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*Studies of mineral sulpho-salts: XIII—Polybasite  
and pearceite.*<sup>1</sup>

(With Plates I and II.)

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THESE two minerals are analogous silver compounds with similar pseudo-hexagonal monoclinic form and similar compositions: polybasite,  $8(\text{Ag,Cu})_2(\text{Sb,As})_2\text{S}_3$ , and pearceite,  $8(\text{Ag,Cu})_2\text{S.As}_2\text{S}_3$ . Cu replaces Ag in considerable and varying amounts in both minerals, and in polybasite there may also be substantial replacement of Sb by As. However, the rather numerous existing analyses do not indicate continuous chemical variation from arsenian polybasite to pearceite, and therefore it is proper to recognize the two minerals as distinct species rather than end-members of a series.

Although most of the specific properties of polybasite and pearceite are known (Dana, 7th edition, 1944, pp. 351–355), there are still some gaps and uncertainties in the descriptions. The occasion to study these minerals was offered by some sharply crystallized polybasite from British Columbia, kindly sent to us by Professor H. V. Warren; the work was carried out partly by the senior author in the University of Toronto and partly by the junior author in Queen's University, Kingston, Ontario.

<sup>1</sup> For the preceding paper of this series see E. W. Nuffield (1946) [M.A. 10–15]. No. II by L. G. Berry on jamesonite appeared in this Magazine, 1940, vol. 25, pp. 597–608.

The material brought together for the present study consisted of the specimens listed below. In this list the collections are indicated as follows: UT (University of Toronto, Department of Geological Sciences); ROM (Royal Ontario Museum of Geology and Mineralogy; specimen kindly loaned by Dr. V. B. Meen); QU (Queen's University, Department of Mineralogy). Specimen no. 4 was kindly presented by Dr. M. H. Froberg.

1. Polybasite, Highland Bell mine, Beavertown, Greenwood mining division, British Columbia (UT, R 151); groups of sharp, bright, intergrown, tabular crystals up to 10 mm. wide.

2. Polybasite, Keeley mine, South Lorrain, Ontario (ROM, M 14781). Boxwork of imperfect plates, occasionally thin enough to transmit red light, with minute adhering octahedra of argentite, implanted on massive radial-fibrous safflorite.

3. Polybasite, Cobalt, Ontario (QU); thin, dark ruby-red hexagonal plates on massive white arsenides.

4. Polybasite, Yankee Boy mine, Ouray County, Colorado (QU); isolated dull hexagonal plates with quartz and galena.

5. Polybasite, Las Chiapas mine, Sonora, Mexico (UT, R 257); massive crystallized polybasite with attached pyrrargyrite and a drusy coating of chalcopyrite.

6. Pearceite, Aspen, Colorado (QU); intergrowth of rough, dull black hexagonal plates.

7. Pearceite, Silver, Montana (ROM, E 2768); a few black crystal chips.

#### POLYBASITE

*Physical properties.*—In all our specimens polybasite shows a marked tendency to develop the characteristic pseudo-hexagonal tabular form, with strong triangular terracing on the basal planes, much oscillatory development of the edge-faces, and intimate subparallel to irregular intergrowth of the crystal plates. The colour is iron-black and the crystals are opaque except in thin splinters which are dark red. The lustre is sub-metallic or adamantine to dull, and the mineral is remarkably brittle, a property which is appropriately expressed in Werner's name *Sprödglasserz* (which included polybasite and stephanite), and the name *Brittle Silver* used by Colorado miners (Penfield, 1896), but is not mentioned in Dana (1944). The basal cleavage is difficult but yields plane-faced fragments.

New specific gravity measurements on polybasite, made with the Berman balance, are compared below with recently published values:

	Sp. gr.	
Beavertown (material no. 1) ... ..	6.30	R. M. Thompson
Beavertown (veinlets) ... ..	6.26	Staples & Warren
Beavertown (coatings) ... ..	6.28	
Beavertown (crystal fragments) ... ..	6.33	(1946, p. 31)
South Lorrain (material no. 2) ... ..	6.27	R. M. Thompson
Sonora (material no. 5) ... ..	6.27	L. G. Berry

Polished sections of the materials from Beaverdell and South Lorrain were examined by R. M. Thompson who noted physical, optical, and etch properties in agreement with those given by Short (1940, p. 128).

*Crystal form.*—Good crystal form and bright faces were shown by a single crystal of polybasite from the Highland Bell mine (material no. 1). This crystal is an incomplete hexagonal tablet about 2 mm. wide, bevelled by numerous bright faces most of which gave good reflections. With an excellent basal plane taken as the pole-face on the two-circle goniometer the edge-faces all lie in three radial zones, and the resulting projection shows no significant deviation from hexagonal symmetry. Later X-ray work confirmed the monoclinic symmetry of polybasite, but no way was found to distinguish the quasi-equivalent ( $h0l$ ) and ( $hhl$ ) zones on the relatively large measured crystal, which has therefore been arbitrarily placed in one of the alternative positions (text-fig. 1). The angles measured on this crystal are compared in table I with angles calculated for polybasite on Penfield's elements (Dana, 1944, p. 351):

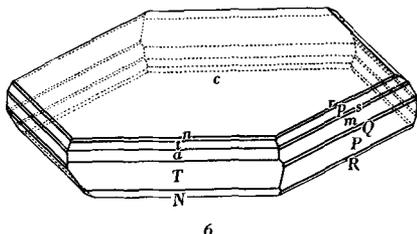


FIG. 1. Polybasite: measured crystal from Highland Bell mine, Beaverdell, B.C.

$$a : b : c = 1.7309 : 1 : 1.5796; \beta = 90^\circ 00'.$$

TABLE I. Polybasite: Measured and calculated angles.

Form.	Measured.		Calculated.	
	$\phi$	$\rho$	$\phi$	$\rho$
$c(001)$ ... ..	—	$0^\circ 00'$	—	$0^\circ 00'$
$a(100)$ ... ..	$90^\circ 00'$	89 56	$90^\circ 00'$	90 00
$m(110)$ ... ..	29 55	89 50	30 01	90 00
$n(101)$ ... ..	90 00	42 09	90 00	42 23
$N(\bar{1}01)$ ... ..	—90 00	42 08	—90 00	42 23
$t(201)$ ... ..	90 00	61 09	90 00	61 17
$T(\bar{2}01)$ ... ..	—90 00	61 06	—90 00	61 17
$r(112)$ ... ..	29 55	42 08	30 01	42 22
$R(\bar{1}12)$ ... ..	—30 01	42 11	—30 01	42 22
$p(111)$ ... ..	29 55	61 12	30 01	61 16
$P(\bar{1}11)$ ... ..	—30 01	61 14	—30 01	61 16
* $Q(\bar{4}43)$ ... ..	—30 01	67 48	—30 01	67 $39\frac{1}{2}$
$s(221)$ ... ..	29 55	75 02	30 01	74 $40\frac{1}{2}$

\*New form.

These observations agree well with those of Penfield and they confirm the uncommon form  $a(100)$  and establish the form  $Q(\bar{4}43)$  which was observed as a good face. A terraced plate from South Lorrain (material no. 2) gave  $ca$  or  $cm = 89^\circ 16' - 89^\circ 57'$  (calc.  $90^\circ 00'$ ),  $co = (001)(114) = 23^\circ 15' - 25^\circ 05'$  (calc.  $24^\circ 31'$ ). An incomplete crystal from Sonora (material no. 5) gave  $cn$  or  $cr = 42^\circ 27'$  (calc.  $42^\circ 23'$ ),  $ct$  or  $cp = 60^\circ 58'$  (calc.  $61^\circ 16'$ ).

*Optics.*—Efforts to add to the incomplete optical data for polybasite were largely unsuccessful. Extremely thin basal plates transmit cherry-red light and occasionally show a poor acute bisectrix figure with small optic axial angle. More often even thin basal plates fail to extinguish between crossed nicols and they yield no useful interference-figure. This suggests lamellar twinning about the axis  $[110]$  with composition on  $(001)$ , as in other minerals with pseudo-hexagonal layer-structures. An attempt to determine the refractive indices in melts of selenium and arsenic selenide likewise failed owing to the apparent solution of the mineral in the melts. Finally, an effort was made to measure a refractive index by finding the angle of incidence of reflected light showing maximum polarization; but, although the base of the measured crystal served well as a reflecting plane on the goniometer, a position of maximum polarization could not be sharply recognized with a suitably placed nicol prism.

*Unit cell.*—The unit cell of polybasite has been determined only once, by Gossner & Kraus (1934), who gave partly unsatisfactory data on unanalysed material from Guanajuato, Mexico. In view of the chemical variation in polybasite the unit cell was determined on all the available materials, from single-crystal X-ray photographs. For this purpose minute relatively thick crystals or basal cleavage plates were rotated about the cleavage normal  $[001]$  and about one or other of the edges  $[010]$  or  $[110]$ , and rotation and zero-layer Weissenberg photographs were taken. The rotation photographs about  $[001]$  all showed a strong set of layer-lines giving a period of about 12 kX and in all crystals, except that from Sonora, faint intermediate layer-lines requiring the double period of about 24 kX. The Weissenberg resolutions of the layer  $(hk0)$  showed perfectly hexagonal symmetry of the spots as regards position, but some exceptions as regards intensity. The rotation photographs about  $[010]$  or  $[110]$  on the different specimens are all alike, showing a strong set of layer-lines requiring a period of about 7.5 kX and a weaker but very clear set of intermediate layer-lines giving a period of about 15 kX (pl. I, fig. 1).

The zero-layer Weissenberg photographs about  $[010]$  or  $[110]$  are

interesting in affording direct proof of the symmetry of polybasite. The spots ( $h0l$ ) and ( $\bar{h}0l$ ), or ( $hhl$ ) and ( $\bar{h}\bar{h}l$ ), are exactly symmetrical in position about the row ( $00l$ ), but they are clearly not symmetrical in intensity (pl. II, fig. 6). The vertical axis is therefore not an even-fold symmetry-axis; and, since trigonal symmetry is excluded by the optical behaviour, the symmetry cannot be higher than monoclinic.

The cell dimensions measured on polybasite are assembled below and compared with those of Gossner & Kraus (table II).

TABLE II. Polybasite: Comparison of cell dimensions (kX).

	<i>a</i> .	<i>b</i> .	<i>c</i> .	$\beta$ .
Beaverdell, B. C. (no. 1) ... ..	26.12	15.08	23.89	90° 00'
South Lorrain, Ont. (no. 2) ... ..	26.12	15.08	23.84	90 00
Cobalt, Ont. (no. 3) ... ..	26.24	15.15	23.90	90 00
Ouray, Colo. (no. 4) ... ..	26.12	15.08	23.88	90 00
Sonora, Mex. (no. 5) ... ..	26.12	15.08	11.92	90 00
Guanajuato, Mex. (Gossner & Kraus, 1934) ... ..	12.99	7.50	11.95	90 —

The new cell dimensions are practically constant, except for the halved *c*-period for no. 5 and the slightly larger values for no. 3, which may be relatively free from copper. The usual dimensions of polybasite are thus about double those of Gossner & Kraus, who noticed indications of a double *b*-period but wrongly attributed this to twinning.

The strictly missing spectra give the conditions: ( $hkl$ ) present only with ( $h+k$ ) even, ( $h0l$ ) present only with *h* even, and ( $h00$ ) present only with  $h = 4n$ . In addition, there are only weak exceptions to the further conditions: ( $hkl$ ) present only with *l* even, ( $h0l$ ) present only with  $h = 4n$  and *l* even. These conditions are compatible with the holohedral space-group  $C2/m$ , but other space-groups are also possible.

The axial ratios from the new cell dimensions are compared below with the structural ratios of Gossner & Kraus and with the axial ratios previously obtained goniometrically by Penfield (1896) and Miers (1889).

TABLE III. Polybasite: Comparison of axial ratios.

	<i>a</i> : <i>b</i> : <i>c</i>	$\beta$
Beaverdell, B. C. (no. 1) ... ..	1.732 : 1 : 1.584	90° 00'
South Lorrain, Ont. (no. 2) ... ..	1.732 : 1 : 1.581	90 00
Cobalt, Ont. (no. 3) ... ..	1.732 : 1 : 1.579	90 00
Ouray, Colo. (no. 4) ... ..	1.732 : 1 : 1.584	90 00
Sonora, Mex. (no. 5) ... ..	1.732 : 1 : $\frac{1}{2}(1.581)$	90 00
Guanajuato, Mex. (Gossner & Kraus, 1934) ...	1.731 : 1 : 1.593	90 —
Ouray, Colo. (Penfield, 1896) ... ..	1.7309 : 1 : 1.5796	90 00
Several localities (Miers, 1889, corrected to suit his angles) ... ..	1.7262 : 1 : 1.576	(90 00)

Except for the values of Gossner & Kraus, which are slightly out of line, the assembled values are remarkably constant, indicating that the geometrical form of polybasite varies but little with variation of the chemical composition.

*Analyses and cell contents.*—The measured cell dimensions and specific gravity of the polybasite from Beaverdell, B.C. (material no. 1) give the molecular weight of the unit-cell contents,  $M = 35,929$ . By combining this number with the analysis of this material in the usual way the atomic content of the unit cell is obtained (table IV). It will be

TABLE IV. Polybasite from Beaverdell, B.C.:  
Analysis and cell content,  $M = 35,929$ .

	1.	2.	3.
Ag ... ..	69.72	232.5	253.4
Cu ... ..	3.70	20.9	
Sb ... ..	10.15	30.0	33.0
As ... ..	0.63	3.0	
S ... ..	15.68	175.9	175.9
	<u>99.88</u>	<u>462.3</u>	<u>464</u>

1. Analysis by R. N. Williams; sp.gr. 6.26. 2. Empirical cell contents. 3. Ideal cell contents.

observed that the ideal cell contents represent only a slight adjustment of the empirical cell contents, giving the formula:



and the calculated density 6.33. Thus the Beaverdell polybasite conforms closely to the accepted composition  $8(\text{Ag,Cu})_2\text{S.Sb}_2\text{S}_3$ , and represents material which is exceptionally low in Cu and As. The new cell dimensions require 16 formula weights, rather than 2 formula weights indicated by the pseudo-cell of Gossner & Kraus.

A full view of the chemical variation in polybasite is given in table V in which the seventeen available analyses have been expressed in terms of a sum of 29 atoms or 1/16 of the full unit cell, and arranged in order of decreasing number of Ag atoms. It will be seen that Cu ranges approximately from 1 to 4 atoms or from 1/16 to 1/4 of the (Ag,Cu) component. Arsenic varies more widely, from zero to over  $\frac{1}{2}$  of the (Sb,As) component. The average totals of the components (Ag,Cu), (Sb,As), and S, excluding only the few values in parentheses, come very close to the ideal numbers, 16, 2, 11, respectively.

*X-ray powder pattern.*—The available samples of polybasite gave practically identical X-ray powder patterns, three of which are repro-

TABLE V. Polybasite: Analyses and cell contents.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Ag ...	70.97	72.01	69.72	68.55	69.80	68.90	69.99	68.39	67.13	67.95
Cu ...	2.50	3.36	3.70	3.36	4.25	5.21	4.11	5.13	2.23	6.07
Fe ...	—	0.34	—	0.14	—	0.09	0.29	—	0.31	—
Zn ...	—	—	—	—	—	—	—	—	—	—
Pb ...	—	—	—	—	—	—	—	—	2.41	0.76
Bi ...	—	—	—	—	—	—	—	—	0.80	—
Sb ...	9.46	5.46	10.15	11.53	10.72	8.85	8.39	10.64	9.50	5.15
As ...	2.37	3.41	0.63	—	0.58	1.07	1.17	0.50	0.78	3.88
S ...	14.69	15.87	15.68	15.55	15.57	15.33	16.35	15.43	16.94	16.37
	99.99	100.45	99.88	99.13	100.92	99.45	100.30	100.09	100.10	100.18
Ag ...	15.09	14.76	14.58	14.51	14.49	14.39	14.33	14.25	13.94	13.69
Cu ...	0.90	1.17	1.31	1.21	1.50	1.85	1.43	1.81	0.78	2.08
Fe ...	—	0.13	—	0.06	—	0.03	0.11	—	0.12	—
Zn ...	—	—	—	—	—	—	—	—	—	—
Pb ...	—	—	—	—	—	—	—	—	0.26	0.08
	15.99	16.06	15.89	15.78	15.99	16.27	15.87	16.06	(15.10)	15.85
Bi ...	—	—	—	—	—	—	—	—	0.09	—
Sb ...	1.78	0.99	1.88	2.16	1.97	1.64	1.52	1.96	1.75	0.92
As ...	0.73	1.01	0.19	—	0.17	0.32	0.35	0.15	0.23	1.13
	(2.51)	2.00	2.07	2.16	2.14	1.96	1.87	2.11	2.07	2.05
S ...	(10.50)	10.94	11.04	11.06	10.87	10.77	11.26	10.83	(11.83)	11.10
	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00
		11.	12.	13.	14.	15.	16.	17.	18.	19.
Ag ...	...	62.10	64.49	64.18	64.30	64.29	62.70	57.96	—	—
Cu ...	...	6.00	9.70	8.13	9.00	9.93	9.57	12.52	—	—
Fe ...	...	1.10	0.41	—	0.70	0.06	0.07	0.91	—	—
Zn ...	...	—	0.34	—	—	—	—	—	—	—
Pb ...	...	—	—	—	—	—	—	—	—	—
Bi ...	...	—	—	—	—	—	—	—	—	—
Sb ...	...	9.50	8.08	11.55	4.20	5.09	10.18	5.36	—	—
As ...	...	—	1.78	—	4.10	3.74	0.78	4.60	—	—
S ...	...	15.30	15.10	16.14	16.10	17.04	(16.70)	17.45	—	—
		100.00	99.90	100.00	100.00	100.15	100.00	100.00	—	—
		11, incl. gangue 6.00.	14, incl. gangue 1.60.	17, incl. gangue 0.67, remainder 0.53.						
Ag ...	...	13.40	13.09	13.06	12.89	12.56	12.51	11.13	—	—
Cu ...	...	2.20	3.34	2.81	3.06	3.29	3.24	4.08	—	—
Fe ...	...	0.46	0.16	—	0.27	0.02	0.03	0.34	—	—
Zn ...	...	—	0.11	—	—	—	—	—	—	—
Pb ...	...	—	—	—	—	—	—	—	—	—
		16.06	(16.70)	15.87	16.22	15.87	15.78	(15.55)	15.97	16.00
Bi ...	...	—	—	—	—	—	—	—	—	—
Sb ...	...	1.82	1.45	2.08	0.75	0.88	1.80	0.91	—	—
As ...	...	—	0.52	—	1.18	1.05	0.22	1.27	—	—
		1.82	1.97	2.08	1.93	1.93	2.02	2.18	2.02	2.00
S ...	...	11.12	(10.33)	11.05	10.85	11.20	11.20	11.27	11.04	11.00
		29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.03	29.00

1. Keeley mine, South Lorrain, Ontario; new analysis by R. N. Williams; sp.gr. 6-27. 2. Cornwall; anal. Joy (1853, in Hintze, 1904, p. 1174); sp.gr. 6-009. 3. Highland Bell mine, Beaverdell, B.C.; anal. Williams in Staples & Warren (1946); sp.gr. 6-26. 4. Johannesgang, Příbram; anal. Tonner, in Reuss (1860); sp.gr. 6-03. 5. Highland Bell mine, Beaverdell, B.C.; anal. Williams in Staples & Warren (1946); sp.gr. 6-28. 6. 'Arizpe?' Sonora, Mexico; anal. Ungemach (1910). 7. Freiberg,

Saxony; anal. Rose (1833). 8. Santa Lucia mine, Guanajuato, Mexico; anal. Prior (1890); sp.gr. 6-33. 9. Highland Bell mine, Beavertell, B.C.; anal. Williams in Staples & Warren (1946); sp.gr. 6-33. 10. Quespiziza, Chile; anal. Bodländer (1895). 11. Tres Puntas, Chile; anal. Domeyko (1879). 12. Las Chiapas, Sonora, Mexico; anal. Ungemach (1910). 13. Tres Puntas, Chile; anal. Taylor (1859, in Hintze, 1904, p. 1174). 14. Tres Puntas, Chile; anal. Domeyko (1879). 15. Guarisamez, Durango, Mexico; anal. Rose (1829); sp.gr. 6-214. 16. Terrible lode, Clear Creek County, Colorado; anal. Genth (1886); sp.gr. 6-009. 17. Silver King mine, Yerranderie, New South Wales; anal. White, in Card (1920, in Dana, 1944, p. 352). 18. Average cell content. 19. Ideal cell content,  $8(\text{Ag,Cu})_2\text{S.Sb}_2\text{S}_3$ .

duced on pl. II, figs. 1, 2, 3. Owing to the hexagonal pseudo-symmetry several sets of monoclinic lattice planes give identical spacings. In the most general case six different sets of monoclinic planes ( $hkl$ ) are equivalent to one set of hexagonal planes ( $h\bar{k}l$ ); for example, the sets of planes with the monoclinic symbols (511), (421), ( $\bar{1}31$ ), ( $\bar{4}21$ ), ( $\bar{5}11$ ), all correspond to the set of planes with the hexagonal symbol ( $2\bar{1}\bar{3}1$ ). It is convenient, therefore, to index the powder spectrum with reference to the hexagonal indices. The reversible transformations are: monoclinic to hexagonal,  $\frac{1}{2}\bar{1}0/010/001$ ; hexagonal to monoclinic,  $210/010/001$ .

TABLE VI. Polybasite  $8(\text{Ag,Cu})_2\text{S.Sb}_2\text{S}_3$ : X-ray powder spectrum.

Monoclinic,  $C2/m$ ;  $a = 26.12$ ,  $b = 15.08$ ,  $c = 23.84$  kX,  $\beta = 90^\circ 00'$ ;  $Z = 16$ .  
Pseudo-hexagonal,  $C$ ;  $a' = 15.08$ ,  $c' = 23.84$  kX.

<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).	( <i>hkl</i> ).	<i>d</i> (calc.).	<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).	( <i>hkl</i> ).	<i>d</i> (calc.).
1	12.3°	3.61	{(3140) (2242)	3.622 3.594	1	23.5°	1.928	{(4.0.4.10) (3368)	1.925 1.921
$\frac{1}{2}$	12.8	3.47	(3142)	3.466				(1.1.2.12)	1.921
$\frac{1}{2}$	13.6	3.27	(4040)	3.265				(4376)	1.889
9	14.0	3.18	(2244)	3.186	6	24.05	1.886	{(6174) (4480)	1.889 1.885
10	14.9	2.99	{(3250) (0008)	2.996 2.980				(4480)	1.885
8	15.55	2.87	{(4044) (4150)	2.864 2.850	$\frac{1}{2}$	24.5	1.854	(5276)	1.861
$\frac{1}{2}$	16.15	2.76	(1128)	2.771	1	25.5	1.785	{(6282) (5384)	1.791 1.780
5	16.6	2.69	{(3146) (3254)	2.677 2.677				(6176)	1.780
6	17.75	2.52	{(4046) (3360)	2.523 2.513	1	26.25	1.738	(4378)	1.742
4	18.55	2.42	(4262)	2.417				{(3.1.4.12) (6284)	1.742 1.733
2	19.25	2.33	(2248)	2.337				(4486)	1.703
2	20.45	2.20	(4048)	2.201	3	26.85	1.702	{(0.0.0.14) (4.0.4.12)	1.703 1.697
$\frac{1}{2}$	21.00	2.14	{(2.1.3.10) (4370)	2.147 2.147	2	27.7	1.654	{(3.2.5.12) (6178)	1.656 1.656
			(6062)	2.141				(5492)	1.656
			(4372)	2.113	1	28.4	1.616	(8082)	1.617
2	21.45	2.10	{(3258) (4266)	2.113 2.097				{(4.3.7.10) (4488)	1.695 1.693
1	21.95	2.06	{(5272) (4158)	2.060 2.059	2	28.9	1.590	{(6394) (7186)	1.586 1.586
			(5166)	2.020				(2.2.4.14)	1.552
3	22.4	2.02	{(4374) (2.2.4.10)	2.020 2.015	1	29.75	1.549	{(6288) (4.2.6.12)	1.548 1.548
$\frac{1}{2}$	22.95	1.971	{(5274) (6172)	1.973 1.964				{(5.1.6.12) (8192)	1.516 1.516
					4	30.55	1.512	{(8086) (4.0.4.14)	1.510 1.510
					1	31.2	1.484	(0.0.0.16)	1.490

TABLE VI. (*cont.*).

<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).	<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).	<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).
$\frac{1}{2}$	31.8°	1.459	$\frac{1}{2}$	38.9°	1.224	$\frac{1}{2}$	41.8°	1.153
2	32.5	1.431	1	39.5	1.208	1	43.0	1.127
1	34.45	1.359	$\frac{1}{2}$	40.7	1.179	1	44.8	1.091
1	35.05	1.338	$\frac{1}{2}$	41.1	1.169	1	46.0	1.069

## PEARCEITE

The two available specimens of pearceite show a dull black mineral with only rough hexagonal tabular form. Specific gravity measurements gave values similar to that noted by Penfield (1896) on analysed material from Montana. Under the microscope thin fragments proved to be practically opaque.

	sp.gr.	
Aspen, Colo. (material no. 6) ... ..	6.13	L. G. Berry
Silver, Mont. (material no. 7) ... ..	6.13	R. M. Thompson
Marysville, Mont. ... ..	6.15	Penfield (1896)

*Unit cell.*—The unit cell was determined on both the available specimens by means of rotation and Weissenberg photographs with [001] and [010] or [110] as the rotation axes. Like the photographs of polybasite (pl. II, fig. 6), those of pearceite show hexagonal symmetry as regards the positions of the spots, but only monoclinic symmetry as regards their intensities; but, unlike the polybasite pictures, those of pearceite show no intermediate layer-lines in the rotation photographs about [001] and about [010] or [110] (pl. I), and all the cell dimensions are about one-half of the corresponding dimensions of polybasite, and consequently the cell volume of pearceite is about one-eighth of that of polybasite. The systematically missing spectra of pearceite are those of the space-group  $C2/m$ .

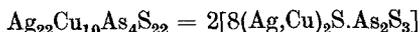
The measured cell dimensions of pearceite are given below and the resulting axial ratios are compared with the goniometric values of

TABLE VII. Pearceite: Cell dimensions (kX) and axial ratios.

	<i>a.</i>	<i>b.</i>	<i>c.</i>	$\beta$ .
Aspen, Colo. (no. 6) ... ..	12.61	7.28	11.88	90° 00'
	1.732 : 1 :		1.631	
Silver, Mont. (no. 7) ... ..	12.77	7.37	11.92	90 00
	1.732 : 1 :		1.618	
Marysville, Mont. (Penfield, 1896) ... ..	1.7309 : 1 :		1.6199	90 09

Penfield (1896). It will be seen that the cell dimensions of the two materials are distinctly different, indicating some substantial difference in their chemical compositions; the structural ratios for Silver, Montana, agree best with Penfield's geometrical ratios.

*Analyses and cell contents.*—The cell content of pearceite was obtained from the cell dimensions and measured specific gravity of the material from Aspen, Colorado, giving the molecular weight  $M = 4052$ , and combining this number with Penfield's analysis on material from the same locality (table VIII). Although the analysis cannot be regarded as very satisfactory the empirical cell content gives very nearly:



which yields the calculated specific gravity 6.07.

TABLE VIII. Pearceite from Aspen, Colorado:  
Analysis and cell content.  $M = 4052$ .

	1.	2.	3.
Ag ... ..	56.90	22.30	} 32.18
Cu ... ..	14.85	9.88	
Sb ... ..	0.30	0.10	} 4.06
As ... ..	7.01	3.96	
S ... ..	16.75	22.10	22
	<u>95.81</u>	<u>58.34</u>	<u>58</u>

1. Mollie Gibson mine, Aspen, Colorado; anal. Penfield, in Penfield & Pearce (1892). After calculation to 100 per cent. after withdrawing 12.81 per cent. of impurities, and removal of Zn 2.81, S 1.38 for blende. 2. Empirical cell content. 3. Ideal cell content.

In table IX all the available analyses of pearceite are expressed in terms of a sum of 29 atoms or half the content of the unit cell. It will be seen that Cu replaces Ag from about 1/16 to 1/3 of the total (Ag,Cu) component; on the other hand, only trivial amounts of Sb take the

TABLE IX. Pearceite: Analyses and cell contents.

	1.	2.	3.	4.	5.	6.	7.	8.
Ag ...	72.43	63.54	59.73	56.90	59.22	55.17	—	—
Cu ...	3.04	10.70	12.91	14.85	15.65	18.11	—	—
Fe ...	0.33	0.60	—	—	—	1.05	—	—
Zn ...	0.59	—	—	—	—	—	—	—
Sb ...	0.25	0.43	0.18	0.30	—	—	—	—
As ...	6.23	7.29	6.29	7.01	7.56	7.39	—	—
S ...	16.83	17.07	16.18	16.75	17.46	17.71	—	—
	<u>99.70</u>	<u>99.63</u>	<u>95.29</u>	<u>95.81</u>	<u>99.89</u>	<u>99.85</u>	—	—
	6, including insol. 0.42.							
Ag ...	14.48	12.20	11.92	11.09	11.05	10.12	—	—
Cu ...	1.03	3.48	4.37	4.91	4.96	5.63	—	—
Fe ...	0.12	0.22	—	—	—	0.37	—	—
Zn ...	0.24	—	—	—	—	—	—	—
	<u>15.87</u>	<u>15.90</u>	<u>16.29</u>	<u>16.00</u>	<u>16.01</u>	<u>16.12</u>	<u>16.03</u>	<u>16.00</u>

TABLE IX (cont.).

	1.	2.	3.	4.	5.	6.	7.	8.
Sb ...	0.04	0.07	0.03	0.05	—	—	—	—
As ...	1.79	2.01	1.82	1.97	2.03	1.96	—	—
	1.83	2.08	1.85	2.02	2.03	1.96	1.96	2.00
S ...	11.30	11.02	10.86	10.98	10.96	10.92	11.00	11.00
	29.00	29.00	29.00	29.00	29.00	29.00	28.99	29.00

1. Schemnitz, Hungary; anal. Rose (1833). 2. Arqueros, Chile; anal. Domeyko (1879, p. 393); sp.gr. 6.33. 3. Mollie Gibson mine, Aspen, Colorado; anal. Pearce in Penfield & Pearce (1892); recalculated after deduction of 28.18 per cent. of impurities and 4.71 per cent. of ZnS; sp.gr. 6.03. 4. Mollie Gibson mine, Aspen, Colorado; anal. Penfield in Penfield & Pearce (1892); recalculated after deduction of 12.81 per cent. of impurities and 4.19 per cent. of ZnS; sp.gr. 6.080. 5. Veta Rica mine, Sierra Mojada, Mexico; anal. Dubois in Van Horn & Cook (1911); sp.gr. 6.062. 6. Drumlummon mine, Marysville, Montana; anal. Knight in Penfield (1896). 7. Average cell content. 8. Ideal cell content for  $8(\text{Ag,Cu})_2\text{S.As}_2\text{S}_3$ .

place of As. Since considerable substitution of Cu for Ag appears to have little effect on the cell dimensions of polybasite it is difficult to explain the considerable variation found in pearceite. Possibly Zn and Fe actually enter the structure in some cases, as suggested by the early analysis of Rose.

*X-ray powder patterns.*—The two specimens of pearceite gave X-ray powder patterns (pl. II, figs. 4, 5) which differ slightly, in keeping with their slightly different cell dimensions, and show distinct differences when compared to the pattern of polybasite (pl. II, figs. 1, 2, 3). The two pearceite patterns have therefore been indexed separately, with reference to hexagonal elements.

TABLE X. Pearceite,  $8(\text{Ag,Cu})_2\text{S.As}_2\text{S}_3$ ; Aspen, Colorado.  
X-ray powder spectrum.

Monoclinic,  $C2/m$ ;  $a = 12.61$ ,  $b = 7.28$ ,  $c = 11.88$  kX,  $\beta = 90^\circ 00'$ ;  $Z = 2$ .  
Pseudo-hexagonal,  $C$ ;  $a' = 7.28$ ,  $c' = 11.88$  kX.

<i>I.</i>	$\theta$ (Cu).	$d$ (meas.).	$(hkl)$ .	$d$ (calc.).	<i>I.</i>	$\theta$ (Cu).	$d$ (meas.).	$(hkl)$ .	$d$ (calc.).
1	14.35°	3.10	(11 $\bar{2}$ )	3.104	1	23.95°	1.893	{(20 $\bar{2}$ 5)	1.897
2	14.65	3.04	(20 $\bar{2}$ 1)	3.047				{(1016)	1.889
10	15.05	2.96	(0004)	2.970				{(21 $\bar{3}$ 4)	1.859
9	16.0	2.79	(20 $\bar{2}$ 2)	2.785	2	24.5	1.854	{(30 $\bar{3}$ 3)	1.856
6	18.15	2.47	(30 $\bar{2}$ 3)	2.466	6	24.95	1.823	(2240)	1.820
5	19.2	2.34	(21 $\bar{3}$ 1)	2.337	$\frac{1}{2}$	25.3	1.799	(2211)	1.799
6	19.55	2.30	(11 $\bar{2}$ )	2.301				{(20 $\bar{2}$ 6)	1.677
$\frac{1}{2}$	20.3	2.22	{(101 $\bar{5}$ )	2.223	3	27.35	1.673	{(31 $\bar{4}$ 2)	1.677
			{(2132)	2.212	$\frac{1}{2}$	27.75	1.651	(2243)	1.654
3	20.85	2.16	(20 $\bar{2}$ 4)	2.162	1	29.6	1.556	(2244)	1.552
$\frac{1}{2}$	21.45	2.10	(30 $\bar{3}$ 0)	2.102				{(40 $\bar{4}$ 2)	1.523
1	21.8	2.07	(30 $\bar{3}$ 1)	2.070	1	30.35	1.521	{(21 $\bar{3}$ 6)	1.523
2	22.15	2.04	(21 $\bar{3}$ 3)	2.042				{(20 $\bar{2}$ 7)	1.494
5	22.75	1.988	{(11 $\bar{2}$ 5)	1.990	2	31.05	1.490	{(0008)	1.485
			{(30 $\bar{3}$ 2)	1.981					

TABLE X (cont.).

<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).	<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).	<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).
1	31.7°	1.463	$\frac{1}{2}$	37.1°	1.274	$\frac{1}{2}$	42.45°	1.139
1	32.5	1.444	1	38.55	1.233	$\frac{1}{2}$	42.95	1.128
1	33.5	1.393	1	39.2	1.216	1	45.35	1.080
$\frac{1}{2}$	34.2	1.368	1	40.25	1.190	$\frac{1}{2}$	46.15	1.066
1	34.85	1.345	1	41.15	1.168	$\frac{1}{2}$	46.95	1.052
$\frac{1}{2}$	35.7	1.324	1	41.65	1.157	$\frac{1}{2}$	48.85	1.021

TABLE XI. Pearceite,  $8(\text{Ag,Cu})_2\text{S}_2\text{As}_2\text{S}_3$ ; Silver, Montana.  
X-ray powder spectrum.

Monoclinic,  $C2/m$ ;  $a = 12.77$ ,  $b = 7.37$ ,  $c = 11.92$  kX,  $\beta = 90^\circ 00'$ ;  $Z = 2$ .  
Pseudo-hexagonal,  $C$ ;  $a' = 7.37$ ,  $c' = 11.92$  kX.

<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).	( <i>hkl</i> ).	<i>d</i> (calc.).	<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).	( <i>hkl</i> ).	<i>d</i> (calc.).
1	6.8°	6.5	(10 $\bar{1}$ 0)	6.385	4	22.5°	2.01	{(30 $\bar{3}$ 2)	2.004
1	7.3	6.0	(0002)	5.960				{(11 $\bar{2}$ 5)	2.002
1	11.95	3.71	(11 $\bar{2}$ 0)	3.685	1	23.75	1.908	{(20 $\bar{2}$ 5)	1.910
$\frac{1}{2}$	12.5	3.55	(11 $\bar{2}$ 1)	3.522				{(10 $\bar{1}$ 6)	1.897
5	14.35	3.10	{(11 $\bar{2}$ 2)	3.135	$\frac{1}{2}$	24.15	1.879	{(30 $\bar{3}$ 3)	1.876
			{(20 $\bar{2}$ 1)	3.084				{(21 $\bar{3}$ 4)	1.875
10	14.9	2.99	(0004)	2.980	5	24.6	1.846	(2240)	1.842
9	15.75	2.83	(2022)	2.814	$\frac{1}{2}$	25.0	1.819	(2241)	1.821
4	17.95	2.49	(20 $\bar{2}$ 3)	2.489				(3142)	1.697
3	18.95	2.37	(21 $\bar{3}$ 1)	2.365	3	27.0	1.693	{(21 $\bar{3}$ 5)	1.696
5	19.35	2.32	(11 $\bar{2}$ 2)	2.317				{(20 $\bar{2}$ 6)	1.687
$\frac{1}{2}$	20.1	2.24	{(21 $\bar{3}$ 2)	2.237	$\frac{1}{2}$	27.35	1.673	(2243)	1.672
			{(10 $\bar{1}$ 5)	2.233	$\frac{1}{2}$	29.4	1.566	(2244)	1.567
3	20.65	2.18	(20 $\bar{2}$ 4)	2.178	$\frac{1}{2}$	29.9	1.542	{(11 $\bar{2}$ 7)	1.545
$\frac{1}{2}$	21.0	2.14	(30 $\bar{3}$ 0)	2.128				{(40 $\bar{3}$ 2)	1.542
2	21.55	2.09	(30 $\bar{3}$ 1)	2.095	1	30.7	1.506	(2027)	1.502
2	21.85	2.06	(21 $\bar{3}$ 3)	2.062	1	31.1	1.488	(0008)	1.490
	<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).		<i>I.</i>	$\theta$ (Cu).	<i>d</i> (meas.).		
	1	31.8°	1.459		1	34.6°	1.354		
	1	33.15	1.406		1	33.0	1.248		

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## EXPLANATION OF PLATES I AND II.

X-ray photographs of polybasite and pearceite.

PLATE I.—X-ray single-crystal photographs with Cu radiation; camera radius  $90/\pi$  mm. ( $1^\circ \theta = 1$  mm. on film); full-size reproductions of contact prints.

Fig. 1. Polybasite, Las Chiapas mine, Sonora, Mexico; rotation about [010], giving  $b = 15.08$  kX.

Fig. 2. Pearceite, Aspen, Colorado; rotation about [010], giving  $b = 7.28$  kX.

PLATE II.—Figs. 1-5, X-ray powder photographs with Cu radiation, Ni filter; camera radius  $90/\pi$  mm. ( $1^\circ \theta = 1$  mm. on film); full-size reproductions of contact prints.

Fig. 1. Polybasite, Highland Bell mine, Beaverdell, B.C.

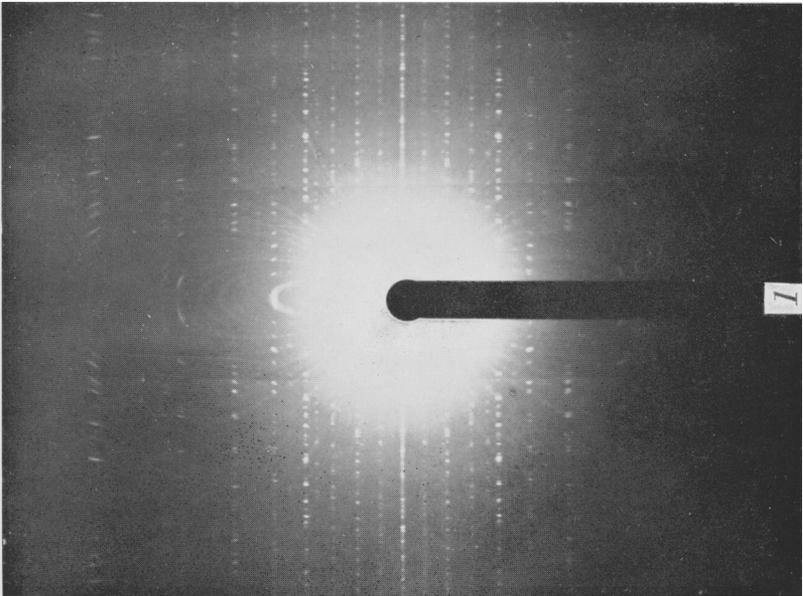
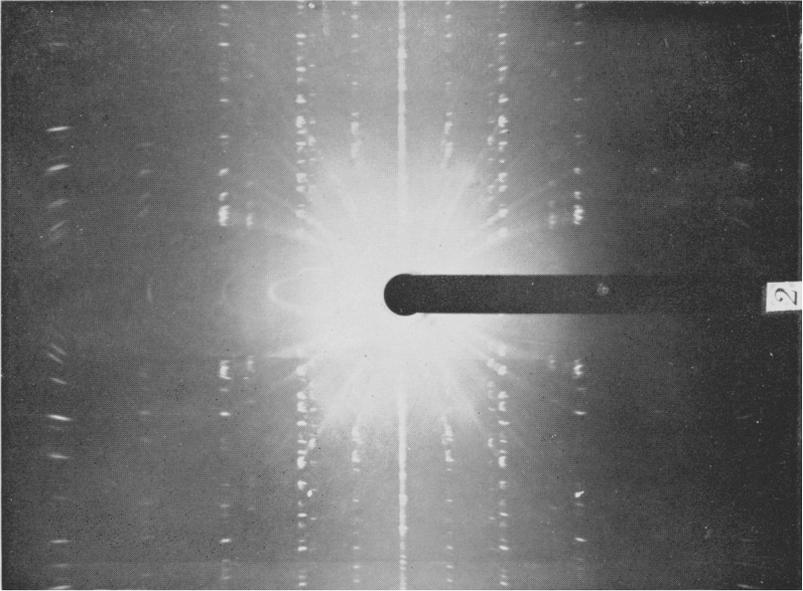
Fig. 2. Polybasite, Keeley mine, South Lorrain, Ontario.

Fig. 3. Polybasite, Las Chiapas mine, Sonora, Mexico.

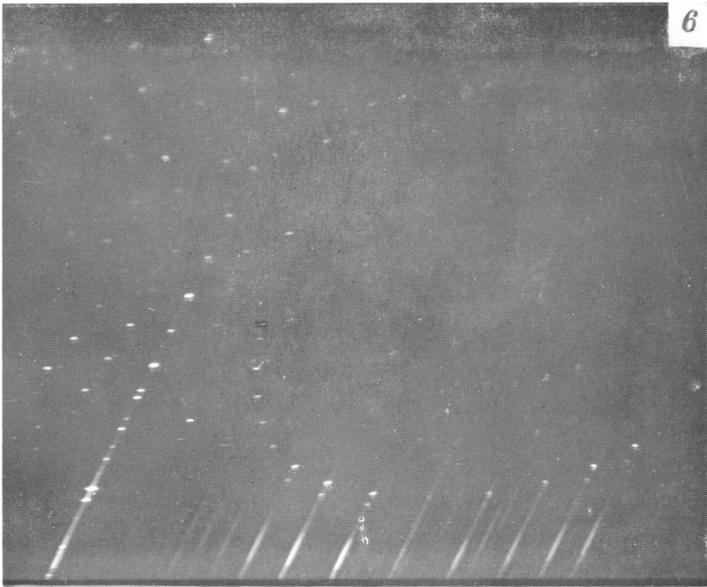
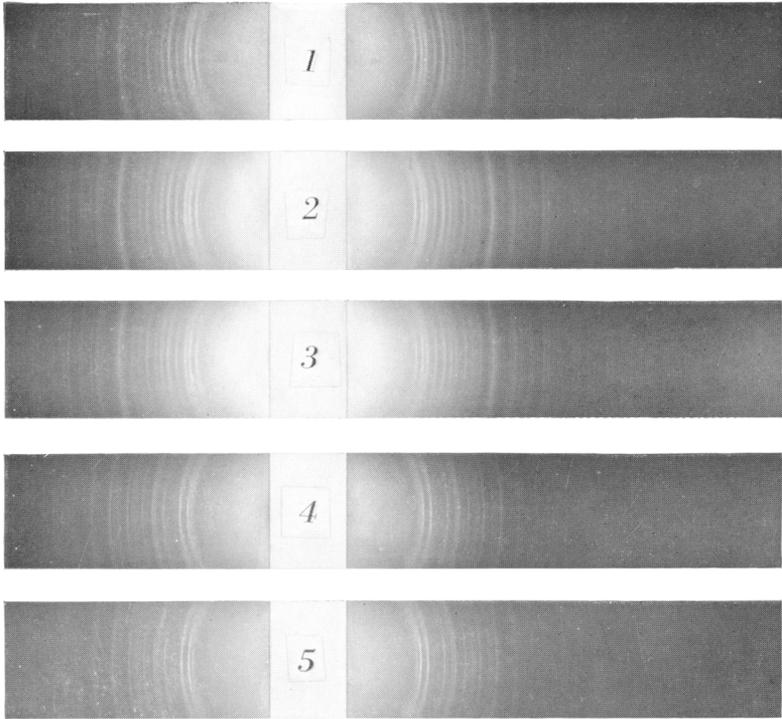
Fig. 4. Pearceite, Aspen, Colorado.

Fig. 5. Pearceite, Silver, Montana.

Fig. 6. X-ray single-crystal photograph, as on plate I. Polybasite, Keeley mine, South Lorrain, Ontario. Weissenberg resolution of the layer ( $h0l$ ) or ( $hhl$ ), showing lack of symmetry of intensity about the ( $00l$ ) row (most prominent slanting row), and therefore the lack of an even-fold vertical symmetry-axis.



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