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TABLE OF CONTENTS

	PAGE
Frontispiece. ARTHUR LEONARD PARSONS, A.B., F.R.S.C.	
Foreword.....	7
Studies of Mineral Sulpho-Salts: VII—A Systematic Arrangement on the Basis of Cell Dimensions, by L. G. BERRY	9
Muscovite from Mattawan Township, Nipissing District, Ontario, by R. B. FERGUSON.....	31
A Note on the Engineering Significance of the Clay Minerals, by R. F. LEGGET.....	43
Prehnite from Ashcroft, British Columbia, by E. W. NUFFIELD	49
The Morphology of Muscovite in Relation to the Crystal Lattice, by M. A. PEACOCK and R. B. FERGUSON.....	65
Hypogene Native Arsenic from Criss Creek, British Columbia, by JOHN S. STEVENSON	83
Quantitative Mineral Relations at the Upper Canada Mines, Dobie, Ontario, by ELLIS THOMSON.....	93
Mineralogical Notes.....	101
Chromite from Manitoba (G. M. BROWNELL). Kyanite from British Columbia (R. L. RUTHERFORD). Boulangerite and Columbite-Tantalite from Manitoba (ELLIS THOMSON).	
The Walker Mineralogical Club.....	105
Notice.....	123
Index, 1938-1943.....	125

*At Professor Parsons' Request the Papers
Contributed to this Issue have been
Arranged for Publication
by Professor Peacock*



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1913-1943
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FOREWORD

The annual *Contributions to Canadian Mineralogy* were founded in 1921 by the late Professor T. L. Walker and carried on by Dr. Walker and his colleagues until he was forced by ill health to lay work aside in 1936. In 1937 Professor A. L. Parsons, who had collaborated with Dr. Walker from the beginning, prepared a special issue of the *Contributions* with a foreword of appreciation of Dr. Walker's work and an index to the entire series, 1921-1937. Since 1937 Professor Parsons has continued to conduct the *Contributions* and thereby to foster the interest in Canadian mineralogy.

In the period from 1937 to the present Professor Parsons initiated or supported several noteworthy developments. Chief of these was the organization of the Walker Mineralogical Club, in which Professor Parsons was the prime mover. In forming this association in honour of his eminent predecessor, Professor Parsons achieved several useful ends: the promotion of local interest in mineralogy by regular meetings of varied interest, the wide extension of the circle of our readers and contributors, and the production of some additional income to augment the limited regular allowance for the cost of publishing the *Contributions*. Professor Parsons also encouraged mineralogical work on modern lines in his department by providing excellent equipment and materials and suggesting interesting subjects for investigation; and he supported improvements in the style of the journal which were brought about with the experienced aid of the University of Toronto Press.

On September 16, 1943, Professor Parsons will reach the age of seventy years. To mark this event the Council of the Walker Mineralogical Club takes this opportunity to congratulate Professor Parsons on his thirty-six years' association with the Department of Mineralogy and Petrography in the University of Toronto and his equally long and fruitful service to Canadian mineralogy, and to wish him continued pleasure in caring for the fine collections he helped to assemble in the Royal Ontario Museum of Mineralogy. In extending these good wishes the Council is sure that it also expresses the feeling of a large circle of friends in the mineralogical profession.

Although an enlarged special number of the *Contributions* could not be undertaken in these times the present number is distinguished from usual issues by the addition of a portrait of Professor Parsons, a list of the members of the Walker Mineralogical Club, and an index to *Contributions to Canadian Mineralogy* for the period 1938-1943.

M. A. PEACOCK
President, Walker Mineralogical Club

STUDIES OF MINERAL SULPHO-SALTS:
VII—A SYSTEMATIC ARRANGEMENT ON THE
BASIS OF CELL DIMENSIONS¹

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Minerals have long been systematically arranged on the basis of crystal form and chemical composition. The steady accumulation of structural data is tending to modify this classification, and in the new *System of Mineralogy* in preparation at Harvard University the impact of structural results on systematic mineralogy will become apparent. The shift from the classical to the modern outlook in mineralogy was recently expressed by Professor M. A. Peacock in a brief address to the *Association canadienne-française pour l'Avancement des Sciences*:

In classical mineralogy a mineral species is defined as a natural substance with a definite crystal form and a definite chemical composition. These fundamental properties are expressed by geometrical ratios giving the relative dimensions of a cell of the crystal lattice, and an empirical chemical formula giving the relative proportions of the constituent atoms. In modern mineralogy we regard a mineral species as a natural substance with a definite atomic structure. Measurements by means of x-rays give the absolute dimensions of the unit cell of the crystal lattice and the actual number of atoms in this cell. Form and composition are functions of structure; and as a consequence the existing classification of minerals on the basis of form and composition is giving place to an improved classification based on the atomic structures of mineral species.

In a general way it may be said that groups of minerals which were formerly classed on the basis of close similarities of crystal form and chemical composition prove to be structurally related, and in such cases the results of structural work completely confirm the existing arrangement. Typical cases of this kind are provided by Richmond's study (1940) of the phosphates, arsenates and vanadates of the type $A_2XO_4(Z)$, and Wolfe's work (1940) on the classification of minerals of the type $A_3(XO_4)_2 \cdot nH_2O$. On the

¹Chapter 19 of a *Thesis* for the degree of Doctor of Philosophy, University of Toronto, 1941; prepared for publication in collaboration with Professor M. A. Peacock. Chapters 2, 3, 4, 5 have already been published (Berry, 1940c, 1939, 1940a, 1940b, respectively); extracts from other chapters were included in Peacock and Berry (1940) (see references).

other hand, minerals which were grouped mainly on the basis of chemical analogy, without thorough-going crystallographic and physical similarities, are found to be structurally unrelated. In such cases the result of structural work is to break down the previous groups into sub-groups or even into unrelated species. It may be said at once that the mineral sulpho-salts as a large class come into the second category. Several well-established pairs of related minerals were already clearly recognized as closely related; the grouping of these pairs is confirmed by the structural data. The majority of the sulpho-salts, however, do not fall into isostructural groups. *X*-ray measurements indicate a great variety of structures in which the only common factors are certain frequently recurring cell dimensions. It thus appears, as might have been expected from the chemical and crystallographic variety shown by these species, that many of the mineral sulpho-salts stand alone without close relatives.

In attempting a systematic arrangement of the sulpho-salts in the light of structural evidence we are thus obliged to place the principal emphasis on similarities in the cell dimensions. This has been done in the following arrangement of those sulpho-salts for which structural data are available. In a general way the arrangement is in order of increasing cell dimensions and increasing chemical complexity. To bring out certain structural connections with minerals of simple composition a few sulphides have been included in the systematic arrangement.

In the following presentation of mineral groups the name of each species is followed by the atomic content of the unit cell expressed as *n* times the empirical formula; after this is given the crystal system and the space group of Schoenflies and International notations. These are followed by the cell dimensions in Ångstrom units with the name of the observer and the reference.

HERZENBERGITE GROUP

Herzenbergite—4[SnS]

Orthorhombic; D_{2h}^{16} —*Pmcn*

a 3.98, *b* 4.33, *c* 11.18 (Hofmann, 1935)

Teallite—2[PbS.SnS]

Orthorhombic; D_{2h}^{16} —*Pmcn*

a 4.04, *b* 4.28, *c* 11.33 (Hofmann, 1935)

Neither of these minerals appears in Dana (1892). Herzenbergite is the name given by Ramdohr (1934) for a mineral with the composition SnS occurring in minute black scales from Bolivia. This mineral had previously been named *kolbeckine* by Herzenberg (1932). Teallite with the composition PbS.SnS, likewise occurring in Bolivia as black folia with perfect basal cleavage, was named by Prior (1904). As shown by Hofmann (1935) the two minerals are isostructural with the same space group and very similar cell edges, and thus they form a well-defined mineralogical group. The orthorhombic cells show pronounced tetragonal pseudo-symmetry, the two transverse periods being nearly alike and nearly 4 Å, the most frequently occurring period among our minerals. The vertical period of about 11 Å is likewise one of the frequently occurring periods. The relatively large spacing of the lattice planes (002) corresponds to the platy habit and basal cleavage. Hofmann (1935, p. 163) has brought out an interesting relationship between the cell edges of herzenbergite, teallite, and galena:

	<i>a</i>	<i>b</i>	<i>c</i>
SnS.....	3.98	4.33	11.18
PbS.SnS.....	4.04	4.28	11.33
PbS.....	$T_{[110]} = 4.19$	$T_{[110]} = 4.19$	$2c = 11.86$

The above table shows that the length of the cube face diagonal [110] in galena corresponds with the *a* and *b* axes of herzenbergite and teallite, while the cube edge of galena is about half the vertical axis of the other two minerals.

STIBNITE GROUP

Stibnite—4[Sb₂S₃]Orthorhombic; D_{2h}^{16} —*Pbnm**a* 11.20, *b* 11.28, *c* 3.83 (Hofmann, 1933b)**Bismuthinite**—4[Bi₂S₃]Orthorhombic; D_{2h}^{16} —*Pbnm**a* 11.13, *b* 11.27, *c* 3.97 (Hofmann, 1933b)**Seleniferous bismuthinite**—4[Bi₂(S,Se)₂]Orthorhombic; D_{2h}^{16} —*Pbnm**a* 11.20, *b* 11.40, *c* 3.99 (Berry)**Guanajuatite**—4[Bi₂(Se,S)₂]

Stibnite and bismuthinite have long been recognized as closely related in composition and crystal form; they are alike also in possessing a strong prismatic habit and perfect cleavage parallel to (010). The older works of reference give pseudo-cubic elements. From a consideration of the morphology Ungemach (1923, p. 169) correctly predicted that the geometrical form of the crystal lattice would be correctly expressed by dividing the old morphological *c*-axis by three. Guanajuatite which is known only in poorly developed and unterminated needles with composition roughly approaching $\text{Bi}_2(\text{Se,S})_3$ is placed with stibnite and bismuthinite in Dana (1892, p. 38).

Complete structural determinations of stibnite and bismuthinite were made by Hofmann (1933*b*) whose lattice constants are given above. Hofmann's work confirms the previously inferred similarity in the two species and proves that the classical *c*-axis should be divided by three. The structural constants of the two species are remarkably alike. They have the same space group D_{2h}^{16} which occurs with astonishing frequency, and they have very similar cell edges, *a* and *b* both being close to 11 Å which is one of the commonly recurring lengths among the sulpho-salts, while *c* is close to 4 Å, a length which occurs with great regularity in the axis of elongation. In stibnite and bismuthinite we have the simple 4 Å, this short period being the cause of the pronounced prismatic to acicular elongation of the crystals in that direction. We shall see later that this fundamental period reappears in many other species sometimes multiplied by 2, 3, 4, or even 8.

An *x*-ray powder photograph of guanajuatite showed that this mineral is indeed isostructural with bismuthinite and therefore properly included in this group. A powder photograph and single crystal measurements of material determined as seleniferous bismuthinite, by qualitative tests, showed that this material is structurally closely related to bismuthinite. Bismuthinite and the seleniferous variety, together with guanajuatite and stibnite, thus form a well-defined structural group. This is one of the cases among the minerals under consideration in which *x*-ray measurements have confirmed the previously inferred relationships.

Aikinite— $2[\text{Cu}_2\text{S} \cdot 2\text{PbS} \cdot \text{Bi}_2\text{S}_3]$

Orthorhombic; D_{2h}^{16} — $Pnam$
 a 11.30, b 11.64, c 4.00 (Peacock, 1942)

Measurements by Professor Peacock (1942) on aikinite from the type locality give values which are remarkably close to those of bismuthinite; again we have the same space group D_{2h}^{16} and the recurrence of the familiar lattice periods, 4 Å in the direction of needle development and 11 Å in the two transverse directions. Aikinite cannot be regarded as mineralogically closely related to the Stibnite Group. It necessarily stands alone like many other species considered in this study.

CHALCOSTIBITE GROUP

Chalcostibite— $2[\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_3]$

Orthorhombic; D_{2h}^{16} — $Pnma$
 a 6.01, b 3.78, c 14.46 (Hofmann, 1933a)

Emplectite— $2[\text{Cu}_2\text{S} \cdot \text{Bi}_2\text{S}_3]$

Orthorhombic; D_{2h}^{16} — $Pnma$
 a 6.12, b 3.89, c 14.51 (Hofmann, 1933a)

Chalcostibite and emplectite were early recognized as mineralogically related and were placed together in the Zinckenite Group of Dana (1892, p. 112). Recent work by Hofmann (1933a) has yielded the atomic arrangement of these minerals and shown that they are isostructural with the same space group and closely similar cell edges. Hofmann retained the classical setting of these minerals in which the axis of elongation is the b -axis and the cleavage is basal. A setting in better keeping with modern practice would make the short cell edge the vertical axis and the longest cell edge the b -axis. Crystals would then show vertical elongation and side pinakoidal cleavage. Thus reoriented the space group and cell edges:

Chalcostibite: D_{2h}^{16} — $Pnam$; a 6.01, b 14.46, c 3.78

Emplectite: D_{2h}^{16} — $Pnam$; a 6.12, b 14.51, c 3.89

show an interesting relation to the structural data of the members of the Galenobismutite Group which follows. The a -period of emplectite and chalcostibite is roughly half the a -period in galenobismutite and berthierite, while the remaining periods in all four species are directly comparable.

GALENOBISMUTITE GROUP

Galenobismutite— $4[\text{PbS} \cdot \text{Bi}_2\text{S}_3]$ Orthorhombic; D_{2h}^{16} —*Pnam**a* 11.72, *b* 14.52, *c* 4.07 (Berry, 1940*c*)**"Cannizzarite**— $\text{Pb}_3\text{Bi}_5\text{S}_{11}$ "Orthorhombic; D_{2h}^{16} —*Pnam**a* 11.73, *b* 14.47, *c* 4.076 (Wolfe, 1938)**Berthierite**— $4[\text{FeS} \cdot \text{Sb}_2\text{S}_3]$ Orthorhombic; D_{2h}^{16} —*Pnam**a* 11.44, *b* 14.12, *c* 3.76 (Buerger, 1936)

Galenobismutite and berthierite were already classed together by Dana (1892, p. 111). The close structural similarity between these two species appeared after the present writer (1940*c*) obtained the above structural elements on the original material described as galenobismutite by Sjögren (1878), and clarified the confusion which has long surrounded the true nature of galenobismutite and the so-called "lillianite."

The mineral named "cannizzarite" presents an interesting situation. The composition as given by the original describers, Zambonini, De Fiore and Carobbi (1925), is PbBi_4S_7 . A recent analysis of type material by Gonyer in Wolfe (1938) indicated the formula $\text{Pb}_3\text{Bi}_5\text{S}_{11}$. This composition is not very different from $\text{Pb}_3\text{Bi}_6\text{S}_{12}$ which gives the ratios in galenobismutite. The new structural data for galenobismutite are almost identical with those obtained by Wolfe (1938) for "cannizzarite"; and therefore, since the two substances are also physically alike, it appears that they are in fact identical. This suggestion was communicated by Professor Peacock to Professor Berman (Harvard University) who replied

... I have your very interesting note on the relationship of cannizzarite and galenobismutite. From all the evidence it certainly seems quite reasonable to suppose that cannizzarite is really the same as galenobismutite.

Galenobismutite and berthierite thus present an interesting case where röntgenographic observations have fully confirmed the presumed relationship between two species neither of which was known in distinct crystals. Again we have the common space group D_{2h}^{16} and the familiar lattice periods, about 11, 15, and 4 Å, the last again corresponding to the direction of elongation of the crystals.

Miargyrite— $4[\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3]$ Monoclinic; C_{2h}^6 a 13.17, b 4.39, c 12.83, β $98^\circ 37\frac{1}{2}'$ (Hofmann, 1938)**Aramayoite**— $3[\text{Ag}_2\text{S} \cdot (\text{Sb}, \text{Bi})_2\text{S}_3]$

Triclinic;

 a 7.76, b 8.79, c 8.34, α $100^\circ 22'$, β $90^\circ 00'$, γ $103^\circ 54'$ (Berman and Wolfe, 1939)**Matildite**— $2[\text{Ag}_2\text{S} \cdot \text{Bi}_2\text{S}_3]$

Orthorhombic;

 a 8.08, b 7.82, c 5.65 (Ramdohr, 1936)**Diaphorite**— $4[3\text{Ag}_2\text{S} \cdot 4\text{PbS} \cdot 3\text{Sb}_2\text{S}_3]$ Orthorhombic; D_{2h}^{21} — $Cmma$ a 15.83, b 32.23, c 5.89 (Palache, Richmond and Winchell, 1938)**Freieslebenite**— $\text{Ag}_3\text{Pb}_3\text{Sb}_5\text{S}_{12}$ Monoclinic; C_{2h}^5 — $P2_1/n$ a 7.53, b 12.79, c 5.88, β $92^\circ 14'$ (Palache, Richmond and Winchell, 1938)**Stephanite**— $2[5\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3]$ Orthorhombic; C_{2v}^{12} — $Cmc2$ a 7.70, b 12.32, c 8.48 (Taylor, 1940)**Andorite**— $2\text{PbS} \cdot \text{Ag}_2\text{S} \cdot 3\text{Sb}_2\text{S}_3$

Orthorhombic;

Needle-axis (pseudo-period) 4.26 (Hofmann, 1935)

Miargyrite, aramayoite, matildite, diaphorite, freieslebenite, stephanite, and andorite may be considered together since they show certain similarities in cell dimensions. These minerals do not constitute a well-defined group since they differ both in crystal system and chemical type.

Matildite and miargyrite were placed together by Dana (1892, p. 111) as an appendix to the Zinckenite Group, with the chemical formula $\text{RS} \cdot (\text{As}, \text{Sb}, \text{Bi})_2\text{S}_3$, R being Ag_2 . More recently Berman and Wolfe (1939) have pointed out the similarities between the foregoing two species and aramayoite for which they obtained the triclinic elements given above.

Diaphorite and freieslebenite were placed together after the Jamesonite Group by Dana (1892, p. 118), the two species being regarded as dimorphous forms of $5(\text{Ag}_2, \text{Pb})\text{S} \cdot 2\text{Sb}_2\text{S}_3$. The recent work of Palache, Richmond and Winchell (1938) has indicated unlike cell contents for the two species. The cell content of freieslebenite is only approximately given by the available analyses and further chemical work might give a better cell content. Dana

(1892, p. 143) places stephanite with geocronite in the basic division of the sulpho-salts. The two minerals show no simple geometrical relation, but reliable *x*-ray measurements on geocronite are not available and therefore we cannot say whether these two minerals are structurally related.

Among the cell dimensions of these six minerals certain familiar lengths appear either in simple or multiple form, but there is no direct comparison between any of the species.

BOURNONITE GROUP

Bournonite— $2[\text{Cu}_2\text{S} \cdot 2\text{PbS} \cdot \text{Sb}_2\text{S}_3]$
Orthorhombic; D_{2h}^{13} —*Pnmm*
a 8.10, *b* 8.65, *c* 7.75 (Ofstedal, 1932)

Seligmannite— $2[\text{Cu}_2\text{S} \cdot 2\text{PbS} \cdot \text{As}_2\text{S}_3]$
Orthorhombic; D_{2h}^{13} —*Pnmm*
a 8.04, *b* 8.66, *c* 7.56 (Fron del, 1941)

Dana (1892, p. 126) took bournonite as the type member of a group of eight minerals with the general composition $3\text{RS} \cdot (\text{As}, \text{Sb}, \text{Bi})_2\text{S}_3$. Of these we have already seen that aikinite is not structurally related to bournonite, neither is boulangerite, as will be shown later. "Lillianite" has been shown to have no individuality. In regard to guitermanite our specimen proved to be identical with baumhauerite; on the other hand, Ferrari and Curti (1934) found that a specimen of guitermanite from the type locality gave the same powder photograph as jordanite. In either case it would seem that the standing of "guitermanite" as a distinct species is very doubtful.

Seligmannite was first described by Baumhauer (1901), and later work by Solly (1903) and Palache (1928) have showed that the geometrical crystallography is very similar to that of bournonite. The recent work of Fron del (1941) shows that the unit cell of seligmannite is closely similar to that of bournonite.

PROUSTITE GROUP

Proustite— $3[3\text{Ag}_2\text{S} \cdot \text{As}_2\text{S}_3]$
Hexagonal; C_{3v}^6 —*R3c*
a 10.74, *c* 8.64 (Harker, 1936)

Pyrargyrite— $3[3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3]$
Hexagonal; C_{3v}^6 —*R3c*
a 11.04, *c* 8.71 (Harker, 1936)

The ruby silvers, proustite and pyrargyrite, constitute a closely related pair of minerals which have long been classed together on the basis of their similar geometrical form and chemical composition. *X*-ray measurements on pyrargyrite by Gossner and Mussnug (1928) gave the space group and approximate dimensions of the rhombohedral cell. More recently Harker (1936) made complete structural determinations of both species, obtaining the cell dimensions (hexagonal notation) given above. The ruby silvers thus present another example in which the structural data completely confirm the close relationship previously inferred from the similarities of crystal form and chemical composition.

Zinckenite— $12[6\text{PbS} \cdot 7\text{Sb}_2\text{S}_3]$
 Hexagonal; $C_6^6-C6_3$ or $C_{6h}^2-C6_3/m$
 a 44.06, c 8.60 (Vaux and Bannister, 1938)

The Zinckenite Group of Dana (1892, p. 111) includes: zinckenite, sartorite, emplectite, chalcostibite, galenobismutite, and berthierite. We have already seen that emplectite and chalcostibite form a well-defined pair and that galenobismutite and berthierite are likewise closely related. In the present treatment sartorite is grouped with the other sulpharsenites of lead, and consequently zinckenite now stands alone. At the same time zinckenite and sartorite show certain similarities suggesting that they may still be regarded as mineralogically related.

Zinckenite was originally described as orthorhombic, sometimes with nearly hexagonal form due to twinning. Recently Vaux and Bannister (1938) obtained a hexagonal cell with the elements given above; these authors found no *x*-ray evidence for orthorhombic symmetry, but it still remains possible that the departure from hexagonal symmetry is real but too small to detect on *x*-ray photographs. Dyscrasite, recently described by Peacock (1940), is a case in which earlier *x*-ray measurements indicated hexagonal symmetry and later refined measurements with the Weissenberg goniometer revealed the true orthorhombic character.

With reference to orthorhombic axes zinckenite and sartorite show the following comparison in the dimensions of their pseudo-cells:

Zinckenite: a 22.03, b 38.15, c 4.30
 Sartorite: c 7.86, a 19.48, b 4.15

These suggest that the two species do have some structural similarity.

In regard to the composition of these two minerals Dana gives the following simple formulas:

Zinckenite: $\text{PbS} \cdot \text{Sb}_2\text{S}_3$

Sartorite: $\text{PbS} \cdot \text{As}_2\text{S}_3$

Structural work on sartorite has given no reason for departing from this simple formula; on the other hand, Vaux and Bannister conclude that the content of the hexagonal cell of zinckenite is closer to $12[6\text{PbS} \cdot 7\text{Sb}_2\text{S}_3]$ than to $81[\text{PbS} \cdot \text{Sb}_2\text{S}_3]$. In view of the possibility that zinckenite is indeed orthorhombic, it seems not improbable that the true content of the unit cell of zinckenite is $160[\text{PbS} \cdot \text{Sb}_2\text{S}_3]$ since orthorhombic cells commonly contain 4 or 8 molecules or multiples of the numbers. In that case the true cell contents of zinckenite and sartorite would be as follows:

Zinckenite: $160[\text{PbS} \cdot \text{Sb}_2\text{S}_3]$

Sartorite: $320[\text{PbS} \cdot \text{As}_2\text{S}_3]$

Cosalite— $8[2\text{PbS} \cdot \text{Bi}_2\text{S}_3]$

Orthorhombic; D_{2h}^{16} — $Pbnm$

a 19.05, b 23.82, c 4.05 (Berry, 1939)

Jamesonite— $2[4\text{PbS} \cdot \text{FeS} \cdot 3\text{Sb}_2\text{S}_3]$

Monoclinic; C_{2h}^5 — $P2_1/a$

a 15.68, b 19.01, c 4.03; β $91^\circ 48'$ (Berry, 1940a)

Cosalite is a member of Dana's Jamesonite Group which comprises dufrenoyite, cosalite, jamesonite, and the ill-defined minerals, schapbachite and kobellite. Of these minerals dufrenoyite, cosalite, and jamesonite are undoubtedly valid species. Schapbachite has been shown to be a mixture of matildite and galena by Ramdohr (1936); a partial examination of kobellite shows a mixture of minerals one of which appears to be the mineral to which the name was given.

Detailed studies of cosalite and jamesonite have already been published (1939, 1940a), but as yet no x -ray measurements of dufrenoyite have been made. Of the specimens labelled dufrenoyite which were examined in the course of the present work, three proved to be baumhauerite, one jordanite, and one sartorite. These are all sulpharsenites of lead occurring in dolomite in the Binnenthal, Switzerland.

Cosalite is an orthorhombic needle-like mineral with the cell

dimensions given above. The lengths 19 and 4 Å are among those that occur repeatedly.

Jamesonite is likewise needle-like but monoclinic in symmetry with a more complex composition than that given in Dana (1892, p. 117). The two species are related by the cell lengths 19 and 4 Å which are common to both, but the minerals cannot be regarded as constituting a closely related pair. These results afford a case where *x*-ray measurements have shown that a number of minerals grouped together mainly on the basis of chemical analogy actually show only partial structural relations.

Livingstonite— $4[\text{HgS} \cdot 2\text{Sb}_2\text{S}_3]$

Monoclinic; $C_{2h}^2-P2_1/c$

a 15.14, b 3.98, c 21.60; β 104° (Richmond, 1936)

Livingstonite occurs in slender prismatic crystals which were originally believed to be orthorhombic and related to stibnite. The recent work of Richmond (1936) yielded the data given above. The period in the needle axis is nearly 4 Å as in stibnite, but there is clearly no further relation between these minerals.

"Falkmanite"— $10[3\text{PbS} \cdot \text{Sb}_2\text{S}_3]$ "

Monoclinic;

a 24.93, b 8.10, c 14.51; β 100°50' (Hiller, 1939)

Falkmanite was recently described by Hiller (1939*b*) and by Ramdohr and Ödman (1940) as a needle-like mineral resembling boulangerite, with a composition near $\text{Pb}_3\text{Sb}_2\text{S}_6$. Falkmanite gave the same *x*-ray powder pattern as boulangerite, but Weissenberg photographs gave monoclinic cell elements differing from the orthorhombic elements, a 17.83, b 4.02, c 14.83, previously obtained for boulangerite by Hiller (1939*a*). Boulangerite, however, has given the monoclinic cell dimensions quoted below (Berry, 1940*b*) and these have recently been confirmed by Hurlbut in Palache and Berman (1942). It will be seen that these agree with those reported for falkmanite except in one cell-edge. Hiller's cell determinations of sulpho-salts (1939*a*) have, so far, proved to be partly or wholly erroneous² and therefore the reported difference

²The unit cells of zinckenite, meneghinite, boulangerite, jamesonite, and pligionite, have recently been redetermined by reliable methods, with results that differ partly or wholly from those of Hiller. Geocronite and heteromorphite remain to be redetermined.

between falkmanite and boulangierite is not convincing. With like *x*-ray powder patterns and similar compositions (falkmanite, $\text{Pb}_6\text{Sb}_4\text{S}_{12}$, sp. gr. 6.2; boulangierite, $\text{Pb}_5\text{Sb}_4\text{S}_{11}$, sp. gr. 6.23), falkmanite cannot be sustained as a distinct species.

Boulangierite— $8[5\text{PbS} \cdot 2\text{Sb}_2\text{S}_3]$

Monoclinic; C_{2h}^5 — $P2_1/a$

a 21.52, *b* 23.46, *c* 8.07; β 100°48' (Berry, 1940*b*)

Meneghinite— $[\text{Cu}_2\text{S} \cdot 26\text{PbS} \cdot 7\text{Sb}_2\text{S}_3]$

Orthorhombic;

a 11.36, *b* 24.04, *c* 8.26 (Berry and Moddle, 1941)

As shown in the detailed study of boulangierite (1940*b*) this mineral is monoclinic with the composition $5\text{PbS} \cdot 2\text{Sb}_2\text{S}_3$, and thus it has no place in the Bournonite Group of Dana (1892, p. 126). The cell dimensions of meneghinite as given above were worked out recently. The two minerals are related by similar cell dimensions.

LEAD SULPHARSENITES

Sartorite— $320[\text{PbS} \cdot \text{As}_2\text{S}_3]$

Orthorhombic; D_2^4 — $P2_12_12_1$ (pseudo-cell)

a 77.9, *b* 83.0, *c* 7.86 (Peacock and Berry, 1940)

Baumhauerite— $4[3\text{PbS} \cdot 2\text{As}_2\text{S}_3]$

Monoclinic; C_{2h}^5 — $P2_1/m$ (Hurlbut, unpublished determination)

a 22.69, *b* 8.29, *c* 7.86; β 96°45' (Peacock and Berry, 1940)

Rathite— $13\text{PbS} \cdot 9\text{As}_2\text{S}_3(?)$

Monoclinic; C_{2h}^5 — $P2_1/n$

a 25.00, *b* 7.91, *c* 8.42; β 99°00' (Peacock and Berry, 1940)

Gratonite— $3[9\text{PbS} \cdot 2\text{As}_2\text{S}_3]$

Hexagonal; C_{3v}^6 — $R3m$

a 17.69, *c* 7.83 (Palache and Fisher, 1940)

Jordanite— $27\text{PbS} \cdot 7\text{As}_2\text{S}_3$

Monoclinic; C_{2h}^2 — $P2_1/m$

a 8.89, *b* 31.65, *c* 8.40; β 118°21' (Peacock and Berry, 1940)

The sulpharsenites, sartorite, baumhauerite, rathite, gratonite, and jordanite are here grouped together in view of certain prevailing structural similarities, although it is clear that they differ widely in symmetry and chemical type. In general these species are characterized by very large cells and remarkably complex cell contents. Except for sartorite they show no chemical or crystallographical relation to any of the other sulpho-salts. Most of the

data given above were derived for the first time in the course of the present work. Gratonite is a new species described recently by Palache and Fisher (1940). All these species, with the exception of gratonite, occur amongst the lead-grey sulpharsenites of the Binnenthal, Switzerland, and as already mentioned many of these are mislabelled in museum collections owing to their similar physical properties.

A connecting thread can be found in the remarkable persistence of two cell dimensions. One of these ranges from 7.83 Å in gratonite to 7.91 Å in rathite; this value appears in jordanite as the spacing of the planes (100) which equals 7.85 Å. The other persistent cell dimension varies from 8.29 Å to 8.42 Å; this length appears multiplied by ten in sartorite ($b = 83.0$ Å) and approximately by two in the hexagonal mineral gratonite ($a = 17.69$ Å). This persistence of two nearly constant structural dimensions clearly suggests the existence of some common structural features in these remarkable diverse minerals.

ENARGITE GROUP

Enargite— $3\text{Cu}_2\text{S} \cdot \text{As}_2\text{S}_5$

Orthorhombic; $C_{2v}^7 - Pnm2$

a 6.46, b 7.43, c 6.18 (Pauling and Weinbaum, 1934)

Famatinite— $3\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_5$

Orthorhombic;

Enargite and famatinite were already classed together in Dana (1892, p. 147). Only enargite has been subjected to single crystal x -ray measurements giving the above cell dimensions. The available work on famatinite is restricted to powder photographs and semi-quantitative spectrographic analyses by Harcourt (1937) who shows that famatinite (luzonite) is structurally distinct from enargite.

TETRAHEDRITE GROUP

Tetrahedrite— $2[\text{Cu}_{12}\text{Sb}_4\text{S}_{13}]$

Cubic; $T_d^3 - I\bar{4}3m$

a 10.32 (Machatschki, 1928)

Tennantite (binnite)— $2[(\text{Cu}, \text{Fe})_{12}\text{As}_4\text{S}_{13}]$

Cubic; $T_d^3 - I\bar{4}3m$

a 10.19 (Pauling and Neumann, 1934)

Colusite— $2[\text{Cu}_{12}(\text{As}, \text{Sn}, \text{V}, \text{Te}, \text{Fe})_4\text{S}_{16}]$

Cubic;

a 10.60 (Berman and Gonyer, 1939)

Sulvanite— Cu_3VS_4

Cubic; T_d^1 — $P\bar{4}3m$

a 5.37 (Pauling and Hultgren, 1933)

Germanite— $\text{Cu}_3(\text{Fe}, \text{Ge})\text{S}_4$

Cubic; T_d^1 — $P\bar{4}3m$

a 5.29 (de Jong, 1930)

Tetrahedrite and tennantite have always been recognized as closely related by the similarity of their crystallography and chemistry. As shown above they also have similar cell edges and similar cell contents. The cell formulas as given above were deduced from numerous analyses which vary widely and differ substantially from the empirical formulas ($\text{Cu}_8\text{Sb}_2\text{S}_7$ and $\text{Cu}_8\text{As}_2\text{S}_7$) given in Dana (1892, p. 137). Thirteen sulphur atoms are incompatible with a cubic structure; Machatschki (1928) considers the true number to be twelve with one extra interstitial atom of sulphur per half unit cell.

Colusite, sulvanite, and germanite are all species described since Dana (1892); they are likewise cubic with cell edges comparable to those of tetrahedrite. Recent work by Berman and Gonyer (1939) has given the above cell content for colusite which Berman considers to be comparable to the cell contents of tetrahedrite and tennantite in spite of the notable discrepancy in the numbers of sulphur atoms. The cell contents of sulvanite and germanite are comparable with that of colusite. However, the atomic arrangements of sulvanite (Pauling and Hultgren, 1933), germanite (de Jong, 1930) and tetrahedrite-tennantite (Machatschki, 1928; Pauling and Neumann, 1934) show distinct differences.

The foregoing arrangement of the sulpho-salts for which structural data are available has brought out a remarkable recurrence of certain cell dimensions which persist irrespective of the chemical complexity of the crystals and differences of symmetry ranging from triclinic to cubic. In emphasizing these persistent lengths the underlying thought is that they represent similarities in atomic arrangements, and it should be emphasized that such similarities have been found in the few cases where the atomic arrangements are known.

A graphical representation of the recurrence of certain lattice dimensions is given by the diagram (Fig. 1) which represents the frequency of occurrence of cell edges ranging from 3 to 32 Å. This graph is based on the actual lengths of the cell edges, except in the case of zinckenite and sartorite in which the lengths of the edges of the well marked pseudo-cells have been used instead of the

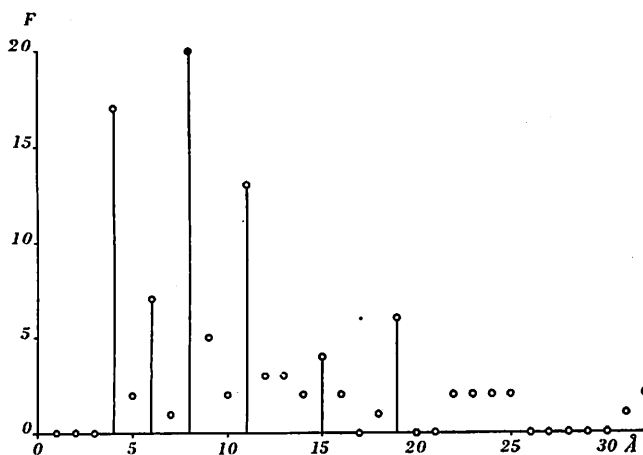


FIG. 1.—Frequency of occurrence (F) of lattice periods, to the nearest whole number of Å, in mineral sulpho-salts.

true cell edges, which are very large and undoubtedly represent multiples of shorter periods. The diagram brings out the marked frequency of lengths close to 4, 6, 8, 11, 15 and 19 Å, in round numbers.

To bring out this persistence of cell lengths more definitely, the minerals under consideration are listed again with their cell contents and the nearly constant cell dimensions in increasing order, in six groups corresponding to the frequently recurring lattice periods. In this tabulation each species in general appears three times since each of its three cell lengths comes into consideration.

LATTICE PERIOD ABOUT 4 Å

Berthierite... <i>c</i>	3.76 (needle axis)	Galeno-	
Chalcostibite <i>b</i>	3.78 (needle axis)	bismutite .. <i>c</i>	4.07 (elong. axis)
Stibnite..... <i>c</i>	3.83 (needle axis)	Meneghinite.. <i>c</i>	4.12 (needle axis)
Emplectite... <i>b</i>	3.89 (needle axis)	Baumhauerite <i>b</i>	2(4.15) (elong. axis)
Bismuthinite. <i>c</i>	3.97 (needle axis)	Sartorite..... <i>b</i>	20(4.15)
Livingstonite. <i>b</i>	3.98 (needle axis)	Galena..... <i>T</i> _[110]	4.19
Herzenbergite <i>a</i>	3.98 (|| to cleavage)	Jordanite..... <i>c</i>	2(4.20)
Aikinite..... <i>c</i>	4.00 (needle axis)	Rathite..... <i>c</i>	2(4.21) (elong. axis)
Jamesonite... <i>c</i>	4.03 (needle axis)	Andorite..... <i>n</i>	4(2.26) (elong. axis)
Boulangerite. <i>c</i>	2(4.03) (needle axis)	Teallite..... <i>b</i>	4.28 (|| to cleavage)
Teallite..... <i>a</i>	4.04 (|| to cleavage)	Zinckenite ... <i>c</i>	2(4.30) (needle axis)
Cosalite..... <i>c</i>	4.05 (needle axis)	Herzenbergite <i>b</i>	4.33 (|| to cleavage)
		Miargyrite... <i>b</i>	4.39

LATTICE PERIOD ABOUT 6 Å

Germanite.... <i>a</i>	5.29	Galena..... <i>a</i>	5.93 (⊥ to cleavage)
Sulvanite.... <i>a</i>	5.37	Chalcostibite. <i>a</i>	6.01
Matildite.... <i>c</i>	5.65	Emplectite... <i>a</i>	6.12
Frcieslebenite <i>c</i>	5.88 (elong. axis)	Enargite..... <i>c</i>	6.18
Diaphorite... <i>c</i>	5.89 (elong. axis)	Enargite..... <i>a</i>	6.46

LATTICE PERIOD ABOUT 8 Å

Enargite..... <i>b</i>	7.43	Bournonite... <i>a</i>	8.10
Frcieslebenite <i>a</i>	7.53	Falkmanite... <i>b</i>	8.10 (needle axis)
Stephanite... <i>a</i>	7.70	Meneghinite.. <i>c</i>	8.24 (needle axis)
Bournonite... <i>c</i>	7.75	Baumhauerite <i>b</i>	8.29 (elong. axis)
Aramayoite .. <i>a</i>	7.76	Aramayoite .. <i>c</i>	8.34
Matildite.... <i>c</i>	7.82	Jordanite..... <i>c</i>	8.40
Gratonite... <i>c</i>	7.83 (elong. axis)	Rathite..... <i>c</i>	8.42 (elong. axis)
Jordanite... <i>d</i> _[110]	7.85	Stephanite... <i>c</i>	8.48 (elong. axis)
Baumhauerite <i>c</i>	7.86	Zinckenite ... <i>c</i>	8.60 (needle axis)
Sartorite..... <i>c</i>	7.86 (elong. axis)	Proustite..... <i>c</i>	8.64 (elong. axis)
Rathite..... <i>b</i>	7.91	Bournonite... <i>b</i>	8.65
Boulangerite. <i>c</i>	8.07 (needle axis)	Pyrargyrite .. <i>c</i>	8.71 (elong. axis)
Matildite.... <i>a</i>	8.08	Aramayoite .. <i>b</i>	8.79

LATTICE PERIOD ABOUT 11 Å

Tennantite... <i>a</i>	10.19	Bismuthinite. <i>a</i>	11.13
Tetrahedrite. <i>a</i>	10.29	Herzenbergite <i>c</i>	11.18 (⊥ to cleavage)
Colusite..... <i>a</i>	10.60	Stibnite..... <i>a</i>	11.20
Proustite.... <i>a</i>	10.74	Bismuthinite. <i>b</i>	11.27 (⊥ to cleavage)
Zinckenite ... <i>a</i>	4(11.01)	Stibnite..... <i>b</i>	11.28 (⊥ to cleavage)
Pyrargyrite .. <i>a</i>	11.04	Meneghinite.. <i>a</i>	11.29

Aikinite..... <i>a</i>	11.30		Galeno-	
Teallite..... <i>c</i>	11.33	(\perp to cleavage)	bismutite .. <i>a</i>	11.72
Berthierite... <i>a</i>	11.44		Galena..... <i>2c</i>	11.86
Aikinite..... <i>b</i>	11.64			

LATTICE PERIOD ABOUT 15 Å

Berthierite... <i>b</i>	14.12		Galeno-	
Chalcostibite. <i>c</i>	14.46	(\perp to cleavage)	bismutite .. <i>b</i>	14.52
Emplectite... <i>c</i>	14.51	(\perp to cleavage)	Livingstonite. <i>a</i>	15.14
Falkmanite... <i>c</i>	14.51		Jamesonite... <i>a</i>	15.68
			Diaphorite... <i>a</i>	15.83

LATTICE PERIOD ABOUT 19 Å

Proustite..... <i>b</i>	18.61	(orthohex.)	Zinckenite ... <i>b</i>	4(19.09)	(orthohex.)
Jamesonite... <i>b</i>	19.01		Pyrargyrite .. <i>b</i>	19.11	(orthohex.)
Cosalite..... <i>a</i>	19.05		Sartorite..... <i>a</i>	4(19.48)	

In the list of minerals with the persistent 4 Å-length are included cell edges which are actually about 4 Å and also several cell lengths which clearly represent double the 4 Å-lengths, indicated by alternate weak and strong layer lines in rotation photographs, as in boulangerite. In the remainder of the tabulation the true lengths are given except in the case of zinckenite, where it is assumed that the *a*-period is four times the 11 Å-length and the *b*-period is four times the 19 Å-length, and in sartorite where the *a*-period is four times the 19 Å-length. It should be noted that for the sake of comparison the orthohexagonal *b*-axis is given for the hexagonal minerals proustite and pyrargyrite, and also for zinckenite, which as previously noted may be truly orthorhombic. Of these persistent lengths the 4 Å-period is perhaps the most striking and a general explanation in terms of atomic structure has been suggested by Hofmann (1935).

It is not proposed to enter further here into the structural significance of this and other persistent lengths. It will be of interest, however, to point out the very persistent relation that exists between the relative lengths of the cell edges of a crystal and the relative proportions of its external development, that is the crystal habit. The principle underlying the relation between the geometrical proportions of the lattice cell and the actual proportions of a typical crystal was already correctly expressed

by the *Law of Bravais* which was formulated long before it was possible to make a direct determination of the crystal lattice. In its original form this law stated that the importance (size and frequency) of external crystal planes is proportional to the relative reticular densities of the corresponding lattice planes. This is strictly equivalent to saying that form importance is proportional to the spacing of lattice planes, since spacing and reticular density are directly proportional. Another expression of the Law of Bravais, which is perhaps more useful in the present connection, is that the greatest crystal growth takes place along the densest lattice rows and that the rate of growth in these rows is proportional to the reticular density of the row, that is inversely proportional to the period of the row. This form of the Law of Bravais was emphasized by Friedel (1926).

As a consequence of the Law of Bravais, a crystal with three equal periods will develop equally in the three directions giving the cubic habit. If one lattice period or cell edge is much greater than the other two the greatest growth will take place along the two shorter periods and the habit will be tabular, the plane of tabular development being transverse to the longest period, this plane is also the most probable plane of cleavage since it has the widest spacing. The converse case is presented when one period is much shorter than the other two, then the crystal will be elongated in the direction of the shortest period and the cleavage or cleavages will be parallel to this direction, since the planes of greatest spacing are parallel to this period and transverse to the longer periods. The degree of elongation can be predicted from the degree of dissimilarity between the shortest period and the longest two; if the difference is great the crystal will be needle like; if it is moderate or slight the crystal will be long or short prismatic in typical habit.

The truth of this generalization is strikingly exhibited in the foregoing list of cell edges. It will be observed that the 4 \AA -period, which is usually much the shortest in each mineral that possesses this period, is commonly the direction of needle-like crystal elongation. In some cases the crystals are slender prismatic or only moderately elongated. The most probable cleavage is parallel to the short 4 \AA -period. Even when the 4 \AA -length is a pseudo-period this direction still remains the direction of maximum growth. The

6 and 8 Å-lengths are also commonly the shortest periods and consequently the directions in which the crystals are typically elongated. The 11, 15, and 19 Å-lengths usually represent the longer dimensions of the unit cells; consequently crystals possessing these lengths are typically tabular transversely to these long periods and commonly exhibit cleavage parallel to the plane of tabular development.

SUMMARY

A review of the available structural data on the mineral sulpho-salts suggests an arrangement of these minerals based mainly on similarities in cell dimensions. This results in breaking down some of the classical groups into smaller groups or unrelated species and occasionally in bringing together minerals formerly regarded as unrelated. The arrangement is far from complete, since structural data for a number of species are still lacking, and it is not offered as a considered mineralogical classification since the usual chemical considerations are subordinated to dimensional considerations. It is thought, however, that some of the changes will prove to be well founded and should appear in a modern classification.

A tabulation of the known cell dimensions brings out a remarkable recurrence of certain lengths, near 4, 6, 8, 11, 15, and 19 Å. It seems likely that these persistent lattice periods are associated with certain recurring styles of atomic arrangement and that the grouping of species with common cell dimensions may eventually find some support when progress has been made with the study of their atomic structures. It is shown that the general habit of the mineral sulpho-salts ranges from needle-like to tabular in keeping with the relative dimensions of their unit cells, as required by the Law of Bravais.

Incidentally to this survey it is found necessary to discredit two species, namely "cannizzarite" which is evidently identical with galenobismutite, and "falkmanite" whose properties do not distinguish it from boulangerite.

REFERENCES

- BAUMHAUER, H. (1901): Über den Seligmannit, ein neues dem Bournonit homöomorphes Mineral aus dem Dolomit des Binnenthals—*Sitzungsber. K. preuss. Akad. Wiss. Berlin*, pp. 110-117.
- BERMAN, H. and GONYER, F. A. (1939): Re-examination of colusite—*Am. Mineral.*, vol. 24, pp. 377-381.
- and WOLFE, C. W. (1939): Crystallography of aramayoite—*Min. Mag.*, vol. 25, pp. 466-473.
- BERRY, L. G. (1939): Studies of mineral sulpho-salts: I—Cosalite from Canada and Sweden—*Univ. Toronto Studies, Geol. Ser.*, no. 42, pp. 23-31.
- (1940a): Studies of mineral sulpho-salts: II—Jamesonite from Cornwall and Bolivia—*Min. Mag.*, vol. 25, pp. 597-608.
- (1940b): Studies of mineral sulpho-salts: III—Boulangerite and "epiboulangerite"—*Univ. Toronto Studies, Geol. Ser.*, no. 44, pp. 5-19.
- (1940c): Studies of mineral sulpho-salts: IV—Galenobismutite and "lillianite"—*Am. Mineral.*, vol. 25, pp. 726-734.
- and MODDLE, D. A. (1941): Studies of mineral sulpho-salts: V—Meneghinite from Ontario and Tuscany—*Univ. Toronto Studies, Geol. Ser.*, no. 46, pp. 5-17.
- BUERGER, M. J. (1936): Crystallographic data, unit cell and space group for berthierite (FeSb_2S_4)—*Am. Mineral.*, vol. 21, pp. 442-448.
- DANA, E. S. (1892): *System of mineralogy*, ed. 6—New York.
- DE JONG, W. F. (1930): Die Kristallstruktur von Germanit—*Zeits. Krist.*, vol. 73, pp. 176-180.
- FERRARI, A. and CURTI, R. (1934): I solfoarseniti di piombo—*Per. min. (Roma)*, vol. 5, pp. 155-174.
- FRIEDEL, G. (1926): *Leçons de cristallographie*—Paris.
- FRONDEL, C. (1941): Unit cell and space group of vrbaitite ($\text{Ti}(\text{As}, \text{Sb})_3\text{S}_6$), seligmannite ($\text{CuPbAs}_2\text{S}_6$) and samsonite ($\text{Ag}_4\text{MnSb}_2\text{S}_6$)—*Am. Mineral.*, vol. 26, pp. 25-28.
- GOSSNER, B. and MUSSGUG, F. (1928): Über die Kristallstruktur von Pyrargyrit—*Centr. Min.*, A, pp. 65-73.
- HARCOURT, G. A. (1937): The distinction between enargite and famatinite (luzonite)—*Am. Mineral.*, vol. 22, pp. 517-525.
- HARKER, D. (1936): The application of the three-dimensional Patterson method and the crystal structures of proustite, Ag_3AsS_3 , and pyrargyrite, Ag_3AsS_3 —*Jour. Chem. Phys.*, vol. 4, pp. 381-390.
- HERZENBERG, R. (1932): Kolbeckin Sn_2S_3 , ein neues Zinnmineral—*Centr. Min.*, A, pp. 354-355.
- HILLER, J. E. (1939a): Röntgenographische Bestimmungsmethoden und Untersuchung der Bleispiessglanze—*Zeits. Krist.*, vol. 100, pp. 128-156.
- (1939b): Über den Falkmanit—*Zeits. Krist.*, vol. 102, pp. 138-142.
- HOFMANN, W. (1933a): Strukturelle und morphologische Zusammenhänge bei Erzen vom Formeltyp ABC_2 . I. Die Struktur von Wolfsbergit CuSbS_2

- und Emplektit CuBiS_2 und deren Beziehungen zu der Struktur von Antimonit Sb_2S_3 —*Zeits. Krist.*, vol. 84, pp. 177-203.
- (1933b): Die Struktur der Minerale der Antimonitgruppe—*Zeits. Krist.*, vol. 86, pp. 225-245.
- (1935): Ergebnisse der Strukturbestimmung komplexer Sulfide. I. Die Struktur von Zinnsulfür SnS und Teallit PbSnS_2 . II. Beitrag zur Kristallchemie der Sulfosalze des Arsens, Antimons und Wismuts—*Zeits. Krist.*, vol. 92, pp. 161-185.
- (1938): Die Struktur von Miargyrit AgSbS_2 —*Sitzungsber. preuss. Akad. Wiss., Phys.-math. Kl.*, pp. 111-119.
- MACHATSCHKI, F. (1928): Präzisionsmessungen der Gitterkonstanten verschiedener Fahlerze. Formel und Struktur derselben—*Zeits. Krist.*, vol. 68, pp. 204-222.
- MOHS, F. (1804): *Null Mineralien-Kabinet*, vol. 3—Vienna [from Dana, 1892, p. lvii.]
- OFTEDAL, I. (1932): Die Raumgruppe des Bournonits (CuPbSbS_3)—*Zeits. Krist.*, vol. 83, pp. 157-158.
- PALACHE, C. (1928): Seligmannite from Bingham, Utah—*Am. Mineral.*, vol. 13, pp. 402-405.
- , RICHMOND, W. E. and WINCHELL, H. (1938): Crystallographic studies of the sulpho-salts: baumhauerite, meneghinite, jordanite, diaphorite, freieslebenite—*Am. Mineral.*, vol. 23, pp. 821-836.
- and FISHER, D. J. (1940): Gratonite—a new mineral from Cerro de Pasco, Peru—*Am. Mineral.*, vol. 25, pp. 255-265.
- and BERMAN, H. (1942): Boulangerite—*Am. Mineral.*, vol. 27, pp. 552-562.
- PAULING, L. and HULTGREN, R. (1933): The crystal structure of sulvanite, Cu_3VS_4 —*Zeits. Krist.*, vol. 84, pp. 204-212.
- and NEUMANN, E. W. (1934): The crystal structure of binnite, $(\text{Cu,Fe})_{12}\text{As}_4\text{S}_{13}$, and the chemical composition and structure of minerals of the tetrahedrite group—*Zeits. Krist.*, vol. 88, pp. 54-62.
- and WEINBAUM, S. (1934): The crystal structure of enargite, Cu_3AsS_4 —*Zeits. Krist.*, vol. 88, pp. 48-53.
- PEACOCK, M. A. (1940): On dyscrasite and antimonial silver—*Univ. Toronto Studies, Geol. Ser.*, no. 44, pp. 31-46.
- (1942): Studies of mineral sulpho-salts: VI—Aikinite—*Univ. Toronto Studies, Geol. Ser.*, no. 47, pp. 63-69.
- and BERRY, L. G. (1940): Röntgenographic observations on ore minerals—*Univ. Toronto Studies, Geol. Ser.*, no. 44, pp. 47-69.
- PRIOR, G. T. (1904): On teallite, a new sulphostannite of lead from Bolivia; and its relations to franckeite and cylindrite—*Min. Mag.*, vol. 14, pp. 21-27.
- RAMDOHR, P. (1934): Nordenskiöldin in einer Zinnerzlagertstätte—*Jahrb. Min., Beil.-Bd.*, A, vol. 68, pp. 288-296.
- (1936): Bleiglanz, Schapbachit, Matildit—*Fortschr. Min.*, vol. 20, pp. 56-57.

- RAMDOHR, P., and ÖDMAN, O. (1940): Falkmanit, ein neues Bleispiessglanzerz, und sein Vorkommen, besonders in Boliden und Grube Bayerland. (Mit einem Beitrag zur Kenntnis des Geokronits).—*N. Jahrb. Min., Beil.-Bd.*, A, vol. 75, pp. 315-350.
- RICHMOND, W. E. (1936): Crystallography of livingstonite—*Am. Mineral.*, vol. 21, pp. 718-720.
- (1940): Crystal chemistry of the phosphates, arsenates and vanadates of the type $A_2XO_4(Z)$ —*Am. Mineral.*, vol. 25, pp. 441-479.
- SJÖGREN, HJ. (1878): Om några vismutmineralier från Nordmarks grufvor i Vermland—*Geol. För. Förh.*, vol. 4, pp. 106-111.
- SOLLY, R. H. (1903): Sulpharsenites of lead from the Binnenthal. Part IV.—Seligmannite: with a supplementary note on baumhauerite—*Min. Mag.*, vol. 13, pp. 336-341.
- TAYLOR, E. D. (1940): Stephanite morphology—*Am. Mineral.*, vol. 25, pp. 327-337.
- UNGEMACH, H. (1923): Sur les formes cristallines de notation compliquée—*Zeits. Krist.*, vol. 58, pp. 150-171.
- VAUX, G. and BANNISTER, F. A. (1938): The identity of zinckenite and keeleyite—*Min. Mag.*, vol. 25, pp. 221-227.
- WOLFE, C. W. (1938): Cannizzarite and bismuthinite from Vulcano—*Am. Mineral.*, vol. 23, pp. 790-798.
- (1940): Classification of the minerals of the type $A_3(XO_4)_2 \cdot nH_2O$ —*Am. Mineral.*, vol. 25, pp. 783-753, 787-809.
- ZAMBONINI, F., DE FIORE, O., and CAROBBI, G. (1925): Su un solfobismutito di piombo di Vulcano (Isole Eolie)—*Rend. Ac. Sc. Fis. Mat. Napoli*, ser. 3, vol. 31, pp. 24-29.

MUSCOVITE FROM MATTAWAN TOWNSHIP NIPISSING DISTRICT, ONTARIO

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The present increased demand for mica suitable for electrical purposes, and the reduced imports of such material from abroad, have stimulated the mining of mica both in Canada and in the United States. Amber mica (phlogopite) has been produced in Canada in substantial amounts for many years, but until recently no important deposit of white sheet mica (muscovite) was known in this country. The discovery in 1941 of a pegmatite dike with large crystals of high grade muscovite, in the Eau Claire area, 13 miles west of Mattawa, Ontario, was thus of considerable economic interest, and the rapid development of the original and neighbouring showings has led to a noteworthy output of this valuable strategic material.²

The muscovite deposits of the Eau Claire area occur almost wholly in the south-west corner of Mattawan Township, about 6 miles north of Eau Claire, the nearest railway station, in Calvin Township. According to Lang (1943) the region is occupied mainly by Precambrian hornblende and biotite gneiss, granite, and granite gneiss, traversed by quartz-microcline pegmatites in which the books of muscovite are developed. The main producer is the Purdy Pit, in the north half of lot 6, concession II, Mattawan Township, an open cut running 55 feet into biotite gneiss and granite pegmatite. At the head of this pit is lodged a gigantic crystal of muscovite whose upper surface measured about 6 by 8 feet. In other workings in the area books exceeding one foot in width are commonly found, and thus the area produces a large proportion of the largest economic width of sheet mica, namely 8 by 10 inches.

¹Extracted from a *Thesis* for the degree of Master of Arts, University of Toronto, 1943, and prepared for publication in collaboration with Professor M. A. Peacock.

²Lang (1943) gives a useful preliminary account of the development and production of mica in the Eau Claire area, with an outline of the geology of the region and a geological sketch-map.

In the summer of 1942 Dr. James E. Thomson briefly examined the Eau Claire mica area for the Ontario Department of Mines, and as Dr. Thomson's assistant I had an opportunity of seeing the deposits. A few days later Professor M. A. Peacock visited the locality on behalf of the Royal Ontario Museum. He noticed striking shear effects in the mica of the Purdy Pit, shown by straight-edged and parallel-sided slabs with a ribbon-like or fibrous

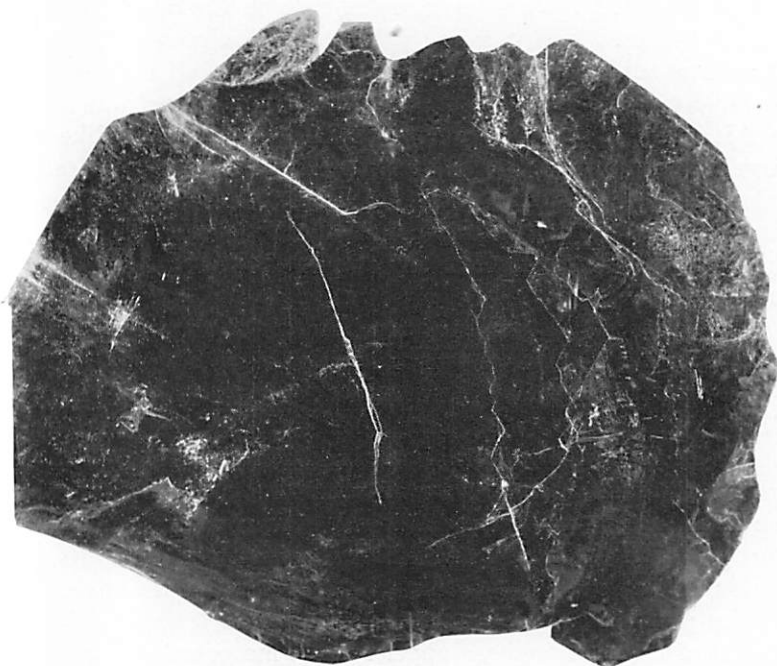


FIG. 1.—Muscovite from the Purdy Pit, Mattawan Township, Ontario; a sheet 6 feet wide, exhibited in the Royal Ontario Museum of Mineralogy.

separation apparently parallel to one or more definite directions in the cleavage plane. Mr. George Purdy kindly gave Dr. Peacock some handsome pieces of this sheared mica, and later, through the kindness of Mr. J. H. Norrie, the Royal Ontario Museum of Mineralogy obtained a fine sheet, 6 feet wide, from the large crystal in the Purdy Pit (Fig. 1).

The present paper gives the results of a mineralogical study of the mica from the Purdy Pit. Although the ordinary properties of the micas are well known a full examination seemed desirable, to obtain the specific properties of material from a new and unique occurrence, and to permit a comparison of the material with the numerous structural types which Hendricks (1939) has found in an x -ray study of a hundred specimens of various micas.

MORPHOLOGICAL AND PHYSICAL PROPERTIES

The observations recorded in this paper were made on two slabs of the sheared mica (Figs. 2 and 3), subsequently referred to as "ruler mica"—to use an appropriate local term—and "tri-

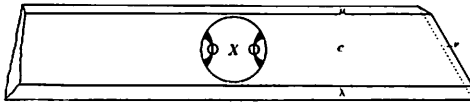


FIG. 2.—Muscovite from the Purdy Pit, with shear surfaces giving strips elongated with the symmetry axis ("ruler mica").

angle mica," respectively. The piece of ruler mica measured about 12 by $1\frac{1}{2}$ by $\frac{1}{2}$ inch while the triangular piece was about 10 inches in greatest length and $\frac{1}{2}$ inch thick. The material is olive green in the mass but perfectly colourless, transparent, and free from inclusions in thin cleavage sheets.

The ruler mica is bounded by three shear surfaces, or gliding planes, marked λ , μ , ν ; the triangle mica shows a shear surface ν

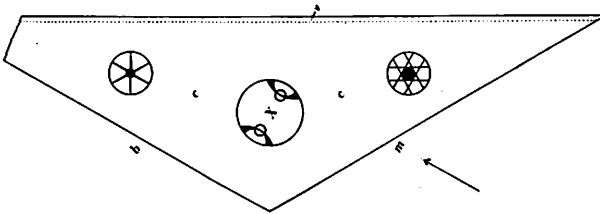


FIG. 3.—Muscovite from the Purdy Pit, with rough side-faces b and m ("triangle" mica). The percussion figure is near letter b , the pressure figure near letter m . View the drawing in the direction of the arrow.

with narrow rough faces $b(0\bar{1}0)$ and $m(1\bar{1}0)$. The surfaces λ and μ show parts which are sufficiently plane to give reflections on the goniometer, and other parts which are covered with ribbons and fibres due to the intersection of the perfect cleavage with the shearing or gliding planes. The surface ν is rough, permitting only a contact measurement. With reference to the orientation subsequently established by optical and x -ray measurements the shear surfaces may be given symbols of the type $\lambda(h0l)$, $\mu(\bar{h}0l)$, $\nu(\bar{h}.3h.\bar{l})$. However the measured angles did not agree well with those calculated for simple indices, and thus it appears that the planes are irrational, although their intersections with the basal cleavage are rational directions, namely $c/\lambda = c/\mu = [010]$, $c/\nu = [310]$. Similar planes have been recorded before on muscovite, such as $\rho(\bar{2}05)$ and $\zeta(135)$, or $(\bar{1}02)$ and (133) , in structural notation, reported by Tschermak (1878). The present observations suggest that such surfaces may be shear planes with only two rational indices (h and k) rather than gliding planes with three rational indices.

Good percussion and pressure figures were obtained on the triangle mica, giving six-rayed figures in the known orientations. In the percussion figure (Fig. 3, upper inset) one ray is parallel to the crystallographic a -axis; in the pressure figure (Fig. 3, lower inset) one ray is parallel to the crystallographic b -axis, and the three directions correspond to the lines of intersection of shearing or gliding planes with the basal plane, as found by Bauer (1874).

The best of several measurements of the specific gravity, with the Berman balance, gave 2.85 for the ruler mica, 2.84 for the triangle mica.

OPTICAL PROPERTIES

Optical orientation. In keeping with the known optical properties of muscovite our material shows the optic axial plane parallel to the symmetry axis, and the acute negative bisectrix nearly normal to the basal cleavage. From observations on the optic axial angle goniometer Tschermak (1878) found that the acute negative bisectrix makes an apparent angle of $-0^{\circ}30'$ to $-1^{\circ}44'$ with the cleavage normal in three plates of muscovite from different localities. An effort was made to repeat this observation by

providing the optic axial angle goniometer with suitable auxiliary apparatus, but eventually it was found that the probable error of observation was about 1° and therefore it was not possible to decide in this way whether the acute bisectrix really deviated from the cleavage normal.

The problem was solved in another way. A perfectly flat cleavage plate of the muscovite, of suitable thickness to give an optic figure with very small sharp eyes, was brought to extinction and the Bertrand lens was adjusted horizontally to bring one of the cross-hairs precisely into the trace of the optic axial plane (Fig. 4). The stage was then turned 180° when it was found that the trace of the optic axial plane was displaced from the cross hair

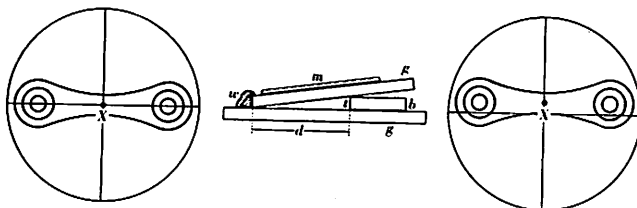


FIG. 4 (left).—Horizontal cross-hair adjusted to bisect the optic figure. FIG. 5 (right).—Displacement of the optic figure on turning stage 180° . FIG. 6 (centre).—Device for measuring small tilts in a mineral plate.

by a small but real amount (Fig. 5). Several plates were examined in this way and each gave the same effect. One plate, taken from the ruler mica, whose crystallographic orientation had been positively determined by *x*-ray photographs, showed that the acute bisectrix lies behind the cleavage normal, as found by Tschermak.

An attempt was made to measure the inclination of the acute bisectrix on the universal stage, but the results were not satisfactory since optic figures of sufficient sharpness could not be obtained with the objectives permitted by the stage. The desired measurement was finally obtained by a simple device (Fig. 6) consisting of two plane parallel object glasses (*gg*) hinged with a piece of wax (*w*) and provided with a wedge-block (*b*) of thickness (*t*) measured with a micrometer. By varying the distance (*d*)

between the block and the hinge the mica plate (m) could be tilted through small angles (A) given by $\tan A = t/d$. With the help of this device several plates of the muscovite were tilted until the horizontal cross-hair exactly bisected the eyes of the optic figure in the 0° and 180° positions. When this condition is reached the angle A is the apparent angle $X : c(001)$ in air. The true angle $T = X : c(001)$ in the mineral is given by $\sin T = (\sin A)/\beta$, where β is the intermediate refractive index. Finally the true inclination of the acute bisectrix to the c -axis is $X : c[001] = \beta - 90^\circ - T$, where β is the (obtuse) angle $[001] : [100] = 96^\circ 24'$. Positive angles are measured from $c(001)$ or $c[001]$ toward $a[100]$; negative angles are measured in the opposite sense.

TABLE I

MUSCOVITE: APPARENT AND TRUE ANGLES $X : c(001)$ AND CORRESPONDING ANGLES $X : c[001]$ ($\beta = 96^\circ 24'$)

Apparent $X : c(001)$		True $X : c(001)$		$X : c[001]$	
Ruler	$-1^\circ 31'$	$-0^\circ 57'$	$+5^\circ 27'$		
($\beta = 1.606$)	$-1^\circ 15'$	$-0^\circ 47'$	$+5^\circ 37'$		
	$-1^\circ 12'$	$-0^\circ 45'$	$+5^\circ 39'$		
	$-1^\circ 10'$	$-0^\circ 37'$	$+5^\circ 47'$		
Average	$-1^\circ 14\frac{1}{2}'$	$-0^\circ 46\frac{1}{2}'$	$+5^\circ 35\frac{1}{2}'$		
Triangle	$-1^\circ 01'$	$-0^\circ 38'$	$+5^\circ 46'$		
($\beta = 1.605$)	$-0^\circ 55'$	$-0^\circ 34'$	$+5^\circ 50'$		
Average	$-0^\circ 58'$	$-0^\circ 36'$	$+5^\circ 48'$		

The results of these measurements are given in Table I which shows that the acute bisectrix lies between the cleavage normal and the c -axis, at less than 1° to the cleavage normal. Thus Tschermak's observations are confirmed. *Pleochroism.* Cleavage plates 2 mm. thick show distinct pleochroism, X greenish brown, Z light brown. Light vibrating parallel to X is only slightly absorbed, the colour being reddish. Derived by Peacock and Ferguson in a revision of the morphology of muscovite, appearing elsewhere in this issue.

brown in a slab with a width of 2.5 cm. The absorption formula is thus $Y > Z > X$, whereas Tschermak noted $Z > Y > X$.

Refractive indices. The refractive indices for Z and Y , the two directions lying practically in the plane of the cleavage, were measured in sodium light by immersion. The measurement of the refractive index for X , nearly normal to the cleavage, presented a special problem for which a new tilting immersion method⁴ was devised and applied. The refractive indices obtained in this way are as follows:

	α	β	γ
Ruler muscovite.....	1.567	1.606	1.611
Triangle muscovite...	1.566	1.605	1.610

}all \pm 0.001

These refractive indices compare with the highest measured by Jefferson, in Hendricks (1939) on a dozen muscovites from different localities. According to Kunitz (1924) high refractive indices are caused by high total iron, whereas Winchell (1925) and Volk (1939) have shown that the refractive indices vary with ferric oxide. With Fe_2O_3 2.69%, FeO 1.53%, as shown by the analysis given later, our material is moderately high in both oxides, and therefore the high indices may be due either to total iron or to ferric oxide alone.

Optic axial angle and dispersion. The optic axial angle ($2V$) was obtained from the apparent optic axial angle in air ($2E$) measured in sodium light with the optic axial angle goniometer, using the formula $\sin V = (\sin E)/\beta$. An independent and probably less accurate value for $2V$ was obtained from the apparent optic axial angle in glass ($2G$) measured in sodium light between glass hemispheres on the universal stage, using the relation, $\sin V = n_G(\sin G)/\beta$, where n_G is the refractive index of the glass hemispheres. The measured values are given in Table 2, with the values calculated from the refractive indices.

The apparent dispersion of the optic axes from red to blue was measured with the optic axial angle goniometer using a mercury vapour arc with Wratten filters transmitting approximately the mean wave-lengths given below. As shown in Table 3 the dispersion is weak, $r > v$.

⁴To be described elsewhere by Ferguson and Peacock.

TABLE 2

MUSCOVITE: APPARENT AND TRUE OPTIC AXIAL ANGLES IN SODIUM LIGHT

Ruler.....	$2E = 67^{\circ}00\frac{1}{2}'$	$2V = 40^{\circ}12'$
	$2G = 40\ 45$ (av. of 8)	$2V = 39\ 26$
		$2V = 38\ 25$ (calc.)
Triangle.....	$2E = 68^{\circ}51\frac{1}{2}'$	$2V = 41^{\circ}15'$
	$2G = 42\ 54$ (av. of 2)	$2V = 41\ 28$
		$2V = 38\ 47$ (calc.)

TABLE 3

MUSCOVITE: APPARENT DISPERSION OF THE OPTIC AXES

Colour Wave-length (Å)	Red 6600	Yellow 5900	Green 5460	Blue 4360
Ruler (2E).....	$67^{\circ}20'$	$67^{\circ}02'$	$66^{\circ}36'$	$65^{\circ}50'$
	67 22	66 59	66 38	65 44
Triangle (2E).....	$69^{\circ}06'$	$68^{\circ}54'$	$68^{\circ}31'$	$67^{\circ}36'$
	69 04	68 49	68 31	67 46

UNIT CELL AND SPACE-GROUP

A minute lath shaped fragment was selected from the partly detached material on the sheared surface λ of the ruler mica, and this was used for a rotation photograph and Weissenberg resolutions of the zero and first layer lines. The projections from the sharp films that were obtained showed that the axis of rotation—the edge c/λ of the ruler mica—is the symmetry axis of muscovite. With reference to the smallest and least oblique cell the cell dimensions in the first column of Table 4 were obtained. The systematically missing spectra, namely (hkl) present only with $(h+k)$ even, $(h0l)$ present only with h even and l even, lead to the space-group C_{2h}^6-C2/c , if muscovite is holohedral. For comparison, the cell dimensions and space-group were also determined on a small well-developed green crystal of muscovite from Lincoln County, North Carolina (Royal Ontario Museum of Mineralogy, E 2284).

As shown in Table 4 the cell dimensions and space-group obtained in this way agree well with those previously determined on muscovite. The atomic arrangement of muscovite was predicted

by Pauling (1930) and worked out in detail by Jackson and West (1930), while Hendricks (1939) has found that muscovite represents a distinct and invariant structural type.

TABLE 4
MUSCOVITE: CELL DIMENSIONS AND SPACE-GROUP

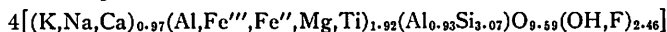
	Mattawan Township	North Carolina	Jackson and West (1930)	Pauling (1930)	Mauguin (1927)
<i>a</i>	5.21 Å	5.20 Å	5.18 Å	5.19 Å	5.17 Å
<i>b</i>	9.02	9.03	9.02	8.99	8.94
<i>c</i>	19.98	20.04	20.04	20.14	20.01
β	96°24'	95°54'	95°30'	96°	96°
Space-group..	<i>C2/c</i>	<i>C2/c</i>	<i>C2/c</i>	.....	<i>C2/c</i>

The above *x*-ray measurements were actually made at the beginning of the study, and thus the identity and crystallographic orientation of the material were positively established at the outset of the work.

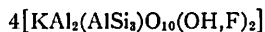
CHEMICAL COMPOSITION AND CELL CONTENT

Following a spectrographic analysis,⁵ a chemical analysis was made of the muscovite from Mattawan Township using standard methods, with suitable modifications to meet the difficulty of obtaining very finely divided material, and the complications introduced by the presence of fluorine. The result of the analysis is given in Table 5, together with the atomic content of the unit cell obtained from the empirical molecular weight of the cell contents, as given by the measured cell dimensions and specific gravity.

From Table 5 the structural formula of muscovite from Mattawan Township may be written:



This differs from the ideal structural formula:



mainly in the term (OH,F) which sums to 2.46 instead of 2. However, many muscovites would show a similar excess in (OH,F)

⁵Made with the help of Dr. V. B. Meen.

TABLE 5
MUSCOVITE FROM MATTAWAN TOWNSHIP: ANALYSIS AND CELL CONTENT

1		2		
SiO ₂	45.66	Si.....	12.28	} 16.00
Al ₂ O ₃	31.80	Al.....	10.08	
Fe ₂ O ₃	2.69	Fe'''.....	0.54	} 7.67
FeO.....	1.53	Fe''.....	0.34	
MgO.....	0.92	Mg.....	0.37	
TiO ₂	0.31	Ti.....	0.06	} 3.89
CaO.....	0.09	Ca.....	0.03	
Na ₂ O.....	0.60	Na.....	0.31	
K ₂ O.....	10.34	K.....	3.55	} 48.21
H ₂ O+.....	5.32	OH.....	9.54	
H ₂ O-.....	0.36	O.....	38.52	
F.....	0.37	F.....	0.31	
O for F ₂	-0.16	O.....	-0.16	
99.83*				

1. Anal. R. B. Ferguson. *Incl. Cr none, Mn none, Li none.
2. Cell content with $M = 1607$.

which is evidently a real and common departure from the ideal composition.

With our cell dimensions the molecular weight of the ideal cell content is $M = 1593$ which gives the calculated specific gravity 2.81. The measured value, 2.84, is higher presumably due to the additional heavy constituents, notably iron, which, as previously shown, is probably responsible for the relatively high indices of refraction of the mineral.

REFERENCES

- BAUER, M. (1874): Ueber einige physikalische Verhältnisse des Glimmers—*Zeits. deutsch. geol. Gesellsch.*, vol. 26, pp. 137-180.
- HENDRICKS, S. B. (1939): Polymorphism of the micas. With optical measurements by M. E. JEFFERSON—*Am. Mineral.*, vol. 24, pp. 729-771.
- JACKSON, W. W., and WEST, J. (1930): The crystal structure of muscovite, $KAl_2(AlSi_3)O_{10}(OH)_2$ —*Zeits. Krist.*, vol. 76, pp. 211-227. *4 v. 76, pp. 211-227*
- KUNITZ, W. (1924): Die Beziehung zwischen der chemischen Zusammensetzung und den physikalisch-optischen Eigenschaften innerhalb der Glimmergruppe—*N. Jahrb. Min., Beil.-Bd.* 50, pp. 365-413.
- LANG, A. H. (1943): Mica deposits in and near Eau Claire, Ontario—*Geol. Surv. Canada* (mimeographed report).

- MAUGUIN, C. (1927): Étude du mica au moyen des rayons X—*Compt. Rend. Ac. Sci. Paris*, vol. 185, pp. 288-291.
- PAULING, L. (1930): The structure of the micas and related minerals—*Proc. Nat. Acad. Sci. U.S.A.*, vol. 16, pp. 123-129.
- TSCHERMAK, G. (1878): Die Glimmergruppe. (I Theil)—*Zeits. Kryst.*, vol. 2, pp. 14-50.
- VOLK, G. W. (1939): Optical and chemical studies of muscovite—*Am. Mineral.*, vol. 24, pp. 255-266.
- WINCHELL, A. N. (1925): Studies in the mica group, parts 1 and 2—*Am. Jour. Sci.*, vol. 9, pp. 309-327; 415-430.

A NOTE ON THE ENGINEERING SIGNIFICANCE OF THE CLAY MINERALS

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Mineralogy is not the least of the sciences the methods and findings of which the engineer applies in the prosecution of his utilitarian work. It is in the practice of the civil engineer that the study of minerals has proved to be most useful but in other branches of professional work, notably ceramic engineering, many useful applications of mineralogy have been made.

This is no new development. Early in the history of road building, it was found necessary to study the mineral contents of rocks thus used. When "water-bound macadam" was the leading type of road construction, numerous detailed mineralogical studies were made in this field (Boswell, 1921). The study of building stones, and especially of their weathering or decay—subjects upon which several treatises have been published—necessarily involved detailed mineralogical study of the rocks in question. One of the very few mineralogical papers to be found in the proceedings of a leading engineering society relates to the staining of building stones (Knight and Knight, 1938). A recent application, of great and growing importance, is in relation to the crushed rock and sand used as concrete aggregate, the mineralogical character of which is often of surprising significance.

Interesting though these and similar applications in civil engineering practice may be, they are not unusual, being typical of many such examples of this "applied science." Within the last decade, however, there has been initiated another connection between mineralogy and civil engineering that is unusual. Even though it is still in process of development, it has achieved such significance that it already warrants the attention devoted to it in this note.

Soils, using that term to include all unconsolidated material in the earth's crust, have always been important to the civil engineer. In excavation he has had to move them, in foundation work to build upon them, in constructing embankments to utilize

them. Strangely, however, it was not until the second decade of the present century that any concerted scientific study of soils was begun, although a certain amount of individual work had been performed and described before that time. "Soil Mechanics" was the term adopted for this new branch of scientific study; the First International Conference on Soil Mechanics and Foundation Engineering was held at Harvard University as recently as 1936. So rapidly has the study of soils advanced, however, that there is now available a 500-page volume dealing solely with the various theories of soil mechanics (Terzaghi, 1943), a book that does not begin to deal with practical applications or laboratory work. Truly has it been said that a new chapter in the history of engineering is thus unfolding.

Various methods have been devised for the classification of soils, one being the analysis of soil particle sizes—by sieving and by an interesting application of Stokes' Law for smaller particles. Thus, in a widely adopted grouping, "sand" has particle diameters ranging from 1.0 mm. to 0.05 mm., "silt" from 0.05 mm. to 0.005 mm., particles smaller than this being called "clay." Even cursory consideration will show that some of the mechanical properties of soils composed of clay-sized particles will differ markedly from those consisting solely of sand, if only because of the wide variation in the specific surface areas of the two soil types. There are, however, factors to be considered other than the size of the particles, in particular the shape and constitution of the soil grains, and these can be studied only by means of mineralogical techniques. It is for this reason that the mineralogy of clay materials is assuming such significance in modern engineering practice.

It is possible, for example, to obtain silica in the form of quartz within the size range of clay-sized particles. Such a material, while conforming to the mechanical requirements of a clay, as regards particle size distribution, exhibits none of the characteristic properties of a true clay. Another example, of a more practical nature, is afforded by a recent study of glacial drift (typical "Boulder Clay") carried out in the Department of Civil Engineering, University of Toronto (Legget, 1942). A study of the utilitarian characteristics of this material which, when wet, was

plastic to the touch, showed clearly that the finer constituents, although of "clay" size, could not possibly be other than finely ground particles of the more common rock-forming minerals. Specific gravity (about 2.77) was one indication; the shearing strength of the soil confirmed this first suggestion since it was found to be almost the same as that for a "cohesionless" soil, such as fine sand.

It has not yet been possible to follow up this study with a mineralogical investigation of the finer particles in glacial drift. A good deal of research, however, has been done elsewhere upon the mineralogy of true clay particles; many of the results have been conveniently summarized in a paper by Grim (1942), a leading worker in this field. X-ray diffraction analysis has been the technique that has made possible this advance in the study of clays, in view of the sizes of the particles involved. Thus it is only within the last two decades that clay minerals have been so studied, the earliest work being apparently that of Hadding (1923).

This recent work has shown, with a reasonable degree of certainty, that true clays consist of crystalline particles of groups of minerals now commonly called the "clay minerals." These are in general hydrous aluminum silicates, magnesium sometimes replacing the aluminum. The principal groups, as listed by Grim, are designated as illite, montmorillonite, and kaolinite; some minor groups are also recognized. Much work has been done on the crystal structure of these groups and there is general agreement as to the main structural features of the more common clay minerals. Some progress has been made in correlating the crystal structures with physical characteristics. It is known, for example, that all the principal clay minerals have a pronounced basal cleavage so that individual particles of true clay take the general form of flat flakes. Long suspected, and detectable from the optical properties of clay suspensions, this characteristic particle-shape has now been "seen" by means of the electron-microscope.

The strongly defined cleavage planes of the clay minerals lead to the breaking down of the clay particles actually occurring in soils into much smaller particles when a clay soil is worked with water. Grim (1940) reports that "the microscopic study of thin sections of numerous clays and some soils have shown the clay

mineral particles to be much larger than the sizes revealed by analyses using the hydrometer or pipette method." As the former method of analysis is that almost always followed in laboratory work relating to engineering soil studies, the significance of this finding will be clear. It is possible that the same mineral characteristic is related to changes in the physical properties of clays that occur when clay is "remoulded," i.e. when it is disturbed from its natural state by being worked or moulded.

Two main groups of crystal structures have been recognized for the clay minerals, a 1 : 1 type characteristic of the kaolin group, and a 2 : 1 type characteristic of the montmorillonite group. It has been shown that the second type expands and contracts with the amount of water that is present. This is reflected in certain physical properties, notably the high hydration of clays of the montmorillonite group, water being absorbed not only on the outer surfaces but also on the internal surfaces of the clay mineral crystals. This property is intimately associated with the swelling of clays. All such volume changes are of importance to the engineer, whether artificially produced or occurring naturally: the field is one in which much work still remains to be done.

Not only may water be absorbed by the crystals of clay minerals but cations also. The associated ionic exchange is intimately related to the physical properties of clays, the subject of base exchange being perhaps the most potentially significant section of the study of the clay minerals. In general, it is found that the base exchange capacity of clays is dependent upon the clay minerals present. Thus, the montmorillonite group displays the highest exchange capacity and the kaolin group the lowest. Further, as the content of iron and aluminum in the clay minerals increases, the total exchange capacity becomes less. It has also been found that the base exchange capacity of the montmorillonite group does not change with the particle size whereas that of the kaolinite group does increase. While these findings are in accord with the structural characteristics of the mineral groups, a full understanding of the base exchange characteristics of the main clay mineral groups has yet to be achieved.

Enough is already known, however, to have enabled engineers to utilize the action of base exchange in practical applications. A

particularly interesting example was given by the clay blanket lining used to make watertight the fresh-water lagoon on "Treasure Island" in San Francisco Bay, a prominent feature of the exhibition of 1939. When this 7-acre artificial lake was filled with fresh water, a seepage loss of one inch per day occurred, a loss so serious that the success of the lagoon was in grave doubt. On the advice of C. H. Lee, who has described the operation (1941), the lagoon was filled with sea water which was left in for about 60 days and then replaced by fresh water. The saline content of the sea water changed the pervious natural soil into an Na-soil and after the excess electrolytes had been washed out from the clay layer, the usual low permeability of a Na-soil resulted. The seepage loss, in consequence, was reduced from 1.0 to 0.1 inch per day, and the lagoon was used as originally planned.

Similar "processing" of clay soils has been followed in a few other engineering projects but the practical possibilities that the method presents have yet to be fully explored. In the field of soil stabilization, an important aspect of modern highway engineering, it would appear that the special characteristics of clay minerals just discussed have an unusual significance. The work of Winterkorn (1941) in this branch of soil study is notable.

Brief mention may finally be made of the electrical properties of the surfaces of clay mineral particles, a matter but little investigated as yet but one that presents some interesting speculative possibilities. Some experimentation has been carried out in Germany on the hardening of soft clay by electrical methods (Endell and Hoffman, 1936) which, in the opinion of the writer, is unusually suggestive. It is possible that corresponding methods might be applied in the case of structures including metallic piling (such as steel sheet piling), in which case the piling itself could serve as an electrode.

Due to the exigencies of the times, it has not yet been possible to attempt any experimental work along the lines just suggested. This brief review is therefore based upon published records of the work of others, to all of whom acknowledgment is here made.

REFERENCES

- BOSWELL, P. G. H. (1921): Some geological characteristics of road stones—*Inst. Quarry Managers* (London).
- ENDELL, K., and HOFFMAN, V. (1936): Electrochemical hardening of clay soils—*Proc. First Int. Conf. Soil Mechanics and Foundation Engineering*, vol. 1, pp. 273-275.
- GRIM, R. E. (1940): The clay minerals in soils and their significance—*Proc. Purdue Conf. Soil Mechanics and its Applications*, pp. 216-223.
- (1942): Modern concepts of clay materials—*Jour. Geol.*, vol. 50, pp. 225-275.
- HADDING, A. (1923): An x-ray method to identify crystalline and crypto-crystalline substances—*Zeits. Krist.*, vol. 58, pp. 108-112.
- KNIGHT, B. H., and KNIGHT, R. G. (1938): Rapid staining in granites used in civil engineering work—*Jour. Inst. Civil Engs.*, vol. 8, pp. 545-552.
- LEE, C. H. (1941): Sealing the lagoon lining at Treasure Island with salt—*Proc. Am. Soc. Civil Engs.*, vol. 106, pp. 577-607.
- LEGGET, R. F. (1942): An engineering study of glacial drift for an earth dam, near Fergus, Ontario—*Econ. Geol.*, vol. 37, pp. 531-556.
- TERZAGHI, K. (1943): *Theoretical soil mechanics*—New York.
- WINTERKORN, H. (1941): Physico-chemical testing of soils and application of the results in practice—*Proc. Highway Research Board*, vol. 20, pp. 798-806.

PREHNITE FROM ASHCROFT, BRITISH COLUMBIA

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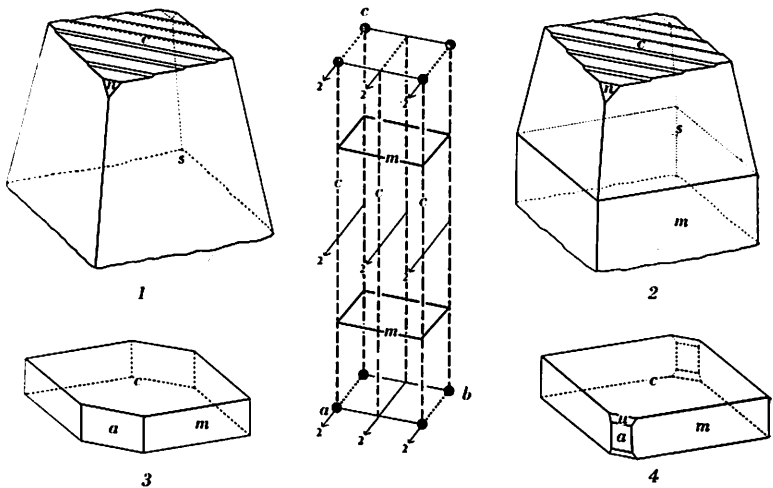
During the summer of 1942 specimens of prehnite were collected in the Ashcroft district, B.C., along the east side of the valley of the Bonaparte River, a short distance north of Ferguson Creek. The mineral fills fissures 3 to 4 inches in width and 2 to 3 feet in length in one of the large peridotite bodies that are common in the area. Although the specific properties of prehnite are now for the most part well known there are still some uncertainties which, it was thought, might be cleared up by a study of the promising crystals in the new material. The study of the Ashcroft material was supplemented by some observations on a specimen from Ottawa County, Quebec, kindly made available by Professor Parsons from the Royal Ontario Museum of Mineralogy. Dr. V. B. Meen gave me valuable advice on the chemical analysis. I am also indebted to Professor M. A. Peacock for supervising the work and assisting me in the preparation of this paper.

MORPHOLOGY

Description of crystals. The Ashcroft crystals (Figs. 1 and 2) are colourless and translucent and 5 mm. in greatest dimension, with pseudocubic appearance due to the combination of $c(001)$ with $s(111)$, sometimes accompanied by $m(110)$, with reference to the structural lattice. The only other form developed is $n(104)$ which makes narrow steps in oscillatory combination with $c(001)$, causing strong striations parallel to $[010]$ on the base. Although the faces are not bright they give sharp signals on the goniometer. Table 1 summarizes the measurements on five crystals and shows that the mean measured angles agree well with the angles calculated from the geometrical elements derived later. The crystals from Ottawa County (Figs. 3 and 4) present the commoner tabular habit with broad faces of $c(001)$ combined with $m(110)$ and $a(100)$ and sometimes small facets of $u(102)$.

Geometrical settings and elements. In the past prehnite has invariably been oriented with the good cleavage as the base and

the well-developed prism with the angle mm nearly 80° as the unit vertical prism. Various authors, however, have used different (hkl) planes as the parametral plane. In all, four settings are to be found in the literature, proposed respectively by Naumann, Miller, Dana, and Goldschmidt, and summarized in Goldschmidt's *Index* (1890, p. 493). The unit cell of prehnite, determined by Gossner and Mussnug (1931) and confirmed in the present paper, gives an axial ratio comparable to the geometrical elements proposed by



FIGS. 1-5.—Prehnite: crystals and crystal lattice. FIGS. 1, 2.—Crystals from Ashcroft, B.C. FIGS. 3, 4.—Crystals from Ottawa County, Que. FIG. 5 (centre)—Crystal lattice and symmetry elements of the space-group $P2cm$.

TABLE 1

PREHNITE: MEASURED and CALCULATED ANGLES

<i>Ashcroft</i>	Measured	Calculated
$mm = (110) : (\bar{1}\bar{1}0) = 80^\circ 10'$ (4)		$80^\circ 12'$
$cs = (001) : (111) = 79^\circ 13\frac{1}{2}'$ (13)		$79^\circ 13'$
$cn = (001) : (104) = 45^\circ 14'$ (2)		$45^\circ 07'$
Azimuth of $s(111) = 49^\circ 55'$ (13)		$49^\circ 54'$
<i>Ottawa County</i>		
$mm = (110) : (\bar{1}\bar{1}0) = 80^\circ 04'$ (5)		$80^\circ 12'$
$cu = (001) : (102) = 63^\circ 17'$ (2)		$63^\circ 31\frac{1}{2}'$

Goldschmidt (1890). This establishes the correctness of Goldschmidt's setting of 1890, which he unfortunately abandoned in his *Winkeltabellen* (1897) in favour of Naumann's setting. The early settings of prehnite are conveniently related to the correct setting by the transformation formulae:

Naumann to Goldschmidt (1890): 100/010/003
 Miller to Goldschmidt (1890): 100/010/004
 Dana to Goldschmidt (1890): 100/010/006

To obtain definitive geometrical elements for prehnite previous goniometric work on this species was examined with a view to obtaining a summary of the best measured angles. From the previous descriptions it was clear that really excellent crystals of prehnite are very rare and that few published measurements can be regarded as very accurate. The most reliable measurements appear to be those made by Beutell (1887) on prehnite crystals from Silesia showing excellent faces of the forms $m(110)$, $o(011)$, $s(111)$, in the structural setting. Beutell's best measurements, average of 5 readings differing by not more than 1', are:

$$(111) : (\bar{1}\bar{1}1) = 78^{\circ}30'; (111) : (\bar{1}11) = 97^{\circ}26'$$

The corresponding calculated two-circle angles for the plane (111) are given below together with the corresponding angles obtained on the Ashcroft crystals by goniometric and x-ray measurements:

$\phi(111)$	$\rho(111)$	
49°54'	79°13'	Beutell
49 55	79 13½	E.W.N. (goniometric)
49 53	79 12	E.W.N. (x-ray)

The three pairs of angles are practically alike and therefore it seems proper to accept the axial ratios from Beutell's angles:

$$a : b : c = 0.8420 : 1 : 3.3817$$

as final geometrical elements of prehnite.

Forms and angle-table. In reviewing the literature on the crystallography of prehnite notes were made on the authors' statements regarding the quality and frequency of the observed forms, and thus material was obtained for a critical revision of the form

system of the species. The results of this revision are given in the following angle-table (Table 2) for the forms regarded as established, and the ensuing notes on the forms which are considered uncertain. For convenient correlation with the standard works of Dana (1892) and Goldschmidt (1920) Table 2 also gives the form-letters and indices used by these authors.

TABLE 2

PREHNITE— $\text{Ca}_2\text{Al}_2\text{Si}_5\text{O}_{10}(\text{OH})_2$
Orthorhombic; pyramidal ($P2cm$)

$a : b : c = 0.8420 : 1 : 3.3817$; $p_o : q_o : r_o = 4.0164 : 3.3817 : 1$

Form	ϕ	$\rho = C$	A	B	Dana 1892	Gold- schmidt 1920
$c(001)$	.....	0°00'	90°00'	90°00'	$c(001)$	$cP(001)$
$b(010)$	0°00'	90 00	90 00	0 00	$b(010)$	$ab(010)$
$a(100)$	90 00	90 00	0 00	90 00	$a(100)$	$ba(100)$
$m(110)$	49 54	90 00	40 06	49 54	$m(110)$	$mM(110)$
$l(012)$	0 00	59 24	90 00	30 36	—(031)	—(032)
$o(011)$	0 00	73 31½	90 00	16 28½	$o(061)$	$o(031)$
$g(043)$	0 00	77 29½	90 00	12 30½	—(081)	—(041)
$v(108)$	90 00	26 39½	63 20½	90 00	$v(304)$	—(308)
$n(104)$	90 00	45 07½	44 52½	90 00	$n(302)$	$n(304)$
$u(102)$	90 00	63 31½	26 28½	90 00	—(301)	$l(302)$
$z(506)$	90 00	73 22	16 38	90 00	—(501)	$z(502)$
$f(101)$	90 00	76 01	13 59	90 00	—(601)	$u(301)$
$h(706)$	90 00	77 57	12 03	90 00	—(701)	$\zeta(702)$
$w(503)$	90 00	81 30	8 30	90 00	—(10.0.1)	$w(501)$
$r(113)$	49 54	60 15½	48 22½	56 00	$r(221)$	$r(111)$
$p(112)$	49 54	69 09	44 22	52 59½	—(331)	—(332)
$s(111)$	49 54	79 13	41 17	50 45	$s(661)$	$s(331)$
$x(443)$	49 54	81 52	40 46½	50 23½	—(881)	$x(441)$

Uncertain: (130), (210), (410), (0.1.15), (0.1.12), (0.4.27), (0.10.9), (1.0.48), (1.0.24), (109), (106), (209), (103), (133).

In the following notes on the forms regarded as uncertain the first symbol refers to the adopted setting (Goldschmidt, 1890), while the next symbol is in the author's original notation. To follow the various notations it should be observed that Naumann's setting was used by Beutell (1887), Traube (1894), Goodchild

(1903),¹ Hlawatsch (1910), Goldschmidt (1920), and Gallitelli (1928). Bøggild (1905) used Dana's setting. Fraser, Butler and Hurlbut (1938) used the correct setting of Goldschmidt (1890).

(130): noted as $p(130)$ by Beutell (1887) as a new form on a crystal from Jordansmühl, Silesia; matt, curved, giving no signal. Meas. (110) : (130) = $28^{\circ}04'$, calc. $28^{\circ}18'$. (In Beutell's Fig. 4 the letters m and p should be interchanged.) Also shown by Goodchild (1903) as a small form on a striated crystal from Boylestone, Scotland.

(210): shown by Goodchild (1903) as a pair of narrow faces on a crystal from Boylestone, Scotland. Heddle (1924) notes a form $q(120)?$ but in his figure representing a crystal from Uphall, Linlithgowshire, the letter q is attached to a pair of faces corresponding to (210).

(410): shown by Bøggild (1905) as $l(410)$ with a pair of small faces on a crystal from Greenland; meas. (410) : (100) = $11^{\circ}33'$, calc. $11^{\circ}53'$.

(0.1.15): reported as (015) by Gallitelli (1928) on a crystal from Toggiano, province of Modena, Italy; 3 faces giving no proper signals; meas. (001) : (015) = $12^{\circ}53'$ ($12^{\circ}46' - 13^{\circ}0'$), calc. $12^{\circ}42\frac{1}{2}'$.

(0.1.12): given in Goldschmidt (1920) as $e(014)$ and attributed to Goodchild (1903).

(0.4.27) \sim (017): described and figured as (049) with broad faces on a crystal from Toggiano, by Gallitelli (1928); meas. (001) : (049) = $27^{\circ}06'$ ($26^{\circ}48' - 27^{\circ}27'$), calc. $26^{\circ}36\frac{1}{2}'$. The form may correspond to (017) in our notation, which gives (001) : (017) = $25^{\circ}47'$.

(0.10.9): noted as (0.10.3) by Gallitelli (1928) on two crystals; meas. (001) : (0.10.3) = $75^{\circ}30'$ ($75^{\circ}24' - 75^{\circ}36'$), calc. $75^{\circ}06'$.

(1.0.48): noted by Hlawatsch (1910) as $\gamma(1.0.16)$, perhaps a vicinal to (001), on striated, dull, and rough crystals from Guanajuato, Mexico; meas. (001) : (1.0.16) = $2^{\circ} - 7^{\circ}$ (34 faces), calc. $4^{\circ}47'$.

(1.0.24): given as $\xi(108)$ in Hlawatsch (1910); attributed by Goldschmidt (1920) to Goodchild (1903).

(109): noted as $i(103)$ by Hlawatsch (1910) on rough crystals from Guanajuato; meas. (001) : (103) = $24^{\circ}56'$ ($24^{\circ}17' - 25^{\circ}32'$), calc. $24^{\circ}03'$.

(106): mentioned by Traube (1894) as (102), occurring on crystals from Jordansmühl; no measurement given.

(209): described as $k(203)$ by Hlawatsch (1910) on rough crystals from Guanajuato; curved faces giving no signals; meas. (001) : (203) = $43^{\circ}07'$ ($40^{\circ}17' - 45^{\circ}48'$), calc. $41^{\circ}45'$. The established form (104) gives, calc. (001) : (104) = $45^{\circ}07\frac{1}{2}'$.

(103): listed as $q(101)$ in Goldschmidt (1920). No measurement has been found for this form.

(133): described as $q(131)$ by Beutell (1887) on a crystal from Jordansmühl as dull line faces giving no reflections; meas. (001) : (131) = $74^{\circ}20'$, calc. $74^{\circ}37\frac{1}{2}'$.

¹Goodchild's work could not be obtained for reference. Observations attributed to Goodchild were taken from Goldschmidt (1920) and Heddle (1924).

Although some of the foregoing forms appear to be reasonably well established by the measurements given, those with complicated symbols are regarded as uncertain in view of the frequently described rounded, apparently etched character of prehnite crystals. Etching frequently produces reflecting surfaces (etch forms) with complex symbols which are vicinal to simple forms.

Actual and theoretical form development. With a view to comparing the form development of prehnite with the development required by Donnay's generalization of the law of Bravais, sixty-two crystal drawings reproduced in Goldschmidt's *Atlas* (1920) together with two drawings representing the occurrences described in this paper, were examined and a table was prepared giving the "frequency" and "mean rank" of each of the established forms in the manner recently explained by Tremblay (1942) in connection with a study of vesuvianite. Table 3 gives the first fourteen sets of lattice planes of prehnite with the corresponding calculated spacings, in conformity with the space group $P2cm$ of the untwinned structure.² To each set of lattice planes that corresponds to a known form the form-letter has been added together with the frequency and mean rank obtained from the crystal drawings.

In a general way there is a fair correspondence between the theoretical and actual order of importance, in that 11 of the 18 established forms appear in the first 14 places, with c , the most important form and a good cleavage, in the first place. In detail however, the agreement is not as good as is usually found, as shown, for example, by the actual second rank of $m(110)$ as compared with its 9th place in the theoretical list. Another peculiarity is shown by the high frequency of $n(104)$ (12th theoretical place) and $v(108)$ which is almost as frequent (35th place). This would suggest that a pseudo-period of $c/4$ operates in the $(h0l)$ zone. The extinction condition, $(h0l)$ only with l even, which is common to the untwinned ($P2cm$) and twinned ($Pnmc$) space-groups, appears clearly in the form development. In regard to the $(0kl)$ zone, $o(011)$ more important than $u(012)$ indicates no extinction condition, as required by the space-group of the untwinned structure. Thus the morphology shows the influence of the lattice

²See the later section on the space-group.

dimensions and space-group symmetry and brings confirmation of the space-group determined by the x -ray extinctions.³

TABLE 3
PREHNITE: RELATIVE IMPORTANCE OF FORMS

(hkl)	$d(\text{Å})$	Form	Frequency	Mean rank
(002)	9.22	<i>c</i>	61	1.2
(010)	5.46	<i>b</i>	28	2.6
(011)	5.24	<i>o</i>	16	3.5
(012)	4.70	<i>l</i>	1	...
(100)	4.60	<i>a</i>	36	3.5
(102)	4.12	<i>u</i>	4	4.8
(013)	4.08	..	..	...
(014)	3.52	..	..	...
(110)	3.52	<i>m</i>	54	2.4
(111)	3.46	<i>s</i>	13	3.1
(112)	3.29	<i>p</i>	1	...
(104)	3.26	<i>n</i>	20	4.4
(015)	3.06	..	..	...
(113)	3.05	<i>r</i>	5	4.8

OPTICAL PROPERTIES

Prehnite commonly displays optical effects which indicate complex twinned aggregates (Dana 1892, p. 531; Fraser, Butler and Hurlbut, 1938). Basal cleavage plates from the Ashcroft crystals, however, show no indication of such lamellar structure and therefore they seem to afford a rare case of apparently homogeneous material well suited for the exact determination of specific properties. The material from Ottawa County on the other hand shows lamellar structure in basal cleavage plates, similar to that which has been described before.

Cleavage fragments of both materials were studied by immersion using fresh liquids and a sodium vapour lamp. The apparent optic axial angle $2G$ was measured on the universal stage and converted to the true optic axial angle by the formula

$$\sin V = n_g \cdot \sin G/\beta$$

where n_g is the refractive index of the glass hemispheres and G

³See the later section on the space-group.

is the apparent optic axial angle in glass. Dispersion was tested with the mercury vapour lamp and Wratten filters. Table 4 gives the optical data obtained on the two materials (indices ± 0.001); the new values for α , β , γ , $2V$, fall within the range of those previously reported (Table 7).

TABLE 4

PREHNITE: OPTICAL PROPERTIES

Ashcroft, B.C.

$X = a[100]$	$\alpha = 1.615$ (Na)	Positive
$Y = b[010]$	$\beta = 1.624$	$2V = 69^\circ$ (calc. 68°)
$Z = c[001]$	$\gamma = 1.644$	Dispersion imperceptible

Ottawa County

$X = a[100]$	$\alpha = 1.619$ (Na)	Positive
$Y = b[010]$	$\beta = 1.627$	$2V = 64^\circ$ (calc. 63°)
$Z = c[001]$	$\gamma = 1.648$	$r < v$ (1°)

STRUCTURAL CRYSTALLOGRAPHY

Cell Dimensions. The unit cell of prehnite was determined by Gossner and Mussnug (1931) from rotation photographs which were admittedly not wholly satisfactory owing to the intergrown structure of the material. The imperfections of the films were particularly noticeable when an attempt was made to determine the space-group from the systematically missing spectra, and consequently these authors did not reach an unequivocal decision on this point. It seemed desirable, therefore, to make new x -ray measurements on prehnite using the optically homogeneous material from Ashcroft, with a view to redetermining the cell dimensions and the space-group and also to obtain verified x -ray powder data.

For this purpose a small, nearly equidimensional basal cleavage fragment was obtained and examined under the microscope to verify the absence of lamellar structure. With this crystal the following photographs were made: rotation about the axis normal to the cleavage and Weissenberg resolutions of the zero, first, and second layer lines. Sharp films were obtained which showed on projection no departure from orthorhombic symmetry. Measure-

ment of the films gave the cell dimensions which are listed below together with those of Gossner and Musssnug.

<i>a</i>	<i>b</i>	<i>c</i>	
4.60Å	5.46Å	18.44Å	E.W.N.
4.65	5.52	18.53	Gossner & Musssnug

The two sets of values are fairly comparable confirming Gossner and Musssnug's structural cell. As previously shown the ratios of the new cell dimensions agree very closely with those obtained by measurements with the reflecting goniometer, confirming the setting of Goldschmidt (1890) and the geometrical elements of Beutell (1887).

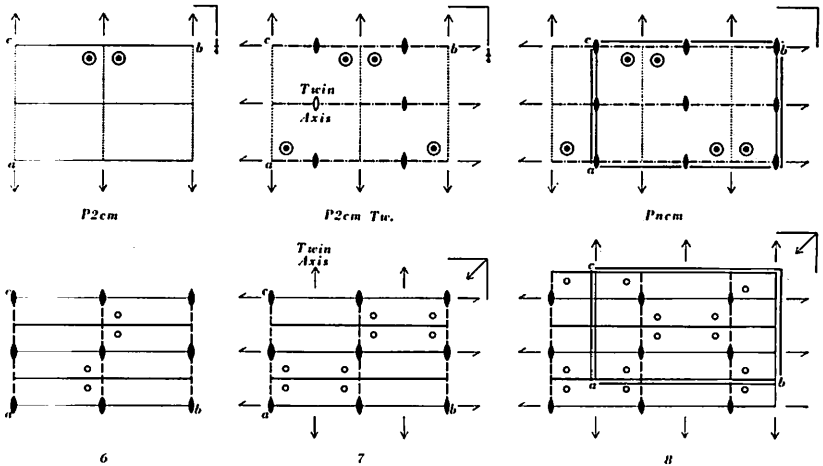
Space-group. Gossner and Musssnug observed the following systematically missing spectra: (*hkl*) present in all orders; (*0kl*) present only with (*k + l*) even; (*h0l*) present only with *l* even; (*hk0*) present in all orders. They note, however, that the conditions both in (*0kl*) and in (*h0l*) are not very certain since they rest on small numbers of reflections, and that the presence of a doubtful reflection (*027*) is contrary to the stated condition in (*0kl*). From these observations Gossner and Musssnug decide that prehnite belongs to the space-group D_{2h}^7 (if dipyramidal) or C_{2v}^4 (if pyramidal with $a[100]$ as the pyroelectric axis). In admitting the pyramidal class C_{2v}^4 it was recognized that the condition in (*0kl*) is superfluous and that therefore the doubtful reflection (*027*) was not incompatible with the space-group. In the *Structurbericht* (1937, p. 588) the abstractor of Gossner and Musssnug's paper remarks that both extinction conditions are explained by the space-group C_{2v}^6 ; but, as shown later, this space-group is incompatible with the polarity of the *a*-axis.

Our films clearly showed the following systematically missing spectra:

(<i>hkl</i>) present in all orders	— <i>P</i>
(<i>0kl</i>) present only with (<i>k + l</i>) even	— <i>n</i>
(<i>h0l</i>) present only with <i>l</i> even	— <i>c</i>
(<i>hk0</i>) present in all orders	— <i>m</i> or 2

These are precisely the conditions observed without certainty by Gossner and Musssnug and by the usual interpretation they indicate either the dipyramidal space-group $D_{2h}^7 = Pncm$ or the pyramidal space-group $C_{2v}^6 = Pnc2$.

Now the pyroelectric character of prehnite is well established and the work of Traube (1894) clearly showed that the polar axis is the a -axis in the universally adopted orientation. Thus the space-groups $Pn\bar{c}m$ and $Pnc2$ are both excluded and some special explanation must be found to reconcile the systematically missing spectra with the polarity of the crystals. This explanation appears to lie in the fact that prehnite belongs to the class $2mm$ and that, therefore, supplementary twinning, which is mentioned by Miers (1929, p. 559), or twinning by merohedry (Friedel), is to be expected in any crystal. Such twinning would occur about any of the missing elements of symmetry, namely the axes $b[010]$, $c[001]$, or the plane $a(100)$. Such twinning would be by interpenetration, without optical discontinuity, and in a given crystal the parts in normal and in twinned position might be comparable in volume. We may assume, therefore, that the x -ray crystal used was such a twin with the symmetry $Pn\bar{c}m$, and the problem is to find a space-group which, when twinned on one of the permissible elements,

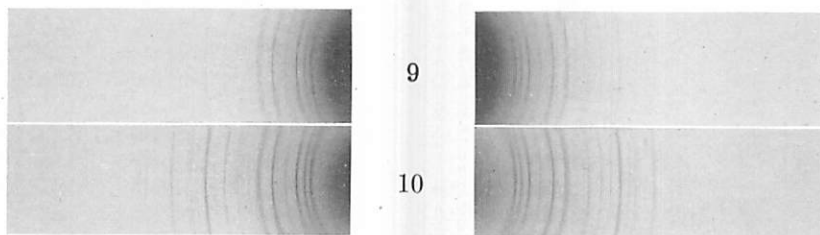


FIGS. 6-8.—Prehnite: projections of the symmetry elements and general atomic positions on the plane ab (above) and the plane bc (below). FIG. 6.—Space-group $P2cm$ of the untwinned crystal (cf. Fig. 5). FIG. 7.—The same, twinned about a vertical 2-fold axis. FIG. 8.—The same, with the origin shifted to $(0, \frac{1}{4})$, giving the space-group $Pn\bar{c}m$ of the untwinned crystal.

will give the symmetry $Pn\bar{c}m$. Only one solution of this problem was found, namely $C_{2v}^4 = P2cm$ which, curiously enough, is the pyramidal space-group inferred by Gossner and Mussgnug on very dubious grounds.

Figs. 6 to 8 give the elements of the space-groups in question in plans on the planes ab and bc , showing the effect of twinning on points in the general positions (xyz) . In these figures the conventional symbols of the *International Tables* have been used.

Fig. 6 gives the symmetry elements of $P2cm$ with the points in the four equivalent general positions (xyz) . In Fig. 7 the space-group and the four points in general position have been twinned about a 2-fold axis parallel to $c[001]$. This axis brings with it three equivalent vertical axes and the various added elements of symmetry shown in the figures. At the same time the four points in general position are twinned to give four new points giving eight equivalent points in general position. To compare the assemblage of symmetry elements in Fig. 7 with the space-group $Pn\bar{c}m$ we must shift the origin to $(0\frac{1}{4}\frac{1}{4})$ as shown by the portions of Fig. 8 which are outlined by extra rectangles. Finally, Fig. 8 may be compared with the symmetry elements for the space-group D_{2h}^7 in the conventional orientation $Pmna$, by a suitable interchange of axes. From the foregoing it is concluded that the true space-group of prehnite is $C_{2v}^4 = P2cm$ and that twinned crystals, which are expected to be common, simulate the symmetry of the space-group $D_{2h}^7 = Pn\bar{c}m$ by twinning about the vertical axis.



FIGS. 9-10.—Prehnite: X-ray powder photographs with copper radiation (nickel filter); 1 mm. on photo = $1^\circ \theta$. FIG. 9.—Ashcroft, B.C. FIG. 10.—Ottawa County, Quebec.

Since the morphology is compatible with the space-group of the untwinned structure, it must be concluded that untwinned crystals are common, as is shown also by the distribution of pyroelectric polarity described by Traube (1894).

Powder photograph. The *x*-ray powder photographs of the

TABLE 5

PREHNITE: $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$ Orthorhombic, $P2cm$; $a = 4.60$, $b = 5.46$, $c = 18.44\text{\AA}$; $Z = 2$

<i>I</i>	$\theta(\text{Cu})$	<i>d</i> (meas.)	(<i>hkl</i>)	<i>d</i> (calc.)	<i>I</i>	$\theta(\text{Cu})$	<i>d</i> (meas.)	(<i>hkl</i>)	<i>d</i> (calc.)
1	8.4°	5.26Å	(011)	5.24Å	7	25.8°	1.766Å	{(119)	1.771Å
			{(100)	4.60				{(220)	1.759
2	9.65	4.59	{(004)	4.61	$\frac{1}{2}$	27.1	1.687	(130)	1.692
			{(102)	4.12	2	27.65	1.656	(217)	1.651
1	10.7	4.14	{(013)	4.08	2	28.1	1.632	(133)	1.632
1	12.6	3.52	(110)	3.52				{(135)	1.538
9	12.8	3.47	(111)	3.46	4	30.05	1.535	{(0.0.12)	1.537
			{(112)	3.29				{(226)	1.527
6	13.6	3.27	{(104)	3.26	$\frac{1}{2}$	30.7	1.506	(302)	1.513
			{(006)	3.07	1	31.8	1.459	(312)	1.458
10	14.5	3.07	{(015)	3.06	1	32.2	1.443	{(1.2.10)	1.450
			{(113)	3.05				{(2.0.10)	1.439
3	15.9	2.81	(114)	2.80	1	33.25	1.402	(228)	1.398
$\frac{1}{2}$	17.1	2.61	(022)	2.62	1	34.1	1.371	(315)	1.371
			{(106)	2.56				{(320)	1.337
10	17.6	2.54	{(115)	2.55	1	35.15	1.335	{(321)	1.333
			{(017)	2.37	1	36.75	1.285	(324)	1.284
4	19.0	2.36	{(024)	2.35	1	39.9	1.198	(146)	1.204
			{(120)	2.35	1	40.8	1.176	(240)	1.174
			{(116)	2.32				{(242)	1.164
4	19.45	2.31	{(008)	2.31	1	41.65	1.157	{(328)	1.157
			{(200)	2.30				{(400)	1.150
$\frac{1}{2}$	20.7	2.17	(123)	2.19	1	41.9	1.151	{(333)	1.152
			{(117)	2.11				{(243)	1.153
1	21.2	2.13	{(211)	2.11	1	42.4	1.140	(402)	1.141
			{(108)	2.06				{(245)	1.119
2	21.8	2.07	{(204)	2.06				{(335)	1.118
			{(118)	1.928	$\frac{1}{2}$	43.5	1.118	{(412)	1.117
3	23.5	1.928	{(214)	1.926				{(404)	1.116
			{(0.0.10)	1.844	2	46.4	1.062	(420)	1.060
2	24.7	1.840	{(215)	1.838	1	47.9	1.036	(417)	1.035

V = 465.9

materials from Ashcroft and Ottawa County (Figs. 9 and 10) show no visible differences in spacings or intensities. These are listed in Table 5 together with the corresponding indices and calculated spacings. So far as known these are the first x-ray powder data to be given for prehnite.

COMPOSITION AND CELL CONTENT

An analysis was made on a sample of picked crystals of the Ashcroft material using standard methods. The results are given in Table 6 together with the content of the unit cell using the empirical molecular weight

$$M = VG/1.649 = 818.7$$

where V is the volume of the unit cell and G is the measured specific gravity, 2.915. The table also gives the assumed grouping of the atoms in equivalent positions in the unit cell. As is commonly the case in alumino-silicates some Al appears to enter Si positions and presumably Fe''', Fe'', Ti, Mg, are to be grouped with the

174
 80.16
 53.94
 84.18
 160.00
 34.02

 412.30
 2

 824.6
 1368.5
 G = 2.94

TABLE 6
 PREHNITE FROM ASHCROFT: ANALYSIS AND CELL CONTENT

$M = 818.7$		
1	2	
SiO ₂ 41.67	Si 5.69	} 6.00
Al ₂ O ₃ 24.44	Al 3.93	
Fe ₂ O ₃ 1.03	Fe''' 0.11	} 3.83
FeO 0.32	Fe'' 0.04	
TiO ₂ 0.12	Ti 0.01	} 4.06
MgO 0.25	Mg 0.05	
CaO 27.25	Ca 3.98	} 23.59
Na ₂ O 0.18	Na 0.05	
K ₂ O 0.18	K 0.03	} 19.55
H ₂ O+ 4.44	OH 4.04	
H ₂ O- 0.00	O 19.55	
99.88		

1. Anal. E. W. Nuffield. 2. Atoms in unit cell and assumed grouping in equivalent positions.

TABLE 7

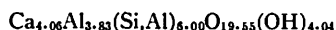
PREHNITE: SELECTED ANALYSES, WITH CELL CONTENTS
OPTICAL PROPERTIES AND SPECIFIC GRAVITIES

	1	2	3	4	5	6	7	A
SiO ₂	42.61	42.78	42.79	42.76	42.86	42.38	41.67	42.55
Al ₂ O ₃	23.82	25.37	24.60	24.83	26.55	24.41	24.44	24.86
Fe ₂ O ₃	1.73	0.87	0.60	0.13	0.08	1.20	1.03	0.81
FeO .....	.....	.....	1.28	1.12	0.65	.....	0.32	0.48
MnO .....	.....	.....	.....	0.05	trace	.....	trace	0.01
MgO	0.13	trace	0.05	0.07	trace	.....	0.25	0.07
TiO ₂ .....	.....	.....	.....	.....	.....	.....	0.12	0.02
CaO	26.10	26.95	26.52	26.84	25.18	27.90	27.25	26.68
Na ₂ O	2.09	0.30	.....	0.03	.....	.....	0.18	0.37
K ₂ O	0.03	trace	.....	0.18	.....	.....	0.18	0.06
H ₂ O+	3.57	4.18	4.51	4.24	4.86	4.10	4.44	4.27
H ₂ O-	0.19	.....	.....	.....	.....	.....	.....	0.03
	100.27	100.45	100.35	"100.42"	100.18	99.99	99.88	100.20
Si	5.97	5.89	5.89	5.91	5.83	5.89	5.79	5.88
Al	3.93	4.11	3.99	4.04	4.26	3.99	4.00	4.05
Fe'''	0.18	0.09	0.06	0.01	0.01	0.13	0.11	0.08
Fe'' .....	.....	.....	0.15	0.13	0.07	.....	0.04	0.06
Mn .....	.....	.....	.....	0.01	.....	.....	.....	0.00
Mg	0.03	.....	0.01	0.01	.....	.....	0.05	0.01
Ti .....	.....	.....	.....	.....	.....	.....	0.01	0.00
Ca	3.92	3.97	3.91	3.97	3.67	4.15	4.05	3.95
Na	0.57	0.08	.....	0.01	.....	.....	0.02	0.10
K	0.01	.....	.....	0.03	.....	.....	0.02	0.01
OH	3.33	3.83	4.14	3.91	4.41	3.80	4.11	3.93
O	20.67	20.17	19.86	20.10	19.60	20.20	19.89	20.07
(Si,Al)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
(Al,Fe''',Fe'', Mn,Mg,Ti)	4.11	4.09	4.10	4.13	4.17	4.01	4.00	4.09
(Ca,Na,K)	4.49	4.05	3.91	4.01	3.67	4.15	4.09	4.05
(O,OH)	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
α	1.615	1.612	1.613	1.613	1.619	1.612	1.615	1.614
β	1.627	1.617	1.620	1.620	1.625	1.618	1.624	1.622
γ	1.647	1.644	1.636	1.635	1.643	1.642	1.644	1.642
2V	55½°	.....	70°	69½°	.....	64°	69°	66°
G .....	.....	2.900	2.928	2.928	2.928	.....	2.915	2.920

1. Botogol, Eastern Sayan Mountains, Siberia (tabular crystals); anal. Vrevskaya, in Kupletsky (1925). 2. Lake Nipigon, Ont., Canada (cream-yellow radiating globules); anal. Rickaby, in Walker and Parsons (1926). 3. From a skarn at Lísná near Nové Město, western Moravia; anal. Kratochvíl (1932).

4. Near Čáslav, eastern Bohemia (spherulitic, comb-like aggregates); anal. Kratochvíl (1934). 5. Val d'Aosta, Piedmont, Italy; anal. Rondolino (1938). 6. Coopersburg, Berks County, Penn. (light green crystals), aver. of 2 analyses with Fe, Mg, Mn, Cu traces (spectrog.); anal. Wiegner, in Fraser, Butler and Hurlbut (1938). 7. Ashcroft, British Columbia, Canada (colourless crystals); anal. Nuffield (this paper). A. Averages of 1—7.

remaining Al. Na and K are grouped with Ca. Neglecting the minor elements the cell content is



or in round numbers



which agrees numerically with the cell content of Gossner and Mussgnug (1931) and corresponds with the composition as written by Berman (1937, p. 383).

With the help of *Mineralogical Abstracts* recent analyses of prehnite with optical data were assembled and reduced to cell contents on the basis of (O, OH) = 24 (Table 7). The data obtained in this way show no systematic variations. On the contrary the analyses indicate a rather constant composition as given by the averages listed under A. It will be seen that there is a persistent slight deficiency in Si and corresponding excess in Al. The optical properties are also fairly constant, the maximum variation being 0.007, 0.009, 0.012, in α , β , γ , respectively. No connection was found between these small variations in optical properties and the variation in Fe_2O_3 and (OH), which might be considered as mainly responsible. Prehnite thus appears to be a mineral with nearly constant chemical and optical properties.

REFERENCES

- BERMAN, H. (1937): Constitution and classification of the natural silicates—*Am. Mineral.*, vol. 22, pp. 342-408.
 BEUTELL, A. (1887): Ueber Prehnit von Striegau und Jordansmühl in Schlesien—*Neues Jb. Min.*, vol. 1, pp. 89-94.
 BØGGILD, O. B. (1905): *Mineralogia Groenlandica*, pp. 291-293—Copenhagen.
 DANA, E. S. (1892): *System of Mineralogy*, ed. 6—New York.
 FRASER, D. M., BUTLER, R. D., and HURLBUT, C. S. Jr. (1938): Prehnite from Coopersburg, Penn.—*Am. Mineral.*, vol. 23, pp. 583-587.

- GALLITELLI, P. (1928): Sulla prehnite di Toggiano—*Atti (Mem.) Soc. Toscana Sci. Nat.*, vol. 38, pp. 267-273.
- GOLDSCHMIDT, V. M. (1890): *Index der Krystallformen der Mineralien*, vol. 2—Berlin.
- (1897): *Winkeltabellen*—Berlin.
- (1920): *Atlas der Krystallformen*, vol. 6—Heidelberg.
- GOSSNER, B., and MUSSGNUG, F. (1931): Röntgenographische Untersuchungen an Prehnit und Lawsonit—*Centr. Min.*, A, pp. 419-423.
- HEDDLE, M. F. (1924): *Mineralogy of Scotland*, vol. 2—St. Andrews.
- HLAWATSCH, C. (1910): Über Prehnit von Guanajuato (Mexiko)—*Min. Petr. Mitt.*, vol. 29, pp. 249-255.
- International tables for the determination of crystal structures*, vol. 1, 1935—Berlin.
- KRATOCHVÍL, F. (1932): Příspěvek k poznání našich prehnitů—*Časopis Národního Musea, Praha*, vol. 106, pp. 134-139 (from *Min. Abs.* 5-282).
- (1934): Prehnity čáslavského okolí—*Rozpravy České Akad.*, class 2, vol. 44, no. 17 (from *Min. Abs.* 6-129).
- KUPLETSKY, B. M. (1925): Sur une roche à prehnite des Monts Botogol en Sibérie—*Compt. Rend Acad. Sci. Russie*, pp. 84-87 (from *Min. Abs.* 3-86).
- MIERS, H. A. (1929): *Mineralogy*, ed. 2—London.
- RONDOLINO, R. (1938): La prehnite delle "Gouffres" di Busserailles in Valtouranche (Val d'Aosta)—*Periodico Min. Roma*, vol. 9, pp. 265-272 (from *Min. Abs.* 7-363).
- Strukturbericht*, vol. 2, 1937—Leipzig.
- KRAUBE, H. (1894): Ueber die pyroelektrischen Eigenschaften und die Krystallformen des Prehnits—*Neues Jb. Min.*, Beil. Bd., vol. 9, pp. 134-146.
- TREMBLAY, Abbé J. A. (1942): Morphologie de l'idocrase—*Jour. Washington Acad. Sci.*, vol. 32, pp. 327-337.
- WALKER, T. L. and PARSONS, A. L. (1926): Zeolites and related minerals from Lake Nipigon, Ontario—*Univ. Toronto Studies*, Geol. Ser. no. 22, pp. 15-19.

THE MORPHOLOGY OF MUSCOVITE IN RELATION TO THE CRYSTAL LATTICE

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Structural studies of the micas have shown that the plane of eminent cleavage in these minerals is parallel to hexagonal layers with $a = 5.2\text{--}5.3 \text{ \AA}$ ($b = 9.0\text{--}9.2 \text{ \AA}$), stacked with a horizontal displacement of $a/3$ and a vertical spacing of nearly 10.0 \AA between successive layers (Fig. 1). If the first layer is structurally identical with the zero layer the least oblique lattice-cell has $\beta_1 = 100^\circ$ (to the nearest degree) and the cell-edges, $a, b, c_1 = d/\sin\beta_1$. If structural identity is not reached until the second layer the least oblique cell has $\beta_2 = 95^\circ$ and the cell-edges, $a, b, c_2 = 2d/\sin\beta_2$. When structural identity is first reached on the third layer the lattice cell is orthohexagonal with $\beta_3 = 90^\circ$ and the cell-edges, $a, b, c_3 = 3d$. These relations were amplified by Hendricks (1939) who made an *x*-ray study of one hundred named micas and discovered an astonishing variety of structural types due to multi-layer arrangements together with differences of arrangement in types having the same number of layers. The geometrical properties of these structural types are briefly listed below.

Single-layer monoclinic type; space-group $C_s^3 = Cm$; $a = 5.3$, $b = 9.2$, $c = 10.2 \text{ \AA}$, $\beta = 100^\circ$; found in 14 phlogopites, 11 biotites, 7 polyolithionites, 5 lepidolites, 3 zinnwaldites, 2 anomites, 1 cryophyllite, 1 lepidomelane, 1 tainiolite.

Two-layer monoclinic muscovite type; space-group $C_{2h}^6 = C2/c$; $a = 5.2$, $b = 9.0$, $c = 20.0 \text{ \AA}$, $\beta = 95^\circ 30'$; 19 muscovites, 1 lepidolite, 1 alurgite.

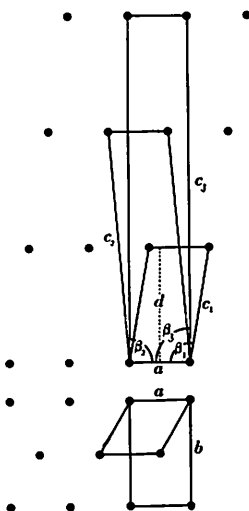


FIG. 1.—Mica lattices:
plan and elevation.

Two-layer monoclinic octophyllite type; space-group $C_{2h}^6 = C2/c$; $a = 5.3$, $b = 9.2$, $c = 20.2 \text{ \AA}$, $\beta = 95^\circ$; 2 biotites, 1 lepidomelane, 1 phlogopite, 1 manganophyllite.

Three-layer rhombohedral type; space-group $D_3^3 = C3_112$ or $D_3^5 = C3_212$; $a = 5.3$, $c = 30.0 \text{ \AA}$; 4 biotites, 1 alurgite, 1 phlogopite, 1 zinnwaldite, 1 lepidolite.

Six-layer monoclinic lepidolite type; space-group $C_s^4 = Cc$; $a = 5.3$, $b = 9.2$, $c = 60.0 \text{ \AA}$, $\beta = 90^\circ$; 3 lepidolites.

Six-layer triclinic biotite type; space-group $C_i^1 = P\bar{1}$; $a = 5.3$, $b = 5.3$, $c = 60.0 \text{ \AA}$, $\alpha = 90^\circ$, $\beta = 90^\circ$, $\gamma = 120^\circ$; 3 biotites.

Twenty-four layer triclinic type; space-group $C_i^1 = P\bar{1}$; $a = 5.3$, $b = 5.3$, $c = 240 \text{ \AA}$, $\alpha = 90^\circ$, $\beta = 90^\circ$, $\gamma = 120^\circ$; 1 biotite.

Mixed structural types; 13 specimens, accounting for 99 specimens in all.

In regard to the distribution of mineral names among the above structural types it will be noted that only muscovite is confined to a single type. Biotites appear in five types, lepidolites in four types, and other common names likewise recur in several types. Muscovite thus appears to be the only mica in which an accepted association of mineralogical properties is connected with a single structure; and, therefore, a clarification of the geometrical crystallography of muscovite is a natural first step in bringing the mineralogy of the micas into line with the structural results.

This revision of the morphology of muscovite was undertaken in connection with the study of muscovite from Mattawan Township, Ontario, appearing elsewhere in this issue (Ferguson, 1943). The present paper illustrates the type of work which is done to obtain definitive crystallographic data for the forthcoming revised *System of Dana*.

GEOMETRICAL SETTINGS

To follow previous descriptions of the crystal form of the micas it is necessary to correlate the crystallographic settings that have been used in the past. Since we are concerned particularly with muscovite it will suffice to indicate the relations of the four settings which have been used more or less specifically for muscovite.

Miller. In Brooke and Miller (1852, p. 389) biaxial mica, as distinct from uniaxial or nearly uniaxial biotite, is described as

monoclinic, with calculated angles which give elements that compare with the ratios of the single-layer monoclinic lattice cell:

$$a : b : c = 0.5774 : 1 : 1.1021; \beta = 99^{\circ}59' \text{ Miller}$$

$$a : b : c_1 = 0.58 : 1 : 1.11 ; \beta_1 = 100^{\circ} \text{ Structure}$$

Thus Miller chose elements which are appropriate to single-layer micas, and may perhaps correspond to the structural type of the Vesuvian crystal which yielded the measurements, by Phillips, that were adopted by Miller. However, Miller's setting is unsuitable for the two-layer muscovite structure. In Miller's geometrical lattice the axes, $[100]$, $[010]$, $[001]$, of the muscovite cell are proportional to $[\bar{1}00]$, $[0\bar{1}0]$, $[102]$, and therefore the formula for transforming Miller's elements and indices to the muscovite lattice is:

$$\text{Miller to muscovite: } \bar{1}00/0\bar{1}0/102$$

Des Cloizeaux. The most widely used setting of the micas is that of Des Cloizeaux (1862, p. 485) which has been adopted, either with rectangular axes as given by Des Cloizeaux, or with nearly rectangular axes, by Tschermak (1878), in his important study of the mica group, and by Groth, Dana, Miers, Goldschmidt, and others. This setting corresponds to the three-layer structural cell, as shown, for example, by Dana's elements for muscovite compared with the structural values:

$$a : b : c = 0.57735 : 1 : 3.3128; \beta = 90^{\circ}05\frac{5}{8}' \text{ Dana}$$

$$a : b : c_3 = 0.58 : 1 : 3.26 ; \beta_3 = 90^{\circ} \text{ Structure}$$

In this setting the structural cell of muscovite is defined by the axes $[300]$, $[030]$, $[\bar{1}02]$, giving the transformation:

$$\text{Des Cloizeaux to muscovite: } 300/030/\bar{1}02$$

Koksharov. The setting of Koksharov is of interest because it was adopted by Hintze (1897) for the mica group as a whole, and by Baumhauer (1900) in his detailed work on the crystal form of muscovite. In his Sixth Appendix to Mica Koksharov (1875, pp. 225-345) states that he is finally convinced that all micas are monoclinic with ac exactly 90° and mm exactly 60° . From numerous precise measurements on crystals from Vesuvius he derived the elements which are given below in modern conventional form. These do not correspond directly to any of the known structural

lattice cells but they compare with the ratios of the three-layer structural cell with a and b both doubled:

$$a : b : c = 0.5774 : 1 : 1.6452; \beta = 90^{\circ}00' \text{ Koksharov}$$

$$2a : 2b : c_3 = 0.58 : 1 : 1.63 ; \beta_3 = 90^{\circ} \text{ Structure}$$

Koksharov's elements and indices are transformed to the muscovite cell by the formula:

$$\text{Koksharov to muscovite: } \bar{3}00/0\bar{3}0/104$$

Tschermak II. Specially for muscovite Tschermak (1878, p. 43) gave an alternate setting, also derived by Friedel (1926, p. 532), which gave a notable general simplification of indices. In this setting the elements, as computed by Dana (1892, p. 621), compare directly with the geometrical form of the unit cell of muscovite:

$$a : b : c = 0.5775 : 1 : 2.2175; \beta = 95^{\circ}05' \text{ Tschermak-Dana}$$

$$a : b : c_2 = 0.58 : 1 : 2.22 ; \beta_2 = 95^{\circ} \text{ Structure}$$

Tschermak's second setting for muscovite is thus the proper one, and it is unfortunate that he eventually returned to the unsuitable setting of Des Cloizeaux (Dana, 1892, p. 621) to force isomorphism in a group which is now known to be characterized by complex polymorphism.

GEOMETRICAL ELEMENTS

The only available geometrical elements computed specially for muscovite (Tschermak-Dana) are based on but a few measured angles¹ and are therefore not very well founded. An effort has therefore been made to obtain new elements giving the best expression of the crystal form of the species. Such an attempt is, of course, limited by the geometrical variation which may be expected in a mineral that varies somewhat in chemical composition.

For this purpose the following data were available: accurate x-ray measurements by Mauguin (1927), Pauling (1930), and Jackson and West (1931), together with two new cell determinations by the present authors; a few early goniometric measurements apparently made on muscovite, by Marignac (1847) and Koksharov (1875); more numerous measurements by Tschermak (1878); a

¹ $cM = 85^{\circ}36'$, $c\mu = 81^{\circ}30'$, $bcM = 60^{\circ}00'$ (assumed); these angles are taken from Tschermak's measurements (1878, p. 42): $cM = 94^{\circ}24'$ (2 meas.), $cm = 81^{\circ}30'$ (1 meas.).

considerable number of precise angles observed by Baumhauer (1900); and some new two-circle measurements.

One method of treating these data would be to derive a grand average of the corresponding angles and elements, but this would have some obvious disadvantages. It seems rather that the definitive elements should represent the largest body of good measurements from well-developed crystals from a single occurrence and that therefore Baumhauer's measurements on about fifteen small bright crystals from Mitchell County, North Carolina, would serve best for our purpose.

Baumhauer adopted the setting of Koksharov, obtained from Vesuvian biotite, and his symbols are complicated both by the unsuitable setting and by many complex indices which he introduced to obtain close agreement between the measured and calculated angles. As shown in Table 6 these complexities can all be cleared away by using simple indices in the proper setting and allowing a moderate range in the measured angles. By treating Baumhauer's angles in this way and taking averages of angles that evidently refer to single simple forms, omitting those marked "ca.", the mean measured angles in Table 1 were obtained. These mean measured angles yielded the elements:

$$a : b : c = 0.5764 : 1 : 2.2372; \beta = 95^\circ 39'$$

which in turn give the calculated angles in the table. The small differences between the measured and calculated angles show that

TABLE 1

MUSCOVITE: BAUMHAUER'S MEASURED ANGLES ON WHICH THE NEW ELEMENTS ARE BASED

	No. of meas.	Range	Mean	P. & F. Calc.	Diff.
<i>cm</i> = (001) : (110).....	18	84°14½'–85°47½'	85°05½'	85°06'	+½'
<i>co</i> = (001) : (111).....	2	72 35½–73 01	72 48	2 746½	–1½
<i>cp</i> = (001) : (1̄11).....	5	81 57¼–82 25	82 07	82 06½	–½
<i>ch</i> = (001) : (1̄12).....	11	69 47¼–70 01¼	69 56	70 03	+7
<i>bm</i> = (010) : (110).....	6	60 09 –60 13	60 10	60 09½	–½

the mean measured angles are consistent among themselves and that they are fairly represented by the derived geometrical elements.

Table 2 gives geometrical elements corresponding to the lattice dimensions that have been determined on muscovite. From our own *x*-ray measurements² we are satisfied that there are measurable differences in different muscovites and that therefore an average for different materials would not be desirable. The values of Mauguin and Pauling compare most closely with the geometrical elements based on Baumhauer's angles. It will be noted that the angle [100] : [110], which equals the interzonal angle *bcm*, has the average value 60°02'. Although this angle is practically 60° it is interesting that the corresponding goniometric angle, as noted in the next section, is always slightly greater than 60°.

TABLE 2

MUSCOVITE: GEOMETRICAL ELEMENTS FROM X-RAY MEASUREMENTS			
<i>a</i> : <i>b</i> : <i>c</i>	β	[100]:[110]	
0.578 : 1 : 2.238	96°	59°58'	Mauguin (1927)
0.577 : 1 : 2.236	96°	60 00	Pauling (1930)
0.574 : 1 : 2.222	95°30'	60 08	Jackson and West (1931)
0.578 : 1 : 2.216	96°24'	59 59	P. & F. (1)
0.576 : 1 : 2.219	95°54'	60 04	P. & F. (2)

FORMS AND ANGLES

Tables 3-6 give the forms and angles which have been reported on muscovite, with the corresponding structural notation and the calculated angles based on the new geometrical elements. This tabulation serves to relate the previously used form letters and symbols with the present notation and to clarify some complex symbols which are due to poor settings or meticulous indexing of vicinals. The tables also indicate the degree of certainty of the described forms, their relative frequencies, and the correspondence between angles measured by various observers on different materials and those calculated from the new elements. To shorten the lists arithmetic averages, followed by the number of observations in brackets, are given in each case where the author gave more than one measurement for an interfacial angle.

²P. & F. refers to cell dimensions in Ferguson (1943); (1) fine sheet mica from Mattawan Township, Ontario; (2) a crystal from Lincoln County, North Carolina, for which some two-circle angles are also given in Table 7.

TABLE 3

MUSCOVITE: MARIIGNAC'S FORMS AND MEASURED ANGLES

<i>Binn valley</i>	Meas.	P. & F.	Calc.
<i>MM</i>	59°20'	<i>mm</i> = (110) : ($\bar{1}\bar{1}0$)	59°41'
<i>LM</i>	60 20	<i>bm</i> = (010) : (110)	60 09½
<i>PM</i>	85 10	<i>cm</i> = (001) : (110)	85 06
<i>PL</i>	90 00	<i>cb</i> = (001) : (010)	90 00
<i>MN</i>	30 (approx.)	<i>mn</i> = (110) : (130)	30 00
<i>PN</i>	88 (approx.)	<i>cn</i> = (001) : (130)	87 10
<i>Pμ</i>	81 30 (approx.)	<i>cp</i> = (001) : ($\bar{1}11$)	82 06½

TABLE 4

MUSCOVITE: KOKSHAROV'S FORMS AND MEASURED ANGLES

<i>Locality (?)</i>	Meas.	P. & F.	Calc.
<i>Pm</i> = (001) : ($\bar{7}72$)	85°02'	(001) : (21.21.1)	
($\bar{4}41$)		<i>cm</i> = (001) : (110)	85°06'
<i>hm</i> = (010) : ($\bar{7}72$)	60 11	(010) : (21.21.1)	
($\bar{4}41$)		<i>bm</i> = (010) : (110)	60 09½
<i>mm</i> = ($\bar{7}72$) : ($\bar{7}72$)	59 39	(21.21.1) : (21.21.1)	
($\bar{4}41$) : ($\bar{4}41$)		<i>mm</i> = (110) : ($\bar{1}\bar{1}0$)	59 41
<i>PM</i> = (001) : (221)	81 53	<i>cp</i> = (001) : ($\bar{1}11$)	82 06½

TABLE 5

MUSCOVITE: TSCHERMAK'S FORMS AND MEASURED ANGLES

<i>Abühl</i>	Meas.	P. & F.	Calc.
<i>cM</i> = (001) : (221)	85°04' (6)	<i>cm</i> = (001) : (110)	85°06'
<i>cb</i> = (001) : (010)	90 00 (2)	<i>cb</i> = (001) : (010)	90 00
<i>bM</i> = (010) : (221)	60 15 (2)	<i>bm</i> = (010) : (110)	60 09½
<i>MM</i> = (221) : (221)	59 34½ (2)	<i>mm</i> = (110) : ($\bar{1}\bar{1}0$)	59 40½
<i>cm</i> = (001) : ($\bar{1}11$)	82 13 (approx.)	<i>cp</i> = (001) : ($\bar{1}11$)	82 06½
<i>cx</i> = (001) : ($\bar{1}31$)	85 19	<i>cx</i> = (001) : ($\bar{1}31$)	85 25½
<i>cN</i> = (001) : (261)	87 (approx.)	<i>cn</i> = (001) : (130)	87 10
<i>bx</i> = (010) : ($\bar{1}31$)	30 30	<i>bx</i> = (010) : ($\bar{1}31$)	30 21½
<i>bN</i> = (010) : (261)	30 33	<i>bn</i> = (010) : (130)	30 09½
<i>Rothenkopf</i>			
<i>cM</i> = (001) : (221)	85°36' (2)	<i>cm</i> = (001) : (110)	85°06'
<i>MM</i> = (221) : (221)	59 49	<i>mm</i> = (110) : ($\bar{1}\bar{1}0$)	59 40½
<i>cm</i> = (001) : ($\bar{1}11$)	81 30	<i>cp</i> = (001) : ($\bar{1}11$)	82 06½
<i>cy</i> = (001) : (043)	77 21	<i>cy</i> = (001) : (021)	77 20½

TABLE 5 (continued)

<i>Soboth</i>	Meas.	P. & F.	Calc.
<i>cM</i> = (001) : (221)	85° (contact)	<i>cm</i> = (001) : (110)	85°06'
<i>ce</i> = (001) : (023)	66 (contact)	<i>ce</i> = (001) : (011)	65 48½
<i>cb</i> = (001) : (010)	90 (contact)	<i>cb</i> = (001) : (010)	90 00
<i>Soboth</i> (gliding planes)			
<i>cρ</i> = (001) : (205)	67°	<i>cρ</i> = (001) : (1̄02)	67°16½'
<i>cξ</i> = (001) : (135)	66 (2)	<i>cξ</i> = (001) : (133)	66 20

TABLE 6

MUSCOVITE: BAUMHAUER'S FORMS AND MEASURED ANGLES

<i>Mitchell Co., N.C.</i>	Meas.	P. & F.	Calc.
<i>ch</i> = (001) : (556) (445)	69°56' (11)	(001) : (1̄5.15.29) <i>ch</i> = (001) : (1̄12)	70°03'
<i>cε</i> = (001) : (447)	61 58½ (1)	<i>cε</i> = (001) : (112)	61 53
(001) : (29.29.30)	72 35½ (1)	(001) : (87.87.91)	
<i>co</i> = (001) : (111)	73 01	<i>co</i> = (001) : (111)	72 46½
<i>cY</i> = (001) : (083)	77 08 (8)	<i>cY</i> = (001) : (021)	77 20½
<i>cμ</i> = (001) : (15.15.7)	82 00 (3)	(001) : (45.45.43)	
<i>ci</i> = (001) : (994) (221)	82 17½ (2)	: (27.27.25)	
		<i>cφ</i> = (001) : (1̄11)	82 06½
<i>ce</i> = (001) : (331)	84 15 (2)	(001) : (991)	
<i>cτ</i> = (001) : (10.10.3)	84 44 (4)	: (15.15.1)	
<i>cδ</i> = (001) : (772)	85 05 (4)	: (21.21.1)	
<i>cθ</i> = (001) : (11.11.3)	85 16½ (2)	: (33.33.1)	
<i>cη</i> = (001) : (23.23.6)	85 26½ (3)	: (69.69.1)	
<i>cm</i> = (001) : (441)	85 42 (3)	<i>cm</i> = (001) : (110)	85 06
<i>cv</i> = (001) : (551)	86 42 (1)	: (15.15.1)	
<i>cb</i> = (001) : (010)	90 00 (4)	<i>cb</i> = (001) : (010)	90 00
<i>bh</i> = (010) : (556) (445)	62 01 (3)	(010) : (1̄5.15.29) <i>bh</i> = (010) : (1̄12)	62 00
<i>bδ</i> = (010) : (772)	69 09 (1)	(010) : (21.21.1)	
<i>bτ</i> = (010) : (10.10.3) (441)	60 10 (5)	: (15.15.1)	
		<i>bm</i> = (010) : (110)	60 09½

Previous measurements. The early measurements of Marignac (1847) on monoclinic mica from the Binn valley—as distinct from rhombohedral mica from Vesuvius—are given in Table 3, from which it is apparent that Marignac found the forms $c(001)$, $b(010)$, $m(110)$, in our notation, and less certainly $n(130)$, $p(\bar{1}11)$. For single measurements on a mineral that rarely forms distinct crystals the observed angles agree very fairly with the new calculated values.

Of the many observations made on mica by Koksharov only those reproduced in modern style in Table 4 (1875, p. 253) appear to refer to muscovite. The measured angles agree well with the calculated values, confirming the forms, c , b , m , p , found by Marignac. It will be noted that Koksharov's ($\bar{7}72$), which transforms to (21.21.1), should be ($\bar{4}41$) which gives (110). Contact measurements by Koksharov (1875, p. 276) on rough crystals of a white biaxial mica of an unusual acute bipyramidal habit have been accepted by Hintze and others as evidence for the additional forms ($\bar{3}32$) [i.e. ($\bar{4}43$)] and (021) in Koksharov's notation, or (221) and (032) in ours, but at best these reported forms may be retained as uncertain.

The crystal measurements of Tschermak (1878) are given in Table 5. On two crystals from Abühl (Sulzbachthal, Salzburg), Tschermak found the previously observed forms, c , b , m , p , also Marignac's n , and the new form $x(\bar{1}31)$. The form m was replaced by vicinals (M_1 , M_2 , M_3) which we have taken together as m . A crystal from Rothenkopf (Zillerthal, Tyrol), showed the new form $y(021)$, indicated by a single measurement. Contact measurements on a crystal from Soboth (Styria) gave a new form $e(011)$ in oscillatory combination with c , and the glide planes $\rho(\bar{1}02)$ and $\zeta(133)$. On the whole Tschermak's measurements for Abühl agree best with the calculated values; the measurements for Rothenkopf are less close, in keeping with Tschermak's conclusion that the two sets of angles are not strictly referable to one set of elements.

The measurements of Baumhauer (1900) on about fifteen small bright crystals of muscovite from Mitchell County, North Carolina, are summarized in Table 6. From the transformed symbols and the comparison of measured and calculated angles it is clear that Baumhauer's measurements give in effect the known forms c , b , m ,

p , y , and the new forms $h(\bar{1}12)$, $\epsilon(112)$, $o(111)$, of which h is well established whereas ϵ and o are indicated by single readings. In Baumhauer's notation (Koksharov's setting) the symbol of h should evidently be (445); the forms μ and i are clearly vicinals to (221); and the forms e , τ , δ , θ , η , ν , are all vicinals to ($\bar{4}41$). The futility of separating δ and τ , for example, is shown by the measured angles $b\delta$ and $b\tau$, as compared to the calculated angle bm . The agreement between Baumhauer's measured angles, averaged as previously described, and the calculated angles, has already been shown in Table 1.

New measurements. In the hope of obtaining further useful data on the crystal form of muscovite, two-circle measurements were made on five crystals from Lincoln County, North Carolina, (Table 7) and three crystals from an unknown locality (Table 8). For these measurements the method of face-adjustment proved convenient, using c as the pole face and the zone-circle $[bc]$ as the prime meridian.

The crystals from Lincoln County (Royal Ontario Museum of Mineralogy, E 2284) were kindly provided by Professor A. L. Parsons. They are pale green hexagonal tables, 1-2 mm. wide with bright faces, showing the common forms c , b , m , p , and also y and o each noted once (Fig. 3). The measurements are only fair since the edge-faces, particularly m , are lightly striated parallel to the base, giving multiple signals from which the strongest reflections were selected. On the other hand the interzonal angle bcm could be measured precisely and it will be seen that the measured and calculated values agree in showing that this angle slightly exceeds 60° .

TABLE 7

MUSCOVITE: MEASUREMENTS ON FIVE CRYSTALS FROM LINCOLN COUNTY, N.C.

	Range	Measured	Mean	Calculated
$cb = (001) : (010)$	$89^\circ 51' - 90^\circ 17'$	(3)	$90^\circ 01'$	$90^\circ 00'$
$cy = (001) : (021)$	....	(1)	$77^\circ 47'$	$77^\circ 20\frac{1}{2}'$
$cm = (001) : (110)$	$84^\circ 14' - 85^\circ 25'$	(10)	$84^\circ 43'$	$85^\circ 06'$
$co = (001) : (111)$	....	(1)	$71^\circ 55'$	$72^\circ 46\frac{1}{2}'$
$cp = (001) : (\bar{1}11)$	$81^\circ 43' - 82^\circ 33'$	(8)	$82^\circ 04'$	$82^\circ 06\frac{1}{2}'$
$bcm = [100] : [\bar{1}10]$	$60^\circ 01\frac{1}{2}' - 60^\circ 04\frac{1}{2}'$	(4)	$60^\circ 03'$	$60^\circ 02\frac{1}{2}'$

TABLE 8

MUSCOVITE: MEASUREMENTS ON THREE CRYSTALS FROM AN UNKNOWN LOCALITY

	Range	Measured	Mean	Calculated
$cb = (001) : (010)$	89°52' - 90°00'	(4)	89°57½'	90°00'
$cy = (001) : (021)$	76 55 - 78 17	(6)	77 13	77 20½
$cm = (001) : (110)$	83 42 - 86 29	(13)	85 02	85 06
$ce = (001) : (112)$	61 19 - 62 20	(4)	61 45	61 53
$co = (001) : (111)$	72 43 - 72 50	(3)	72 46	72 46½
$ch = (001) : (\bar{1}12)$	69 53 - 69 56	(2)	69 54½	70 03
$cp = (001) : (\bar{1}11)$	82 00 - 82 20	(4)	82 13	82 06½
$bcm = [100] : [\bar{1}10]$	60 03 - 60 05	(4)	60 03½	60 02½

The crystals from an unknown locality (University of Toronto, Department of Mineralogy, A 910) are incomplete greenish hexagonal plates up to 3 mm. wide, which were attached to a larger green crystal projecting from calcite. Two of these crystals are individuals (Fig. 4), the third is a twin (Fig. 6) which will be described later. The measurements show the forms, c , b , m , y , p , also Baumhauer's h , and his less well established ϵ and o , all as good faces. Again the angle bcm is slightly and consistently greater than 60°.

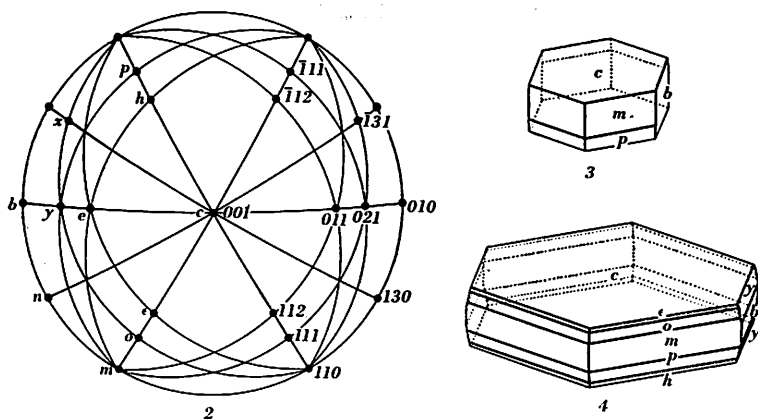


FIG. 2.—Muscovite: stereographic projection of the established forms.

FIGS. 3, 4.—Muscovite: measured crystals.

Thus the available measured angles on muscovite agree satisfactorily with the calculated angles—considering the probable

variations in different crystals and the tendency to develop vicinal faces—and therefore the new geometrical elements may be accepted as fairly representing the various measured crystals. The established forms are $c(001)$, $b(010)$, $n(130)$, $m(110)$, $e(011)$, $y(021)$, $\epsilon(112)$, $o(111)$, $h(\bar{1}12)$, $p(\bar{1}11)$, $x(\bar{1}31)$. The forms (032) and (221), determined only by contact measurements on dubious material, are considered uncertain. The origin of $(\bar{3}02)$, listed by Tschermak (1878) as $H(\bar{2}01)$, but not seen by him and not retained by Dana (1892), was not discovered and the form is considered uncertain. From the assembled information on the crystal development of muscovite the order of importance (size and frequency) of the established forms may be written about as follows: c ; b m p ; y o h ϵ ; e n x . In this sequence the forms in each group are about of equal importance.

Fig. 2 gives a stereographic projection of the established forms and Table 2 provides two-circle and interfacial angles in a standard style, and also the useful interzonal angles, $Z = (010)(001)(hkl)$.

TABLE 9

MUSCOVITE— $KAl_2(AlSi_3)O_{10}(OH,F)_2$ Monoclinic— $C2/c$ $a : b : c = 0.5764 : 1 : 2.2372$; $\beta = 95^\circ 39'$ $p_0 : q_0 : r_0 = 1.7434 : 1 : 0.4492$; $\mu = 84^\circ 21'$ $p_0' = 3.9002$, $q_0' = 2.2372$, $x_0' = 0.0989$

Form	φ	ρ	φ_2	$\rho_2 = B$	C	A	Z
$c(001)$	$90^\circ 00'$	$5^\circ 39'$	$84^\circ 21'$	$90^\circ 00'$	$0^\circ 00'$	$84^\circ 21'$	...
$b(010)$	0 00	90 00	...	0 00	90 00	90 00	$0^\circ 00'$
$n(130)$	$30\ 09\frac{1}{2}$	90 00	0 00	$30\ 09\frac{1}{2}$	87 10	$59\ 50\frac{1}{2}$	$30\ 02\frac{1}{2}$
$m(110)$	$60\ 09\frac{1}{2}$	90 00	0 00	$60\ 09\frac{1}{2}$	85 06	$29\ 50\frac{1}{2}$	$60\ 02\frac{1}{2}$
$e(011)$	2 32	65 56	84 21	$24\ 11\frac{1}{2}$	$65\ 48\frac{1}{2}$	$87\ 41\frac{1}{2}$	0 00
$y(021)$	1 16	$77\ 24\frac{1}{2}$	84 21	$12\ 39\frac{1}{2}$	$77\ 20\frac{1}{2}$	88 46	0 00
$\epsilon(112)$	61 22	$66\ 48\frac{1}{2}$	26 01	63 52	61 53	36 13	$60\ 02\frac{1}{2}$
$o(111)$	$60\ 46\frac{1}{2}$	77 41	$14\ 02\frac{1}{2}$	$61\ 30\frac{1}{2}$	$72\ 46\frac{1}{2}$	31 30	$60\ 02\frac{1}{2}$
$h(\bar{1}12)$	$-58\ 51\frac{1}{2}$	65 11	$151\ 37\frac{1}{2}$	62 00	70 03	$140\ 58\frac{1}{2}$	$-60\ 02\frac{1}{2}$
$p(\bar{1}11)$	$-59\ 31\frac{1}{2}$	$77\ 13\frac{1}{2}$	$165\ 15\frac{1}{2}$	60 21	$82\ 06\frac{1}{2}$	$147\ 11\frac{1}{2}$	$-60\ 02\frac{1}{2}$
$x(\bar{1}31)$	$-29\ 31\frac{1}{2}$	82 37	$165\ 15\frac{1}{2}$	$30\ 21\frac{1}{2}$	$85\ 25\frac{1}{2}$	$119\ 15\frac{1}{2}$	$-30\ 02\frac{1}{2}$

Doubtful forms: (032), $(\bar{3}02)$, (221). Gliding planes: $(\bar{1}02)$, (133).

ACTUAL AND THEORETICAL FORM DEVELOPMENT

When freed from errors and uncertainties the symbols and projection of the forms of muscovite present the elegant simplicity

that is usually associated with a well-developed and properly described crystal species. The regularity of the morphological development can be more definitely verified with reference to the Law of Bravais, which states that the relative importance of crystal forms is in first approximation proportional to the reticular densities (or the spacings) of the corresponding crystal lattice planes. This early generalization became neglected, even refuted, no doubt because it could not be proved—since the crystal lattice could be found only by assuming the truth of the law. Now that the crystal lattice can be determined directly by x -rays interest in the Law of Bravais has been renewed and recently examples in most of the systems have been discussed.³ In spite of the accumulated evidence for the truth of the Bravais principle, especially in the improved form due to Donnay, we find in a recent text-book reference to “. . . the fallacious assumption that a given crystal species has a habit characteristic of its lattice” (Buerger, 1942, p. 367).

It may be useful, therefore, to compare the theoretical and actual form development of muscovite by listing the real lattice planes in structural notation, in order of decreasing spacing, and adding form-letters to those planes which are known as crystal forms. The space-group of muscovite is $D_{2h}^6 = C2/c$ which gives the conditions, (hkl) present only with $(h + k)$ even (base-centred lattice), and $(h0l)$ present only with h even and l even (c -glide in the symmetry plane). The real lattice planes are those with the smallest indices compatible with these conditions. The indices and spacings in the following list were obtained by a convenient general graphical method (Peacock, 1938) which gives the spacings with an accuracy of about 0.5% using the geometrical elements and one lattice period, in this case $b = 9.02 \text{ \AA}$.

hkl	(002)	(020)	(110)	($\bar{1}11$)	(021)	(111)	($\bar{1}12$)	(022)	(112)
d (Å) . . .	10.00	4.51	4.51	4.47	4.42	4.29	4.25	4.12	3.99
Form . . .	c	b	m	p	y	o	h	e	ϵ

The first nine sets of lattice planes, which include all the forms observed by us and also Tschermak's e , correspond without excep-

³Donnay (1942) treats the Scheelite Group in the light of the generalized Law of Bravais [Law of Donnay] and gives references to other published examples in which the crystal lattice and the space-group have been correctly inferred from the morphology, thus affording cogent proof of the Bravais principle.

tion to established crystal forms, and the theoretical order of importance is substantially the same as in the observed order: c ; $b m p$; $y o h \epsilon$; $e n x$. The position of c as the greatly predominant form and facile cleavage is predicted by the spacing of (002) which is more than twice that of the next set of planes. After (112) there are eleven sets of lattice planes in the theoretical list which are not known as crystal forms; these are followed by the two remaining rarely observed forms, $n(130)$ 2.60 Å, $x(\bar{1}31)$ 2.59 Å, after which comes (200) 2.58 Å, which has not been observed.

The theoretical or predictable habit of muscovite is thus tabular or platy on c and pseudo-hexagonal with nearly equal development of b , m , p , as in Fig. 3, and further modified by y , o , h , e , ϵ , almost as in Fig. 4. Thus it is no fallacious assumption, but rather an evident fact, that the habit of muscovite is characteristic of its lattice, and the same is true, though rarely with such remarkable regularity, of other crystal species.

Owing to the special form and centring of the lattice cell the front pinakoid (200) is not expected and not known as a crystal form and consequently there are no forms of the type ($h0l$) which have still smaller spacings. In this case, therefore, the space-group cannot be inferred from the morphology by Donnay's Law since the characteristic zone is not developed on the crystals.

TWINNING

Muscovite commonly forms twins in which the two individuals are in contact on a common plane $c(001)$ and symmetrical by reflection in a plane (hhl) which is perpendicular to $c(001)$. Reflection in (hhl) gives a "right" twin which is distinct from a "left" twin resulting from reflection in ($h\bar{h}l$). In the settings of Des Cloizeaux and Koksharov, with $\beta = 90^\circ$, this reflection plane is (110), which becomes ($33\bar{1}$) in the proper muscovite setting. The relative simplicity of the indices of this "twin plane" in the earlier settings influenced Hintze, for example, in adopting Koksharov's setting.

The new geometrical elements for muscovite give the calculated angle (001) : ($33\bar{1}$) = $89^\circ 22\frac{1}{2}'$ and consequently reflection in ($33\bar{1}$) gives the angle $1^\circ 15'$ between the basal planes of the two individuals. This is a gross departure from parallelism. It is true a more

complicated symbol for the "twin plane" would give more nearly the observed parallelism, but since the form of muscovite may vary slightly with chemical composition it is clear that this device will not do and that the twin law has been improperly defined.

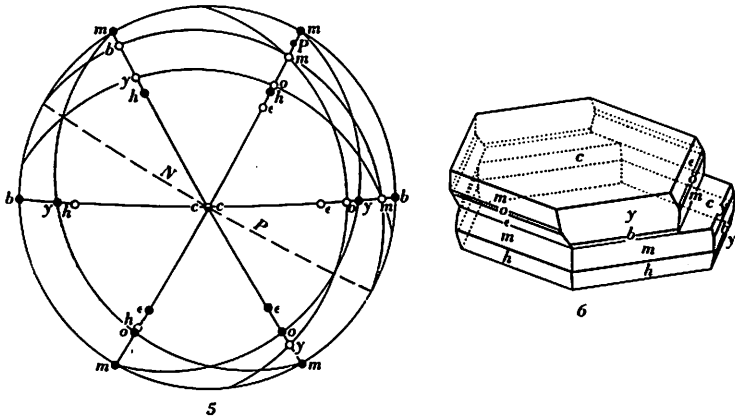
In this connection we may turn to Friedel's illuminating treatment of twinning (1904, 1926), according to which twinning is recognized as an operation of pseudo-symmetry, to be defined either by a rotation of $2\pi/n$ ($n = 2, 3, 4, 6$) about a simple lattice row $[uvw]$ or by reflection in a simple lattice plane (hkl) . Rotations through angles other than $2\pi/n$, irrational twin axes, and irrational twin planes are thus excluded. If the twinned individuals are in contact on a common lattice plane the twin element is either this plane or a rational axis contained by this plane. This excludes twinning by reflection in one plane with composition on another plane and requires, for example, that the Carlsbad law be defined as: "twin axis $[001]$, composition plane (010) ," not as: "twin plane (100) , composition plane (010) ."

In the case of muscovite the composition plane is (001) , and since the twin is not symmetrical by reflection in (001) the twin element is an axis in the plane (001) , namely $[310]$. Rotation of 180° about $[310]$ produces the geometrical relations which have been observed before and are confirmed on our measured twin. The basal planes on the two individuals are brought into exact parallelism, as in the measured twin, and the zones $[cb]$, $[cm]$, $[cm']$, on one individual fall very nearly over the zones $[cm]$, $[cb]$, $[cm']$, respectively, on the other individual, with a special sequence of planes which is not given by twinning about $[110]$. With the new elements the calculated angle $[cb] : [cm]$ (twinned) is $0^\circ 06'$ as compared with $0^\circ 06'$ measured on our twin. This angle would be zero if the interzonal angle bcm were exactly 60° .

The twin law of muscovite is thus correctly and uniquely defined as: "twin axis $[310]$, composition plane (001) ." The plane $(3\bar{3}\bar{1})$, formerly taken as the twin plane, is quasi-normal to the twin axis and therefore the twinned edifice is pervaded by a common lattice which suffers a small deviation at the plane $(3\bar{3}\bar{1})$. This common lattice carries one third of the points of the crystal lattice and its departure from rectangularity, as given by the calculated angle between $[310]$ and the true normal to $(3\bar{3}\bar{1})$, is

$0^{\circ}38'.$ ⁴ In Friedel's terminology the twin law is thus an example of twinning by "reticular pseudo-merohedry" with index 3 and obliquity $0^{\circ}38'$, and the probability of the twin law may be predicted from the smallness of these values.

Figs. 5, 6 give a stereographic projection and drawing of the measured twin of muscovite, which is a "left" twin with the twin axis $[3\bar{1}0]$. To emphasize the symmetry of the twin the projection shows all the forms observed on both individuals, the normal poles being filled points, the twin poles blank points. The pole of the twin axis is marked P and the trace of the irrational plane normal



FIGS. 5, 6.—Muscovite: stereographic projection and drawing of a measured "left" twin with twin axis $[3\bar{1}0]$ (P).

to the twin axis, formerly taken as the twin plane, is marked NP . The drawing is a symmetrical restoration of the twin based on the observed relative widths of the faces in the nearly coincident zones: $[c \epsilon o m]$ — $[c y b y]$ and $[c y b]$ — $[m h]$, with the upper individual in twinned position.

After the above conclusions had been reached regarding the twinning of muscovite we found that Friedel himself (1904, p. 222) had given a similar general explanation of the twinning in micaceous

⁴Calculated from general formulae given by Friedel (1926, p. 245). Since the calculation of the obliquity involves finding the cosine of a small angle it will be found convenient to use eight place tables.

minerals, suggesting that the twin element would prove to be $[310]$ or $[110]$ rather than the quasi-normal planes (110) or (130) (on rectangular axes). Observation shows that the first of these assumptions is correct.

Just as the truth of the Bravais-Donnay principle is proved by the fact that it enables one to predict the normal crystal habit from the crystal lattice and the space-group, or, conversely, to predict the lattice and the space-group from the morphology, so the significance of Friedel's development of twinning theory is shown by the fact that a consideration of the merohedry and pseudo-symmetry of a crystal species permits a prediction of the probable twin laws and their relative frequencies. Such a prediction was strikingly verified on β -quartz, for example, by Drugman (1927) who discovered three new twin laws which Friedel had previously considered probable on purely theoretical grounds.

SUMMARY

Previously used geometrical settings of muscovite are related to the structural setting by appropriate transformation formulae. A critical revision of the previous goniometric data, together with new measurements, lead to the monoclinic elements,

$$a : b : c = 0.5764 : 1 : 2.2372; \beta = 95^{\circ}39'$$

and the established forms, $c(001)$, $b(010)$, $n(130)$, $m(110)$, $e(011)$, $y(021)$, $\epsilon(112)$, $o(111)$, $h(\bar{1}12)$, $p(\bar{1}11)$ $x(\bar{1}31)$; doubtful forms, (032) , $(\bar{3}02)$, (221) ; gliding planes, $(\bar{1}02)$, (133) . A measured twin gives the law, twin axis $[310]$, composition plane (001) , for which the index is 3, the obliquity $0^{\circ}38'$. This statement of the muscovite law is preferable to that usually given, namely, twin plane (hhl) normal to (001) , composition plane (001) . The morphological development of muscovite agrees remarkably with the prediction of the Bravais-Donnay principle and the twin law is predictable on Friedel's twinning theory.

REFERENCES

- BAUMHAUER, H. (1900): Über die Krystallform des Muscovit—*Zeits. Kryst.*, vol. 32, pp. 164-176.
 BROOKE, H. J., and MILLER, W. H. (1852): *An elementary introduction to mineralogy by the late WILLIAM PHILLIPS*—London.

- BUERGER, M. J. (1942): *X-ray crystallography*—New York.
- DANA, E. S. (1892): *System of mineralogy*—New York.
- DES CLOIZEAUX, A. (1862): *Manuel de minéralogie*, vol. 1—Paris.
- DONNAY, J. D. H. (1942): Morphologie cristalline du groupe de la schéelite—*Mém. Soc. Roy. Canada*, vol. 36, sec. 4, pp. 37-57.
- DRUGMAN, J. (1927): On β -quartz twins from some Cornish localities—*Min. Mag.*, vol. 21, pp. 366-381.
- FERGUSON, R. B. (1943): Muscovite from Mattawan Township, Nipissing District, Ontario—*Univ. Toronto Studies*, Geol. Ser., no. 48, pp. 31-41.
- FRIEDEL, G. (1904): Étude sur les groupements cristallins—*Bull. Soc. Indus. Min.*, ser. 4, vols. 3 and 4.
- (1926): *Leçons de cristallographie*—Paris. [M. A. 3-222.]
- HENDRICKS, S. B. (1939): Polymorphism of the micas. With optical measurements by M. E. JEFFERSON—*Amer. Mineral.*, vol. 24, pp. 729-771. [M. A. 7-496.]
- HINTZE, C. (1897): *Handbuch der Mineralogie*, vol. 2—Leipzig.
- JACKSON, W. W., and WEST, J. (1931): The crystal structure of muscovite— $\text{KAl}_2(\text{AlSi}_3\text{O}_{10}(\text{OH})_2)$ —*Zeits. Krist. A*, vol. 76, pp. 211-227. [M. A. 4-467.]
- [KOKSHAROV] KOKSHAROV, N. V. (1875): *Materialien zur Mineralogie Russlands*, vol. 7—St. Petersburg.
- MARIGNAC, C. (1847): Notices minéralogiques—*Suppl. Bibl. Universe. Genève, Arch. Sci. Phys. Nat.*, vol. 6, pp. 293-304.
- MAUGUIN, C. (1927): Étude du mica muscovite au moyen des rayons X—*Compt. Rend. Acad. Sci. Paris*, vol. 185, pp. 288-291.
- PAULING, L. (1930): The structure of the micas and related minerals—*Proc. Nat. Acad. Sci. U.S.A.*, vol. 16, pp. 123-129. [M. A. 4-368.]
- PEACOCK, M. A. (1938): A general graphical method for determining the spacings of lattice planes—*Zeits. Krist. A*, vol. 100, pp. 93-103.
- TSCHERMAK, G. (1878): Die Glimmergruppe. (I Theil.)—*Zeits. Kryst.*, vol. 2, pp. 14-50.

HYPOGENE NATIVE ARSENIC FROM CRISS CREEK, BRITISH COLUMBIA

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The native arsenic on Criss Creek, British Columbia, possesses striking colloform structures but is of hypogene rather than supergene origin. Of the few British Columbia occurrences of native arsenic mentioned in the literature, one from Wolf Lake has been described by Gunning (1931, p. 76 A) as the product of oxidation, and one from Alder Island (Hurst, 1927, p. 39) may be hypogene. Native arsenic is known to occur on a tributary of China Creek on Vancouver Island. Specimens of this China Creek material, examined in 1943, appear to be of hypogene origin.

On Criss Creek abundant native arsenic is found in a dolomite vein about one-half mile from the Deadman River road. Criss Creek crosses this road about 12 miles north of the village of Savona on Kamloops Lake. The vein is a lenticular gash vein that ranges from 2 to 8 inches in width over its exposed length of 30 feet. It cuts across both the strike and the dip of the enclosing carbonatized argillaceous sediments. The vein outcrop and adjacent rock are marked by white arsenious oxide which has spread out along joints and fissures, particularly down the dip of intersected partings of shale.

Texturally the vein is of the filled vein-breccia type in which the vein-minerals cement angular inclusions of the wall rock. These vein-minerals include colloform dolomite, which rims the fragments, and colloform native arsenic which forms the matrix of the breccia. The vein has formed entirely by filling of open spaces, and there is practically no replacement of the wall-rock by the vein-minerals.

VEIN-DOLOMITE

The dolomite is found as rhythmically-banded material that lines the vein-walls and vugs and surrounds all the included fragments of carbonatized wall-rock. The bands consist of elongated

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dolomite crystals which have grown normal to the curvature of the bands and resulted in a well-developed comb-structure. The comb-structure of the dolomite and the presence of dolomite-lined vugs indicate that, during deposition of this mineral, open spaces prevailed in the vein. The colloform nature of the banding and growth of crystals normal to this banding is suggestive of colloidal origin. The vein-dolomite is white and, where strongly weathered, a light buff colour. Its composition is as follows:

		Reduced to 100 per cent
CaCO ₃	52.38	56.3
MgCO ₃	25.47	27.3
FeCO ₃	15.25	16.4
	<hr/>	<hr/>
	93.10	100.0

Such a carbonate may be called ankeritic dolomite as determined from Winchell's diagram (1933, p. 70). Vein-dolomite of almost identical composition and associated with carbonatized wall-rock, has been found by the writer in an epithermal scheelite deposit in the Bridge River area (1940*b*, p. 103), and in epithermal cinnabar deposits of the Kamloops Lake area (1940*a*, pp. 33-59).

NATIVE ARSENIC

Colloform native arsenic forms the matrix for the dolomite-rimmed fragments and is the main constituent of the vein. The arsenic is dark grey to black in colour on weathered surfaces but is bright steely grey on fresh surfaces. It is not chemically pure; on chemical analysis it is found to contain 8 per cent of antimony.

The etch reactions of the polished mineral are similar to those for native arsenic as described by Short (1940, pp. 121, 125) and by Schneiderhöhn and Ramdohr (1931, pp. 26, 29). Both 1 : 1 and 1 : 7 HNO₃ etch and stain the mineral black but leave unetched or slightly tarnished small blebs of native antimony that have exsolved from the arsenic on the cooling of a solid solution of the two minerals.

In strong polarized light both the native arsenic and included antimony blebs are anisotropic. The anisotropic effects are steel grey to black. The droplets of native antimony are definitely anisotropic but much less so than the enclosing arsenic.

When examined in polarized light, many of the grains show twinning lamellae. The twinning is very unevenly developed; in some grains it is entirely absent, and in others the whole grain is polysynthetically twinned. Many of the lamellae are bent and often displaced. The twinning is undoubtedly formed as the result of deformation, but the vein itself does not seem to have been subjected to any deformation since its formation. However, stresses sufficient to induce twinning may have been set up during grinding and polishing of the specimen; or perhaps they developed as a result of volume change in the arsenic crystals due to exsolution of the antimony. Buerger and Buerger (1934) describe twinning in chalcopyrite as probably resulting from volume changes in chalcopyrite crystals due to exsolution of cubanite.

In external form the arsenic is reniform. Curved masses of arsenic never form complete spheres but are discontinuously spheroidal and are packed together like thick fragments of pottery cemented one to the other. It is from this latter feature of its external form that native arsenic derives its German name of "Scherbenkobalt." The imperfectly spheroidal form is common to minerals of colloidal origin and is probably due to the effects of surface tension on a flocculating colloidal precipitate which would be highly viscous in consistency.

Curving shrinkage cracks which range from one to several millimetres apart are common (Fig. 1). These cracks generally conform to the colloform banding present in the arsenic, but a few cross the bands radially. Where the colloform banding is interrupted by an inclusion, the shrinkage cracks do not cut through the fragment, but commence again on the other side. These shrinkage cracks have formed as the result of shrinkage, or, as Boydell (1925, p. 164) terms the process, syneresis, of gels on setting or drying.

Colloform banding of the arsenic is well brought out by etching polished surfaces in air for several days. After exposure to air, such banding is seen to consist of groups of bands of two main sizes, a wide, relatively unetched group, about 15 mm. wide, and a narrow, strongly etched group about 5 mm. wide. The bands are mineralogically alike. However, occasionally a narrow band will be more finely crystalline than the adjacent wider band. The only reason that can be given for the greater susceptibility of the

narrow bands to etching is that they are more porous on a sub-microscopic scale than the coarser bands. The difference in porosity is not evident in microscopic study of the polished sections. The increase in porosity would result from the deposition of colloidal material as a gel rather than as a gelatinous precipitate. As contrasted to the precipitate, the gel would contain considerable water (Boydell, 1928, p. 164) and would on drying be more porous than the gelatinous precipitate. Because of the similarity in material found in the different bands, this banding cannot be referred to as Liesegang rings, where the banding is caused by two alter solutions (electrolytic) meeting in a gel (Bastin, *et al.*, 1931, p. 582; Lindgren, 1933, p. 189).



FIG. 1.—Vein breccia. Native arsenic (grey) cementing fragments of carbonated wall-rock (dark grey to black) which are rimmed by colloform dolomite (white to grey). Shrinkage cracks in arsenic in upper left and lower right. Natural size.

The arsenic is anisotropic and its internal texture can best be studied in polarized light (Figs. 2, 3). The various etch-tests mentioned by Schneiderhöhn and Ramdohr (1931, p. 26) were tried, but, although a satisfactory grain structure was brought out, the details of the structure were not as good as those seen in polarized light.

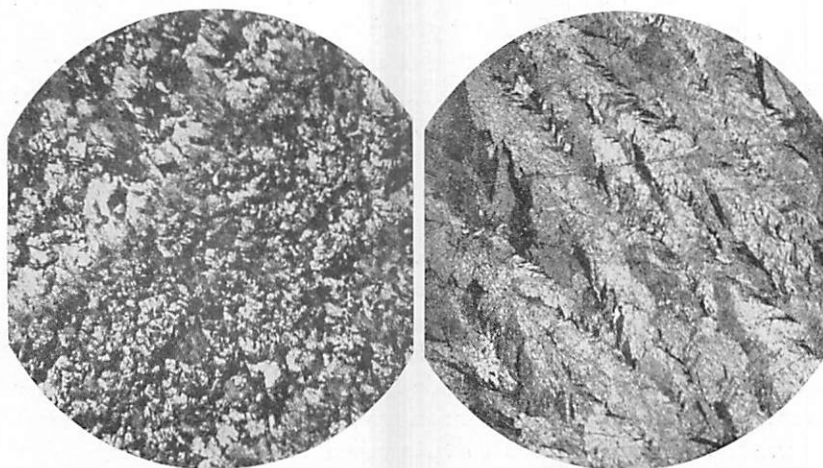


FIG. 2 (left).—Finely crystalline, native arsenic showing banding and variation in degree of crystallinity with banding. Crystals are normal to the banding. Polished section with crossed nicols. $\times 75$.

FIG. 3 (right).—Coarsely crystalline, native arsenic showing plume or sheaf-like crystals of arsenic. These are normal to the banding of the arsenic. Polished section with crossed nicols. $\times 75$.

The crystallinity varies from fine (Fig. 2) to coarse (Fig. 3) with a tendency for the grain size to vary from layer to layer (Fig. 2). Frequently, however, large grains, either solid or skeletal, may be seen growing in the midst of smaller grains.

The large grains are plume- or sheaf-like in form (Fig. 3), but the small grains tend to be equigranular (Fig. 2). The larger grains grow at right angles to the colloform bands (Figs. 2, 3) even where the degree of curvature is sharp. This cross-cutting feature of the crystals indicates that they grew after the deposition of the arsenic in colloform bands. Boydell (1925, pp. 200-201) reasons

by analogy to crystal growth in metallurgy that the fibrous crystallinity developed in colloform material is the result of crystal growth in originally amorphous material rather than the result of re-crystallization of already crystalline material.

ARSENIC-ANTIMONY INTERGROWTH

Antimony is found as small droplets within the native arsenic. Its identity was confirmed by etch-reactions and indirectly by chemical analysis of a specimen of native arsenic containing these blebs. The antimony droplets range in size from 0.2 to 1.0 mm. but most of them are around 0.3 mm. in maximum dimension. In outline the droplets are tear-drop shaped, pointed at one end; they become rounded or more equidimensional as they become smaller. They are distributed at random and are not concentrated into bands. Schwartz (1931, p. 741) states that Schneiderhöhn refers to such a texture as "emulsion structure" where microscopic to submicroscopic globules appear to have separated from the parent crystal on cooling below a certain point.

Rosiwal determinations made in several microscope fields give amounts of antimony that range from 6 to 10 per cent. A large surface area would have to be studied to determine accurately the amount of antimony occurring as blebs. Since a chemical analysis of a sample of the native arsenic gave 8 per cent and this figure corresponds to the amount of exsolved material as determined by Rosiwal analysis it appears that nearly all the antimony has exsolved and that very little if any remains in solid solution in the arsenic.

Neither the texture of the intergrowth nor the relative amounts of arsenic and antimony present suggest "allemontite" as defined by Schneiderhöhn and Rahmdohr (1931, p. 30). These writers restrict the term "allemontite" to an arsenic-antimony compound that has been found to have a unique subgraphic texture (see their Fig. 8) and an arsenic-antimony ratio of 3 : 1. In the Criss Creek material the arsenic-antimony intergrowths form an emulsion texture and the ratio of arsenic to antimony is about 12 : 1.

The arsenic-antimony intergrowth in the Criss Creek deposit satisfies many of the criteria of exsolution that have been listed by various writers on the subject (Schwartz, 1931, pp. 761-776;

1942, pp. 363-364) (Bastin *et al.*, 1931, p. 570). The antimony droplets or inclusions have smooth boundaries and are fairly uniformly distributed throughout the arsenic. In polarized light, each droplet extinguishes as a whole, indicating that it comprises a single crystal. The distribution and shape of the inclusions have no relation to the grain boundaries of the arsenic, to shrinkage cracks, or to colloform bands. Schneiderhöhn and Ramdohr (1931, p. 28) describe the crystal structure of the antimony as that of the "arsenic type." This similarity in crystal structure indicates that the arsenic could hold a small amount of antimony in solid solution at higher temperatures which would probably exsolve on cooling.

CONDITIONS OF DEPOSITION

The probable colloidal origin of many minerals, including native arsenic, has received the attention of many writers in the past few years, particularly Lindgren (1924, 1925), Boydell (1925, 1926, 1928) and Lasky (1930). These writers have investigated probable causes for the precipitation of colloidal material. Some consider the presence of calcium, probably as a carbonate, as responsible for the flocculation of some colloidal minerals. At Santa Eulalia, Mexico, Boydell (1928, pp. 102-112) thinks that the limestone there was responsible for precipitating the zinc, lead, and silver minerals from colloidal solutions. At Kennecott, Alaska, Lasky (1930, p. 756) concludes that the copper sulphides were transported in a highly dispersed condition and were flocculated upon reaching such an ideal flocculating agent as limestone.

At Criss Creek it is very probable that the calcium from the carbonatized wall-rock and inclusions served to flocculate the colloform vein-dolomite. The native arsenic is in contact only with the vein-dolomite and this mineral probably supplied the calcium instrumental in flocculating the colloidal native arsenic. This colloidal precipitate of arsenic later crystallized and on cooling exsolved the blebs of native antimony.

Several features indicate that the native arsenic on Criss Creek, though colloform in structure, is hypogene in origin. A small amount of boron was found on spectrographic analysis of the arsenic. It is unlikely that this element, commonly described as a constituent of mineralizers in the formation of ore deposits, would

be other than of hypogene origin (Lindgren, 1933, pp. 118, 752). The exsolution textures shown by the arsenic and the antimony strongly indicate a hypogene origin. By proving exsolution, Bateman and Lasky (1932) have proven the hypogene origin of the Kennecott covellite which Lasky (1930) showed to be also of colloidal origin. It may be concluded then that the colloidal native arsenic on Criss Creek is hypogene.

The Criss Creek arsenic vein was probably formed under conditions of both low pressure and low temperature. It therefore belongs to the epithermal class of mineral deposits as defined by Lindgren (1933, pp. 210, 444-447) and Gratton (1933, p. 540). A gash-like form and the brecciated texture of the vein suggests formation under light load. The mineralogy and in particular the colloform nature of the minerals suggest deposition at low temperature.

REFERENCES

- BASTIN, E. S., *et al.* (1931): Criteria of age relations of minerals with especial reference to polished sections of ores—*Econ. Geol.*, vol. 26, pp. 561-610.
- BATEMAN, A. M., and LASKY, S. G. (1932): Covellite-chalcocite solid solution and ex-solution—*Econ. Geol.*, vol. 27, pp. 52-86.
- BOYDELL, H. C. (1925): The rôle of colloidal solutions in the formation of mineral deposits—*Trans. Inst. Min. Met.* (London), vol. 34, pt. 1, pp. 145-252.
- (1926): A discussion on metasomatism and the linear "force of growing crystals"—*Econ. Geol.*, vol. 21, pp. 1-55.
- (1928): Operative causes in ore deposition—*Trans. Inst. Min. Met.* (London), vol. 37, pp. 50-134.
- BUERGER, N. W., and BUERGER, M. J. (1934): Crystallographic relations between cubanite segregation plates, chalcopyrite matrix and secondary chalcopyrite twins—*Am. Mineral.*, vol. 19, pp. 289-303.
- GRATTON, L. C. (1933): The depth-zones in ore deposition—*Econ. Geol.*, vol. 28, pp. 513-555.
- GUNNING, H. C. (1931): Buttle Lake map-area, Vancouver Island—*Geol. Surv. Canada*, Summ. Rept., 1930, pt. A.
- HURST, M. E. (1927): Arsenic-bearing deposits in Canada—*Geol. Surv. Canada*, Econ. Geol. Ser., no. 4.
- LASKY, S. G. (1930): A colloidal origin of some of the Kennecott ore minerals—*Econ. Geol.*, vol. 25, pp. 737-757.
- LINDGREN, W. (1924): The colloidal chemistry of minerals and ore deposits—in BOGUE, R. H. (1924): *The theory and application of colloidal behaviour*, pp. 415-465—New York.

- LINDGREN, W. (1925): Gel replacement, a new aspect of metasomatism—*Proc. Nat. Acad. Sci. U.S.A.*, vol. 11, pp. 5-11.
- (1933): *Mineral deposits*—New York.
- SCHNEIDERHÖHN, H., and RAMDOHR, P. (1931): *Lehrbuch der Erzmikroskopie*, vol. 2—Berlin.
- SCHWARTZ, G. M. (1931): Textures due to unmixing of solid solutions—*Econ. Geol.*, vol. 26, pp. 739-763.
- (1942): Progress in the study of exsolution in ore minerals—*Econ. Geol.*, vol. 37, pp. 345-364.
- SHORT, M. N. (1940): Microscopic determination of the ore minerals—*U.S. Geol. Surv.*, Bull. 914.
- STEVENSON, J. S. (1940a): Mercury deposits of British Columbia—*B.C. Dept. Mines*, Bull. 5.
- (1940b): An epithermal scheelite deposit in the Bridge River district, B.C.—*Univ. Toronto Studies*, Geol. Ser., no. 44, pp. 95-105.
- WINCHELL, A. N. (1933): *Elements of optical mineralogy*, pt. 2—New York.

QUANTITATIVE MINERAL RELATIONS AT THE UPPER CANADA MINES, DOBIE, ONTARIO

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For some years the writer has been interested in studying suites of ores from different mines with a view to the possible establishment of quantitative relations between the productive ore mineral or minerals and the associated rock minerals. It has been his hope that these relations might prove useful to the practical mining man. With the introduction of the superpanner and improved microscopic methods this has been made possible even for the minor constituents of the ore. The present study was started in 1942 but, due to difficulties of securing during that year adequate material for the completion of the work, it was not finished until the spring of 1943. The writer, at the very beginning of this article, would like to acknowledge the kindly co-operation that was rendered to him by the management of the Upper Canada Mines. In particular he wishes to express his thanks to Mr. R. J. Henry and Mr. Massey Williams. Without their assistance it would have been impossible to conduct this investigation.

At this mine, which is situated in the Kirkland Lake-Larder Lake district, several ore chutes have been developed. It was the original intention to study all of these ore-bodies but, after some consideration, it was decided to limit the scope of the present investigation to two of them, namely Ore-body H and Ore-body M. These two ore-bodies had been opened out to a depth of 1000 feet. So that a fairly complete picture of the mineral associates might be obtained, the ore-minerals were studied in polished sections and the associated rock-forming minerals in thin section. In Ore-body H twenty-seven sections of each kind were examined under the microscope, while for Ore-body M seventeen of each were investigated. For convenience of reference the results of the study of these forty-four sections of each kind are placed in tabular form in the following tables.

TABLE 1
MINERALS OF THE UPPER CANADA MINES ORE-BODIES

Sect. no.	Level	Ore-body	Major ore minerals	Minor ore minerals	Major rock minerals	Minor rock minerals
1-1	125'	H	pyrite	chalcopyrite galena sphalerite magnetite	quartz carbonate green mica	—
2-1	125'	H	pyrite	magnetite galena gold	carbonate	quartz green mica chlorite rutile
3-1	125'	H	pyrite	galena sphalerite	carbonate quartz white mica	feldspar apatite
3-2	250'	H	pyrite	chalcopyrite galena gold	carbonate	quartz white mica
3-3	250'	H	pyrite	chalcopyrite galena gold	carbonate white mica plagioclase	quartz chlorite
3-4	250'	H	pyrite	chalcopyrite galena tetrahedrite altaite gold	carbonate white mica	quartz rutile
3-5	250'	H	pyrite	chalcopyrite magnetite	carbonate white mica	quartz rutile chlorite
2-3	375'	H	pyrite	chalcopyrite galena gold	feldspar carbonate quartz white mica	—
3-5a	375'	H	pyrite	magnetite	carbonate white mica	chlorite quartz

TABLE 1 (continued)

Sect. no.	Level	Ore-body	Major ore minerals	Minor ore minerals	Major rock minerals	Minor rock minerals
3-5b	375'	H	chalcopyrite galena	pyrite limonite silver	carbonate orthoclase quartz	—
3-7	375'	H	pyrite	chalcopyrite	carbonate white mica	plagioclase quartz chlorite
1-4	500'	H	pyrite	galena sphalerite altaite gold	plagioclase carbonate white mica	quartz
2-4	500'	H	pyrite	chalcopyrite altaite	white mica carbonate quartz	—
3-8	500'	H	pyrite	chalcopyrite galena altaite gold magnetite	carbonate white mica	quartz
1-5	625'	H	pyrite	chalcopyrite galena sphalerite	carbonate white mica quartz	—
2-5a	625'	H	pyrite	gold pyrrhotite	carbonate white mica	quartz
2-5b	625'	H	pyrite	chalcopyrite galena	carbonate white mica quartz	—
3-9	625'	H	pyrite	chalcopyrite galena gold	plagioclase white mica	carbonate quartz rutile
1-6	750'	H	pyrite	chalcopyrite gold	carbonate white mica	quartz rutile chlorite

TABLE 1 (*continued*)

Sect. no.	Level	Ore-body	Major ore minerals	Minor ore minerals	Major rock minerals	Minor rock minerals
2-6	750'	H	pyrite	chalcopyrite galena gold	carbonate	quartz white mica chlorite
3-10	750'	H	pyrite	chalcopyrite galena gold	carbonate white mica quartz	—
1-7	875'	H	pyrite	chalcopyrite galena magnetite gold	carbonate	quartz plagioclase
2-7	875'	H	pyrite	galena sphalerite	white mica quartz carbonate	chlorite plagioclase apatite
3-11	875'	H	pyrite	galena altaite gold	white mica carbonate	quartz plagioclase rutile
1-8	1000'	H	pyrite	magnetite galena	white mica carbonate quartz	plagioclase
2-8	1000'	H	pyrite	chalcopyrite galena gold	white mica carbonate	quartz
3-12	1000'	H	pyrite	chalcopyrite galena	white mica carbonate	quartz chlorite

TABLE 2
MINERALS OF THE UPPER CANADA MINES ORE-BODIES

Sect. no.	Level	Ore-body	Major ore minerals	Minor ore minerals	Major rock minerals	Minor rock minerals
23	250'	M	pyrite	magnetite chalcopyrite	carbonate	white mica quartz
105 St.	250'	M	pyrite	chalcopyrite galena magnetite sphalerite	carbonate	quartz green mica hornblende feldspar
24	375'	M	magnetite	ilmenite hematite pyrite chalcopyrite	carbonate feldspars quartz white mica	—
105 St.	375'	M	pyrite	magnetite chalcopyrite	carbonate quartz green mica	hornblende plagioclase
25	500'	M	pyrite	magnetite	carbonate feldspars quartz green mica	—
106 St.	500'	M	pyrite	magnetite chalcopyrite	green mica quartz carbonate	—
26	625'	M	pyrite	chalcopyrite	carbonate feldspars quartz white mica	—
107 St.	625'	M	pyrite	chalcopyrite	carbonate quartz white mica	—
27	750'	M	pyrite	chalcopyrite gold	carbonate	white mica quartz

TABLE 2 (continued)

Sect. no.	Level	Ore-body	Major ore minerals	Minor ore minerals	Major rock minerals	Minor rock minerals
108.5a	750'	M	pyrite	galena sphalerite gold	} plagioclase carbonate white mica chlorite }	} quartz
108.5b	750'	M	pyrite	galena sphalerite gold		
108.5c	750'	M	pyrite	sphalerite		
28	875'	M	pyrite	chalcopyrite altaite galena gold magnetite	carbonate feldspar quartz white mica	—
Stope	875'	M	pyrite	chalcopyrite galena gold magnetite	white mica carbonate quartz	plagioclase
108.5 St.	875'	M	pyrite	chalcopyrite galena	green mica chlorite carbonate	quartz rutile
T.D.B.5	1000'	M	—	pyrite galena sphalerite	} green mica chlorite quartz }	} carbonate plagioclase
T.D.B.6	1000'	M	pyrite	galena sphalerite		

A careful study of these tables from a quantitative standpoint reveals certain obvious facts and points to some general trends in mineral association. First of all pyrite is much the commonest of all the ore-minerals being present as a major constituent in most of the sections. The remaining metallic minerals occur for the most part as minute inclusions either in the larger pyrite areas or in the gangue material. Of these minor metallic constituents chalcopyrite and galena are present in approximately equal quantities,

followed by magnetite, sphalerite, altaite, and the others, in about that order. Turning to the rock-forming or gangue minerals, carbonate, a white or green mica, and quartz are the most abundant, with chlorite and the remainder occupying minor roles. If an attempt is made to analyse the quantitative mineral relations of gold to those metallic minerals which were deposited at about the same general period, some interesting trends are noticed. If a rough estimation be made, purely on the basis of the number of occurrences of the mineral in question with a double unit for a major constituent and a single unit for a minor constituent, certain rough percentages for each of the minerals associated with the gold may be obtained in the following way. If, for instance, chalcopyrite is found to occur in Ore-body H 20 times and in 11 of those gold is associated with it, the percentage for the chalcopyrite-gold association is found to be 55. If this estimation is carried out for the minerals altaite, chalcopyrite, galena, and sphalerite, the following figures are obtained:

TABLE 3

	Ore-body H	Ore-body M
Altaite.....	75%	100%
Galena.....	64%	50%
Chalcopyrite.....	55%	27%
Sphalerite.....	25%	33%

This would seem to show that altaite and galena were somewhat more important as associates of the gold than either chalcopyrite or sphalerite. Incidentally the 100% figure for altaite in Ore-body M is rather misleading as this is computed from but one occurrence of the telluride mineral in that ore-body. A study of the relations between the gold and the gangue minerals did not seem to assign any special importance to any one of them. The only other tendency that might be mentioned very briefly is to be noted in the marked difference in distribution of the gold occurrences in the two ore-bodies. It will be noted that whereas gold was found throughout all the levels from 125' to 1000' in H ore-body, it was confined in M ore-body to two levels, namely the 750' and 875' levels. This may be due in part to the greater number of sections examined in Ore-body H and to the fact that more sections were

examined from the 750' and 875' levels in Ore-body M than from the other levels in that ore-body. It may be well at this point to emphasize the need for caution in evaluating the results of this investigation. It must always be borne in mind that the microscopic study of from 2 to 4 sections from each level for each ore-body represents the irreducible minimum number from the examination of which any reasonable conclusions can be drawn. Increasing the number of such sections would not of necessity change the quantitative relations very materially but it would provide a sounder basis for deduction. In conclusion it is realized that this simple quantitative study has nothing startling to offer either in the scientific field or in the domain of economic mineralogy. It is however the hope of the writer that it may induce the carrying out of similar investigations in other mining fields, which may prove to be more productive of useful results.

MINERALOGICAL NOTES

CHROMITE FROM MANITOBA

During the summer of 1942 extensive deposits of chromite were discovered in a folded sill of peridotite-gabbro north of Bird River in south-east Manitoba. The chromite is all of the disseminated type, occurring as small octahedral crystals and grains up to 0.5 mm. in a matrix of serpentine. Sharp boundaries commonly separate the barren peridotite from the chrome bands.

Examination in polished section under high magnification, preferably with an oil immersion lens, reveals minute crystals of a white metallic mineral distributed throughout each grain of chromite. In a few grains these small white platy crystals display good hexagonal outlines, but generally one sees only their rod-shaped cross-sections which are arranged in a pattern corresponding to the octahedral planes of the chromite (Fig. 1). The length of the rod-shaped sections varies up to 15 or 20 microns and one exceptional individual measures 30 microns. Their manner of occurrence strongly suggests that they developed by exsolution during the cooling of the chromite.

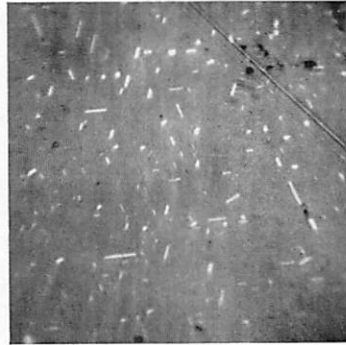


FIG. 1.—Chromite enclosing small crystals of hematite (white). $\times 270$.

Positive identification of an exsolution product in such minute crystals is difficult, but some data are available. The mineral is galena white, possesses a metallic lustre, is negative to all common etching solutions, and is distinctly anisotropic. It also crystallizes in hexagonal plates. These facts, taken with the chemical analyses which show an excessive iron content ($\text{Cr} : \text{Fe} = 1.2 : 1$), are the basis for concluding that the mineral is hematite.

Ramdohr (*Zeits. prak. Geol.*, **39**, 90, 1931) refers briefly to the occurrence of platelets of hematite in abundance along the (111) planes of chromite from the Bushveld norite. The writer is not aware of any other observation of hematite crystals in chromite.

From these observations one would conclude that a portion of the iron content as reported in chemical analyses of the chromite from Bird River is not part of the molecule but is actually present as exsolved hematite. They also suggest that more of the iron may remain as ferric oxide in solid solution within the chromite, a possibility that has some support from preliminary heat treatment experiments.

G. M. BROWNELL
University of Manitoba

KYANITE FROM BRITISH COLUMBIA

Late in 1934 Mr. W. Rutter of Jasper, Alberta, brought in a small specimen of kyanite from the Albreda district, B.C., for identification. The nearest railway point to this kyanite deposit is Mi. 2487, west of Jasper; from this point it is accessible by pack trail. By the fall of 1937 Mr. Rutter had made further examinations of the extent of the deposit and had sent samples to several laboratories and industrial plants for analyses. Further specimens were also brought to our department.

The kyanite in our specimens is the translucent blue bladed variety. The individual crystals, mostly of macroscopic dimensions, are embedded in a groundmass of fractured quartz. The largest crystal fragment is 5 mm. thick, 16 mm. wide, and 35 mm. long—the length being determined by the common parting planes. The largest piece embedded in the matrix is 55 mm. long while the average crystal has dimensions about one-third to one-half of those given above. Most of the blades of kyanite are subparallel in the quartz matrix but some are transverse to the main direction. The kyanite is optically negative with $Z : c$ on (100) 30° , $Z : c$ on (010) 7° .

The abundant quartz matrix suggests that these deposits are of the pegmatite type rather than the disseminated variety, but both types may be present in this district. The pegmatite would be more readily detected since in this type the physical properties of kyanite are attractively displayed, as in our specimens which are composed of about 25 per cent kyanite and 75 per cent quartz.

No detailed geological information on the rocks of this district

has been published since that contained in the report of the reconnaissance survey made by McEvoy in 1898, and little is known of the local geology. Some interest in the district has been created at times when the possibilities of the development of the mica deposits have been considered.

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BOULANGERITE AND COLUMBITE-TANTALITE FROM MANITOBA

These minerals have been identified by microscopic, chemical, and blowpipe examination (Ellis Thomson) and *x*-ray photographs (E. W. Nuffield) in ore specimens obtained through the kindness of Mr. R. J. Jowsey. Boulangerite was found in a large specimen of lead-zinc ore from Eskamanish River, a tributary of the Nelson River, north-east of Lake Winnipeg; columbite-tantalite was identified in a small sample of ore from a potash pegmatite dike on Bird River, south-east of Lake Winnipeg.

Six polished sections of the ore from Eskamanish River showed massive aggregates of sphalerite enclosing short veins and blebs of galena and an anisotropic lead sulphantimonide which proved to be boulangerite. The larger galena-boulangerite areas contain inclusions of tetrahedrite; marcasite and rod-like crystals and crystal aggregates of pyrrhotite are associated with the main ore mineral, and chalcopyrite occurs in occasional tiny inclusions in the small amount of quartz gangue.

A section of the specimen from Bird River showed mainly columbite-tantalite in granular form, some cassiterite in grains and narrow stringers, and occasional included crystals of hematite.

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- MACDONALD, Frederick, B.A. Lieut., R.C.E. *Emsdale, Ontario.*

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- VONSEN, M. *Petaluma, California.*
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PROCEEDINGS

FIRST MEETING

The first meeting of the season was held at 5 P.M., October 22, in Room 64, Royal Ontario Museum, with the President, Mr. W. E. Chantler, in the chair. It was moved by Professor Parsons and seconded by Professor Thomson that a letter of sympathy be sent to Mrs. Walker, the widow of our late Honorary President, Professor Thomas Leonard Walker.

The Secretary read the report of the nominating committee which recommended the following gentlemen:

President: Professor M. A. PEACOCK

Secretary-Treasurer: Dr. V. B. MEEN

Councillor for Ordinary Members, 1942-45: Mr. G. G. WAITE

Councillor for Department of

Mineralogy: Professor ELLIS THOMSON

Councillor for Student Members: Mr. R. B. FERGUSON

It was moved by Professor Thomson and seconded by Dr. Jack Satterly that this report be accepted and that ballots for the election of officers be sent out; that the poll close December 8 at 5 P.M., and that the Council be instructed to canvass the ballot and report the results at the December meeting.

The Editor, Professor Parsons, announced that the annual number of *Contributions to Canadian Mineralogy* was ready for distribution and would be sent to each member in good standing. He also reported that the volume was somewhat restricted in size for the sake of economy.

The Secretary-Treasurer reported that the annual dues for 1942-3 were payable and that the dues of those members on Active Service would be remitted for the duration. The Royal Ontario Museum of Mineralogy has kindly paid these dues for the present year.

Dr. Jack Satterly and Dr. J. E. Thomson, both of the Geological Staff of the Department of Mines of Ontario, spoke on "Some Mineral Occurrences in Eastern Ontario," illustrating their re-

marks with lantern slides and specimens collected during their summer's field work. Many questions were asked at the close of their remarks. The thanks of the Club were extended to these gentlemen by the President.

SECOND MEETING

The second meeting was held at the house of Mr. Andre Dorfman, 27 Old Forest Hill Road, Forest Hill Village, at 8 P.M., December 10. The retiring President, Mr. W. E. Chantler, occupied the chair. The Secretary reported that the ballot had been canvassed and the officers elected as nominated. The new President, Professor Peacock, then took the chair. Dr. M. E. Hurst, seconded by Dr. Jack Satterly, proposed a vote of thanks to the outgoing officers.

The Secretary read a letter received from Mrs. T. L. Walker in reply to the letter of sympathy sent to her on behalf of the Club.

In the absence of Mr. Andre Dorfman due to illness, his son, Mr. L. A. Dorfman, outlined briefly the history of his father's fine collection of minerals. A vote of thanks to Mr. Dorfman and his family for their kindness in opening their home to the Club was proposed by Mr. C. W. Knight and seconded by Mr. John A. Knox. The meeting then adjourned for examination of the beautiful collection of minerals. Refreshments were served through the courtesy of the retiring President, Mr. Chantler.

THIRD MEETING

The third meeting was held on February 22, 1943, at 5 P.M., in Room 56, Mining Building, University of Toronto. The President, Professor Peacock, occupied the chair. Professor R. F. Legget gave an interesting talk on "Mineralogy in Civil Engineering" with particular reference to its role in soil mechanics. At the end of the address the President offered a few remarks and a number of questions were asked by the members. A vote of thanks to Professor Legget was proposed by Professor Parsons and unanimously approved.

FOURTH MEETING

The fourth meeting was held in Room 56, Mining Building, University of Toronto, at 8 P.M. The President, Professor Peacock,

occupied the chair. It was moved by Professor Parsons and seconded by Professor Thomson that the President be authorized to appoint a nominating committee, which committee would suggest officers for the coming year and report to the October meeting. It was moved by Professor Parsons and seconded by Mr. John Reid that an auditing committee consisting of Mr. J. G. Dickenson and Mr. George E. Steel meet with the Treasurer and audit the accounts of the Club. The Secretary reported that at the Council meeting earlier in the evening it was recommended that a committee be formed to investigate the possibility of revising the constitution of the Walker Mineralogical Club and to report to the Council at the October meeting. It was moved by Professor Thomson and seconded by Professor Parsons that this recommendation be adopted and that the President be authorized to appoint such a committee.

The following papers from the Department of Mineralogy and Petrography, University of Toronto, were then read: "Muscovite from Mattawan Township, Nipissing District, Ontario," by R. B. Ferguson (pp. 31-41); "Prehnite from Ashcroft, British Columbia" by E. W. Nuffield (pp. 49-64); "Parkerite ($\text{Ni}_3\text{Bi}_2\text{S}_2$) from Sudbury, Ontario: Redefinition of the Species" by C. E. Michener and M. A. Peacock (*Am. Mineral.*, vol. 28, pp. 343-355, 1943). In Dr. Michener's absence the last paper was read by the President.

After some discussion, Professor Thomson, on behalf of the members, tendered an expression of thanks to the speakers for their interesting addresses.

The membership of the Club as on June 18, 1943, is as follows:

Honorary Members	2
Ordinary Members	317
Student Members	14

There are 31 members known to be on Active Service, and in addition, a number of members have taken civilian positions attached to a branch of the Armed Services.

Our Honorary President, Dr. Thomas Leonard Walker, for whom the Walker Mineralogical Club is named, died on August 6, 1942. Memorials with portraits and bibliographies have recently

been published (*Am. Mineral.*, vol. 28, p. 167, 1943; *Geol. Soc. Am., Proc.*, 1942, p. 241, 1943). In addition, the Club lost three other members by death: Professor Arthur Honess, Department of Geology, The Pennsylvania State College; Colonel Joseph Hyde Pratt, Chapel Hill, North Carolina; Professor V. A. Vigfusson, Department of Chemistry, University of Saskatchewan.

FINANCIAL STATEMENT OF THE WALKER MINERALOGICAL CLUB
FROM JUNE 22, 1942, TO JUNE 18, 1943

June 22, 1942, Cash on hand and in bank..... \$211.54

RECEIPTS

Dues.....	\$257.00	
Contribution (anonymous).....	10.00	
Bank interest and premium, less charges.....	4.40	
	<u> </u>	\$271.40
		<u> </u> \$482.94

EXPENDITURES

University of Toronto Press (toward the cost of <i>Contributions to Canadian Mineralogy, 1942</i>)	\$219.19	
Postage.....	28.20	
University of Toronto Press.....	55.12	
Royal Ontario Museum (multigraphing).....	1.92	
University of Toronto (room rent).....	2.50	
	<u> </u>	\$306.93
June 18, 1943, Cash on hand and in bank.....	176.01	
		<u> </u> \$482.94

BALANCE SHEET

June 18, 1943

ASSETS

Cash on hand and in bank..... \$175.01

LIABILITIES

Dues in advance.....	\$ 30.00
Surplus.....	146.01
	<u> </u> \$176.01

Examined and found correct.

GEO. E. STEEL,
J. G. DICKENSON, *Auditors*

V. B. MEEN, *Secretary-Treasurer*

July 2, 1943.

NOTICE

THE WALKER MINERALOGICAL CLUB

Membership is open to all interested persons and institutions. To join the Club, send your name and address (see list of Members) to the Secretary-Treasurer with the membership fee of one dollar. This includes a subscription to the annual publication, *Contributions to Canadian Mineralogy*, which normally appears in October.

CONTRIBUTIONS TO CANADIAN MINERALOGY

The annual *Contributions to Canadian Mineralogy* are non-consecutive numbers of the *Geological Series* of the *University of Toronto Studies* (see back cover). Back numbers, with few exceptions, may be obtained by members directly from the Secretary-Treasurer of the Club.

MANUSCRIPTS AND ILLUSTRATIONS. In preparing papers to be offered for publication, authors are asked to consider the style and limited space in recent issues. Short communications may be suitable for the new section entitled *Mineralogical Notes*. Illustrations should be planned economically, and in view of the rising cost of publication financial assistance toward the cost of illustrations will be appreciated. *To allow time to prepare the entire manuscript for the press before the summer field season, contributors are requested to send their material to reach the Editor before May 1.*

REPRINTS. Fifty reprints, with covers, of each regular article are provided free. Extra reprints normally cost about 50 cents per page per hundred.

INDEX

CONTRIBUTIONS TO CANADIAN MINERALOGY 1938-1943

Index (AUTHORS, subjects, *localities*) to *Contributions to Canadian Mineralogy, 1938-1943* (University of Toronto Studies, Geological Series, nos. 41, 1938; 42, 1939; 44, 1940; 46, 1941; 47, 1942; 48, 1943). See also the indexes to *Mineralogical Abstracts* (London), vols. 7, 1938-1940; 8, 1941-1943, in preparation.

- Aikinite, *Ural*, sp. grav., unit cell, powder pattern, 1942—63
Albreda, B.C., kyanite, 1943—102
 ALLEN (J. S.) *v.* THOMSON (E.), 1939—135
Amaranth, Man., anhydrite, gypsum, quartz concretions, 1942—7
 Analcite, *Man.*, cryst., opt., 1938—20
 Andesite, *Que.*, anal., 1938—79
Andreasberg, Harz, Germany, dyscrasite, 1940—31, 55
Anglesea Tp., Lennox & Addington Co., Ont., meneghinite, 1940—61, 1941—5
 Anhydrite, *Man.*, 1942—7; *Que.*, 1941—75
 Anthraxolite, *N.W.T.*, anal., 1939—124
 Antimony in arsenic, *B.C.*, 1943—84
 Apatite, gem, *Ont.*, 1938—46
 ARCHAMBAULT (M.), anal. by, 1939—49
 Arsenic, *B.C.*, pol. sect., 1943—84
 Arsenopyrite, *Ont.*, 1938—23
Ashcroft, B.C., prehnite, 1943—49

Bancroft, Ont., cancrinite, 1938—35
Baumhauerite, Switzerland, unit cell, 1940—52
Berezovsk, Ural, aikinite, 1942—63
 BERRY (L. G.), Boulangerite & "epiboulangerite," 1940—5
 ——— Cosalite, 1939—23
 ——— Pseudocopiapite, 1938—7
 ——— Sulpho-salt minerals, 1943—9
 ——— & MODDLE (D. A.), Meneghinite, 1941—5
 ——— *v.* PEACOCK (M. A.), 1940—47
Beuthen, Upper Silesia, Germany, jordanite, 1940—59
Binn Valley, Switzerland, baumhauerite, 1940—52; jordanite, 1940—59; rathite, 1940—63; sartorite, 1940—64
Bird River, Man., chromite & hematite, 1943—101; columbite-tantalite, 1943—103
 Bismuth, *Ont.*, powder pattern, 1941—96; 1942—31
 Bismuthinite, *B.C.*, sp. grav., 1940—107
 Bi₂Te₃, powder pattern, 1941—96
Black Lake, Que., garnet, 1941—19
Bottino, Tuscany, Italy, meneghinite, 1940—61, 1941—5
 Boulangerite, sp. grav., pol. sect., unit cell, powder pattern, 1940—5; *Czechoslovakia*, powder pattern, 1941—7; *Idaho*, unit cell, 1940—53; *Man.*, 1943—103; *Que.*, anal., pol. sect., powder pattern, 1941—25

- Breithauptite, *Ont.*, 1938—23
Broken Hill, New South Wales, Australia, willyamite, 1940—69
Brosso, Piedmont, Italy, pyrite, 1940—62
- BROWNELL (G. M.), Chromite, *Man.*, 1943—101
 ——— Quartz concretions, *Man.*, 1942—7
 ——— Zeolites, *Man.*, 1938—19
Buckingham, Que., phlogopite, 1938—34
- BURR (S. V.), & PEACOCK (M. A.), Pd-Bi alloys, 1942—19
- $\text{CaB}_2\text{O}_4 \cdot 6\text{H}_2\text{O}$, prep., anal., cryst., opt., unit cell, 1939—113
Calumet Island, Ottawa River, Que., anhydrite, 1941—75; gypsum, 1941—75
Calvin Tp., Nipissing, Ont., pyroaurite, 1939—33
 Cancrinite, *Ont.*, opt., anal., 1938—35
 Cannizzarite = galenobismutite, 1943—14
- Carbonaceous sediments, *Ont.*, anal., 1939—141
Cariboo, B.C., cosalite, 1939—24, 151
Carinthia, Germany, corynite, 1940—54
Carrock Fells, Cumberland, England, grüningite, 1940—60, 1941—86
Castle Tretheway Mine, Gowganda, Ont., smaltite, 1940—65
- Chabazite, *Man.*, cryst., opt., 1938—20
 Chalcocite, *N.W.T.*, 1939—53
 Chloanthite, *Germany*, powder pattern, 1940—65
- Chromite, *Man.*, pol. sect., 1943—101
Chuguicamuta, Chile, copiapite, 1938—12
- Cinchona alkaloids, cryst., opt., 1938—49
- Clay minerals and engineering, 1943—43
- Cleavage-luminescence in mica, 1938—33
- Cobalt, Ont.*, antimonial silver, 1940—42; bismuth, 1941—96; cobaltite, 1940—54; pararammelsbergite, 1940—62; rammelsbergite [pararammelsbergite], 1939—95; skutterudite, 1940—65
- Cobaltite, *Ont.*, 1938—23; *Ont.*, *Sweden*, unit cell, 1940—54
Coleman, Alta., orthoclase, 1938—67
Coleraine Tp., Que., magnesiochromite, 1939—75
- Columbite-tantalite, *Man.*, 1943—103
 Copiapite, *Chile*, cryst., unit cell, 1938—7; (pseudocopiapite), *Chile*, cryst., unit cell, opt., 1938—7
- Copper minerals, *B.C.*, 1939—127
Cornwall, England, goethite, opt., 1942—53; jamesonite, 1940—58
- Corynite, *Germany*, unit cell, 1940—54
 Cosalite, *B.C.*, 1940—108; anal., pol. sect., 1939—151; *B.C.*, *Ont.*, *Sweden*, unit cell, powder pattern, 1939—23; *Ont.*, unit cell, 1940—54
- Criss Creek, B.C.*, antimony in arsenic, 1943—84
- DADSON (A. S.), Electrical potential in ore deposition, 1938—23
- DAVIS (P.), v. WARREN (H.V.), 1940—107
- Diopside, *Que.*, 1938—48
- Dispersion, recrossing, 1942—53
- Dobie, Ont.*, ore minerals, 1943—93
- DONNAY (J. D. H.), Point-groups, 1942—33
 ——— School of Mines, *Quebec, Que.*, 1940—21
 ——— & FAESSLER (C.), Garnet, *Que.*, 1941—19
- Dufresnoy Tp., Abitibi Co., Que.*, andesite, 1938—79
- Duprat Tp., Abitibi Co., Que.*, rhyolite, 1938—79
- Dyscrasite, *Germany*, sp. grav., pol. sect., cryst., unit cell, powder pattern, 1940—31, 55

- Easton, Pennsylvania*, limonite [goethite], 1940—60
- Eau Claire, Calvin Tp., Nipissing, Ont.*, muscovite near, 1943—31
- Eisleben, Thuringia, Germany*, maucherite, 1940—61; rammelsbergite, 1940—63
- Electric potential in ore deposition, 1938—23
- Elk Lake, Gowganda, Ont.*, parammelsbergite, 1940—62; rammelsbergite [parammelsbergite], 1939—95; maucherite, 1940—61
- ELLESTAD (E. B.), anal. by, 1939—76
- ELLSWORTH (H. V.), Pyroaurite, 1939—33
- Eskamanish River, Man.*, boulangerite, 1943—103
- FABRY (R. J. C.), anal. by, 1938—58, 79
- FAESSLER (C.), Suzorite, 1939—47
— v. DONNAY (J. D. H.), 1941—19
- Falkmanite = boulangerite, 1943—19
- Falun, Sweden*, weibullite (mixture), 1940—68
- Ferberite, *N.W.T.*, 1939—53
- FERGUSON (R. B.), Muscovite, *Ont.*, 1943—31
— v. PEACOCK (M. A.), 1943—65
- Fort Churchill, Hudson Bay, Man.*, lazulite, 1938—48
- Fort Wrangel, Alaska*, garnet, 1941—64
- FORWARD (F. A.), anal. by, 1940—110
- Gabbro, orbicular, *Ont.*, anal., 1940—75
- Galenobismutite, *B.C.*, anal., 1940—108; *Sweden*, sp. grav., unit cell, 1940—56
- Garnet, *Que.*, cryst., 1941—19; *Alaska*, age, 1941—64
- Gersdorffite, *Ont.*, 1938—23; unit cell, 1940—57
- Glacier Gulch, Smithers, B.C.*, bismuth, bismuthinite, 1940—107; joseite, 1940—107, 1941—85
- Gladhammar, Sweden*, lillianite = galenobismutite, 1940—56
- Goethite, *England*, opt., 1942—53
- Gold, *N.W.T.*, 1939—53
- GOULD (E. C. S.), anal. by, 1941—29
- Great Slave Lake, N.W.T.*, gold, 1939—53; vesuvianite, 1939—69
- Grenville, Que.*, scapolite, cat's eye, 1938—47
- Grünlingite, *England*, 1940—60; = joseite, powder pattern, 1941—96
- Guanajuatite, *Mexico*, powder pattern, 1940—58
- Guanajuato, Mexico*, guanajuatite, 1940—58
- Gypsum, *Man.*, 1942—7; *Que.*, 1941—75
- Hackensboda, Västmanland, Sweden*, cobaltite, 1940—54
- HARRINGTON (J. B.) [B. J.], portrait, 1938—frontispiece
- HAWLEY (J. E.), Boulangerite, *Que.*, 1941—25
— Gold, tungsten, tin, *N.W.T.*, 1939—53
— Heat effects on sulphides, 1941—33
- Helium index, unreliability of, 1941—39
- Hematite, *B.C.*, 1939—127; in chromite, *Man.*, 1943—101
- Hesse, Germany*, smaltite, 1940—65
- Highland Valley, Ashcroft, B.C.*, copper minerals, hematite, tourmaline, 1939—127
- Huelva, Spain*, smaltite, 1940—65
- Hydrotalcite, *Que.*, anal., 1938—39
- Iron ores, *Ont.*, pol. sect., comp., 1942—71
- Irtom, Morocco*, smaltite, 1940—65

- Jamesonite, *Bolivia*, powder pattern, 1941—7; sp. grav., unit cell, 1940—58; *England*, powder pattern, 1940—58
- Jaspilite, *Ont.*, 1938—46
- JOHNSON (E. W.), anal. by, 1939—153; 1940—108
- Johnston Asbestos Mine, Thetford, Que.*, natrolite, 1938—57
- Jordanite, *Germany, Sweden, Switzerland*, sp. grav., unit cell, powder pattern, 1940—59
- Joseite, sp. grav., pol. sect., unit cell, powder pattern, 1941—83; *B.C., Brazil*, 1940—60, 110
- Kallilite, *Germany*, unit cell, 1940—60
- KEEVIL (N. B.), Helium index, 1941—39
- Keeewatin lavas, *Que.*, anal., 1938—75
- Khutze Inlet, Swanson Bay, B.C.*, telurbismuth, 1940—67, 107
- Kilmar, Que.*, mica, 1938—34; pseudomorphs after spinel, hydrotalcite, 1938—39; serpentine, 1938—47
- Kisbánya, Romania*, semseyite, 1940—65
- Kyanite, *B.C.*, 1943—102
- Lake Clear, Renfrew Co., Ont.*, sphene, 1938—59
- Lake of the Woods, Ont.*, carbonaceous sediments, 1939—141
- LANG (W. A.), anal. by, 1939—124
- Larder Lake, Ont.*, ore minerals, 1941—141
- Laurel, Que.*, diopside, 1938—48; vesuvianite, gem, 1938—47
- Lazulite, *Man.*, 1938—48
- Leadville, Colorado*, pyrite, 1941—110
- LEGGET (R. F.), Clay minerals and engineering, 1943—43
- LEITH (E.), Salt hoppers, *Man.*, 1941—69
- Lillianite = galenobismutite, *Sweden, Tasmania*, 1940—56
- Limonite [goethite], *Pennsylvania, Ont.*, 1940—60
- Lincoln Co., North Carolina*, muscovite, 1943—38, 74
- Loellingite, *Ont.*, 1938—23
- Magnesiochromite, Coleraine Tp., Que.*, anal., unit cell, 1939—75
- Mattawan Tp., Nipissing, Ont.*, muscovite, 1943—31
- Maucherite, *Germany, Ont., Que.*, sp. grav., unit cell, powder pattern, 1940—61; (temiskamite), *Ont.*, 1938—23
- McElroy Tp., Timiskaming, Ont.*, cosalite, 1939—24; 1940—54
- McInnes Lake, Patricia, Ont.*, jaspilite, 1938—46
- MEEN (V. B.), Cancrinite, *Ont.*, 1938—35
- Cleavage-luminescence in mica, *Que.*, 1938—33
- Vesuvianite, *N.W.T.*, 1939—69
- anal. by, 1941—92; x-ray meas. by, 1940—51
- Meneghinite, *Italy, Ont.*, powder pattern, 1940—61; sp. grav., pol. sect., cryst., unit cell, powder pattern, 1941—5
- Mica, *Kilmar, Que.*, opt., 1938—33
- MICHENER (C. E.), v. PEACOCK (M. A.), 1939—95
- MODDLE (D. A.), v. BERRY (L. G.), 1941—5
- Monmouth Tp., Haliburton Co., Ont.*, apatite, gem., 1938—46
- Montenarba, Sardinia, Italy*, ullmannite, 1940—68
- Montgay Tp., Abitibi Co., Que.*, boulangierite, jamesonite (?), plagionite, (?), 1941—25
- Montlucon, France*, semseyite, 1940—65
- Mount Farrell, Tasmania*, lillianite = galenobismutite, 1940—56

- Mullan, Idaho*, boulangerite, 1940—5, 53
- Muscovite, *cryst.*, 1943—33, 65; *North Carolina*, unit cell, 1943—38; *Ont.*, *opt.*, anal., unit cell, 1943—31
- Natrolite, *Man.*, *cryst.*, *opt.*, 1938—20; *Que.*, *cryst.*, *opt.*, anal., 1938—57
- Niccolite, *Ont.*, 1938—23
- Nordmark Mines, Värmland, Sweden*, cosalite, 1939—24; galenobismutite, 1940—56
- NUFFIELD (E. W.), Prehnite, *B.C.*, 1943—49
- & PEACOCK (M. A.), Recrossing dispersion, 1942—53
- Obersdorf, Siegen, Germany*, kallilite, 1940—60
- Ont. Provincial Assay Office*, anal. by, 1939—143, 1940—79, 1941—119
- Ore minerals, unit cells, *sp. grav.*, 1940—47; *Ont.*, 1938—71, 1941—141, 1943—93
- Orford, Que.*, maucherite—1940, 61
- Ornamental stones, *Can.*, 1938—45
- Orthoclase, *Alla.*, *cryst.*, 1938—67
- Oruetite = josite, *Spain*, powder pattern, 1941—96
- OSBORNE (F. F.), Anhydrite & gypsum, *Que.*, 1941—75
- Pseudomorphs after spinel, *Que.*, 1938—39
- Ottawa Co., Que.*, prehnite, 1943—49
- Outpost Islands, Great Slave Lake, N.W.T.*, chalcocite, gold, ferberite, 1939—53
- Pararammelsbergite, *Ont.*, *sp. grav.*, unit cell, 1940—62
- *v.* also rammelsbergite
- PARSONS (A. L.), *Roy. Ont. Mus. Min.*, 1939—7
- Magnesiochromite, *Que.*, 1939—75
- Semi-precious & ornamental stones, *Can.*, 1938—45
- Pd, powder pattern, 1942—31
- Pd-Bi alloys, *prep.*, *sp. grav.*, *pol. sect.*, powder patterns, 1942—19
- Pd, Bi, unit cell, 1942—26
- PdBi, *sp. grav.*, powder pattern, 1942—24
- PdBi₂- α , *sp. grav.*, unit cell, powder pattern, 1942—21
- PdBi₂- β , *sp. grav.*, powder pattern, 1942—23
- Pd₆Bi₃, *sp. grav.*, powder pattern, 1942—25
- PEACOCK (M. A.), Aikinite, 1942—63
- Cinchona alkaloids, 1938—49
- Dyscrasite & antimonial silver, 1940—31
- Josite, grünlingite, oruetite, 1941—83
- X-ray apparatus, 1939—79
- & BERRY (L. G.), X-ray meas. on ore minerals, 1940—47
- & FERGUSON (R. B.), Morphology of muscovite, 1943—65
- & MICHENER (C. E.), Rammelsbergite [pararammelsbergite], 1939—95
- & SMITH (F. G.), Pyrite & Ni-pyrite, cube-edge, 1941—107
- & VIGFUSSON (V. A.), CaB₂O₄·6H₂O, 1939—113
- *v.* BURR (S. V.), 1942—19; *v.* NUFFIELD (E. W.), 1942—53
- Phlogopite, *Que.*, 1938—34
- Pillow lavas, *Ont.*, anal., photos, 1941—119
- Point-groups, derivation of, 1942—33
- POITEVIN (E.), Natrolite, 1938—57
- Poopo, Bolivia*, jamesonite, 1940—58, 1941—7
- Prehnite, *B.C.*, *cryst.*, *opt.*, anal., unit cell, powder pattern, 1943—49; *Que.*, *cryst.*, *opt.*, 1943—49
- Příbram, Bohemia*, boulangerite, powder pattern, 1941—7
- PRINCE (A. T.), Canadian sphene, 1938—59

- Pseudocopiapite = copiapite, 1938—16
 Pseudomorphs after spinel, *Que.*, 1938—39
- Pyrite, sp. resist., powder pattern, 1940—83; *Colorado*, sp. grav., unit cell, 1941—110; *Italy*, unit cell, 1940—62, sp. grav., unit cell, 1941—110; *Man.*, 1938—21
 ——— nickeliforous, *Ont.*, 1941—114; 1938—73; anal., unit cell, pol. sect., powder pattern, 1939—135
- Pyroaurite, *Ont.*, anal., comp., dehyd., opt., 1939—33
- Quartz, concretions, *Man.*, 1942—7; rock crystal, *Que.*, 1938—45
Quebec, *Que.*, School of Mines, 1940—21
- Rathite, *Switzerland*, unit cell, 1940—63
- Rhyolite, *Que.*, anal., 1938—79
Riechelsdorf, *Hesse*, *Germany*, smaltite, 1940—65
Rio Marina, *Elba*, *Italy*, pyrite, 1940—62, 1941—110
- Rocks & minerals, 200 helium age meas., 1941—43
- RUTHERFORD (R. L.), Anthraxolite, *N.W.T.*, 1939—123
 ——— Asterism in selenite, 1940—71
 ——— Kyanite, *B.C.*, 1943—102
 ——— Orthoclase, *Alla.*, 1938—67
- Safflorite, *Ont.*, 1938—23
Sala, *Sweden*, jordanite, 1940—59
Salchendorf, *Siegen*, *Germany*, ullmanite, 1940—68
- Salt-hoppers, *Man.*, 1941—69
San José, *Minas Geraes*, *Brazil*, joseite, 1940—60, 1941—85
- Sartorite, *Switzerland*, unit cell, 1940—64
- SATTERLY (J.), Orbicular gabbro, *Ont.*, 1940—75
 ——— Pillow lavas, *Ont.*, 1941—119
- Scapolite, cat's eye, *Que.*, 1938—47
Scheelite, *B.C.*, 1940—95, 1941—137
- Schneeberg*, *Saxony*, *Germany*, chloanthite, 1940—65; rammelsbergite, 1940—63; smaltite, 1940—65
- Schubkau*, *Schemnitz*, *Hungary*, tetradymite, 1940—67, 1941—96
- Selenite, asterism, 1940—71
- Semi-precious stones, *Can.*, 1938—45
- Semseyite, *France*, *Romania*, powder pattern, 1940—65
- Serpentine, *Que.*, 1938—47
- Serrania de Ronda*, *Malaga*, *Spain*, oruette, 1941—86
- Sherritt Gordon Mine*, *N. Man.*, analcite, chabazite, natrolite, pyrite, siderite, 1938—19
- Siderite, *Man.*, opt., 1938—21
- Sierra Gorda*, *Chile*, copiapite, 1938—12
- Silver, *Ont.*, 1938—23
 ——— antimonial, *Ont.*, pol. sect., unit cell, 1940—41, 51
- Sixteen Island Lake*, *Argenteuil Co.*, *Que.*, sphene, 1938—59
- Skutterudite, *Ont.*, 1938—23, sp. grav., unit cell, 1940—65
- Smaltite, *Germany*, *Morocco*, *Ont.*, *Spain*, powder pattern, 1940—65; *Ont.*, 1938—23
 ——— -chloanthite, *Ont.*, 1938—23
- SMITH (F. G.), Elect. conduct., pyrite, 1940—83
 ——— Iron ores, *Ont.*, 1942—71
 ——— v. PEACOCK (M. A.), 1941—107
- South Lorrain*, *Ont.*, pararammelsbergite, 1940—62
- South Nahanni River*, *N.W.T.*, anthraxolite, 1939—123
- Sphene, *Ont.*, *Que.*, cryst., opt., anal., 1938—59
- Squamish*, *Howe Sound*, *B.C.*, tellurbismuth, 1940—67, 107
- St. Remi d'Amherst*, *Que.*, rock crystal, 1938—45
- Ste-Croix aux Mines*, *Alsace*, stephanite, 1940—66
- Steepprock Lake*, *Atikokan*, *Ont.*, iron ores, 1942—71; limonite [goethite], 1940—60
- Stephanite, *Alsace*, unit cell, 1940—66

- STEVENSON (J. S.), Arsenic, *B.C.*, 1943—83
 ——— Copper - tourmaline - hematite veins, *B.C.*, 1939—127
 ——— Scheelite deposit, *B.C.*, 1940—95
 ——— Stolzite, *B.C.*, 1941—137
 Stolzite, *B.C.*, opt., 1941—137
 Sudbury, *Ont.*, gersdorffite, 1940—57; maucherite, 1940—61; nickeliferous pyrite, 1939—135, 1941—114; ore minerals, 1938—71
 Sulphides, heat effects on, 1941—33
 Sulpho-salt minerals arranged by cell dimensions, 1943—9
 Suzorite (new rock type), *Que.*, anal., 1939—47
Suzor Tp., Lavolette Co., Que., suzorite, 1939—47
 TAYLOR (E. D.), X-ray meas. by, 1940—51
 Tellurbismuth, *B.C.*, artif., sp. grav., unit cell, 1940—67, 109
 Temiskamite = maucherite, 1940—61; *Ont.*, 1938—23
 Tetradymite, *Hungary*, 1940—67; powder pattern, 1941—96
Theftord Asbestos Mines, Que., natrolite, 1938—57
 THOMSON (E.), Boulangerite, columbite-tantalite, *Man.*, 1943—103
 ——— Ore minerals, *Denison Mines, Ont.*, 1938—71
 ——— Kerr-Addison Mines *Ont.*, 1941—141
 ——— Upper Canada Mines, *Ont.*, 1943—93
 ——— & ALLEN (J. S.), Nickeliferous pyrite, 1939—135
 THOMSON (J. E.), Carbonaceous sediments, 1939—141
Tierra Amarilla, Chile, copiapite (pseudocopiapite), 1938—12
Timiskaming, Ont., arsenopyrite, breithauptite, cobaltite, gersdorffite, loellingite, maucherite (temiskamite), niccolite, parammelsbergite (rammelsbergite), safflorite, silver, skutterudite, smaltite-chloanthite, 1938—23
 Tourmaline, *B.C.*, opt., 1939—127
Tremeer Lake, Kenora, Ont., orbicular gabbro, 1940—75
 Triclinic transformations, 1938—8
Tunaberg, Södermanland, Sweden, cobaltite, 1940—54
 Tungstite, *B.C.*, 1941—137
Tyauhton Creek Valley, Bridge River, B.C., scheelite, 1940—95
 Ullmannite, *Germany, Italy*, unit cell, 1940—68
 Vesuvianite, gem, *Que.*, 1938—47, *N.W.T.*, cryst., opt., anal., 1939—69
 VIGFUSSON (V. A.), v. PEACOCK (M. A.), 1939—113
Wabigoon Lake, Dryden, Ont., pillow lavas, 1941—119
 WALKER (T. L.) [1867-1942], obit., 1942—5
 Walker Mineralogical Club, 1938—83, 1939—157, 1940—113, 1941—140, 1942—77, 1943—105
 WARREN (H. V.), Cosalite, *B.C.*, 1939—151— & DAVIS (P.), Bismuth minerals, 1940—107
 Weibullite, mixt., *Sweden*, pol. sect., powder pattern, 1940—68
Wells, Cariboo, B.C., cosalite, galenobismutite, 1940—107; galenobismutite, 1940—56; scheelite, stolzite, tungstite, 1941—137
 Willyamite, *Australia*, unit cell, 1940—69
 WILSON (M. E.), Keewatin lavas, *B.C.*, 1938—75
Wolfsberg, Harz, Germany, zinckenite, 1941—7
 Zeolites, *Man.*, cryst., opt., 1938—19
 Zinckenite, *Germany*, powder pattern, 1941—7