biotite, with skeletal ilmenite and associated sphene as a common accessory. Apatite is rare; a few grains of quartz were seen in one of the two thin sections examined.

An analysis by the Provincial Assay Office follows, with a number of other analyses which have the same C.I.P.W. symbol for comparison.

The analyses show clearly the affinities of the orbicular gabbro with other basic rocks, and attention is drawn to the very marked similarity in composition between the Tremeer and Corsica orbicular gabbro.

---

[2] Lent by the Department of Physics, University of Toronto.

[3] Lent by the Department of Mineralogy, University of Toronto.

TABLE 2.—ANALYSES OF ORBICULAR GABBRO AND RELATED ROCKS

	1	2	3	4	5	6	7
SiO_2	49.36	46.26	44.39	45.54	47.97	48.86	45.29
Al_2O_3	23.14	27.40	36.55	23.39	22.16	21.88	22.69
Fe_2O_3	1.24	2.72	—	1.98	1.12	1.83	2.76
FeO	5.46	1.87	—	6.98	4.10	4.87	5.56
MgO	5.24	3.97	—	4.60	4.58	3.79	5.75
CaO	10.64	13.67	18.67	11.82	11.96	11.69	11.95
Na_2O	1.94	1.80	0.83	2.50	3.23	3.30	2.84
K_2O	0.36	0.32	—	0.44	0.29	0.20	0.52
H_2O	1.75	1.15	—	1.34	2.20	2.26	1.47
CO_2	0.21	0.34	—	—	—	—	—
TiO_2	0.52	0.12	—	1.06	0.44	1.26	0.75
P_2O_5	0.06	0.05	—	0.13	1.14	0.28	0.03
MnO	0.09	0.02	—	0.27	—	0.34	0.08
Cr_2O_3	None	—	—	—	—	—	—
FeS_2	0.22	—	—	—	0.35	—	—
	100.23	99.93	100.44	100.05	99.54	100.66	99.69
Sp. Gr.	2.863	2.81	—	—	—	—	—
Symbol	II.5.4.(4)5	(I)II.5.(4)5.(4)5	—	II.5.4.(4)5	II.5.4.5	II.5.4.5	II.5.4.(4)5

1. Orbicular gabbro, Tremeer Lake, Dryden-Wabigoon area, Kenora District, Ontario.
2. Orbicular gabbro, Santa Lucia di Tallano, Corsica (Johannsen, 1937, p. 231): incl. BaO 0.08, S 0.16.
3. Plagioclase of an orbicule, orbicular gabbro, Dehesa, San Diego County, California (Lawson, 1904, p. 394).
4. Olivine dolerite, Coire Buidhe, Mull, Scotland (Washington, 1917, anal. no. 77, p. 538); incl. S none.
5. Gabbro, Breiteloh, Hesse, Germany (Washington, 1917, anal. no. 91, p. 540).
6. Anorthosite, Dundas, near Sydney, N.S.W., Australia (Washington, 1917, anal. no. 138, p. 546); incl. Ni 0.10.
7. Diorite, New Caledonia (Washington, 1917, anal. no. 148, p. 548).

The norms for the Tremeer Lake and Corsica orbicular gabbros as calculated by the writer are:—

TABLE 3.—NORMS OF ORBICULAR GABBROS

1		2	
Quartz	2.40		
Orthoclase	2.22	Orthoclase	1.67
Albite	16.24	Albite	8.91
Anorthite	51.43	Anorthite	65.89
Corundum	0.61	Nephelite	3.41
Hypersthene	21.28	Olivine	7.92
Magnetite	1.86	Magnetite	3.94
Ilmenite	0.91		
Pyrite	0.22		
Calcite	0.50		
C.I.P.W. Symbol	II.5.4.(4)5		(I)II.5.(4)5.(4)5

1. Orbicular gabbro, Tremeer Lake.
2. Orbicular gabbro, Santa Lucia di Tallano, Corsica.

The feldspars of these orbicular gabbros are very basic, as the following data show. It is interesting to note that the composition of the feldspar as calculated from the norm is very close to that actually found.

Tremeer Lake	$Ab_{20}An_{80}$ bytownite (from refractive index as determined by immersion liquids Ab_{24} An_{76} bytownite (from the norm, calculated by the writer)
Corsica	Ab_{12} An_{88} bytownite (from the norm, calculated by the writer) Ab_{20} An_{80} bytownite (microscopic determination, Johannsen, 1937, p. 231)
Dehesa	Ab_7An_{93} anorthite (from analysis, Lawson, 1904, p. 394)

An attempt to recast the analysis of the Tremeer Lake orbicular gabbro is not very satisfactory. The following formulae and assumptions were used:

Plagioclase—bytownite, Ab_{20} An_{80}.

Biotite—$K_2O.4(Mg, Fe)O.2Al_2O_3.6SiO_2.H_2O$; the ratio of MgO to FeO was assumed to be 1:1.

Hornblende—$4CaO.Na_2O.8(Mg, Fe)O.3Al_2O_3.12SiO_2.2H_2O$; the balance of FeO left after forming ilmenite, magnetite, and biotite was assigned to hornblende. This gives a ratio of MgO to FeO of 1.15:1.

Chlorite (amesite)—$2MgO.Al_2O_3.SiO_2.2H_2O$; the balance of MgO was used to make chlorite.

Despite numerous trial and error calculations with other formulae there always remains a large amount of unassigned silica, in this case 14.82 per cent. Unassigned alumina is 0.41 per cent.

TABLE 4.—MODE OF TREMEER LAKE ORBICULAR GABBRO

Bytownite	42.57
Hornblende	26.81
Chlorite	8.30
Biotite	3.60
Titaniferous magnetite	2.47
Titanite	0.39
Calcite	0.50
Pyrite	0.22

The origin of orbicular structures has been exhaustively reviewed by Sederholm (1928). Shorter discussions and descriptions of orbicular rocks have been made by a number of writers. As the orbicules of the Tremeer Lake rock have a relatively simple structure, no complicated process is required to explain their origin, as is necessary for orbicules showing a repeated concentric structure. In the case of the Tremeer Lake rock, it is presumed that in the process of fractional crystallization of a basaltic magma crystallization began at numerous centres with the formation of a cluster of ferromagnesian minerals (pyroxene ?, olivine ?), now represented by a chlorite aggregate. This resulted in the magma becoming supersaturated with feldspar and rings of radially arranged bytownite crystals deposited on the clusters of ferromagnesian minerals. Following this event both plagioclase and ferromagnesian minerals crystallized together to form the matrix to the orbicules. Metamorphism, probably mainly caused by the nearby Algoman granite batholith, has resulted in the formation of hornblende, biotite, and probably the recrystallization of the feldspars. Whether metamorphism is partly responsible for the development of the orbicular structure is questionable, but it has undoubtedly considerably modified the mineral composition, and it may have accentuated structures present prior to metamorphism.

REFERENCES

JOHANNSEN, A. (1937): *A descriptive petrography of the igneous rocks*, vol. 3—Chicago.

LAWSON, A. (1904): The orbicular gabbro at Dehesa, San Diego Co., California —*Univ. California Pub., Bull. Dept. Geol.*, vol. 3, pp. 383-396.

SATTERLY, J. (1939): Preliminary report on the Dryden-Wabigoon area, District of Kenora—*Ont. Dept. Mines* (mimeographed).

SEDERHOLM, J. J. (1928): On orbicular granites—*Comm. géol. Finlande*, Bull. 83 (bibliog. with 98 titles).

WASHINGTON, H. S. (1917): Chemical analyses of igneous rocks—*U.S. Geol. Surv.*, Prof. Pap. 99.

VARIATION IN THE ELECTRICAL CONDUCTIVITY OF PYRITE[1]

By F. GORDON SMITH
University of Toronto

Observations on the electrical conductivity of pyrite appear in several papers on the conductivity of minerals. Beijerinck (1897, p. 433) states that pyrite is an excellent conductor. Königsberger and Reichenheim (1906, p. 20) measured the variation in the conductivity of pyrite with change of temperature. Kerr and Cabeen (1925) found that pyrite, and many other species, show a large range of electrical conductivity. Harvey (1928) confirmed this variation, giving a range of about 10^{-2} to 10^{2} ohms/cm. cube for the specific resistance of pyrite. Bain (1935) noted a similar range, but his limiting values, 1 to 10,000 ohms/cm. cube, are 100 times greater than those of Harvey. The possible variation of electrical conductivity in different directions of a single crystal of pyrite does not appear to have been adequately studied.

The object of the present work was to verify the reported variation in the electrical conductivity of pyrite and to seek an explanation of the variation. The present paper gives measurements of the specific resistance of oriented and random prisms cut from numerous specimens, and shows that the enormous variation, which certainly exists, is related to none of the observed mineralogical properties.

MEASUREMENT OF THE SPECIFIC RESISTANCE OF PYRITE

Material. The specimens assembled for this work were chosen to represent the mineralogical variables which might be connected with variations in conductivity, namely geographical distribution, variety of crystal habit and lustre, optical behaviour, and probable temperature of formation. The notes in the following list indicate the orientation of the rectangular prism cut from each specimen. A "normal" prism is one whose edges are parallel to the crystal axes.

1. Part of a large pure crystal with large conchoidal fracture; locality unknown. Random prism.

---

[1] Work carried out with the aid of a Scholarship of the National Research Council of Canada and published with the permission of the Council.

2. Striated cube in talc-chlorite schist; Denton Township, Ontario. One edge of prism parallel to a cube-edge, the other two parallel to cube face-diagonals.

3. Striated cube; same locality as 2. One edge of prism parallel to the cube body-diagonal.

4. Striated cube; same locality as 2. Normal prism.

5. Large unstriated pyritohedron containing some inclusions of pyroxene and biotite; optically isotropic; Godfrey, Frontenac Co., Ontario. This is considered to be a pneumatolytic deposit. Random prism.

6. Fragment of a fairly pure crystal with cubic parting; same locality as 5. Random prism.

7. Fragment of a large pure crystal; locality unknown. Random prism.

8. Striated cube; Virtuous Lady Mine, Tavistock, Devon (ROM, M/15563). Normal prism.

9. Pyritohedron; Premier Mine, Transvaal. Normal prism.

10. Massive pyrite; locality unknown. Contains about 5 per cent quartz particles.

11. Part of a large pure crystal; locality unknown. Random prism.

12. Part of a large pure crystal; locality unknown. Random prism.

13. Fragment of a large crystal with small conchoidal fracture; locality unknown. Random prism.

14. Small striated cube; Placer Co., California. Normal prism.

15. Large striated cube of bright yellow colour and high lustre; optically anisotropic; locality unknown. One edge of prism parallel to a cube-edge, the other two parallel to cube face-diagonals.

16. Coarsely striated cube; Miner's Delight Mine, Ophir Dist., Tooele Co., Utah. Normal prism.

17. Finely striated cube; same locality as 16. Normal prism.

18. Cube in chlorite schist; the cube faces were not striated with the trace of the pyritohedron faces, but were smooth, except for a few diamond-shaped markings, the trace of the octahedron faces; Chester, Vermont. Normal prism.

19. Finely striated large cube; locality unknown. Normal prism.

20. Combination of cube and octahedron, with smooth faces; euhedral crystal in calcite; Franklin, New Jersey. Normal prism.

21. Massive whitish-yellow pyrite, with octahedron faces visible; Sargents, Gunnison Co., Colorado. Random prism.

22. Large cube; Brosso, Piedmont, Italy. The three cube faces were unstriated, but had a peculiar appearance, as if they were built up by piling irregular-shaped shingles on each face. The faces were somewhat rounded. Optically anisotropic. Normal prism.

23. Massive yellow pyrite with terminal faces, encrusting sphalerite; optically anisotropic; Joplin, Missouri. Random prism.

24. Large striated cube with the faces cylindrically rounded parallel to the striations; locality unknown. Normal prism.

25. Large pyritohedron with fine striations parallel to the cube faces; small finely striated diploid faces and very small and bright octahedron faces; Rio Marina, Elba. Random prism.

26. Large pure compact crystal, with brass-yellow colour and high lustre, nearly cubic, the cube faces being heavily striated due to oscillatory combination with the pyritohedron faces; corners of the cube truncated by small diploid faces, dull and oxidized, and small octahedron faces; optically anisotropic; Leadville, Colorado. One edge of prism parallel to a cube-edge, the other two parallel to cube face-diagonals.

27. Large pyritohedron with irregular striations perpendicular to the trace of the cube faces; optically anistotropic; Rio Marina, Elba. Random prism.

28. From the same crystal as 26. One prism edge parallel to a cube body-diagonal, one parallel to a cube face-diagonal.

29. Large light-coloured crystal with a low lustre; combination of the octahedron and a diploid; Brosso, Piedmont, Italy. Random prism.

30. Part of a large pure crystal; the cube faces heavily striated by oscillatory combination between neighbouring pyritohedron faces and the cube face; large conchoidal fracture and high lustre; Leadville, Colorado. Random prism.

31. Part of a large brecciated crystal with many splendent faces; Russell Gulch, Gilpin Co., Colorado. Random prism.

32. Large cube with platy markings and the appearance of a cubic parting; Yechigo, Japan. Normal prism.

33. Light-coloured fragment of a crystal showing no faces; locality unknown. Random prism.

34. Small striated cube; locality unknown. Normal prism.

35. Cube and pyrithohedron, with simple, unstriated faces, but with fine curved and concentric markings on the faces; Gellivara, Sweden. Normal prism.

36. Part of a large cube with fine striations and a few lozenge-shaped accessory forms on the faces; Chalcidice, Macedonia, Greece.

Method of Measurement. A prism orientated in a random or determined direction in a pure compact crystal was made by sawing and grinding on a lap. The faces were made mutually perpendicular and about one centimetre square. The prism was then measured with a micrometer. Four of the faces were insulated with cellulose adhesive tape, leaving two opposite faces free. The tape was made to extend beyond one of the free faces, forming a cup which was partly filled with mercury. The prism was floated in mercury as shown in Fig. 1, and thus good electrical contacts were obtained between the free faces of the prism and the thick amalgamated copper conductors. The resistance in ohms between the two copper wires was found by means of a resistance tester of the Megger type, which had been calibrated a short time previously. Repeated measurements gave practically identical results, showing that the method of insulating the sides of the prism and making contact on the ends was satisfactory.

The relation between the resistance R (ohms) of a right prism of length l (cm.) and area of cross-section A (sq. cm.), and the specific resistance ρ (resistance in ohms of a centimetre cube), is $\rho = RA/l$.

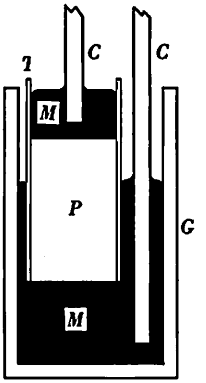


FIG. 1.—Arrangement for making electrical contacts on opposite faces of a pyrite prism. P—Pyrite prism. T—Jacket of cellulose tape insulating the vertical faces. M—Mercury. C—Thick amalgamated copper conductors. G—Glass vessel.

Specific Resistance in Different Directions in a Single Crystal. This was studied with a large crystal from Leadville, Colorado (26, 28) which proved to be optically anisotropic and also electrically anisotropic.

The resistance along each of the four body-diagonals was measured on a nearly cubical normal prism with equal octahedral planes ground on each corner. Three of the body-diagonals gave a resistance of 110 ohms, one gave 250 ohms (relative values). This suggested rhombohedral symmetry, the body-diagonal with high resistance being the principal axis C [111], the other three being equivalent axes B [$\bar{1}11$] (Fig. 2, rhombohedral notation). The specific resistances along the cube-edge F [001] and the cube face-diagonals D [$\bar{1}10$] and E [110] were measured on prism 26; the values obtained were 17.1, 13.3, and 70.5, respectively. Prism 28 gave the specific resistances along the mutually perpendicular directions C [111], D [$\bar{1}10$], G [$11\bar{2}$], namely 71.5, 14.2, 4.3, respectively. The value 14.2 for *D* is close to 13.3 found for this direction on prism 26. These measurements are tabulated below for convenience.

TABLE 1.—PYRITE: VARIATION OF RESISTANCE IN A SINGLE CRYSTAL (RHOMBOHEDRAL NOTATION)

Direction	Rel. Resistance	Sp. Resistance	
B $[\bar{1}11]$	110	—	—
C [111]	250	—	71.5
D $[\bar{1}10]$	—	13.3	14.2
E [110]	—	70.5	—
F [001]	—	17.1	—
G $[11\bar{2}]$	—	—	4.3

The observations indicate that the figure representing the direction and magnitude of the specific resistance in the crystal is a body of remarkable form. It is greatly elongated in the direction of the vertical axis (71.5) and sections containing the vertical axis may be considered to be elliptical. The horizontal section, however, is not

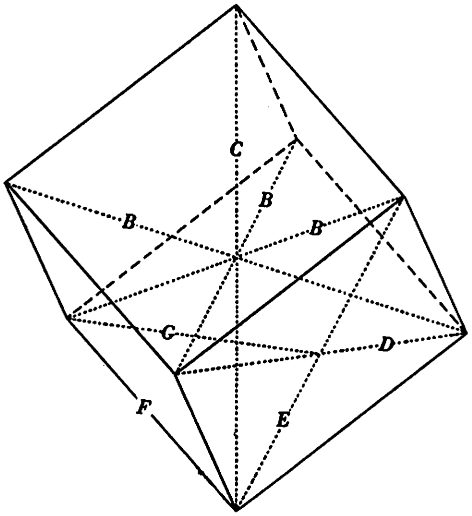


FIG. 2.—Cube in rhombohedral orientation, showing the directions in which the resistance of a pyrite crystal was measured: *B* $[\bar{1}11]$, *C* [111], *D* $[\bar{1}10]$, *E* [110], *F* [001], *G* $[11\bar{2}]$ (rhombohedral notation).

circular but has the form of a six-rayed star whose largest diameters are 13.8 and smallest diameters (hexagonal *A*-axes) are 4.3.

The maximum observed variation of specific resistance in this single crystal is thus about 17 to 1. Only one other specimen (prism 33) showed a greater ratio, namely 18 to 1. In round numbers, therefore, the maximum ratio of the greatest to the least specific resistance in a single crystal of pyrite is about 20 to 1.

Specific Resistance in Different Crystals. The results obtained for the prisms cut from different specimens are given in Table 2,

TABLE 2.—PYRITE: SPECIFIC RESISTANCE IN DIFFERENT CRYSTALS

No.	Direction	ρ		No.	Direction	ρ	
27	—	0.021		24	[100]	1.2	1.15
18	[100]	0.030			[010]	0.85	
5	—	0.039			[001]	1.4	
25	—	0.044		31	—	1.4	
6	—	0.049		12	—	1.7	
2	[110]	0.11		33	—	0.27	1.96
14	[100]	0.12	0.13		—	5.3	
	[010]	0.13			—	0.30	
	[001]	0.13		8	[100]	2.3	
3	[111]	0.15		7	—	3.5	
29	—	0.16		30	—	4.9	4.0
4	[100]	0.17			—	4.9	
11	—	0.09	0.18		—	2.1	
	—	0.37		36	[100]	5.0	
	—	0.07		16	[100]	2.8	5.3
19	[100]	0.20			[010]	1.8	
32	[100]	0.20			[001]	11.2	
13	—	0.42		20	[100]	5.78	
17	[100]	0.78	0.87	10	—	7.03	
	[010]	0.77		21	—	7.53	
	[001]	1.07		15	[110]	24	
34	[100]	0.94	0.94	28	[111]	71.5	30.0
	[010]	0.93			$[\bar{1}10]$	14.2	
	[001]	0.94			$[11\bar{2}]$	4.3	
9	[100]	0.97	0.97	26	[001]	17.1	33.6
	[010]	0.96			$[\bar{1}10]$	13.3	
	[001]	0.97			[110]	70.5	
1	—	1.1		23	—	48	
				22	[100]	246	

which gives the specimen number, the direction in which the resistance was measured ([100], [010], [001], indicate cube-edges, [110] a face-diagonal, [111] a body-diagonal, [11$\bar{2}$] perpendicular to [111] and [$\bar{1}$10], and — a random direction), and the specific resistance ρ in ohms/cm. cube.

The table shows a range of specific resistance from 0.021 to 246 ohms/cm. cube, or a ratio of about 1 to 10,000, in good agreement with the previous observations. The absolute values confirm the order of magnitude reported by Harvey (1928) whose measurements were made by an entirely different method, namely by point contacts on polished sections.

The frequency of distribution of the values for the specific resistance is plotted in Fig. 3 which shows that specimens of pyrite most commonly have specific resistances between $\rho = 0.1 - 1$ and $\rho = 1 - 10$.

The ratio of the greatest to the least specific resistance in different crystals is about 500 times the ratio found in a single crystal,

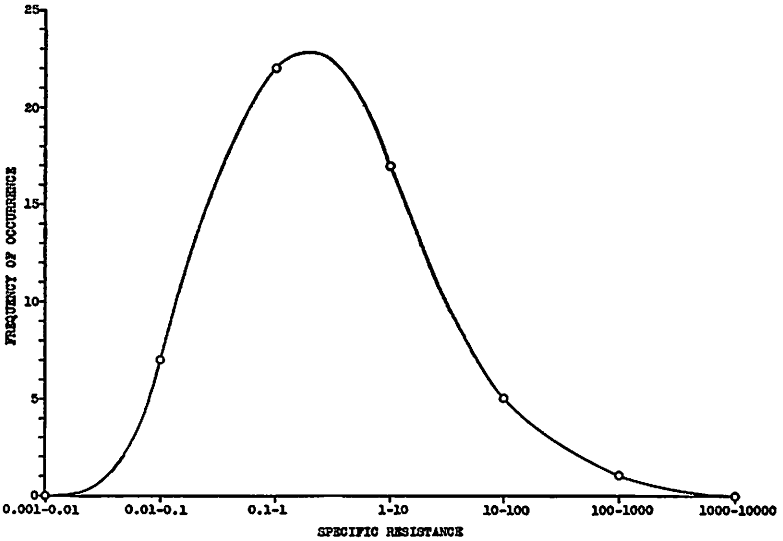


FIG. 3.—Curve relating the specific resistance to the frequency of occurrence in prisms cut from a number of crystals of pyrite.

and therefore the variation in different crystals is clearly not explained by variation due to direction.

RELATION OF CONDUCTIVITY TO MINERALOGICAL PROPERTIES

In some cases, crystals from one locality had similar resistivities (5 and 6, 25 and 27); in others, they had dissimilar resistivities (16 and 17, 22 and 27, 26 and 30). Thus there appeared to be no relation between resistivity and geographical distribution.

The forms seen, in order of frequency of occurrence, were the cube, pyritohedron, octahedron, and diploid. These were found in good-conducting and poor-conducting pyrite, and therefore no connection could be seen between resistivity and crystal habit.

The colour of the specimens of pyrite studied varied from very pale yellow to brass yellow. The noticeably whiter specimens (21, 33) were better conductors than the noticeably yellower examples (15, 23, 26). However, there were many specimens of average pyrite-colour which were better conductors than the whitish variety.

Many of the poor conductors had a high, almost resinous lustre and most of the good conductors had a lower, more metallic lustre. This distinction was not sharp, however, and would not be of use in differentiating the two types.

The streak of pyrite is given by Dana as brownish black or greenish black. Both streaks could be obtained from one specimen using smoother or rougher streak plates. When using a smooth plate considerable heat is generated on grinding off the powder; this probably oxidizes the mineral, giving a brownish streak. The colour of a mixture of chalk and pyrite ground together in water is the same tone of grey whether the conducting or the resistant variety is used.

The best conductor (27) and the poorest conductor (22) are both optically anisotropic, and therefore the cause of optical anisotropism is apparently not connected with variation in conductivity.

There seemed to be some connection between temperature of formation and specific resistance. The specimens of pyrite known to have formed at high temperature (2, 3, 4, 5, 6, 18) all had a specific resistance below 0.2 ohms/cm. cube. The pyrite from Joplin (23) is recognized as having a low temperature of formation and it had a specific resistance of 48 ohms/cm. cube. However, further observations would be necessary to establish a generalization.

EFFECT OF HEAT TREATMENT

It was found by accident that heat treatment of an anisotropic specimen rendered it isotropic. A fragment of the same crystal as 22 was ground flat and polished by hand on cloth laps (fine alundum, rouge and tin oxide). It showed distinct anisotropism, the colours with the nicols nearly crossed being light blue-green to light orange-red. Seven sections were mounted in bakelite for mechanical polishing, three sections parallel to the three cube-faces, and four sections perpendicular to the body-diagonals of the cube. All were isotropic. The maximum temperature of the bakelite moulding die was 135°C. and cooling to about 100°C. took place in 5 minutes.

The effect of heat treatment on the electrical conductivity was then determined. The prisms 5, 21, and 22 were covered with finely ground pyrite in a crucible. A thermocouple was embedded in the pyrite, the crucible was covered with asbestos, and the whole was heated to 220°±10°C. in 45 minutes, cooled slowly to 100°C. in 120 minutes, and then allowed to cool to room temperature in air. The resistivities were found as before, and the results were as follows:

No.	Before heating ρ	After heating ρ
5	0.039	0.04
21	7.53	7.6
22	246	246

There is evidently little or no permanent change in the conductivity of pyrite by this type of heat treatment.

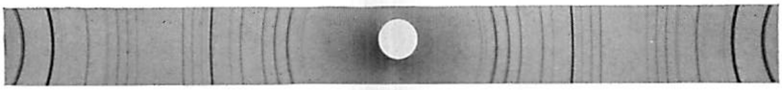


FIG. 4

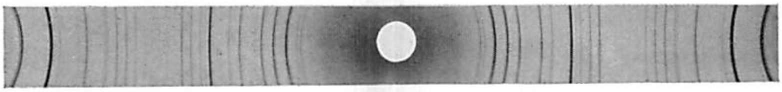


FIG. 5

FIGS. 4, 5.—*X*-ray powder photographs with unfiltered Fe*K* radiation; camera radius 360/4π mm. Fig. 4.—Pyrite (27), Rio Marina, Elba; $\rho=0.021$ ohms/cm. cube in a random direction. Fig. 5.—Pyrite (22), Brosso, Piedmont, Italy; $\rho=246$ ohms/cm. cube in the direction [100].

STRUCTURAL DATA

X-ray powder patterns were obtained of the two extreme types of pyrite, the best conductor (27) and the poorest conductor (22). The photographs were made under identical conditions, with iron radiation and a camera of radius $360/4\pi$ mm. The two materials gave very clear films (Figs. 4 and 5) which showed no visible difference in the positions or relative intensities of the lines. The cube-edge given by the films is $a_0 = 5.410 \pm 0.005$ Å, in agreement with the established value. Consequently, there is no sensible difference in the cube-edge or in the sulphur parameter of the two types.

SUMMARY

The specific resistance in various directions in a single crystal of pyrite was found to be greatest in the direction of one body-diagonal and least in a direction at right angles to that body-diagonal. The ratio of the greatest to the least specific resistance was 17 to 1. The resistance figure was found to have rhombohedral symmetry.

The specific resistance in thirty-five crystals was found to range from 246 to 0.021 ohms/cm. cube giving a ratio of about 10,000 : 1. The most frequent values lay between 0.1 and 10 ohms/cm. cube.

No obvious connection was found between the variation in conductivity and the place of origin or the habit, colour, lustre, streak, or anisotropism of the pyrite studied. There seemed to be some relation between conductivity and temperature of formation, the crystals known to have formed at high temperature all being good conductors, whereas one known to have formed at low temperature was a relatively poor conductor.

Heat treatment of one optically anisotropic crystal of high resistance rendered it isotropic. Heat treatment of a good conductor, an average conductor, and a poor conductor made no permanent change in the specific resistance.

X-ray powder patterns showed that there is no appreciable structural difference between the two extreme types of pyrite.

No explanation for the great difference in conductivity of pyrite is advanced, but it is hoped that a continuation of this work, with special consideration of the possible influence of impurities, departures from the ideal Fe:S ratio, and other factors, may yield an explanation of this surprising variation in a common mineral.

It is a pleasure to acknowledge the great help and encouragement given me in this work by Professor M. A. Peacock. My thanks are also due to Professor A. L. Parsons for some of the pyrite crystals, Mr. L. G. Berry for the x-ray photographs, Mr. G. E. Steel for cutting some of the orientated prisms of pyrite, to Professor E. F. Burton and Dr. A. A. Brant of the Department of Physics for equipment and help with the electrical measurements, and to Professor E. S. Moore for laboratory facilities in the Department of Geology.

After this work was completed the writer's attention was drawn to the fact that Cesàro (*Acad. Roy. Belgique, Bull. Cl. Sci.*, p. 120, 1904) had found that pyritohedrons striated parallel to the cube-edge are poor conductors of a direct current, whereas pyritohedrons striated perpendicular to the cube-edge are good conductors. This observation was confirmed by Donnay (*Ann. Soc. géol. Belgique*, vol. 59, p. B32, 1935). The complementary pyritohedrons are also known to have opposite thermoelectric character (Tutton, *Crystallography*, p. 168, 1911).

REFERENCES

BAIN, G. W. (1935): Pyrite oxidation—*Econ. Geol.*, vol. 30, pp. 166-169.

BEIJERINCK, F. (1897): Ueber das Leitvermögen der Mineralien für Elektricität—*N. Jahrb. Min.*, Beilage-Bd. 11, pp. 403-474.

HARVEY, R. D. (1928): Electrical conductivity and polished mineral surfaces—*Econ. Geol.*, vol. 23, pp. 778-803.

KERR, P. F., and CABEEN, C. K. (1925): Electrical conductivity of ore minerals—*Econ. Geol.*, vol. 20, pp. 729-737.

KÖNIGSBERGER, J., and REICHENHEIM, O. (1906): Ueber die Elektrizitätsleitung einiger natürlich kristallisierter Oyxde und Sulfide und des Graphits. Nebst Anhang: Ueber einige polymorphe Modifikationen—*N. Jahrb. Min.*, vol. 2, pp. 20-49.

AN EPITHERMAL SCHEELITE DEPOSIT IN THE BRIDGE RIVER DISTRICT, B.C.[1]

By JOHN S. STEVENSON
British Columbia Department of Mines

INTRODUCTION

A deposit of epithermal scheelite was discovered by Edwin Phillips in the summer of 1939 in the Tyaughton Creek Valley, fourteen miles north of Minto City in the Bridge River district, British Columbia, on ground originally staked for cinnabar. The only working at the time of the writer's examination in September, 1939, consisted of a 14-foot stripping along the strike of the scheelite discovery veins. Since then, however, a considerable amount of work has been done and one ton of high-grade ore has been cobbed from the veins and shipped to eastern manufacturers.

Tungsten minerals are ordinarily considered to be high temperature minerals, but many important tungsten deposits in the United States are epithermal (Lovering, 1933, pp. 668-671). However, only one group of these, the Atolia deposits (Lovering, 1933, pp. 670-671; Hulin, 1925, pp. 70-78) are deposits of epithermal scheelite. It is hoped that the following notes on the Bridge River occurrence, the first published description to the writer's knowledge of epithermal scheelite from Canada, will serve to illustrate the point that scheelite, even when the main constituent of a vein, may be epithermal, the term epithermal being used in the sense of mineral deposition under conditions of low temperature, and in this deposit also of low pressure.

The structure and mineralogy of the scheelite veins on the Phillips' property are such as to indicate that this scheelite was formed under conditions of both low pressure and low temperature.

GEOLOGY

A large irregular area of carbonatized serpentine, in which the scheelite veins occur, intrudes both ribbon chert and volcanics,

---

[1] Published by permission of the Honourable Minister of Mines for British Columbia.

but is, in turn, intruded by many dykes and irregular masses of feldspar porphyry. The serpentine extends as an irregular area for 200 feet north-westerly and south-easterly, 100 feet south-westerly, and 30 feet north-easterly from the scheelite. The serpentine has been extensively carbonatized and consists almost exclusively of ankeritic carbonate with small amounts of mariposite, residual antigorite, and chromite.

The ribbon chert, in contact with serpentine, outcrops approximately 200 feet south-eastward from the scheelite. The chert, strike easterly and dip vertical, consists of slightly crenulated ribbons of dark grey to black chert that range from 1 to 3 inches in width.

Volcanic rocks, or greenstone, consisting of flow rocks and volcanic breccia, begin to outcrop 400 feet easterly from the scheelite veins and extend for an unknown distance eastward. The flow rocks consist of massive, fine-grained andesitic lava with an amygdaloidal phase. The volcanic breccia consists of poorly defined angular fragments of andesitic material similar to that of the flow rocks, and set in an altered groundmass of the same material.

Feldspar porphyry, the youngest rock on the property, occurs as dykes that range from 50 feet to 100 feet in width, and as an irregular stock-like area with an exposed diameter of 300 feet. It is a medium-grained, porphyritic rock that contains closely-packed feldspar phenocrysts, averaging $\frac{1}{8}$ inch in maximum dimension, set in a brown weathering, altered matrix consisting mostly of carbonate. No quartz was seen in any of the specimens examined.

The ages of the various rock types on this property are not known definitely. However, in the Gun Lake area, eight and a half miles southward, Cairnes (1937, pp. 8-9) assigns lithologically similar chert and intercalated volcanics provisionally to the Permian, serpentine intrusives provisionally to the Jurassic, and feldspar dykes to the Post Lower Cretaceous.

VEINS

Scheelite occurs in two small parallel veins, one of which is predominantly stibnite and the other predominantly scheelite, both of which possess features that relate them to epithermal veins.

These veins are 2 feet apart and range from 1 inch to 3 inches in width. They strike north-westerly in conformity with the contact between the serpentine and feldspar porphyry but lie 30 feet south-westerly from the contact.

Structure

Over the short distance exposed, the veins maintain a uniform strike and dip, and a fairly uniform width. The veins frequently split and smaller veins branch sharply from the main vein (Fig. 1), and extend for 2 or 3 feet into the wall rock and die out or may turn, following other branch fractures that lead back into the main vein. Shearing along the vein walls and branch-fractures appears to have been absent for there are no slickensides and the veins are frozen to the wall rock. This branching type of fracture is suggestive of fracturing under a light load, presumably near the surface.

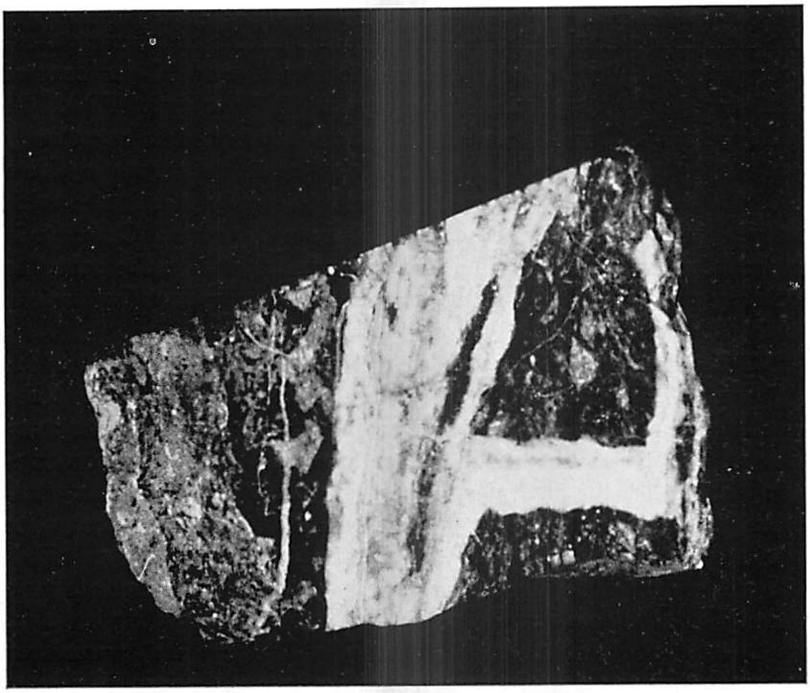


FIG. 1.—Hand specimen showing branching of the scheelite vein. Scheelite, white; wall-rock dark grey to black. ×1½.

The veins show marked crustification or banding by deposition. Crustification is particularly well shown in the stibnite-scheelite vein where scheelite is followed inwards from both walls of the vein by finely crystalline chalcedonic quartz, then by coarsely crystalline comb quartz, and finally by a central band of stibnite.

A definite comb-structure is shown both by the coarsely crystalline quartz and by the scheelite. This structure is expressed in the development of pyramidal crystals that have grown normal to the walls of temporary openings within the vein.

Mineralogy

The vein-minerals include, listed in order of abundance: scheelite, stibnite, quartz, and carbonate. These minerals are distributed between the two veins, the scheelite vein and the stibnite-scheelite vein. The scheelite vein, ranging from 1 to 3 inches wide, consists predominantly of scheelite and carbonate with some quartz and isolated crystals of stibnite. In sections of the vein, sometimes as much as 3 feet in length, scheelite amounts to 75 per cent of the vein-matter (equivalent to assays of 60.7 per cent WO_3). In other sections there is less scheelite and in places it is completely replaced by carbonate. The stibnite-scheelite vein, ranging from 1 inch to 3 inches wide, consists predominantly of stibnite with varying amounts of scheelite, carbonate, and quartz. Scheelite is more abundant in the stibnite vein than stibnite in the scheelite vein; in one place the scheelite amounts to 38.5 per cent (equivalent to 31.1 per cent WO_3) of the vein-matter.

Scheelite. The scheelite is nearly pure white in colour, much lighter in colour than is characteristic of scheelite from other occurrences in British Columbia. Megascopically it is quite massive and compact, but under the microscope it is seen to be coarse-grained and for the most part well crystallized. Where the crystals have not been shattered by intra-vein fracturing, the scheelite exhibits a well-defined comb-structure that results from pyramidal-shaped crystals of scheelite arranged normal to the walls of the vein fissure. The average size of these pyramidal crystals is 4 mm. by 2 mm. Some of the scheelite is badly fractured and granulated along the inner sides of the scheelite bands and broken fragments are surrounded by a matrix of chalcedonic quartz. The scheelite occurs most commonly along the borders of the veins, and was apparently the first vein mineral to form in the open-vein fissure; that the fissure was open during mineralization is indicated by the comb-structure displayed by the scheelite. Subsequent to its deposition, the scheelite was badly fractured along the middle of the vein and chalcedonic quartz was deposited.

A partial analysis of as pure a sample of scheelite as could be obtained by panning and by separation with methylene iodide, gave the following results:

WO_3.....79.7 per cent
CaO.....19.3 per cent
MoO_3....trace

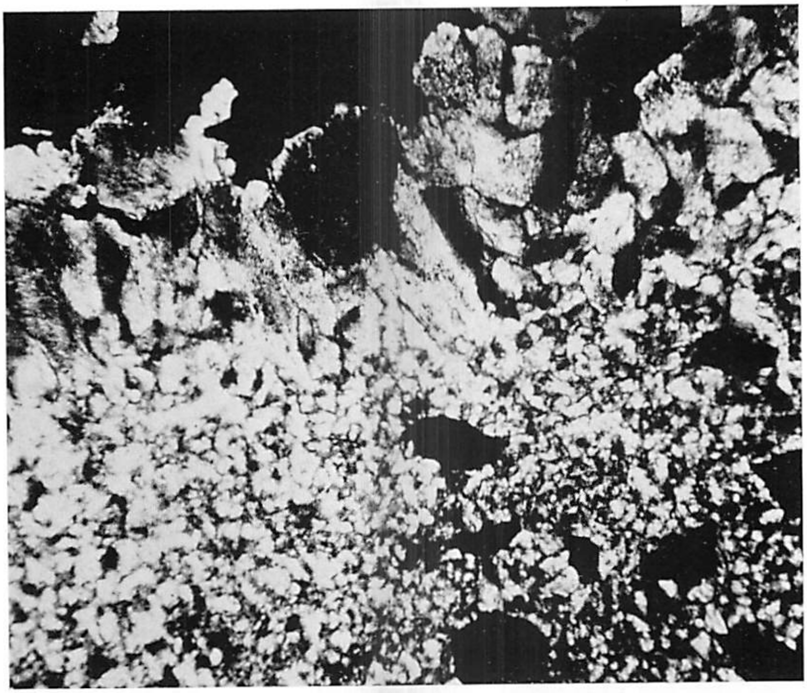


FIG. 2.—Thin-section showing banding of comb-quartz (upper part of picture) and chalcedonic quartz (lower part of picture). Black areas are stibnite. Crossed nicols; ×100.

Quartz. Quartz occurs in small amounts in both the scheelite and stibnite veins as two non-gradational types, fine-grained chalcedonic quartz and coarse-grained comb-quartz (Fig. 2).

The chalcedonic quartz consists of fine quartz grains, which average 0.01 mm. in diameter. Chalcedonic quartz fills the interstices between scheelite crystals in the scheelite vein and occurs as bands between the earlier scheelite and the later comb-quartz and stibnite in the stibnite-scheelite vein.

The comb-quartz occurs commonly as pyramidal-shaped crystals that measure, in general, 0.1 mm. by 0.05 mm. It frequently occurs between earlier chalcedony and later stibnite as bands in which the crystals have grown normal to the direction of the band (Fig. 2). However, it also occurs as rosettes (Fig. 3) of pyramidal-

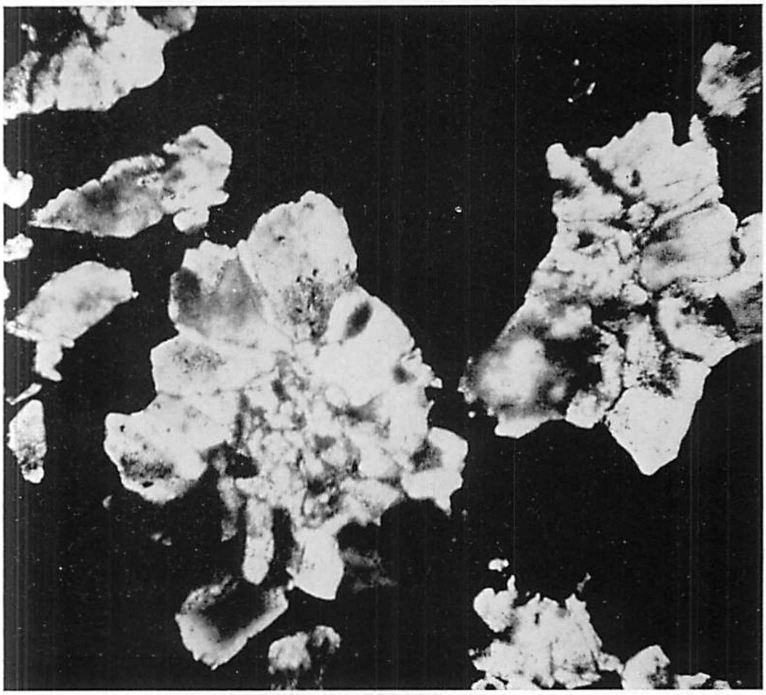


FIG. 3.—Thin-section showing rosettes of comb-quartz (white and grey) surrounded by stibnite (black). Crossed nicols; ×100.

shaped crystals within the central band of stibnite, the stibnite in many instances being moulded around the ends of the quartz crystals. The presence of comb-quartz indicates a period of re-opening of the vein between the time of deposition of the chalcedony and the stibnite.

Stibnite. Stibnite occurs predominantly as the central band in the stibnite-scheelite vein. The stibnite is of the usual metallic steel grey colour, and consists of occasional glistening blades of stibnite, in general measuring 5 mm. by 0.5 mm., set in a dense structureless mass of the sulphide. In the central part of the band the stibnite blades are non-directional, but towards the borders of the band they show a marked tendency towards parallelism with

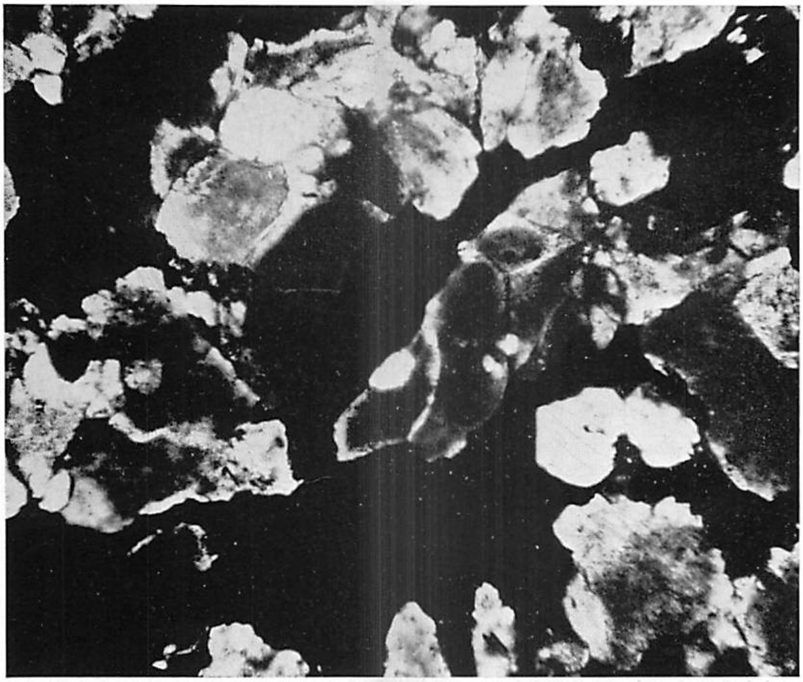


FIG. 4.—Thin-section showing veining of comb-quartz (grey and white) by stibnite (black); note stibnite vein going diagonally upwards to the right. Crossed nicols; ×100.

the walls of the vein, and where occurring in a gangue of chalcedonic quartz the crystals are seen to follow fractures parallel to the walls of the vein.

With the exception of the carbonate, stibnite has been the latest mineral to form. It veins the scheelite and both the chalcedonic and comb-quartz (Fig. 4), and is moulded around the ends of the crystals of the comb-quartz; it is, however, veined by the carbonate.

Ankeritic Dolomite. Carbonate occurs predominantly in the scheelite vein. It occurs as veinlets that tend to cross the banding of the scheelite vein at a small angle. Very commonly the direction of the carbonate veinlets is influenced by the cleavage planes of the scheelite (Fig. 5). Where scheelite is subordinate or almost entirely

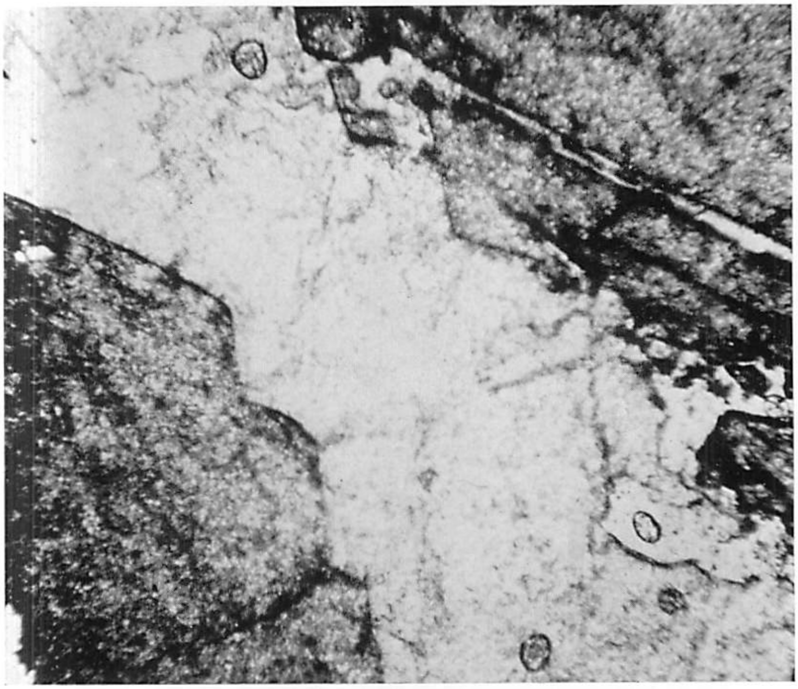


FIG. 5.—Thin-section showing carbonate veinlet (light grey) cutting scheelite (dark grey); note tendency of veinlet to follow cleavage of the scheelite. Plane polarized light; ×100.

absent, the carbonate is massive and is the only constituent of the vein.

The chemical composition[2] of the carbonate is as follows:

$CaCO_3$	54 per cent
$MgCO_3$	40 per cent
$FeCO_3$	5 per cent

The ω index is 1.689.

On the basis of chemical composition the carbonate may be named ankeritic dolomite (Winchell, 1933, p. 70).

Paragenesis of the Vein Minerals. The paragenesis of the vein minerals is summarized in Fig 6.

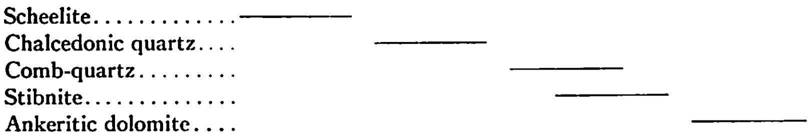


FIG. 6.—Summary of mineral paragenesis.

It will be noted that, with the exception of probable overlap in deposition between the comb-quartz and stibnite, the paragenesis of the vein-minerals is characterized by successive deposition.

The most interesting feature of the mineral succession is the number of times that the vein-fissure appears to have been open during mineral deposition. These periods of successive opening of the vein are recorded by the comb-structure seen in the early scheelite and in the later quartz.

GENESIS

Information concerning rocks genetically associated with the deposit is lacking. The veins are close to a feldspar porphyry intrusion, but the close spatial relationship of but one deposit does not prove that the mineralizing solutions emanated from the intrusive itself. Dykes of feldspar porphyry are abundant in the area between this property and the Empire Mercury Mines, one and a half miles northward, but they contain no mineralization. Isolated patches of Tertiary lavas are common in the area northward, and a volcanic neck has been described by Mackenzie (1920, p. 78-A)

---

[2] Analyst—G. C. Brown-Cave.

from the head of Relay Creek, approximately fifteen miles northwesterly from the scheelite. It is possible that the scheelite-bearing solutions, together with those responsible for other epithermal deposits in the area, are related to centres of Tertiary volcanics similar to the volcanic neck at the head of Relay Creek, and have emanated from the same general deep-lying source. Such a relationship of epithermal mineralizing solutions both to volcanic necks or centres of volcanism and to deep-lying sources, has been suggested by Lindgren (1933, p. 455).

SUMMARY

Structurally, the veins are characteristic of epithermal veins. A branching type of fracture, frozen vein-walls, and marked crustification of the vein-matter are characteristic of deposits formed under a light load.

Mineralogically, the veins are also characteristic of epithermal veins. Such low temperature minerals as stibnite and chalcedonic quartz are characteristic of the deposits. Minerals characteristic of high temperature deposits are absent.

Areally, the scheelite deposit is associated with deposits of epithermal or low-temperature minerals. Cinnabar occurs in small amounts 450 feet south-easterly from the scheelite and in somewhat larger amounts one and a half miles northward at the Empire Mercury Mine. Cinnabar has also been found six miles southerly at the Conardon Mercury Mine and twenty miles easterly on the Yalakom River. A deposit of stibnite occurs twenty-four miles easterly on Watson Bar Creek. Within the area of these discoveries, deposits characterized by high temperature minerals are as yet unknown.

This deposit is one in which the scheelite is the most abundant mineral and yet it possesses all the features of epithermal veins.

It is hoped that the description of this epithermal deposit will serve to illustrate the point that scheelite, though occurring as the main vein mineral, does not necessarily characterize a deposit as having been formed at a high temperature.

ACKNOWLEDGMENTS

The writer wishes to thank Dr. John F. Walker and Mr. Philip B. Freeland of the British Columbia Department of Mines who, though not necessarily concurring with all the views held by the writer, kindly read and criticized the manuscript. He also wishes to thank Mr. John M. Cummings of the Department for his generous assistance in the taking of photographs.

REFERENCES

CAIRNES, C. E. (1937): Geology and mineral resources of Bridge River Mining Camp, B.C.—*Geol. Surv. Canada,* Mem. 213.
HULIN, C. D. (1925): Geology and ore deposits of the Randsburg quadrangle, California—*California State Mining Bureau,* Bull. 95.
LINDGREN, WALDEMAR (1933): *Mineral deposits*—New York.
LOVERING, T. S. (1933): Ore deposits of the Western States: Tungsten deposits —*Am. Inst. Mining Met. Eng.,* Lindgren volume.
MACKENZIE, J. D. (1920): A reconnaissance between Taseko Lake and Fraser River, British Columbia—*Geol. Surv. Canada,* Summ. Rep.
WINCHELL, A. N. (1933): *Elements of optical mineralogy,* part 2—New York.

SOME BISMUTH MINERALS FROM BRITISH COLUMBIA

By HARRY V. WARREN and PHILIP DAVIS
University of British Columbia

The minerals described in these notes are bismuthinite, galenobismutite, cosalite, tellurbismuth, joseite, and a related mineral which may be a new bismuth telluride. These minerals are of interest in view of their rarity, at least in British Columbia, and the fact that some of them have been incorrectly identified in the past. It is also noteworthy that each of these minerals is associated with native gold which generally occurs in important quantities wherever bismuth minerals are found.

The bismuth minerals occur at the following localities: Glacier Gulch, Hudson Bay Mountain, near Smithers (bismuthinite, joseite, and a related bismuth telluride); Cariboo Gold Quartz Mine, Wells, Cariboo District (cosalite and galenobismutite); Hunter Group Claims, Khutze Inlet, near Swanson Bay (tellurbismuth); Ashloo Mine, near Squamish, Howe Sound (tellurbismuth).

BISMUTHINITE

Bi_2S_3

Bismuthinite occurs in the ore from Glacier Gulch, associated with bismuth tellurides (described later) and electrum (Au 85.72, Ag. 14.28) in quartz. In the specimens examined, bismuthinite is not actually in contact with the tellurides. The mineral appears in poorly formed, flattened prisms, $\frac{1}{2}$-1 inch by $\frac{1}{8}$-$\frac{1}{4}$ inch, with perfect cleavage and specific gravity 6.77±0.03 (10 measurements[1]). This value is notably higher than the range given in Dana (1892, p. 38), but agrees well with 6.78±0.03 (measured), 6.81 (calculated), given by Hofmann (1933, p. 228).

GALENOBISMUTITE

$PbS.Bi_2S_3$

This mineral has been identified in the ore from the Cariboo Gold Quartz Mine. The mineral occurs intergrown with cosalite,

---

[1] These and other measurements given in this paper were made on the density balance described by Berman (1939).

together with an unidentified telluride and gold, in quartz. From etch tests and a spectographic analysis on material from this mine, Haycock (1933) inferred the presence of matildite or cosalite ("Mineral Y"). Further work on numerous specimens has confirmed the identification of cosalite and has established the presence of galenobismutite, a rare mineral whose specific properties are not yet well known.

Galenobismutite is a metallic grey mineral resembling galena in colour. In the specimens available it shows no cleavage or crystal form. Hardness, 2½. Specific gravity, not determined. In polished sections galenobismutite is creamy white, darker than cosalite and rougher, when polished by hand. Soft. Strongly anisotropic. Etch tests: HNO_3, rapidly turns black with slight effervescence; HCl, stains dark grey to black; KCN, negative; $FeCl_3$, stains light brown; KOH, negative; $HgCl_2$, negative. These reactions differ from those given by Short (1934) for a seleniferous mineral from Falun, Sweden.

Owing to the intimate intergrowth with cosalite, a pure sample could not be obtained for analysis. A sample containing some cosalite and presumably a little pyrite was analysed by E. W. Johnson under the supervision of the late Professor H. N. Thomson; the result is sufficiently close to the ideal values of $PbBi_2S_4$ to indicate this composition.

	Analysis	$PbBi_2S_4$
Pb	30.5	27.5
Bi	51.0	55.4
S	16.4	17.1
Fe	1.5	——
	99.4	100.0

An incomplete analysis by Mr. G. S. Eldridge, on a less pure sample, gave a Pb : Bi ratio of about 1 : 2. The identity of this mineral was confirmed by Mr. L. G. Berry, who obtained an *x*-ray powder pattern identical to that given by galenobismutite (type material) from Nordmark, Sweden.

COSALITE

$2PbS.Bi_2S_3$

Cosalite occurs as hair-like crystals in vugs and in fibrous masses with one perfect longitudinal cleavage, associated and intergrown with galenobismutite in the ore from the Cariboo Gold Quartz Mine. This material was recently described in detail (Warren, 1939), the identity being confirmed by an *x*-ray powder photograph by Berry (1939, Fig. 5). An approximate measurement of the specific gravity gave 6.8, which lies in the range of the measured and calculated values given by Berry. Cosalite has also been identified at the Island Mountain Mine, Wells, Cariboo District (Berry, 1939, Fig. 6).

TELLURBISMUTH

Bi_2Te_3

This mineral, which resembles tetradymite, Bi_2Te_2S, has been recognized in ores from the Hunter and Ashloo Mines. In both these localities gold is found in close association with the tellurbismuth, which is locally known as tetradymite. In the ore from the Ashloo Mine, Haycock (1936, p. 175) noted a single grain of gold associated with a mineral ("Undetermined, No. 2") which may have been tellurbismuth.

In the Hunter material, tellurbismuth appears in grains (0.001-0.03 mm.) in pyrite, rarely in plates up to ½-inch wide and ⅛-inch thick, with chalcopyrite, arsenopyrite, pyrrhotite, sphalerite, sylvanite (?), and gold, in pyrite and quartz. The same association, with the addition of galena, is found at Ashloo. In both cases, the associated gold occurs in grains in contact with tellurbismuth, occasionally in tiny sheets which are embedded parallel to the cleavage and are left behind on dissolving the enclosing mineral.

The physical properties of tellurbismuth are very like those of tetradymite. Specific gravity, 7.82 (Hunter), 7.80 (Ashloo). In many fragments small amounts of an earthy mineral were revealed on splitting along the perfect cleavage. Tellurbismuth may be distinguished from tetradymite by the etch tests:

	HNO_3	HCl	KCN	$FeCl_3$	KOH	$HgCl_2$
Tellurbismuth..........	+	−	+	+	−	−
Tetradymite............	+	+	−	+	−	?

Professor F. A. Forward kindly made two analyses on samples containing some non-metallic impurities. The results, when reduced to 100 per cent, agree well with the composition of Bi_2Te_3.

	Hunter		*Ashloo*		
	Analysis	Reduced to 100 per cent	Analysis	Reduced to 100 per cent	Bi_2Te_3
Bi	49.7	52.4	47.7	49.9	52.2
Te	45.1	47.6	47.9	50.1	47.8
S	none	——	none	——	——
	94.8	100.0	95.6	100.0	100.0

The identification of both materials was confirmed by Professor M. A. Peacock who obtained identical *x*-ray powder patterns from the mineral and the artificial compound Bi_2Te_3.

JOSEITE AND A RELATED TELLURIDE

The bismuth tellurides, associated with bismuthinite at Glacier Gulch, occur in cleavable platy masses as large as 2 by 1 by 1 inches and also in similarly oriented fragments intergrown with quartzose gangue. These minerals closely resemble tetradymite and tellurbismuth in possessing a perfect cleavage giving soft flexible sheets, but they differ in having higher specific gravities. Numerous measurements on small fragments gave a surprising range, from slightly less than 8 to nearly 9. In part, this variation might be due to enclosed impurities, namely electrum, and also other metallic and non-metallic grains noted in polished sections.

A picked sample consisting of fragments with specific gravity not less than 8.3, and believed to have an average specific gravity of 8.6, was analysed by Professor Forward, who obtained the following result indicating the formula Bi_4TeS_2.

	Analysis	Reduced to 100 per cent	Bi_4TeS_2
Bi	79.3	81.3	81.4
Te	12.2	12.5	12.4
S	6.0	6.2	6.2
Se	none	——	——
Au	trace	——	——
Insol	trace	——	——
	97.5	100.0	100.0

This composition is close to the reported composition of joseite (Bi 78.40-81.23) and grünlingite (Bi 78.82-79.31) but not identical with either of them (Hintze, 1904, p. 409). One constituent of the Glacier Gulch material may therefore be a new species with the composition Bi_4TeS_2.

After the above preliminary description was completed, Professor Peacock made some further observations on this material. Three fragments with specific gravity close to 8.0 gave identical *x*-ray powder patterns which proved to be the same as that of joseite (type specimen) from San Jose, Brazil and of grünlingite from Carrock Fells, Cumberland (type locality). A fragment with specific gravity close to 9.0 gave a distinctly different pattern. Possibly this heavier material corresponds to the analysed sample. The Glacier Gulch material thus contains the mineral previously named joseite (grünlingite) and perhaps a new species with the composition Bi_4TeS_2.

ACKNOWLEDGMENTS

The authors are indebted to Professor F. A. Forward, University of British Columbia, for making several of the analyses given in this paper; to Professor M. A. Peacock and Mr. L. G. Berry, University of Toronto, for examining some of the described materials; and to Dr. V. Dolmage and Dr. W. Smitheringale, and Mr. J. M. Meldrum, Mr. S. F. Campbell, Mr. R. R. Rose, Mr. E. Johnson, Mr. R. Maconachie, and Mr. P. N. Pitcher for providing specimens.

REFERENCES

BERMAN, H. (1939): A torsion microbalance for the determination of specific gravities of minerals—*Am. Mineral.*, vol. 24, pp. 434-440.

BERRY, L. G. (1939): Studies in mineral sulpho-salts; 1—Cosalite from Canada and Sweden—*Univ. Toronto Studies, Geol. Ser.*, no. 42, pp. 23-31.

DANA, E. S. (1892): *System of mineralogy*, ed. 6—New York.

(HAYCOCK, M. H.) (1933): The determination of the minerals in samples from the Cariboo Gold Quartz Company, Barkerville, British Columbia—*Can. Dept. Mines, Mines Branch, Division of Ore Dressing and Metallurgy* (unpub. rep.).

——————— (1936): Gold-copper ore from the Ashloo gold mining syndicate, Squamish, Vancouver mining district, B.C.—*Can. Dept. Mines, Mines Branch, Investigations in ore dressing and metallurgy*, Jan. to June, 1935, pp. 175-181.

HINTZE, C. (1904): *Handbuch der Mineralogie*, vol. 1, part 1—Leipzig.

HOFMANN, W. (1933): Die Struktur der Minerale der Antimonitgruppe—*Zeits. Krist.* (A), vol. 86, pp. 225-245.

SHORT, M. N. (1934): Microscopic determination of the ore minerals—*U.S. Geol. Surv.*, Bull. 825, Revision of Part 3, Determinative Tables (mimeographed).

WARREN, H. V. (1939): An occurrence of cosalite in British Columbia—*Univ. Toronto Studies, Geol. Ser.*, no. 42, pp. 151-155.

THE WALKER MINERALOGICAL CLUB

OFFICERS FOR 1939-1940

Honorary President	Professor T. L. Walker
President	Mr. C. W. Drury
Secretary-Treasurer	Mr. W. E. Chantler
Councillors for Ordinary Members	
For 1939-40	Mr. D. E. Craigie
" 1939-41	Mr. W. C. Ringsleben
" 1939-42	Mr. G. E. Steel
Councillor for Department of Mineralogy	Professor M. A. Peacock
Councillor for Student Members	Mr. I. H. Milne
Past President and Editor	Professor A. L. Parsons

A special meeting was held in Room 22 of the Mining Building on Thursday, October 5, 1939, at 5 P.M. The purpose of the meeting was to take advantage of the presence of Dr. George Tunell of the Geophysical Laboratory, Washington, D.C., who was in Toronto on a business visit. He gave a very illuminating and instructive address on "The Crystal Structures and Paragenesis of the Gold-Silver Tellurides." His talk was illustrated. We are greatly indebted to Dr. Tunell for his very clear exposition of a subject which should be of great value to Canadians interested in the telluride ore of Northern Ontario.

The first regular meeting was held on Thursday, October 26, 1939, at 5 P.M. in Room 56 of the Mining Building. The Committee appointed to nominate officers for the Club for the year 1939-1940 nominated the following:

President	Mr. C. W. Drury
Secretary-Treasurer	Mr. W. E. Chantler
Councillors for Ordinary Members	
For 1 year	Mr. D. E. Craigie
" 2 years	Mr. W. C. Ringsleben
" 3 years	Mr. G. E. Steel
To represent Department of Mineralogy	Professor M. A. Peacock
To represent Student Members	Mr. I. H. Milne
Past President	Professor A. L. Parsons

The Secretary-Treasurer was instructed to send out ballots for the election of officers and the Council was instructed to canvass the ballot and announce the result at the December meeting.

On motion by Professor Thomson, the Secretary-Treasurer was instructed to submit the following amendment to the constitution to the members for ballot, the result of the ballot to be announced at the December meeting:

> "The Editor shall be the head or acting head of the Department of Mineralogy and Petrography in the University of Toronto and shall be a member of the Council."

The speaker for the meeting, Mr. Walter M. Tovell, then gave a talk on the "Mineral Museums of Northern Europe" which he had visited during the summer. Views showing museums and mineralogists of note in Warsaw, Helsinki, Stockholm, Upsala, Oslo, Copenhagen, Berlin, Dresden, Freiberg, Vienna, Budapest, Munich, Heidelberg, Paris, and London were accompanied by a most interesting narrative of the tour and were received with a hearty vote of thanks.

The second meeting of the Club was held on Thursday, December 14, 1939, at 5 P.M. in Room 56 of the Mining Building. The Secretary announced that the ballot for officers had resulted in the election of all those nominated by the Committee appointed to nominate the officers for the year, as reported at the first regular meeting, and that the amendment to the constitution proposed at the October meeting had received a favourable ballot.

The new President, Mr. C. W. Drury, was called to the chair and made a brief but very effective inaugural address. A vote of thanks to the retiring President, Professor A. L. Parsons, for his excellent work in promoting the Club was moved by Professor Thomson and seconded by Dr. J. Satterly.

It was moved by Professor Parsons and seconded by Professor Thomson, that the Secretary be instructed to convey to the families of Mr. Wm. T. Love, a graduate of Queen's University, and Mr. E. Shamley, a graduate of the University of Toronto, the sympathy of the Club in their bereavement.

It was moved by Professor Parsons and seconded by Professor A. MacLean that, for the duration of the war, memberships be maintained for all members on active service.

It was moved by Professor Thomson and seconded by Professor Parsons, that the recommendation of the Council be adopted that members who are two years or more in arrears in payment of dues be dropped from the roll of members. Mr. Horwood moved an amendment "that notice be given before dropping these members," but as there was no seconder, it was ruled out.

Dr. Moore introduced the speaker of the evening, Dr. Jack Satterly, who presented a very able paper on "War Minerals." It was a very timely subject and keen interest was shown by the large audience.

The third meeting was held on Thursday, February 22, 1940, at 5 P.M. in Room 56 of the Mining Building. The speaker of the evening was Mr. L. Heber Cole of the Department of Mines and Resources, Ottawa. His topic was "Salt Deposits in Eastern Canada." He handled the subject in a very able manner and at the end of his address answered many questions asked by the audience, drawing on his wealth of experience with the salt deposits of Canada. The attendance was probably one of the largest in the history of the Club. We wish to thank Mr. Cole for his splendid address and for so generously giving of his time in coming from Ottawa for our meeting.

The fourth meeting was held in Room 26 of the Mining Building on Thursday, April 11, 1940, at 8 P.M. The Secretary read a memo reminding members that some of them had not yet paid their dues, that some were in arrears, and that it was very important to get all dues in, in order to pay the Club's share of the cost of publishing the *Contributions to Canadian Mineralogy* which goes to each member.

It was moved by Professor Parsons and seconded by Professor Thomson that the President be empowered to name a nominating committee. The President nominated the present Council plus Dr. Hurst and Dr. Moore.

The programme for the evening was in charge of Dr. M. A. Peacock. The topic was "Progress of Research in the Department of Mineralogy and Petrography at the University of Toronto." Dr. Peacock outlined the research that had been done in pure mineralogy in relation to the revision of Dana's *System of Mineralogy*. He briefly described some of the modern methods and the principles involved and summarized some of the results that had been obtained recently. He then introduced the other speakers of the evening, who gave a detailed account of their part in the work.

Dr. A. S. Dadson spoke on the work done in proving that rammelsbergite and pararammelsbergite were distinct forms of nickel diarsenide. Dr. V. B. Meen gave an account of the *x*-ray powder method applied to the cobaltite group. Mr. L. G. Berry's talk was "The Weissenberg Method Applied to Jamesonite and Boulangerite." Mr. J. S. Allen, the last speaker of the evening, explained the Berman balance for measuring the specific gravity of small samples.

Dr. Hurst, of the Department of Mines, moved the vote of thanks to the speakers of the evening, after which the members grouped around the various instruments on display, inspecting them and asking questions.

Dr. Peacock is to be congratulated on the organizing of such an instructive and highly interesting meeting.

The membership of the Club as on June 1, 1940, is as follows:

Honorary members	3
Ordinary members	269
Student members	18
Total	290

Of these, five are on active military service and are exempt from dues. In addition to the above, the Club has lost four members by death and four members by resignation during the year.

FINANCIAL STATEMENT OF THE WALKER MINERALOGICAL CLUB FROM JUNE 1, 1939, TO JUNE 15, 1940

June 1, 1939, Cash on hand and in bank		$227.85	
Receipts			
Dues, 1937-38	$5.00		
Dues, 1938-39	60.00		
Dues, 1939-40	211.50		
Dues in advance	21.40		
Bank interest	1.04		
Sales of Journal	2.50		
Contribution, T. Lindsley	88.00		
P. E. Hopkins	5.00		
Exchange less bank charges	2.96		
		$397.40	
		625.25	
Less uncredited receipt in 1938-39		1.15	
			$624.10
Expenditures			
December 9, 1939, University of Toronto Press	$19.81		
December 9, 1939, Superintendent, University of Toronto	2.00		
January 2, 1940, Superintendent, University of Toronto	1.00		
January 2, 1940, University of Toronto Press	341.35		
April 13, 1940, Superintendent, University of Toronto	1.00		
April 13, 1940, University of Toronto Press	5.97		
May 9, 1940, Superintendent University of Toronto	4.00		
June 8, 1940, University of Toronto Press	12.64		
		$387.77	
June 15, 1940, Cash on hand and in bank		236.33	
			$624.10

BALANCE SHEET

June 15, 1940

Assets		
Cash on hand and in bank	$236.33	
Unpaid dues 1938-39	20.00	
1939-40	47.00	
		$303.33
Liabilities		
Dues paid in advance	$ 52.00	
Surplus	251.33	
		$303.33

W. E. Chantler,

Secretary-Treasurer