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**Canada**  
**Department of Mines**

Hon. CHARLES STEWART, Minister  
CHARLES CAMSELL, Deputy Minister

**Geological Survey**

W. H. COLLINS, Director

**Bulletin No. 46**

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GEOLOGICAL SERIES, No. 47

JULY 21, 1927

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**CONTRIBUTIONS TO CANADIAN MINERALOGY  
AND PETROGRAPHY**

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OTTAWA  
F. A. ACLAND  
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY  
1927

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**Canada**  
**Department of Mines**

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## BULLETIN No. 46

### CONTRIBUTIONS TO CANADIAN MINERALOGY, 1926

*By Eugene Poitevin*

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## A NEW CANADIAN OCCURRENCE OF PHOSPHORITE FROM NEAR FRANÇOIS LAKE, BRITISH COLUMBIA

The first two lots of the original phosphorite specimens were sent to the Geological Survey simultaneously by J. D. Galloway, now Provincial Mineralogist, Victoria, B.C., and by Mrs. O. Collier, François Lake, B.C. Later on, Mr. G. Hanson collected a large specimen which is represented on Plate I. Recently the writer has received, for museum purposes, half a ton of selected material from Mr. E. M. Dotson, François Lake.

The outcrop from which these specimens were derived is on the farm of Mrs. Collier and about 1,000 feet from her house. The farm is 2 miles northwesterly from the ferry-landing on the north side of François lake. The ferry-landing is 14 miles by motor road from the town of Burns Lake on the Canadian National railway. The discovery is credited to Mr. E. N. Dotson, a brother of Mrs. Collier.

The phosphorite occurs as a small, irregular vein 4 to 12 inches wide, which outcrops at intervals for a distance of about 100 feet. The vein is almost horizontal and probably does not extend far either in length or width. The vein material, which is partly black and partly brown, consists of botryoidal phosphate associated with some asphalt and brecciated andesite.

The geological information regarding Lake François district can be summed up very briefly. G. M. Dawson<sup>1</sup> made a geological reconnaissance of François lake and the area to the south in 1876, and J. D. Galloway,<sup>2</sup> who collected the vein matter for the present study, made a brief examination in 1923 and again in 1924,<sup>3</sup> in company with G. Hanson.

The following account of the mineral occurrence is from the cited report by Hanson.

In the vicinity of Burns and François lakes, the predominant rocks are fragmental and massive volcanic rocks of the Hazelton group (Jurassic). . . . Unconformably on this older basement rest isolated patches of Tertiary sediments and lava flows. The Tertiary rocks were noted especially in the vicinity of François Lake post office, where basaltic lava flows, 100 feet thick, apparently overlie conformably soft, sedimentary rocks. Fossiliferous sediments are present along the northern shore of François lake. The Tertiary rocks do not appear to occupy extensive areas, and the formation is probably only rarely over 200 feet thick. Fossils . . . from these rocks on the northern shore of François lake . . . have been examined by W. A. Bell . . . (who concludes that the formation is) of Upper Eocene age. (The country rock of the vein holding phosphorite, etc.) is basaltic lava, 100 feet thick, and apparently overlies Tertiary sediments . . . The . . . vein lies between basalt walls and has a gentle dip parallel to the dip of the lava flows. . . . The wall-rock is rather friable, and the vein has the appearance of a filling between two flows of lava rather than the filling of a fracture. The possibility is also suggested that the material which gave rise to the phosphate minerals and bitumen accumulated on the surface of one lava flow and was covered by a later lava flow. The phosphate minerals and bitumen may have resulted from guano by a process of distillation in situ occasioned by the heat of the lava.

Galloway states<sup>4</sup> that the occurrence is vein-like . . . and may represent a cooling fracture in the volcanic rock. It is apparent that the fracture was first partly filled with the brown mineral (phosphate); later the asphaltum in a liquid or semi-liquid condition penetrated along the fissure and in places the brown mineral is soaked and

<sup>1</sup>Dawson, G. M.: Geol. Surv., Canada, Rept. of Prog. 1876-77, pp. 17-94 (1878).

<sup>2</sup>Galloway, J. D.: Ann. Rept., Minister of Mines, B.C., 1923, pp. 116-118 (1924); 1924, pp. 101-104 (1925).

<sup>3</sup>Hanson, George: Geol. Surv., Canada, Sum. Rept. 1924, pt. A, pp. 42-43 (1925).

<sup>4</sup>Ann. Rept., Minister of Mines, B.C., 1923, p. 117 (1924).





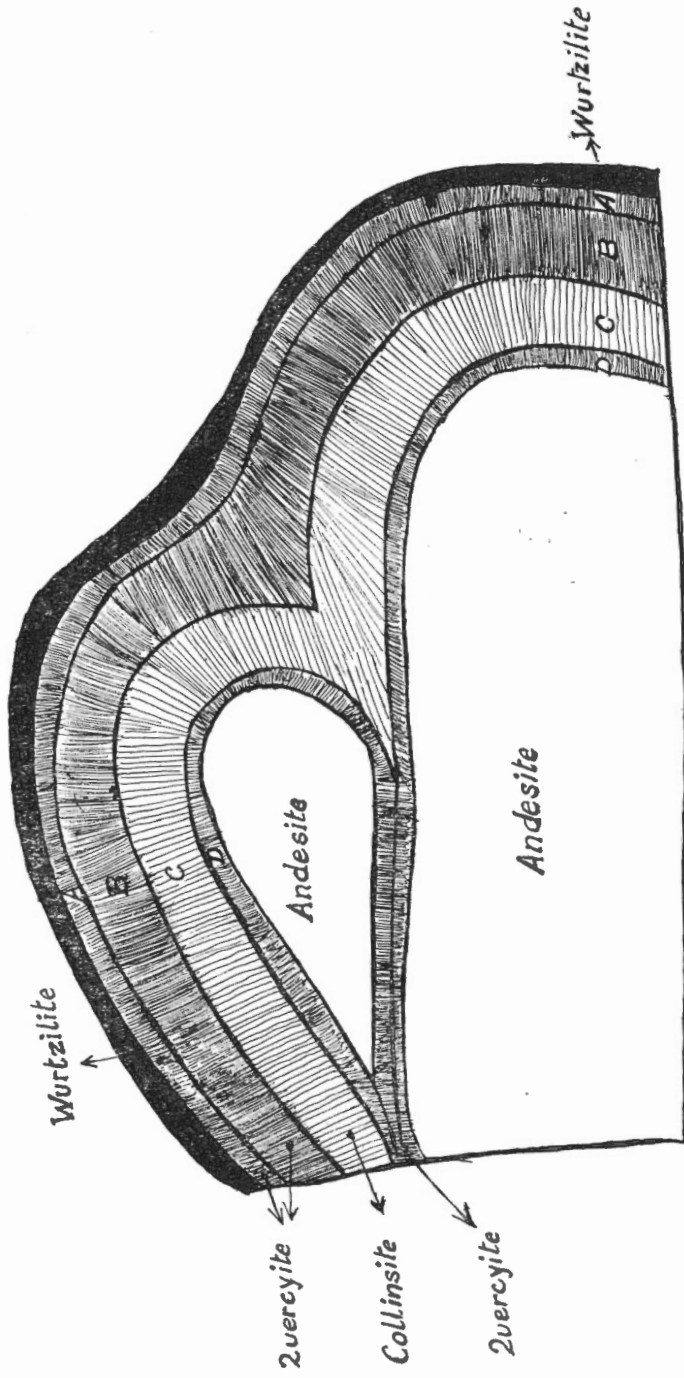


Figure 1. Structure of the phosphate nodules, François lake, B.C. (Natural size.)

the information of American mineralogists. The following extracts from Schaller's paper will facilitate the description of the Canadian phosphorite.

The French phosphorites are of three types: (1) holocrystalline, fibrous; (2) amorphous (isotropic), homogeneous; (3) mixture of the amorphous and holocrystalline.

(1) The holocrystalline, fibrous type is composed of either dahllite or francolite. Dahllite is a hydrous carbonate and phosphate of lime (free from fluorine), francolite and staffelite are considered by Lacroix to be identical, but the name staffelite is kept for the fibrous variety of francolite. Damour's hydroapatite also is francolite. Francolite is similar to dahllite in composition, but contains notable amounts of fluorine.

(2) The amorphous, perfectly isotropic type is composed of the mineral collophanite, which is a hydrous carbonate and phosphate of lime, generally free from any appreciable amount of fluorine, but rarely containing a small amount (fluocollophanite).

(3) The third type is composed of the following minerals, in varying amounts:

(a) Dahllite; (b) francolite (var. staffelite); (c) an unknown mineral, similar to dahllite and francolite in chemical composition, but differing optically from them; (d) collophanite.

This type of phosphorite, composed of an amorphous mineral and one or more crystalline minerals, is called quercyite. If the unknown mineral ((c) above) is absent, the subtype is called  $\alpha$ -quercyite; if the unknown mineral is present, the subtype is called  $\beta$ -quercyite. Quercyite is in many cases formed of alternating layers of  $\alpha$ -quercyite and of  $\beta$ -quercyite.

The Lake François phosphorite is unlike anything that has yet been described. It is essentially an association of quercyite and collinsite, a new mineral which was named after W. H. Collins, Director of the Geological Survey, Canada. A characteristic specimen containing both minerals is illustrated in Figure 1. The three layers A, B, and D are quercyite. They are of variable width and where narrowest have a somewhat wavy structure in addition to their general botryoidal curvature. They are characterized by their dark brown colour and by having a cryptocrystalline appearance. The layer C represents collinsite. This mineral is very prominent and can be easily distinguished from quercyite by its lighter colour and coarser crystallization.

#### COLLINSITE, A NEW MINERAL

The collinsite layers consist of a medium brown mass of elongated blades having their axis approximately perpendicular to the surfaces of the layers. The blades vary in size from 1 centimetre in length by  $\frac{1}{2}$  millimetre in width, to those of microscopic dimensions, and are not grouped with any particular optical orientation. The blades of collinsite are light brown and somewhat translucent, with a silky lustre. The specific gravity is 2.95 and the hardness is 3.5. Before the blowpipe the mineral fuses, with intumescence, at 3 into a brownish slag. It is easily soluble in acid and gives a strong reaction for water in the closed tube. Since quercyite decrepitates and does not fuse before a blowpipe, collinsite may be easily distinguished from it by a simple fusibility test.

#### *Optical Properties*

The collinsite blades lack crystallographic forms and in order to determine the relationships between the optical and the crystallographic elements, the writer employed the Fedoroff method as revised by Nikitin, using the universal stage on a microscope specially designed for the purpose.

By oil immersion on crushed fragments the indices of refraction were found to be as follows:

$$\alpha = 1.632 \pm 0.003; \beta = 1.642 \pm 0.003; \gamma = 1.657 \pm 0.003.$$

The birefringence is positive and as calculated from the above figure is:

$$(\gamma - \alpha) = 0.025; (\beta - \alpha) = 0.010; (\gamma - \beta) = 0.015.$$

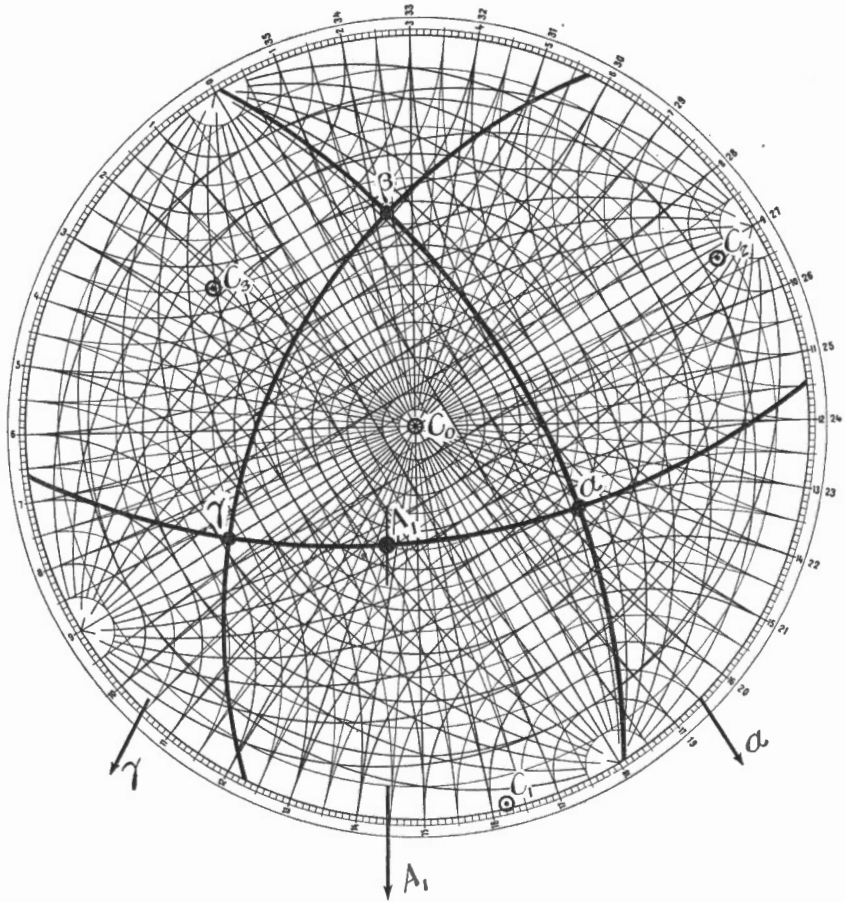


Figure 2. Collisite from lake François, B.C. Optical and crystallographic elements plotted on the stereographic plat of Fedoroff. ( $C_0$ ,  $C_1$ ,  $C_2$ , and  $C_3$  are cleavages.)

The elongation was also determined to be positive.

The results of an extensive study using the Universal stage are presented in Figure 2, constructed with a Fedoroff stereographic plat as a basis.

Examination of the figure ( $C_0$  is the best cleavage) shows that  $\gamma$  being the acute bisectrix, the mineral is positive; it shows also that  $2V = 80^\circ$  and that four cleavages, numbered  $C_0$ ,  $C_1$ ,  $C_2$ ,  $C_3$  in order of perfection, have

no symmetrical relationship with the axial plane and hence that the mineral can be safely assigned to the triclinic system. Using a special compass designed by Fedoroff the cleavage angles were determined to be as follows:

$$\begin{aligned} C_0 \wedge C_1 &= 88^\circ 40' \\ C_1 \wedge C_2 &= 108^\circ 00' \text{ or } 72^\circ \\ C_2 \wedge C_3 &= 111^\circ 00' \text{ or } 69^\circ \\ C_1 \wedge C_3 &= 131^\circ 00' \text{ or } 49^\circ \end{aligned}$$

Likewise the angles between the normal to the axial plane and the normals to cleavages were found to be:

$$\beta \wedge C_1 = 150^\circ; \beta \wedge C_2 = 66^\circ; \beta \wedge C_3 = 44^\circ.$$

These last figures fully locate the position of the axial plane with respect to the cleavages. Again, from the plat it may be seen that, owing to their large polar distances, the  $\gamma$  and  $\beta$  axes could not, respectively, be brought into parallel position with the microscope tube by tilting the stage. It was possible, however, to do so in the case of the  $\alpha$  axis and, therefore, to calculate the birefringence ( $\gamma - \beta$ ). The actual amount of retardation  $R_1$  of one of the rays transmitted by the crystal plate behind the other was measured with a babinet compensator, whereas the thickness of the mineral section was determined by Nikitin's method using a micrometer ocular. The value  $(\gamma - \beta) = 0.015$ , thus obtained, is exactly what was determined by calculation from the indices of refraction.

As shown in the chemical discussion farther on, collinsite belongs to the Roselite group. This being so, and because of the correspondence of the measured angles in the two minerals as tabulated below, it follows that the cleavages in collinsite correspond in all probability to the faces indicated in the same table.

<i>Roselite</i>	<i>Collinsite</i>
Mm = $48^\circ 47'$	$C_1C_2$ $49^\circ$
CM = $89^\circ 20'$	$C_0C_1$ $88^\circ 40'$
bm = $66^\circ 09'$	$C_2C_3$ $69^\circ 00'$
bM = $65^\circ 03'$	$C_1C_3$ $72^\circ 00'$
C (001)	$C_0$
b (010)	$C_2$
m (110)	$C_3$
M ( $\bar{1}\bar{1}0$ )	$C_1$

### *Chemical Properties*

Material suitable for analysis was carefully prepared by the writer, and through the courtesy of the Chemical Division of the Mines Branch the analytical work was carried on in duplicate by Mr. E. A. Thompson, with the following results:

	1	Molecular ratio		2
P <sub>2</sub> O <sub>5</sub> .....	39.83	0.280	0.280 = 1 x 0.280	37.72
CaO.....	32.18	0.575	0.575 = 2 x 0.287	31.11
FeO.....	6.86	0.095		15.63
Fe <sub>2</sub> O <sub>3</sub> .....	0.80	0.005		
Mn <sub>2</sub> O <sub>3</sub> .....	0.36	0.005		
MnO.....			0.268 = 1 x 0.268	trace
Al <sub>2</sub> O <sub>3</sub> .....	0.39	0.004		
MgO.....	6.34	0.159		1.45
F.....	0.27	0.014		
CO <sub>2</sub> .....	0.23	0.006	0.710 = 2½ x 0.284	
H <sub>2</sub> O -105.....	0.15	0.690		
+105.....	12.28			12.15
C.....	0.18			
SiO <sub>2</sub> .....	0.10			Insol. 1.40
	99.97			99.46
Less O				
Equivalent to F.....	0.11			
	99.86			

(Cr, Na, K, Sn, Ba, Ti, Cl, and WO<sub>3</sub> were absent.)

Analysis 1. Collinsite from lake François, B.C., by E. A. Thompson.

Analysis 2. Composition of messelite is given for comparison. E. S. Dana, "System of Mineralogy," p. 812.

The formula for collinsite derived from the above ratios may be written P<sub>2</sub>O<sub>5</sub> Ca<sub>2</sub> (Mg Fe) 2½ H<sub>2</sub>O in which the magnesium oxide is decidedly in excess of the ferrous oxide. Thus, collinsite is a new mineral representing the magnesium end member of an isomorphous series of which messelite represents the iron end. The formula for messelite is given by Dana<sup>1</sup> as P<sub>2</sub>O<sub>5</sub> (CaFe)<sub>2</sub> 2½ H<sub>2</sub>O. Since the calcium oxide content seems to be constant for collinsite and messelite, Dr. Wherry<sup>2</sup> suggests that in the formula the calcium should not be included with the iron and magnesium in a parenthesis to show isomorphism, but that the parenthesis contains only Mg and Fe. The C and SiO<sub>2</sub> are no doubt derived respectively from wurtzilite and andesite impurities and the F and CO<sub>2</sub> may be due to some admixed quercyite.

Collinsite and messelite may be briefly compared as follows:

	Collinsite	Messelite
Crystallography.....	Triclinic.....	Triclinic
Optically.....	+	+
2V.....	80°	Medium
α.....	1.632	1.640
β.....	1.642	1.653
γ.....	1.657	1.680
Birefringence.....	0.025	0.040
Gravity.....	2.95	3.00
Hardness.....	3-3.5	3-3.5
Composition.....	P <sub>2</sub> O <sub>5</sub> Ca <sub>2</sub> (Mg Fe) 2½H <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub> Ca <sub>2</sub> (Fe Mg) 2½ H <sub>2</sub> O
Ratio of MgO to FeO.....	62.6 : 37.4	14.2 : 85.8

<sup>1</sup>Dana, E. S.: "A System of Mineralogy," p. 812.

<sup>2</sup>Private communication.

If the refractive indices for collinsite and messelite are plotted with respect to their magnesium and iron oxides content it is feasible by extrapolation to obtain approximate values of the indices for the possible pure end members of the series, that is, the pure magnesium and the pure iron compounds (See Figure 3). The pure magnesium compound will be optically negative and have approximately the following indices:

$$\alpha = 1.623; \beta = 1.633; \gamma = 1.640.$$

The pure iron compound will be optically positive and have:

$$\alpha = 1.648; \beta = 1.657; \gamma = 1.687.$$

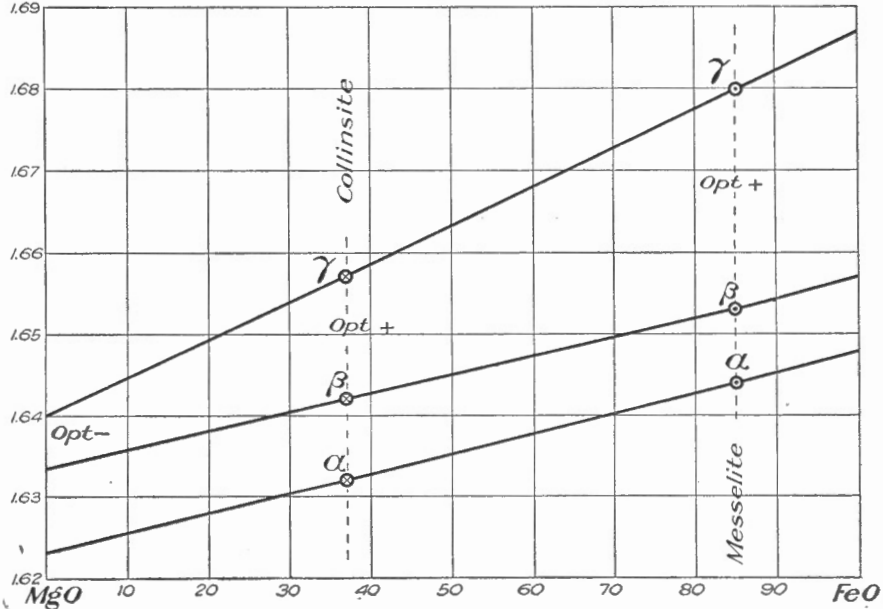


Figure 3. Refractive indices of the collinsite-messelite series.

#### QUERCYITE

As already stated the British Columbia phosphorite is composed of collinsite, wurtzilite, and quercyite. The name quercyite is given to a substance which was found to have the same chemical composition as the original material described by Lacroix under that name.

Another factor which would seem to strengthen the view that the British Columbia mineral is typical quercyite is that a microphotograph of a thin section made from it (Plate II) is practically identical with a microphotograph of French quercyite given by Alfred Lacroix in the "Mineralogy of France."<sup>1</sup> On the other hand the original quercyite is described as an admixture of dahllite or francolite, with variable proportions of isotropic collophanite. Microscopic examination reveals that the Canadian quercyite is practically composed of one mineral, probably closely related to the fibrous form of francolite. The mean refractive

<sup>1</sup>Lacroix, Alfred: Tome Quatrieme, 2e Partie, fig. 1, p. 580.

index for quercyite is given by Lacroix as 1.608. The figures obtained for the British Columbia mineral are quite different, and are as follows:

$$\alpha = 1.613 \pm 0.002; \beta = 1.626 \pm 0.002; \gamma = 1.629 \pm 0.002.$$

Thus the birefringence is slightly higher than that of dahllite or francolite. The Canadian quercyite is distinctly biaxial with  $2V = 5^\circ$  to  $10^\circ$ . The specific gravity of French quercyite varies from 2.83 to 2.87, whereas the density of Canadian quercyite is 3.04, a figure closer to the gravity of pure francolite than to the original quercyite. The British Columbia quercyite has a hardness of 4.5. It does not fuse under the blowpipe, but decrepitates violently, emitting a perceptible amount of volatile matter.

Material carefully prepared by the writer was analysed in duplicate by E. A. Thompson of the Mines Branch. The average of these two analyses is given below in column 1; the other three analyses are quoted from Lacroix's "Mineralogy of France."

#### *Analysis of Quercyite*

—	1	2	3	4
P <sub>2</sub> O <sub>5</sub> .....	34.96	37.60	36.60	37.75
CaO.....	50.22	51.85	50.45	52.50
FeO.....	1.90			
Fe <sub>2</sub> O <sub>3</sub> .....	0.12	Fe <sub>2</sub> O <sub>3</sub> } Al <sub>2</sub> O <sub>3</sub> }	1.30	0.85a
Mn <sub>2</sub> O <sub>3</sub> .....	0.12			
Al <sub>2</sub> O <sub>3</sub> .....	0.60			
MgO.....	0.62			
F.....	1.83	1.50	0.83	
CO <sub>2</sub> .....	5.45	4.00	4.62	5.70
H <sub>2</sub> O + 105.....	4.20	4.80	6.00	3.20
SiO <sub>2</sub> .....	0.19			
C.....	0.82			
	101.03			
Less O equiv. to F.....	0.77			
	100.26	99.75	99.80	100.00

No. 1 (Cr, Na, K, Sn, Ba, Ti, SO<sub>2</sub>, Cl, and WO<sub>3</sub> were absent.)

Analysis 2. From Mouillac, Tarn-et-Garonne, France.

Analysis 3. From Mouillac, Tarn-et-Garonne, France.

Analysis 4. From Belmez, Cordova, Spain.

a—Contains a little F.

From analyses 1 to 4 given above, the following molecular ratios are obtained:

#### *Molecular Ratios, Quercyite Analyses*

—	1	2	3	4	Average
CaO.....	0.896	0.926	0.900	0.937	
P <sub>2</sub> O <sub>5</sub> .....	0.246	0.264	0.257	0.265	
F.....	0.096	0.080	0.043		
CO <sub>2</sub> .....	0.124	0.090	0.105	0.130	
H <sub>2</sub> O.....	0.233	0.270	0.333	0.180	
CaO.....	100	100	100	100	100
P <sub>2</sub> O <sub>5</sub> .....	27	28	28	27	27½
F.....	10	9	5		8
CO <sub>2</sub> .....	13	10	10	13	11½
H <sub>2</sub> O.....	26	28	37	19	27½

The quercyite from British Columbia is certainly not pure francolite nor dahllite as the following ratios show:

Molecular ratio	(Quercyite)	(Dahllite)	(Francolite)
	1	2	3
CaO.....	100	100	100
P <sub>2</sub> O <sub>5</sub> .....	27	29	29
F.....	10	.....	18
CO <sub>2</sub> .....	13	12	7
H <sub>2</sub> O.....	26	10	9

Analysis 1. Quercyite, B.C.

Analyses 2 and 3. Schaller, W. T.: U.S. Geol. Surv., Bull. 509, Mineralogical Notes, ser. 2, pp. 98 and 99 (1912).

It appears to be typical quercyite which carries an appreciable amount of collophanite, but this contradicts the results furnished by microscopical examination, as these show the British Columbia quercyite to be composed of one definite mineral having characteristic indices of refraction, birefringence, and specific gravity. The simple formula  $3\text{CaO P}_2\text{O}_5 \text{CaO CO}_2 \text{H}_2\text{O } \frac{1}{2}\text{CaF}_2$  derived from chemical analysis strongly suggests that quercyite may not only be one mineral but a new one. Further research on foreign quercyite should prove very interesting.

#### ORIGIN OF PHOSPHORITE

The phosphate deposit at François Lake has not been examined in detail, consequently it is not definitely known how the phosphates formed. The deposit in some respects is similar to a deposit of quercyite referred to by Professor Lacroix<sup>1</sup>, which is found at Bozouls in the department of Aveyron, France, and which unlike other French quercyite deposits does not occur in limestone but in basaltic tuffs. The quercyite occurs as concretions here and there in the eruptive rocks. Professor Lacroix does not attempt to describe the origin of this particular deposit. It might be of interest, however, to give his views on the origin of the deposits which occur in the limestone.

Following a long period of marine invasion in the beginning of Tertiary time, caverns and fissures were made in the limestone. These were later on (in Eocene and Oligocene time) filled with debris from running water in a fashion somewhat similar to the one seen today in action in caverns. Clays which were residual products of limestone were concentrated in these caverns. The remains of animals who once lived in these caverns or were carried there by running water yielded phosphate to solutions which attacked the limestone walls, and also added themselves to the lime phosphate already contained in the residual clays. Running water carrying carbonic acid remanipulated these phosphates and determined their crystallization as concretions in clay or on the walls of the caverns. The importance of the role played by carbonic acid is strongly put in evidence by the fact that it is an essential element of all the phosphate deposits. At Hérault, where numerous interesting deposits of phosphate occur, a blue Oxfordien limestone is found containing large amounts of bats' bones, and the brain is sometimes entirely transformed into phosphate.

Mr. G. Hanson believes that the phosphorite of lake François is a filling between two flows of lava rather than the filling of a fracture. He also suggests that the material of the vein accumulated on the surface

<sup>1</sup>Loc. cit.  
37233-2



of one lava flow, and was covered by a later lava flow. According to him, the phosphate minerals and bitumen have probably resulted from guano or other organic material by a process of distillation in situ occasioned by the heat of the lava. Without consulting Mr. Hanson, the writer had arrived at the same conclusion, and would say further that careful prospecting in similar geological horizons will probably be rewarded by the discovery of deposits which might have more favourable commercial chemical composition (that is to say—freedom from iron, magnesium, and alumina).

### Other Identified Minerals Associated with the Phosphates and the Brecciated Andesite

#### VIVIANITE

Vivianite occurs sparingly in several specimens as a thin crust on wavy veinlets of quercyite. It probably has been derived from quercyite through the action of iron-bearing solutions.

#### PYRITE

Small cubes of iron pyrites were recognized in several specimens of andesite.

#### OLIVINE

Olivine is an important constituent of a basalt collected in the vicinity of the phosphate occurrence.

#### CALCITE

Natrolite, heulandite, and chalcedony were observed filling geodes which are abundant in the andesite associated with the phosphate-bearing vein.

#### QUARTZ

Some quartz crystal aggregates of common habit, a few millimetres long, coat the quercyite-collinsite nodules. They appear to be older than the asphalt.

### OPTICAL PROPERTIES OF CHEMICALLY ANALYSED FERROPREHNITE FROM ADAMS SOUND, BAFFIN ISLAND

Although prehnite is a common mineral and often has been described and analysed, very little data regarding its refractive indices have so far been published. Johannsen, Larsen, Winchell, Iddings, Dana, and others, in their text books give the same indices and apparently derived them from the work of Levy and Lacroix on prehnite from Ratschinges, Tyrol. These indices are as follows:

$$\alpha = 1.616, \beta = 1.626, \gamma = 1.649.$$

They are of a prehnite having the following composition:

*Prehnite from Ratschinges, Tyrol*

	Per cent
SiO <sub>2</sub> .....	43.40
Al <sub>2</sub> O <sub>3</sub> .....	24.53
Fe <sub>2</sub> O <sub>3</sub> .....	.....
CaO.....	27.37
H <sub>2</sub> O.....	4.48
Total.....	99.78

Dana's Textbook<sup>1</sup> contains fourteen analyses of prehnite differing considerably from one another, but only a slight variation of the axial angle and of the birefringence has been observed on prehnite from various localities, although the varying chemical composition strongly suggests that their refractive indices should appreciably differ. A few years ago, R. A. A. Johnston<sup>2</sup> described a prehnite from Adams sound containing 6.89 per cent of ferric oxide, to which variety the name ferroprehnite was given. This prehnite is somewhat similar in composition to a prehnite from Cornwall, Pennsylvania, analysed by Genth. The present writer undertook the determination of the optical properties of the ferroprehnite from Adams sound in order to compare them with those of the Ratschinges prehnite which is free from iron.

The ferroprehnite examined under the microscope came from the same specimen that furnished the material analysed by Johnston. The principal constituents of the specimen, which has a granitic structure, are quartz, calcite, and ferroprehnite, all intimately associated. The colour of the ferroprehnite is light apple green, but in thin section it is colourless. Thus in physical appearance it does not differ from common prehnite.

The axial plane is either parallel to b(010) or to a(100); the mineral is biaxial and positive; and the cleavage angle  $m \wedge m = 80^\circ$ . The indices of refraction carefully measured were found to be as follows:

$$\alpha = 1.632 \pm 0.001; \beta = 1.642 \pm 0.001; \gamma = 1.665 \pm 0.001.$$

2V measured =  $68^\circ 10'$ , and calculated from the above figures is = to  $67^\circ 38'$ . Thus the Ratschinges prehnite which represents one pole of a series may be compared as follows with the ferroprehnite of Adams sound representing the other pole.

	Ratschinges, Tyrol	Adams sound, Baffin island
SiO <sub>2</sub> .....	43.40	41.85
Al <sub>2</sub> O <sub>3</sub> .....	24.53	20.36
Fe <sub>2</sub> O <sub>3</sub> .....	.....	6.89
CaO.....	27.37	26.70
H <sub>2</sub> O.....	4.48	4.19
Total.....	99.78	100.00
Specific gravity.....	2.90	2.924 at 15.5°C.
$\alpha$ .....	1.616	1.632
$\beta$ .....	1.626	1.642
$\gamma$ .....	1.649	1.665
2V calculated.....	67° 40'	67° 38'

<sup>1</sup>Dana, E. S.: "A System of Mineralogy," p. 531.

<sup>2</sup>Johnston, R. A. A.: Geol. Surv., Canada, Bull. No. 1, pp. 95-98 (1913).

ZIRCON FROM DUNGANNON TOWNSHIP, HASTINGS  
COUNTY, ONTARIO

The specimens which furnished the material for this note were obtained from lots 12 and 13, concession XI, Dungannon township, Hastings county, Ontario, and were collected by Dr. W. F. Ferrier in 1896. They consist of a coarse-grained nepheline syenite characterized by the presence of zircon crystals which are abundantly disseminated through it. Dr. F. D. Adams<sup>1</sup> in his study of this rock mentions the occurrence of zircon, but does not give any description of the crystals. The zircon crystals do not seem at first inspection to be of any special interest. They vary in size from those of microscopic dimensions to others 5 mm. in diameter. Although dull,

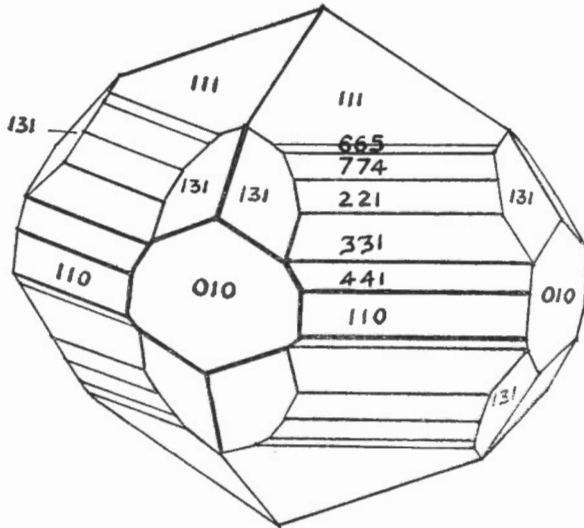


Figure 4. Zircon from Dungannon township, Hastings county, Ontario.  
Crystal showing new forms 665 and 441.

and in appearance crystallographically simple, when placed on the goniometer they prove to be excellent material for measurement. Parallel growth was observed, but no sign of twinning could be detected. These crystals are essentially of pyramidal habit (Figure 4). As a rule the unit prism  $m(110)$  is small or missing, the unit pyramid  $s(111)$  is always a large face, whereas the diametrical prisms  $a(010)$  and the ditetragonal pyramids  $\lambda(131)$  are of medium size. The other unit pyramids  $221$ ,  $231$ , etc., can only be observed as mere truncations.

The following forms were measured on the two-circle goniometer:

$a(010)$ ;  $m(110)$ ;  $s(111)$ ;  $\lambda(131)$ ;  $\varphi(774)$ ;  $\pi(331)$ ;  $\rho(221)$ ;  $*(441)$ ;  $*(665)$ .

The last two forms have not so far been recorded. The angular measurements obtained agree closely with the figures accepted by Goldschmidt, and for this reason it has not been thought necessary to recalculate the axial ratios.

<sup>1</sup>Adams, F. D.: Am. Jour. Sci. and Arts, vol. XLVIII, pp. 10-16 (1894).

For the calculation of  $\varphi$  and  $\rho$  of the new forms 441 and 665 the accepted figures were used.

	Calculated		Measured	
	$\varphi$	$\rho$	$\varphi$	$\rho$
*665.....	45° 00'	47° 23'	45°	47° 55'
*441.....	45° 00'	74° 34'	45°	74° 35'

\*New forms.

### EPIDESMINE FROM THETFORD MINES, MEGANTIC COUNTY, QUEBEC

This mineral was collected by the writer on the dump of the King asbestos pit. It was found in a slightly altered granitic rock which contained a number of vugs appearing at first to be entirely filled with calcite. Examination of the material under the binocular microscope reveals, in addition to the calcite, the presence of minute, yellowish white, prismatic crystals older than the carbonate. On the edge of the vugs some orthoclase cleavages fresh and altered are also visible.

The yellowish white prismatic mineral which is referred to here as "epidesmine" is not available in sufficient quantity to afford a complete chemical analysis. By qualitative examination it was found to be an hydrated silicate of aluminium and calcium. Sodium and potassium were identified by microchemical tests. The mineral fuses with intumescence, behaving like scolecite under the blowpipe. Its specific gravity after careful manipulation with heavy liquids was found to be 2.16.

The crystals, which range in size from microscopic to individuals 3 mm. in length, are not suitable material for the goniometer. Only the three pinacoid are measurable and their interfacial angle is 90°. This mineral is biaxial, negative, and orthorhombic. The refractive indices are:

$$\alpha = 1.485 \pm 0.002 \text{ and } \gamma = 1.501 \pm 0.002.$$

These figures are almost identical with those given by Larsen.<sup>1</sup>

Thus the composition and the optical properties of the Thetford mineral are those of epidesmine, a mineral from Schwarzenberg, which has the composition of stilbite, but differs otherwise and was described and named by V. Rosicky and St. J. Thugutt in 1913.<sup>2</sup>

### HALOTRICHITE FROM ASHCROFT, B.C.

In 1918 Mr. Mandell of Vancouver submitted to Mr. Charles Camsell, then geologist in charge of the Vancouver office of the Geological Survey, specimens which were eventually transferred to the Division of Mineralogy for investigation. Later on, L. Reinecke collected the same substance as a loose block in a tunnel on Mr. M. Ahearn's ranch, 17 miles from Ashcroft and east of Bonaparte road, B.C.

<sup>1</sup>Larsen, E. S.: U.S. Geol. Surv., Bull. 679, p. 243.

<sup>2</sup>Dana, E. S.: See Appendix No. 3.

These specimens of halotrichite appear to be vein material. They display a columnar structure and certain parts of their mass carry considerable disseminated iron pyrites and some massive and crystallized gypsum. This halotrichite, when fresh, looks somewhat like asbestos. It forms greenish white, silky fibres, several inches in length, but unfortunately, when exposed to ordinary atmospheric conditions, it soon becomes yellowish, dull, and pulverulent. The mineral tastes inky-astringent, and is essentially composed of sulphur trioxide, alumina, iron protoxide, and water. The halotrichite under consideration has a large extinction angle and the following indices of refraction:

$$\alpha = 1.482 \pm 0.003; \gamma = 1.487 \pm 0.003.$$

#### TREMOLITE CRYSTALS FROM ADMASTON TOWNSHIP, RENFREW COUNTY, ONTARIO

Amongst several specimens collected by F. J. Alcock from a zinc prospect on lot 2, concession III, Admaston township, Renfrew county, Ontario, there was one of special interest. It consisted of an association of calcite, tremolite crystals, feathery tremolite, and a little sphalerite. The tremolite crystals measured up to 1 cm. in length and were colourless, white, or greyish. On the two-circle goniometer a few crystals yielded the following forms:

$$a(100), b(010), m(110), e(130), l(101), r(\bar{1}11).$$

These crystals are optically negative. The maximum extinction angle in the vertical zone is  $16^\circ$ . The axial plane is parallel to  $b(100)$  and  $\beta$  was found to be 1.622. The optical properties of the feathery tremolite do not differ from those of the well-crystallized variety.

It was observed that the tremolite crystallized before the deposition of the sphalerite.

#### YELLOWISH BARITE FROM PORT ARTHUR, ONTARIO

The specimen containing the barite here described consisted of an association of green, purple, and colourless fluorite, white massive barite, and crystals of yellow barite. The locality as given by the collector, Mr. T. L. Tanton, is the west boundary of the city limit of Port Arthur.

The yellow barite crystals are excellent material for goniometer measurements. They have the common tabular habit, and although small, some individuals measure one centimetre in diameter. The prism zone is missing or is represented by mere truncations. The base and the domes are the predominant forms. The following forms were identified:

$$b(010), a(100), m(110), n(120), d(102), l(104), o(011), c(001).$$

The indices of refraction determined by the oil-immersion method were found for sodium light to be:

$$\alpha = 1.637 \pm 0.003; \beta = 1.638 \pm 0.003; \gamma = 1.648 \pm 0.003.$$

#### ALUNOGEN FROM VERNON, B.C.

The specimens holding alunogen were collected by Mr. James L. Silver and were said to occur near Vernon, B.C., in a vein 9 inches wide. The material is not uniform in mineral composition. Quartz, epsomite, and

other minerals are readily seen. The following analyses were made in the chemical laboratory of the Central Experimental Farm under the direction of Dr. F. T. Shutt, Dominion Chemist, who submitted the specimens to the writer.

	No. 63124	No. 63489
Mineral matter insoluble in water.....	21.25	18.35
Aluminium sulphate $(Al_2(SO_4)_3 \cdot 18 H_2O)$ .....	59.55	53.63
Magnesium sulphate $MgSO_4 \cdot 7 H_2O$ .....	18.73	26.87
Iron, soda, etc., by difference.....	0.47	1.15
	100.00	100.00

The alunogen is easily recognized. It occurs as minute, acicular, or capillary, pinkish white crystals forming intricate masses or filling druses. The indices of refraction of the minute alunogen crystals were found to be as follows:

$$\alpha = 1.463 \pm 0.003; \beta = 1.475 \pm 0.003; \gamma = 1.483 \pm 0.003.$$

#### WOLFRAMITE FROM MUD CREEK, ROCHER DÉBOULÉ MOUNTAINS, NEAR HAZELTON, B.C.

The specimen which furnished the material for this note was forwarded by Mr. H. H. Little of Hazelton, B.C. It consisted of a granular wolframite yielding a few incomplete crystals on disintegration. The specimen came from a quartzose stringer in a shear zone of granodiorite on Mud creek. J. J. O'Neill<sup>1</sup> has reported the presence of wolframite from the Black Prince group of claims, which are situated in the neighbourhood of Mud creek.

The crystals of wolframite suitable for measurement were small, of prismatic habit, and flattened parallel to the macro pinacoid. The forms identified were:

$$a(100); m(110); b(010); \text{ and } *(130).$$

The last form is not given in Goldschmidt Winkeltabellen and is probably a new form.

	Calculated		Measured	
	$\varphi$	$\rho$	$\varphi$	$\rho$
*130.....	21° 59'	90° 00'	22° 05'	90° 00'

\*New form.

#### ZIRCON FROM MONMOUTH TOWNSHIP, HALIBURTON COUNTY, ONTARIO

A beautiful crystal of zircon, 15 mm. in length by 7 mm. in diameter, was collected by M. E. Wilson at the mine of the Molybdenum Products Company, Limited, on lot 33, concession XVI, Monmouth township, Haliburton county, about one-half mile from the village of Wilberforce.

<sup>1</sup>O'Neill, J. J.: Geol. Surv., Canada, Mem. 110, pp. 25, 26 (1919).

This crystal is of prismatic habit, showing the unit prism  $m(110)$  as the predominating form. The diametrical prism  $a(010)$  is a mere truncation. The base  $c(001)$  is very minute—on the other hand the unit pyramids are large forms.

The following forms were identified:

$a(010)$ ,  $m(110)$ ,  $c(001)$ ,  $s(111)$ ,  $\pi(331)$ . (Goldschmidt's letters.)

### TOURMALINE FROM BAGOT TOWNSHIP, RENFREW COUNTY, ONTARIO.

The tourmaline crystals described below were collected by M. E. Wilson on lot 15, concession X, Bagot township, Renfrew county, Ontario. They occur in crystalline limestone at the immediate contact with a granite dyke. By dissolving the carbonate of lime in a weak acid solution the crystals were freed from their matrix. They were found to be for the most part prismatic in habit, black in colour, and somewhat brittle. They range in size from microscopic to individuals more than 1 centimetre long. Many crystals were measured on the two-circle goniometer and the following forms were identified:

Large forms:  $\bar{2}\bar{2}41$ ;  $P:(7\bar{1}\bar{8}1)$ ;  $p(1\bar{1}\bar{2}1)$ ;  $a(1\bar{0}\bar{1}0)$ ;  $b(1\bar{1}\bar{2}0)$ .

Small forms:  $c(0001)$ ;  $m'(44\bar{8}1)$ ;  $\omega(31\bar{4}0)$ ;  $\eta(21\bar{3}0)$ ;  $(4\bar{1}\bar{5}0)$ ;  $*(\bar{2}\bar{1}.\bar{7}.28.4)$ ;  $*(\bar{9}.\bar{5}.14.1)$

To calculate the  $\varphi$  and  $\rho$  of the two new forms  $(\bar{2}\bar{1}.\bar{7}.28.4)$  and  $(\bar{9}.\bar{5}.14.1)$  Goldschmidt's accepted figures were used.

Calculated		Measured	
$13^{\circ} 54'$ 20 38	$62^{\circ} 01'$ 74 45	$14^{\circ} 01'$ 20 56	$61^{\circ} 50'$ 74 46

### SCOLECITE FROM THETFORD MINES, MEGANTIC COUNTY, QUEBEC

Although there are several Canadian localities rich in zeolites, up to date only three were known where scolecite was to be found.<sup>1</sup> Recently the writer collected the mineral at the Jacob asbestos pit within the city of Thetford Mines. At this place very fine crystals of scolecite occur filling fissures in a highly altered, fine-grained leucocratic rock which on microscopic examination shows microcline, albite, biotite, and their alteration products. The particular specimen under examination did not contain any quartz. The veinlets have a minimum width of 2 centimetres. They are filled with scolecite crystals which have grown outward from both sides of the fissures and are somewhat interlocked. Very minute acicular crystals of brownish red diopside orientated in all directions and attached to the wall of fissure, lie in the scolecite crystals. Thus the diopside was a well-crystallized species when scolecite crystals began to grow.

<sup>1</sup>Nova Scotia. Cumberland county, cape D'Or and Two Islands. (N.S. Inst. Nat. Sci., vol. 5, p. 293.)  
Quebec. Megantic county, Black Lake (Geol. Surv., Canada, vol. v, pt. A, p. 68).  
Poitevin and Graham: Geol. Surv., Canada, Mus. Bull. 27, p. 63.

The scolecite crystals range in size from microscopic to individuals 3 millimetres in diameter, their maximum length being  $1\frac{1}{2}$  centimetres. As a rule that part of a crystal close to the walls of the vein is opaque and milky white; the other end is colourless and translucent. Triangular corrosion figures are occasionally visible on the unit pyramid. Simple scolecite crystals are rare. Many that appear to be a single crystal on closer examination are found to be a group of crystals with  $a(100)$  as twinning plane and attached to one another with  $b(010)$  as a common

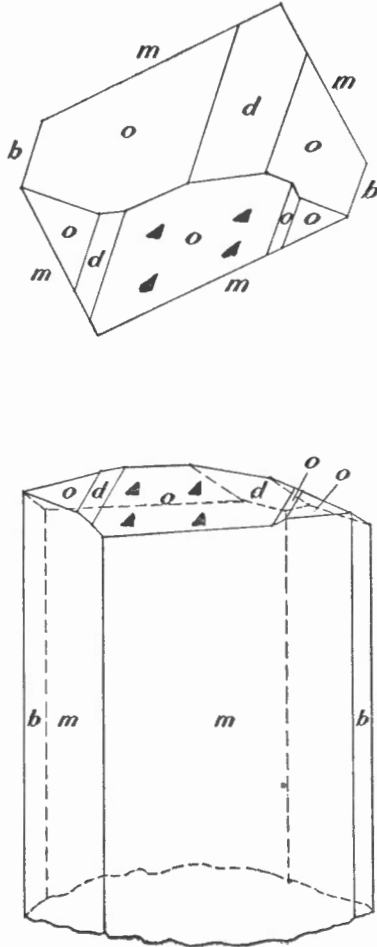


Figure 5. Orthographic and clinographic projections of scolecite from Thetford Mines, Megantic county, Quebec.

face. Otherwise the scolecite crystals are simple in habit. An actual crystal is represented in Figure 5. Several crystals were measured, but only the following forms could be identified:

(According to Goldschmidt)  $b(010)$ ;  $a(100)$ ;  $m(110)$ ;  $d(101)$ ;  $o(111)$ .



The mineral is optically negative and its elongation is also negative. The acute bisectrix makes an angle of 16 degrees with C in the obtuse angle  $\beta$ .

$$\alpha = 1.513 \pm 0.001; \beta = 1.519 \pm 0.001; \gamma = 1.520 \pm 0.001.$$

Thus the birefringence ( $\gamma - \alpha$ ) = 0.007 is weak.

### BARITE FROM MADOC TOWNSHIP, HASTINGS COUNTY, ONTARIO

Hastings county is well known from the handsome specimens of green fluorite it has furnished many American museums. The encrustation of crystalline barite, which generally covers the fluorite, does not, as a rule,

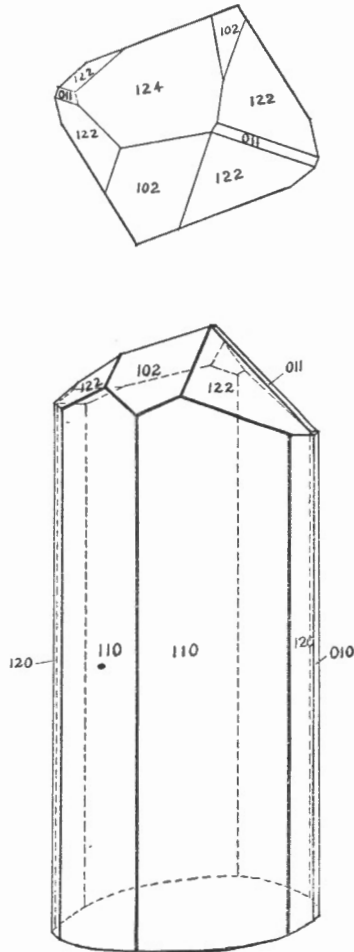


Figure 6. Orthographic and clinographic projections of barite from Madoc township, Hastings county, Ontario.

furnish suitable crystals for measurement with the goniometer. The very few crystals which have been measured were almost opaque and of very common tabular habit. While examining some specimens of this fluorite from lot 4, concession I, Madoc township, the writer's attention was attracted by minute, almost fibrous, translucent crystals, which upon investigation were identified as barite. The habit of these acicular barite crystals is figured on page 20 (Figure 6).

The following forms were identified:

$b(010)$ ,  $m(110)$ ,  $n(120)$ ,  $y(122)$ ,  $d(102)$ ,  $u(124)$ ,  $o(011)$ .

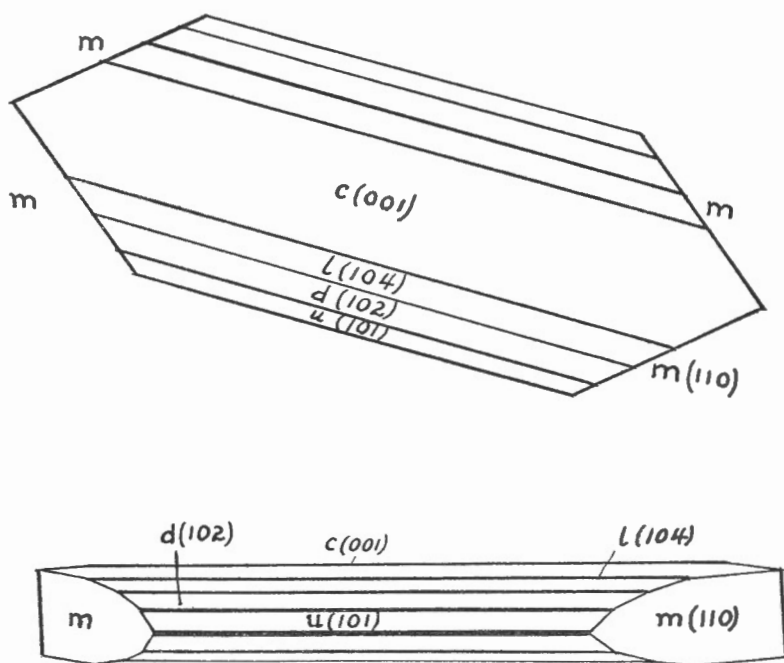


Figure 7. Orthographic and clinographic projections of barite from Madoc township, Hastings county, Ontario.

Yellowish crystals of barite collected by A. T. McKinnon in the vicinity of the above locality were measured on the two-circle goniometer. These crystals of tabular habit under 2 mm. in diameter yielded the following forms (Figure 7).

$m(110)$ ,  $c(001)$ ,  $u(101)$ ,  $d(102)$ ,  $l(104)$ .

## SOME CHEMICAL CHANGES IN ROCKS, CAUSED BY SHEARING

By *H. C. Cooke*

PAGE

## Illustrations

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10. Straight-line diagram illustrating results of shearing of a greenstone	29

Although the changes that take place in rocks during the processes of weathering, contact metamorphism, and hydrothermal alteration have been widely studied, and their chemistry is now fairly well known, little has yet been learned of the chemical changes that go on when a rock is converted into a schist under the influence of pressure only. One reason undoubtedly is, that up to recent years no one thought that mere pressure could cause chemical change, although rearrangement of the constituents into new mineral combinations was recognized. But even when the possibility of chemical change has been recognized, the physical difficulty still confronts the investigator of securing material suitable for chemical analysis. The first requisite is a rock of fairly uniform composition, part of which has been rendered schistose. Having found this, it becomes necessary to secure specimens unaffected by weathering processes. As the cleavage planes of schist readily permit the ingress of surface waters, it is commonly impossible for a geologist, equipped only with a hammer, to get below the weathered zone, even in glaciated areas; and he must, therefore, turn to the relatively small areas where mining is going on and he can go underground. But in these areas of ore deposition, sheared zones have commonly served as channels for the ascent of juvenile waters, have suffered more or less alteration from them, and have received additions of quartz, calcite, and other vein-forming minerals. Hence the opportunities for collecting material free from contamination, from one source or another, are extremely rare.

C. K. Leith and W. J. Mead in their "Metamorphic Geology" have summarized most of the few known instances in which the sheared and unsheared varieties of the same rock have been analysed. These include three instances of the alteration of a quartzite to a sericite schist, three of a gabbro to a schist, two of a greenstone, and one of a granitoid gneiss. The writers conclude that shearing tends to eliminate from a rock those constituents in excess of the amounts required for production of the common schist-making minerals, such as the micas, chlorites, and hornblendes.

During the summer of 1925 the writer examined the Canadian Associated Goldfields mine, situated on claim T. C. 699 in the southern part of McVittie township, Ontario. The ore-body in this mine has been formed by the replacement of Keewatin lavas and tuffs by fine-grained quartz and carbonates, accompanied by considerable amounts of oligoclase, hematite, and auriferous pyrite and arsenopyrite.<sup>1</sup> A post-mineral fault, locally known as the graphite fault, cuts the rocks and ore-bodies. The fault is large, converting the rocks over widths of several feet into fissile schist; and it branches repeatedly, the branches re-uniting farther along the strike,

<sup>1</sup>Cooke, H. C.: Geol. Surv., Canada, Sum. Rept. 1923, pt. C I, p. 61.

so as to enclose lenses of unsheared rock. It parallels the ore-body closely, but is clearly of later date, as the reddish ore is crushed to a red gouge within the fault zones, lenses of unsheared ore are found surrounded by sheared material, and the graphite fault cuts unbroken across other faults which have themselves cut across the ore-body and caused displacements of 2 to 6 feet. Some mineralization took place later than the graphite fault, however, as the schist of the fault in places contains lenses of glassy quartz accompanied by some calcite and a little free gold.

The rocks are of two kinds, greenstones, considered as altered Keewatin lavas, and thin-bedded tuffs. The tuffs are blackish, due to a small content of carbon. The fault, within the mine, lies mainly in these tuffs and so much graphite is developed along the planes of shear that cars of waste coming from the shear zone look like cars of coal. *In two or three places, however, where the fault or a branch of it passes from the tuffs into the greenstones for any considerable distance, graphite disappears;* and the conclusion seems inevitable that the graphite of the fault is related in some way to the tuffs. As the tuffs contain carbon, the graphite may have been concentrated by elimination of some of the other constituents during the shearing.

Accordingly, specimens showing the gradation from unsheared to sheared material were collected, though difficulty was experienced in securing reliable samples, owing to the universal presence, between the leaves of schist, of paper-thin lenses of light-coloured vein material. Finally, on the 1,000-foot level of the mine, a place was found, near mine station 1010, where such contamination appeared to be a minimum. It was also considered that if material were really eliminated during shear, some of this material would naturally be deposited along the planes of shear probably toward the close of the shearing, when pressure began to decrease; hence much of this contaminating vein material may not be foreign matter, but part of the rock itself arrested during departure. The analyses below seem to confirm this supposition, for although all the sheared samples contained more or less vein-like matter, only one, No. 5, exhibits any pronounced aberration such as would suggest introduction of foreign material. It contains about 6 per cent more silica than would normally be expected, on this hypothesis.

The samples taken from the graphite fault are Nos. 1 to 6. Nos. 1 and 2 are of unsheared black tuff, taken as checks on one another; Nos. 3, 4, and 5 consist of partly sheared material; No. 6 is the most schistose material present, and consisted of chips about as thin as postcard, pried loose with the point of a penknife from the slickensided faces of shear-planes.

Under the microscope the unsheared tuffs appear to consist largely of sericite or talc and carbonate, with some quartz, some obscure material that may be feldspar, and a little blackish material, probably carbon. A little pyrite is commonly also present. The sheared materials are too much obscured by graphite for microscopic identification.

At another point on the 1,000-foot level, near mine station 1016, a branch of the main fault cuts the greenstones, shearing them to a fissile schist. Some of this material was also taken as a second instance of the effect of shearing, and the results are seen in analyses 7, 8, and 9. No. 7 consists of the unsheared greenstone; No. 8 of sheared greenstone contain-

ing more or less white, vein-like material in the interlamellar spaces; No. 9, like No. 6, consists of bits chipped with a knife-point from slickensided faces. Nos. 6 and 9, therefore, are specimens in which the development of schist-making minerals has reached a maximum.

The unsheared greenstone is composed entirely of secondary minerals, except for some remnants of the original feldspar. Examination of a number of sections shows that carbonates form 25 to 50 per cent of the rock, and talc the bulk of the remainder. From 5 to 10 per cent of chlorite, 2 or 3 per cent of quartz, and 1 or 2 per cent of leucoxene are the principal remaining constituents.

The analyses were made by E. A. Thompson, chemist, Mines Branch, Department of Mines, Ottawa, and are as follows:

	1	2	3	4	5	6	7	8	9
SiO <sub>2</sub> .....	57.80	58.40	58.20	58.20	62.80	55.10	35.85	43.55	43.35
Al <sub>2</sub> O <sub>3</sub> .....	16.12	16.49	17.30	17.81	17.42	17.65	6.58	9.63	7.59
Fe <sub>2</sub> O <sub>3</sub> .....	1.28	1.92	4.42	3.50	3.40	4.54	0.84	0.75	0.58
FeO.....	4.96	4.67	5.11	5.95	3.35	6.02	9.34	9.93	9.90
P <sub>2</sub> O <sub>5</sub> .....	0.02	0.03	0.01	0.02	0.02	Nil	Nil	Nil	Nil
TiO <sub>2</sub> .....	0.49	0.23	0.74	0.66	0.33	0.66	Tr.	Tr.	Tr.
MnO.....	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
CaO.....	3.20	1.65	1.50	0.80	Nil	0.40	6.90	3.40	3.90
MgO.....	2.47	2.76	1.52	1.85	1.88	1.92	23.43	22.67	23.97
Na <sub>2</sub> O.....	2.12	2.69	1.76	1.38	1.30	1.09	Tr.	Tr.	Tr.
K <sub>2</sub> O.....	3.96	3.23	3.91	3.66	4.63	4.39	Tr.	Tr.	Tr.
As.....	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
CO <sub>2</sub> .....	3.00	2.75	1.40	1.70	1.10	2.30	11.10	3.00	3.40
C.....	0.76	1.02	1.31	1.39	1.25	1.52	0.04	0.05	0.14
S <sup>i</sup> .....	1.13	1.17	1.31	1.67	1.00	1.80	0.11	0.05	0.14
S <sup>2</sup> .....	0.05	0.04	0.07	0.11	0.06	0.05	Nil	Nil	Nil
SO <sub>2</sub> .....	Nil	Nil	Nil	Nil	Nil	0.45	Nil	Nil	Nil
H <sub>2</sub> O + 105° C.....	2.40	2.40	1.60	1.60	1.81	2.40	5.82	6.75	7.20
H <sub>2</sub> O - 105° C.....	0.15	0.50	0.10	0.05	0.11	0.09	0.11	0.25	0.20
	99.91	99.95	100.26	100.35	100.46	100.38	100.12	100.03	100.37

S<sup>2</sup> in Pyrrhotite

S<sup>1</sup> in Pyrite

1. 0.05% S = 0.09% FeS+S	1. 1.13% S = 2.11% FeS <sub>2</sub> = 1.40% Fe <sub>2</sub> O <sub>3</sub>
2. 0.04% S = 0.08% FeS+S	2. 1.17% S = 2.19% FeS <sub>2</sub> = 1.46% Fe <sub>2</sub> O <sub>3</sub>
3. 0.11% S = 0.21% FeS+S	3. 1.67% S = 3.12% FeS <sub>2</sub> = 2.08% Fe <sub>2</sub> O <sub>3</sub>
4. 0.07% S = 0.13% FeS+S	4. 1.31% S = 2.45% FeS <sub>2</sub> = 1.63% Fe <sub>2</sub> O <sub>3</sub>
5. 0.06% S = 0.11% FeS+S	5. 1.00% S = 1.87% FeS <sub>2</sub> = 1.25% Fe <sub>2</sub> O <sub>3</sub>
6. 0.05% S = 0.09% FeS+S	6. 1.80% S = 3.37% FeS <sub>2</sub> = 2.24% Fe <sub>2</sub> O <sub>3</sub>

NOTES:

- (1) Determination of carbon present as free carbon and in carbonates.
  - i. Total carbon determined by ignition in a stream of oxygen. Carbonates decomposed with evolution of CO<sub>2</sub>, and free carbon converted into CO<sub>2</sub>. Absorption in ascarite and weighed directly.
  - ii. Free carbon. Portion of sample treated with HCl to decompose carbonates. Residue containing free carbon ignited in oxygen as in (i) above. CO<sub>2</sub> so found calculated to carbon. Difference between i and ii = carbon present in carbonates.
- (2) Determinations of sulphur.
  - i. Total sulphur determined by fusion with Na<sub>2</sub>CO<sub>3</sub> + KNO<sub>3</sub> extracting and precipitating as BaSO<sub>4</sub>.
  - ii. Sulphur in pyrrhotite determined by distilling with HCl (converting S into H<sub>2</sub>S) into CdCl<sub>2</sub> solution and titrating with iodine.
  - iii. Sulphur in pyrite = difference between i and ii. As a check, total sulphur present in sulphides determined by ignition of sample in oxygen by which S is converted into SO<sub>2</sub>. This is oxidized to SO<sub>3</sub> and precipitated as BaSO<sub>4</sub>.

As pyrite and pyrrhotite are more or less accidental and variable constituents of the tuff, it was considered that their presence might partly mask regularities that would otherwise appear. The sulphur was, therefore, deducted with corresponding amounts of iron, and the analyses recalculated to 100 per cent, as follows:

—	1	2	3	4	5	5a	6
SiO <sub>2</sub> .....	59.38	60.05	59.94	60.38	64.00	61.64	57.50
Al <sub>2</sub> O <sub>3</sub> .....	16.56	16.98	17.78	18.50	17.80	18.95	18.43
Fe <sub>2</sub> O <sub>3</sub> .....		0.47	2.87	1.47	2.19	2.34	2.40
FeO.....	4.95	4.76	5.18	6.07	3.36	3.59	6.26
(Fe).....	(3.85)	(4.04)	(6.12)	(5.75)	(4.14)	(4.43)	(6.55)
CaO.....	3.30	1.69	1.54	0.83			0.42
MgO.....	2.54	2.84	1.56	1.90	1.91	2.04	2.00
Na <sub>2</sub> O.....	2.18	2.77	1.80	1.43	1.32	1.41	1.14
K <sub>2</sub> O.....	4.08	3.32	4.02	3.80	4.72	5.03	4.58
CO <sub>2</sub> .....	3.08	2.83	1.44	1.76	1.12	1.20	2.40
C.....	0.78	1.05	1.35	1.45	1.27	1.36	1.57
P <sub>2</sub> O <sub>5</sub> .....	0.02	0.03	0.01	0.02	0.02	0.02	.....
TiO <sub>2</sub> .....	0.50	0.23	0.76	0.68	0.34	0.36	0.69
H <sub>2</sub> O+.....	2.48	2.47	1.65	1.66	1.84	1.97	2.50
H <sub>2</sub> O-.....	0.15	0.51	0.10	0.05	0.11	0.11	0.09

In the tables above the attempt has been made to correct No. 5 for excess silica, and the result is shown in No. 5a. The original analysis, when pyrite and pyrrhotite were subtracted, totalled 98.10 per cent with silica 62.80 per cent. From both figures 6.10 per cent was taken, reducing the silica to 56.70 per cent and the sum of all constituents to 92 per cent. Each constituent was then increased proportionately to bring the sum to 100 per cent. The result, however, is not very satisfactory, as both silica and alumina still appear somewhat too high, and the results are, therefore, omitted from the curves below.

The recalculated analyses have been plotted on Mead's straight-line diagram (*See* Figures 8 and 9)<sup>1</sup>. According to this method, the percentage of a constituent in the fresh rock is divided by its percentage in the altered rock, and the quotient multiplied by 100. The result represents, for each constituent, the number of grammes of altered rock required to contain the amount of that constituent originally present in 100 grammes of the fresh rock. The positions of the various points, plotted on the straight-line diagram, at once show the relative behaviour of the several constituents during alteration. If any constituent is assumed to have remained constant during alteration, all constituents whose points fall to the right have decreased in absolute amount, and those whose points fall to the left have increased. When lack of information makes it impossible to fix any point as a constant, only the relative gains and losses can be seen from the positions of the points.

In Figure 8 the points are obtained using No. 1 as the fresh rock, whereas in Figure 9 No. 2 is regarded as the fresh rock. It will be seen that the diagrams are similar, although the absolute position of the points varies.

It would seem reasonably safe to assume that free carbon, on account of its high degree of insolubility and inalterability, remained constant

<sup>1</sup>Mead, W. J.: *Ec. Geol.*, vol. VII, pp. 141-4 (1912).

Also Leith, C.K., and Mead, W. J.: *Metamorphic Geology*, pp. 12-13, H. Holt & Co., New York, 1915.

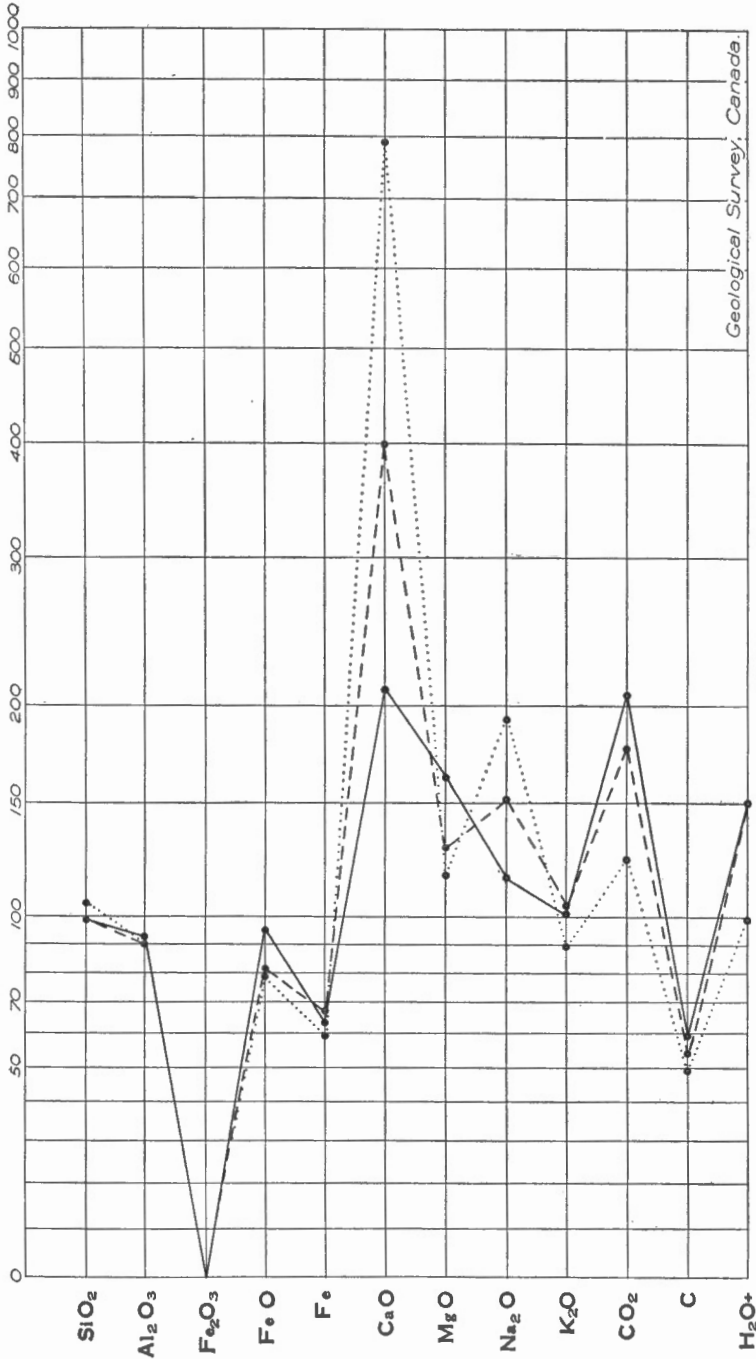


Figure 8. Straight-line diagram illustrating results of shearing of carbonaceous tuff, assuming that rock No. 1 of table of analyses represents the unshattered rock; the full line represents rock No. 3 of the table of analyses, the line of dashes, No. 4 of the table, and the line of dots, No. 6 of the table.

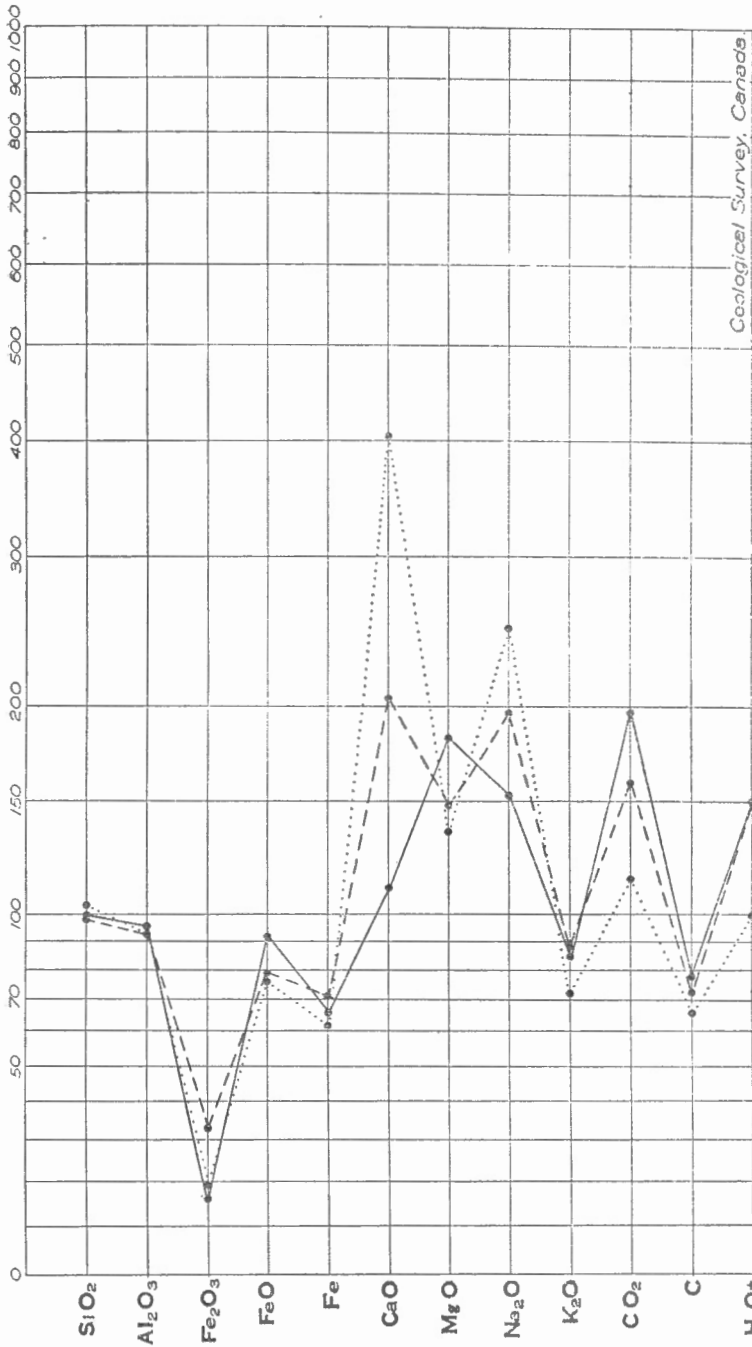


Figure 9. Straight-line diagram illustrating results of shearing of carbonaceous tuff, assuming that rock No. 2 of table of analyses represents the unshattered rock; the full line represents rock No. 3 of the table of analyses, the line of dashes, No. 4 of the table, and the line of dots, No. 6 of the table.



during the shearing. Carbon also is directly altered into the schist-making mineral graphite, and this fact additionally suggests that it would be stable during shear, as the tendency of shear is to eliminate the non-schist-making constituents. If this be true, then it becomes evident that between 35 and 45 per cent of the weight of the original tuff was eliminated during the shearing process. All the other constituents decreased in relative amount, except iron. The iron remained practically constant in Figure 9, although Figure 8 shows a slight decrease; but surprisingly enough the ferric iron greatly increased, indicating that the shearing process caused oxidation of the ferrous iron. Some of the curves shown by Leith and Mead in "Metamorphic Geology" suggest a similar conclusion. Potash suffered little or no elimination, presumably because it entered into the stable mineral sericite. Lime is the constituent most strongly eliminated, with soda second, and magnesia third. Alumina and silica, compared with carbon, appear to have been eliminated only to the extent of 25 or 30 per cent.

It will be noted from the diagrams that although certain constituents, like carbon and iron, exhibit continuous increase with increasing shear, and certain others, like lime and soda, are successively decreased, there are some whose behaviour is more complex. These, magnesia, potash, CO<sub>2</sub>, and water, were eliminated to a considerable extent, *but the elimination was greatest in the less sheared specimens, and proportional increases occurred with more intensive shear.* Moreover, in the case of potash and magnesia at least, the proportional increase is approximately the same as for carbon. The only possible explanation appears to be, that with the first pressures these constituents were converted into the schist-making minerals, sericite or other mica, talc, and chlorite, and amounts in excess were at once eliminated. The new minerals thus formed were stable thereafter, and increased relatively as lime and soda continued to be eliminated by increasing pressures. Just why CO<sub>2</sub> should behave in this manner is a puzzle, however, as it is not a constituent of any known schist-making mineral.

The result of the shearing of the greenstones, analyses 7 to 9, is shown in Figure 10. Here unfortunately there is no constituent like carbon that is reasonably certain to have remained constant. It might be assumed that, as in the case of the tuff, 35 per cent or more of the weight was eliminated by shearing; this may well have occurred, as the shear is of approximately the same intensity as in the case of the tuff. On the contrary, the amount eliminated is probably not regulated by the intensity of the shear alone, but also by the relative proportions of the constituents. If the exact proportions were present for the conversion of the whole mass into micas, chlorites, and other schist-making minerals, none might be eliminated even under severe stress, hence the eliminations may be confined to those constituents which are present in excess. In this instance, therefore, it would seem dangerous to assume a greater loss of weight than the diagram indicates. Silica, water, and alumina all lie on about the same vertical line to the left of the 100-line; and if it be assumed that these oxides remained constant, it follows that about 15 per cent of the total weight was lost during shear. The loss has been distributed between CO<sub>2</sub>, lime, and magnesia, in the order named; presumably, therefore, the lime and magnesia were carried away as carbonates. A very small

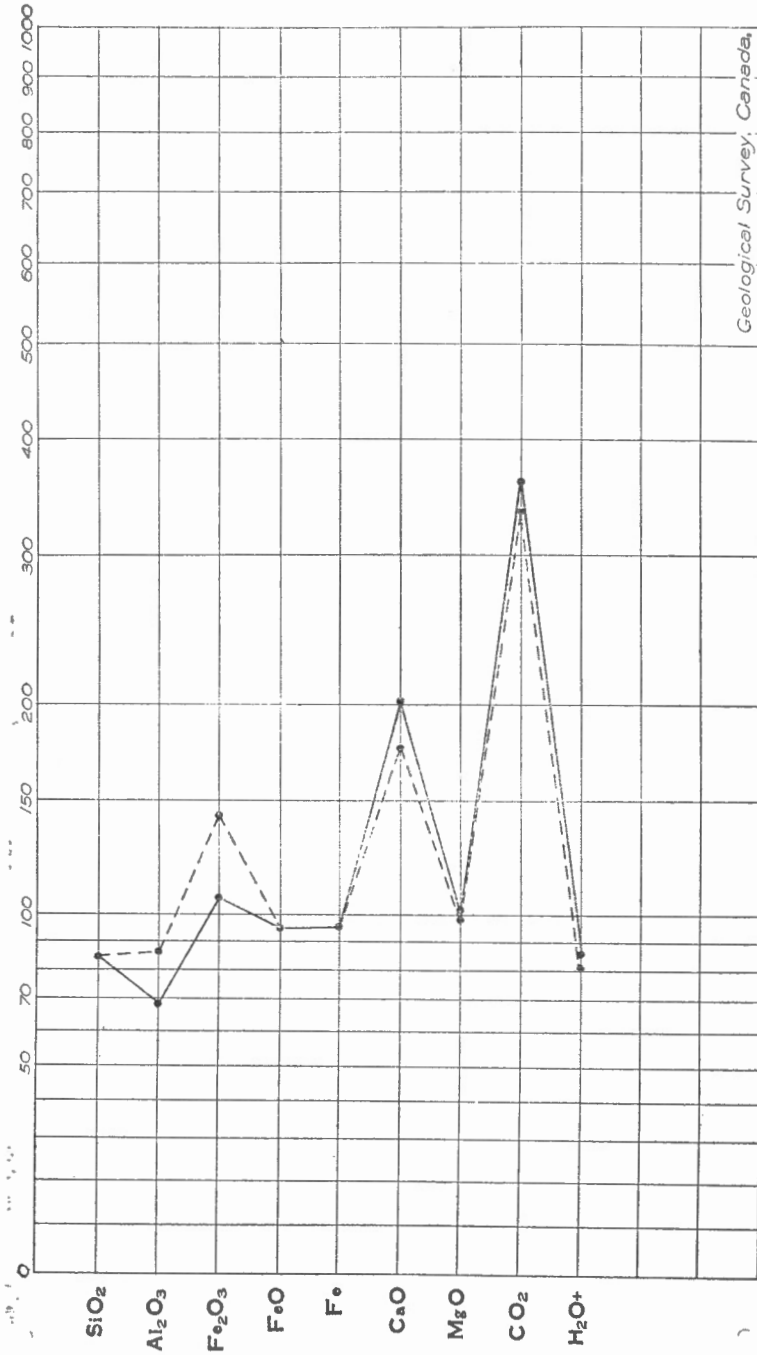


Figure 10. Straight-line diagram illustrating results of shearing of a greenstone, assuming that rock No. 7 of table of analyses represents the unsheared rock; the full line represents rock No. 8 of the table of analyses, and the line of dashes, No. 9 of the table.

proportion of the iron was also removed, and it is noticeable that there was no oxidation from ferrous to ferric iron as in the other instance described. Potash and soda are absent in these rocks, but it will be noted that magnesia,  $\text{CO}_2$ , and lime also display the same peculiarity of behaviour, noted previously, of increasing relatively after the large initial loss.

Both sets of analyses concur, therefore, in indicating large absolute losses of material during shear. Apparently, any constituent may be driven out if present in excess of the amount needed to form the schist-making minerals. Lime is the constituent most severely affected in both sets of analyses, presumably because very little of it entered into any of these minerals. The analyses suggest that the conversion of magnesia, potash, and water into sericite, chlorite, and talc took place at a very early stage in the shearing process, and that the excess amounts of these constituents was at once eliminated, so that thereafter they increased in relative amount. The behaviour of  $\text{CO}_2$  is very puzzling, suggesting that it entered in some form into one or more of the schist-making minerals.

### CONCLUSION

This paper describes the analysis of samples taken from the Associated Goldfields mine, McVittie township, Ontario. The samples consist of rocks varying from unsheared materials outside of a strong fault to highly sheared materials within the fault. The results confirm those announced by C. K. Leith and W. J. Mead in "Metamorphic Geology." The shearing in each case tended to eliminate constituents in excess of those required for formation of the schist-making minerals.

The writer realizes to the full the weaknesses inherent in the data. It is clear that a fault zone in an area where juvenile solutions have been active is not an ideal spot for securing entirely reliable samples, as some of them might be altered by such solutions; and in fact one analysis, No. 5, had to be discarded because such vitiation seemed evident. It is also evident that the two samples of unaltered rock, 1 and 2, show that it is not as uniform in composition as might be desired. In spite of these defects, however, the results appear so clean-cut and definite as to be worth presentation.

It will also be observed that the writer has carefully avoided discussion of the processes by which elimination of material took place. Such discussion would be pure guess-work. Presumably liquefaction must have taken place, possibly by combination with water or some other volatile constituent; but at present there are no data at hand to furnish a basis for theory. It is interesting and suggestive to note, however, the uniform presence in the sheared zone of very thin veinlets, mainly of carbonates, the presence of which does not cause unexpected variations in composition except in a single instance. It is difficult to explain them except under the supposition that they represent a part of the original rock constituents arrested during departure. Were they composed of materials introduced by juvenile or other solutions, there would surely be pronounced irregularities in all the analyses.

## SYENITE PORPHYRY OF BOISCHATEL TOWNSHIP, QUEBEC

By *H. C. Gunning*

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### INTRODUCTION

The area of syenite porphyry under consideration<sup>1</sup> lies in the west-central part of Boischatel township in the province of Quebec, some 13 miles east of the Ontario boundary and about 12 miles west of Rouyn and the Noranda mines property. Renaud lake lies 3 miles southwest of the porphyry. A wagon road from Larder Lake, Ontario, to Rouyn, passes along the north side of Renaud lake, and a good trail leads from the lake to the Chance property situated on the south edge of the syenite porphyry.

The occurrence was first mentioned by H. C. Cooke<sup>2</sup>. The writer studied the syenite porphyry during the summer of 1924, while acting as field assistant to Mr. Cooke. The time spent investigating the syenite porphyry was necessarily limited to some three days in all. About forty hand specimens, believed to represent the main types of the rock, were collected, and these along with twenty-five thin sections have been studied in the laboratory of the Massachusetts Institute of Technology, Department of Geology. Thanks are due Professors Waldemar Lindgren, and Joseph L. Gillson of the Department of Geology, Massachusetts Institute of Technology, and Professor E. S. Larsen, of Harvard University, for advice and assistance during the laboratory study.

### GENERAL GEOLOGY

The region is typical of the great Canadian Shield. It is a country of low relief, covered with a heavy mantle of drift, thickly wooded except where denuded by forest fires, and drained by sluggish, meandering streams. The area under consideration has been cleared of a large part of its timber and underbrush by fire and the rocks are well exposed in many places. However, much of the porphyry is still covered by swamp and brush, and

<sup>1</sup>See Map: Opasatika Area, Timiskaming County, Quebec, Publication No. 1985, Geol. Surv., Canada, to accompany report by H. C. Cooke, in Sum. Rept. 1922, pt. D.

<sup>2</sup>Geol. Surv., Canada, Sum. Rept. 1923, pt. C I, p. 122.

most contacts of porphyry and greenstone are particularly well hidden in this way.

The Keewatin rocks, which underlie the larger part of the district, consist principally of rhyolites, basalts, and fragmental rocks. Cutting these Keewatin rocks are dykes or sills of gabbro,<sup>1</sup> whose courses in a general way correspond with the east-northeast strike of the volcanic rocks.

The syenite porphyry, in the form of a stock-like intrusion, about 1.5 miles from north to south, and 1 mile from east to west, cuts all the above-mentioned rocks. Numerous dykes of the porphyry cut the Keewatin rocks in the neighbourhood of the main mass, but rarely attain a width of more than a few feet. Such dykes appear to be particularly abundant on the northwest and south borders of the intrusion. Going northwest one passes within a distance of half a mile or more from massive syenite porphyry over areas that consist of 50 per cent or more porphyry in the form of dykes in the Keewatin, to places where only a few dykes occur, and finally to continuous Keewatin. The syenite porphyry, in turn, is cut by at least one large dyke of the so-called Later Gabbro of the region, which in this case approaches a true diabase. According to Cooke<sup>2</sup> all these intrusive rocks are pre-Huronian, that is, they do not cut the Cobalt conglomerate, which is well developed a few miles to the south, and they do cut the Timiskaming series. The only evidence obtained by the author is that the syenite porphyry is post "Older Gabbro" and pre "Later Gabbro."

#### DESCRIPTION OF SYENITE PORPHYRY

Within the main mass the rock varies from acidic, light-coloured material to basic, dark green to black varieties, and from an extremely fine, dense mass to a very coarse-grained rock with brown feldspar phenocrysts, many of which attain a length of several inches. The acidic varieties are highly feldspathic and as a rule contain free quartz; the basic hold abundant ferromagnesian constituents and quartz is scarce or lacking.

The various phases almost invariably exhibit intrusive contacts with one another. Gradational changes, such as would result from differentiation after intrusion, are conspicuously lacking. The earliest phases are dark green, fine-grained to porphyritic, and, in some cases, of trachytic texture. The ferromagnesian minerals are present in amounts ranging from about 25 per cent to 60 per cent. The successively younger phases are lighter and lighter in colour, the ferromagnesian constituents decreasing in amount and feldspar becoming more abundant. The final phases are fine-grained dyke rocks composed almost altogether of feldspar (albite) and quartz, and they are accompanied by stringers and irregular areas of blue or green amphibole.

The most basic phase is a fine-grained, very dark green rock. In the hand specimen, on freshly broken surfaces, it appears to consist largely of ferromagnesian constituents. On weathered surfaces tiny white grains of feldspar, about one millimetre in diameter, are visible, and the rock assumes a lighter colour. The ferromagnesian elements form somewhat more than 50 per cent of the rock and are principally biotite and a dark green or black pyroxene.

<sup>1</sup>Cooke, H. C.: *Op. cit.*, p. 79. "Older Gabbro."

<sup>2</sup>*Op. cit.*

With an increase in the percentage of feldspar, the rock, on the average, becomes distinctly coarser. One peculiar and interesting phase is quite abundant. It consists of approximately 75 per cent feldspar, in the form of white or pink laths, varying in length up to an inch or more and in thickness up to one-quarter or even half an inch. These feldspar crystals stand in parallel arrangement and, on weathered surfaces, in many places exhibit zoning. The rock presents the trachytic texture characteristic of material that has solidified under differential pressure or during movement of the magma. The spaces between the closely crowded feldspar crystals are filled with a fine-grained mass of biotite and a dark green pyroxene. A few tiny specks of pyrite can be seen in the more basic varieties.

A large part of the intrusive body consists of a coarse-grained rock made up of brownish feldspar crystals, varying in length up to 2 or 3 inches, with a very minor amount of white mica and a green, fibrous mineral between the feldspar grains. In some varieties there is a large amount of a fine-grained, grey matrix; in others there is practically none.

The most acid phases occur as small dykes that cut all the above-mentioned varieties. The dykes seldom are more than a foot wide. These varieties produce some very beautiful rocks. One type is brownish white, weathers to a brick red, and shows numerous stubby laths of brown feldspar set in a fine-grained, white groundmass. A few quartz crystals appear. Ferromagnesian minerals are essentially lacking.

Numerous small dykes, none more than a few inches wide, consist of a fine-grained, grey rock that is essentially feldspar. Dark minerals, in greater or less amount, may or may not be present. In some cases, shreds of a blue-green amphibole have developed at or near the contacts of these dykes. This is particularly true where the dykes cut the more basic varieties of syenite porphyry.

The final differentiation product appears to be represented by a few very coarse-grained dykes consisting of coarse crystals of feldspar and a considerable amount of quartz. They have an almost pegmatitic appearance. In one or two specimens of the more acidic types a few tiny specks of a brown mineral, taken to be garnet, were observed in the field. No garnet has been identified during the petrographic study in the laboratory.

The minerals that have been identified in the syenite porphyry are: orthoclase, microcline, micropertite, plagioclase (predominantly albite), quartz, amphibole (three varieties), augite, aegirine-augite, aegirine, biotite, muscovite, apatite, magnetite-ilmenite, titanite, rutile (?), zircon (very sparingly), and pyrite. Alteration has produced calcite, epidote, chlorite, limonite, and kaolinitic material.

The indices of refraction given below for several minerals were determined by the immersion method, as outlined in Bulletin 679 of the United States Geological Survey, by Esper S. Larsen. The liquids used belong to the set in the petrographical laboratory of the Massachusetts Institute of Technology. The indices of the different liquids differ by about 0.006. Accordingly, by immersing a mineral grain in successive members of the set, its indices can be obtained accurately, in nearly all cases, to within 0.003. The grains examined were taken from hand specimens of which thin sections have been studied. The other optical properties were obtained either from isolated grains or from thin sections.

## ACID TYPES

The most acid variety occurs as small dykes cutting all the other phases of syenite. Under the microscope it is seen to consist of phenocrysts, up to one-fourth of an inch long, of microcline and orthoclase, with some very irregular micropertthite and a few, large, rounded grains of quartz, set in a fine-grained holocrystalline groundmass of feldspar and quartz. The feldspar of the groundmass is predominantly pure albite exhibiting an extinction angle of 16 degrees on faces cut perpendicular to 010. Some orthoclase is present and considerable quartz. The only other constituents of the rock are some scattered, minute shreds of a blue-green mineral that is probably an amphibole, and a few, large, altered cubes of pyrite.

Throughout all the large phenocrysts of this section numerous fine grains of plagioclase feldspar are disseminated. They are of the same composition as the feldspar of the groundmass and always show a higher index of refraction than that of the phenocrysts in which they are embedded. These fine grains of sodic feldspar also occur in the quartz phenocrysts where, however, instead of being irregularly placed, as in the feldspar, they are concentrically arranged, paralleling the hexagonal outlines of basal sections of quartz (Plate III).

The explanation of such a structure is not readily apparent. From a preliminary examination it might appear that the quartz and feldspar had crystallized contemporaneously. On closer inspection, however, such an explanation, in several cases at least, seems to be impossible (Plate III). The aggregations of fine-grained feldspar cut across the quartz at right angles to the hexagon faces, and spread out in irregular areas, along lines approximately parallel to the crystal faces. This is repeated several times within a single individual of quartz until a fine, concentric arrangement is obtained, as many as a dozen layers of feldspar in some cases being present in a quartz crystal one-eighth of an inch in diameter. The cross-cutting relations are particularly apparent without crossed nicols. A few regular lines of bubble-like, extremely minute inclusions traverse the basal section of one quartz crystal. These lines of inclusions do not continue across the concentric layers of fine-grained feldspar, nor do they appear in any way to control the arrangement of the feldspar. The planes of these regular lines of inclusions seem to be approximately perpendicular to the C axis of the quartz; that is, they lie approximately perpendicular to the planes of arrangement of the feldspar, which are roughly parallel to prism faces. Some of the large phenocrysts of quartz, however, show typical resorbed outlines against the groundmass of feldspar and quartz and the quartz has very evidently been replaced, within the crystal, by the feldspathic groundmass. Other cases, however, show a much more complicated structure. No regularity appears in the distribution of fine-grained albite in quartz. Large areas of the latter show optical continuity, but no crystal boundaries as seen in Plate III are in evidence. The whole intergrowth is so extremely irregular that it is impossible to decide upon the relative ages of the two minerals. Whether such areas are the result of replacement or of contemporaneous intergrowth remains open to question. Disregarding these doubtful cases, however, evidence has been given to show that quartz formed as large, hexagonal crystals and that later it became unstable in the still fluid, highly feldspathic residuum and was replaced by it.

A thin section of another type of rock, of similar appearance except for its much finer texture, shows a holocrystalline mass of plagioclase grains, less than one millimetre in diameter, with a very minor amount of orthoclase. The plagioclase, by index of refraction and extinction angle, is proved to be nearly pure albite. The only other important constituent is a blue amphibole occurring as shreds and radiating aggregates that cut across the feldspar crystals. It is clearly a late mineral, produced after the crystallization of the feldspar.

The amphibole is biaxial and negative, has negative elongation, and  $Y=b$ . Its pleochroic scheme is:  $X=$ blue;  $Y=$ violet;  $Z=$ pale yellow. The dispersion,  $\gamma < \nu$ , is strong. The optic angle is large. The optic plane is parallel to the elongation. The indices are:

$$\alpha = 1.677 \pm 0.003; \beta = 1.687 \pm 0.005; \gamma = 1.692 \pm 0.003.$$

Typical amphibole cleavage is well developed on basal sections.

The extinction angle  $X \wedge C$  is essentially  $0^\circ$ . On account of the small size and scattered occurrence of the mineral grains, it is impossible to separate any for a chemical analysis.

The amphibole falls in the hastingsite-riebeckite-arfvedsonite group of amphiboles, but does not check optically with any of them. In pleochroism it most closely approaches arfvedsonite, but its index is decidedly lower. What is probably a similar mineral is mentioned by Ussing<sup>1</sup> in connexion with the peculiar soda granite that has formed around sandstone inclusions in augite syenite. His mineral, however, has an extinction angle of about 10 degrees and occurs as a marginal zone around a katophorite-like hornblende. A similar occurrence in the syenite porphyry will be described later.

Other varieties of the late acidic dykes are distinctly porphyritic, with phenocrysts of orthoclase, microcline, and albite, the latter in many cases showing zoning. Fine needles and larger prisms of aegirine (negative elongation and extinction  $Z \wedge C$  in the neighbourhood of 90 degrees) are common. The blue amphibole described above is also quite commonly present. Magnetite, mostly in euhedral grains, apatite, and titanite are common accessories, and kaolinitic alteration products in many cases cloud the feldspar. Epidote occurs in a few cases, resulting from alteration of the pyroxenes.

In one extremely fine-grained dyke a large crystal of pyroxene was observed. The interior is faintly green and exhibits an extinction angle of 40 degrees, thus checking up as augite. Surrounding this is a layer of green, pleochroic aegirine-augite (extinction angle of 66 degrees). Outside the aegirine-augite zone, near the edge of the crystal, are abundant small grains of magnetite or ilmenite and the pyroxene is practically entirely altered to an indistinct, colourless material. The iron oxide evidently is a decomposition product of the original pyroxene. The zone of aegirine-augite may be taken to indicate an increase in the amount of soda in the magma following the crystallization of the augite nucleus.

In one or two thin sections a considerable amount of muscovite, in large plates, occurs. Some green biotite was noticed in the more acid varieties that occur as small dykes. Chlorite has in many cases formed at the expense of biotite, rarely from muscovite. A clear, red, iron oxide lies in some cases along the cleavage cracks in the muscovite; it is also a common associate of apatite.

<sup>1</sup>Ussing, N. V.: *Geology of Julianehaab, Greenland*, 1911, pp. 54 and 117.



## INTERMEDIATE TYPES

The intermediate types form large areas of the main intrusion. One peculiar variety consists, in the hand specimen, of brown or pink feldspar crystals, up to one-half inch in length, set in a fine-grained, holocrystalline, greenish grey groundmass, the green colour being due to tiny needles of pyroxenes. Under the microscope large phenocrysts of orthoclase and microcline can be discerned. They are considerably kaolinized. Several large crystals of quartz also occur and they contain fine-grained feldspar irregularly or concentrically arranged as already described. The groundmass is fine-grained, holocrystalline, and consists of albite, some orthoclase, and a small amount of quartz.

Scattered throughout the section and largely confined to the groundmass are numerous prisms of pyroxene, up to 2 millimetres in length. This pyroxene has yellow to green pleochroism, negative elongation, and an extinction angle  $X \wedge C$ , of 5 degrees to 10 degrees, thus being proved to be nearly pure aegirine. Also occurring in the groundmass, are numerous prisms, of about the same average size as those of pyroxene, of a colourless mineral which in a few sections exhibits very good amphibole cleavages, inclined at 124 degrees and 56 degrees. The optical properties of this mineral follow. It is biaxial negative. The optic angle is  $0^\circ +$  to about 60 degrees. It has positive elongation. The dispersion  $\gamma < \nu$ , is extreme. The indices of refraction are:

$$\alpha = 1.623, \beta = 1.630, \gamma = 1.635.$$

The birefringence is about 0.012. The plane of the optic axes coincides in general direction with the elongation or the prismatic cleavage traces. The extinction  $Z \wedge C$  is approximately 40 degrees, but it was extremely difficult to obtain the exact extinction angle on account of the great dispersion, an anomalous berlin blue colour being the lowest obtainable. The mineral is commonly twinned parallel to 100. In thin section the mineral is absolutely colourless.

From the well-developed cleavage the mineral may safely be assumed to be an amphibole of some variety that, as far as the author can ascertain, has not heretofore been described microscopically. Separation by heavy liquids, with a view to obtaining sufficient material for analysis, was attempted, but a sufficiently clean product could not be obtained. Even the purer grains of the amphibole were found to contain many impurities. The writer's conclusion as to the nature of this mineral is that it is a NaAl or NaCa MgAl amphibole.

The edges of all the large feldspar and quartz phenocrysts are extremely irregular and have apparently been considerably resorbed by the groundmass before it solidified. A few, very coarse grains of apatite constitute the only other primary minerals in the slide. Titanite and limonitic material are the chief alteration products.

The original feldspar phenocrysts are cut and replaced by numerous stringers of the fine-grained groundmass and in many cases numerous fine laths of albite appear isolated in the interior of the crystals. These laths are particularly abundant in the centres of the phenocrysts, in some cases uniting to form large areas of clear plagioclase, suggesting that the interior of the phenocrysts is slightly different in composition from the exterior, and is thus more susceptible to replacement by albite.

One of the most common types of rock that covers large areas within the body of syenite porphyry is represented by a specimen consisting almost entirely of large phenocrysts of orthoclase and microperthite. Later than these, and apparently replacing the larger phenocrysts, is considerable albite. It occurs as large and small grains, with some orthoclase and very little quartz, around the edges of the large feldspar crystals. Muscovite and green biotite altering to chlorite are also quite abundant in the interstices between the phenocrysts. Magnetite is quite abundant and calcite occurs as an alteration of the feldspars of the later generation. The feldspar phenocrysts are much kaolinized, whereas the plagioclase of the groundmass is surprisingly fresh. Plagioclase and some accompanying calcite also occur within some of the larger phenocrysts as irregular blebs or quite extensive patches.

Another phase of the syenite porphyry, somewhat less abundant, consists of stubby, brown feldspar crystals up to three-fourths of an inch in length and three-eighths of an inch in breadth, forming more than 75 per cent of the rock. Under the microscope the large phenocrysts are seen to be principally microcline and orthoclase, with some plagioclase near albite in composition. Large plates of a green amphibole form 5 to 10 per cent of the rock. Its optical properties follow. The mineral is biaxial and negative. The axial angle ( $2V$ ) is approximately 30 degrees. The elongation is positive. The dispersion,  $\gamma \wedge v$ , is moderate. The indices of refraction are;

$$\alpha = 1.64 \pm 0.005, \beta = 1.657 \pm 0.002, \gamma = 1.660 \pm 0.003.$$

The pleochroism is fairly strong in shades of green. The extinction,  $Z \wedge C$ , varies up to 43 degrees.

Judging from its high extinction angle this mineral seems to belong to the katophorite group. The latter, however, according to Johannsen and Iddings, is positive. Lacroix states that katophorite may be either positive or negative, and that its optic angle varies from  $2E = 33$  to  $2E = 60$  degrees.

A rim of blue amphibole, with nearly parallel extinction, occurs around the edges of many of the large amphibole plates just described. It is clearly an alteration product, the gradation from one to the other being very gradual, the later blue type projecting into and from the earlier green amphibole in an irregular, shred-like manner. A few isolated areas of the blue mineral also occur well within the plates of the green variety. This is probably a result of action by later soda-rich solutions. Similar occurrences have been mentioned by Ussing<sup>1</sup> and Brögger.<sup>2</sup> The latter speaks of it as a zoning, giving a gradual transition from a "katoforit kern" to an outside rim of the character of arfvedsonite. Brögger also mentions the not-infrequent occurrence of an outer zone of aegirine. These occurrences are in sölvbergite.

What were, apparently, either plates of amphibole or crystal of pyroxene have in some cases been altered to a mass of calcite and magnetite with a few irregular patches of blue amphibole, having a very small extinction angle.

A few fine shreds of aegirine also occur in this rock and have likewise been altered, around their edges, to the blue amphibole. The latter has apparently also formed at the expense of biotite, which is present in rela-

<sup>1</sup>Ussing, N. V.: Geology of Julianehaab, Greenland, 1911, p. 117.

<sup>2</sup>Brögger, W. C.: Eruptivgesteine des Kristianiagebietes, vol. 1, p. 71 (1894).

tively small amount. In one case, a large, fibrous plate of blue amphibole has cut directly across an area of brown biotite, and the perfect cleavage lines of the latter can still be seen cutting across the cleavage of the amphibole. It is extremely difficult to avoid the conclusion in these cases that soda has been concentrated in the final stages of intrusion and has found expression in the development of albite and blue amphibole.

In this particular rock there is also good evidence of the replacement of the original potassium-feldspar phenocrysts by albite. Some quartz has evidently been introduced at about the same times as the soda-feldspar.

Titanite and apatite, the latter in many cases very coarse, are common accessories in the rock.

#### TRACHYTIC TYPE

The trachytic type of syenite porphyry is quite abundant. Phenocrysts of orthoclase and microperthite, up to three-fourths of an inch in length, form about 50 per cent of this rock; they are in parallel orientation. Between the grains of feldspar lie large grains of aegirine-augite, showing twinning, and numerous large plates of brown biotite. Apatite and titanite are abundant in coarse grains, and magnetite is more sparingly present. A small amount of albite is present, mostly as rims around the larger grains of potassium-feldspar. The aegirine-augite is in many instances altered to the blue-green amphibole, with a small extinction angle.

#### BASIC TYPE

The most mafic variety of rock encountered consists of about 50 per cent ferromagnesian constituents. Pyroxene, in idiomorphic grains up to one millimetre in length, predominates. This colourless to light green mineral has an extinction angle of 54 degrees and its  $\beta$  index is approximately 1.70, thus being confirmed as augite. Apatite occurs as large crystals. Biotite, containing fine needles that are presumably rutile and numerous pleochroic haloes probably due to zircon inclusions, is common. A relatively small amount of finely crystalline groundmass consists largely of albite, with some orthoclase and very little quartz.

In this rock the augite, apatite, and biotite have been corroded and replaced by the groundmass. This phenomenon is apparently quite characteristic of minerals which have crystallized in alkaline magmas.<sup>1</sup>

#### CONTACT EFFECTS

Some interesting features occur where the more basic varieties are cut by small dykes of the more acid type. In numerous places dark coloured varieties of the syenite porphyry, more or less trachytic in texture, are cut by brown, coarsely crystalline stringers of the more acidic types. One thin section, across such a contact, shows that the stringer consists of large phenocrysts of feldspar, principally microperthite, many of which have rims and hold irregular areas of clear albite. Aegirine-augite is very sparingly evident, as also is the blue amphibole described above. Titanite and magnetite or ilmenite are present in small amount.

<sup>1</sup>Adams, F. D., and Barlow, A. E.: *Geology of Haliburton and Bancroft Areas*; Geol. Surv., Canada, Mem. 6, p. 232 (1910).

The rock through which the stringer cuts consists of some 50 per cent of coarse crystals of aegirine-augite, very near to aegirine in composition, as determined by the large extinction angle, set in a matrix of well-crystallized micropertthite, albite, and a little quartz. Biotite, magnetite, and very coarse grains of apatite also occur. In the hand specimens, brown crystals of titanite are easily discernible. In the thin section most of the latter are altered to a mass of leucoxene (?)—yellowish and practically isotropic—and calcite, with clear crystals of albite within them.

The original aegirine-augite is altered, near the stringers, to a fibrous mass of blue or green amphibole whose extinction angle increases from essentially  $0^\circ$  in the blue to violet varieties to  $35^\circ \pm$  in the green varieties. The  $\beta$  index of the greenish amphibole was determined as  $1.670 \pm 0.003$ . It seems that all varieties between the green and the blue to violet amphiboles result from the alteration of aegirine-augite. The amphiboles may replace the pyroxenes very irregularly in shred-like manner or they may perfectly preserve the original crystal form of the pyroxenes. Some crystals of the aegirine-augite show, especially on acute corners in basal section, areas of the deep blue amphibole which reach a position of extinction at the same moment as the original pyroxene and are likewise basal sections. Amphibole, in shreds, also cuts across large and small grains of feldspar and is distinctly later than this mineral. This is a striking example of the conversion of pyroxene to amphibole and in view of the large amount of blue amphibole, the alteration seems to necessitate the introduction of soda, although it is possible that sufficient quantities of that element were supplied by the original aegirine-augite.

One of the most interesting thin sections shows a trachytic, dark green, syenite porphyry cut by a one-half inch, greyish green, fine-grained dyke. The older rock consists of coarse crystals of feldspar, principally orthoclase and microcline, with a large proportion of aegirine-augite and biotite. These components are now badly altered.

The greenish dyke is of a fine-grained, holocrystalline mass of albite, microcline, and orthoclase, the latter two being very minor in quantity. These are cut by shreds of blue to green amphibole which, in some cases at least, have resulted from the alteration of tiny needles of aegirine that is very sparingly present. Considerable apatite, titanite, and magnetite or ilmenite are present throughout the section. The pyroxene has been largely converted to amphibole and the latter has also developed abundantly throughout the feldspar. This conversion is most pronounced along the edge of the light-coloured dyke. Numerous varieties of amphibole occur. A green variety, when examined, was found to have a maximum index of  $1.65+$ . It is biaxial, negative, has an optic angle of medium size, and its extinction approximates 18 degrees, evidently representing a stage intermediate between the blue-violet and dark green varieties described above.

On the western edge of the intrusive mass, just north of a small hut on the "Chance" claims, a considerable area of dark, fine-grained rock occurs. It consists of well-crystallized, green to colourless prisms of augite with extinction up to 52 degrees, set in a somewhat finer-grained mass of orthoclase and albite. An important amount of green biotite, containing numerous microscopic needles of rutile(?), is present. Magnetite or ilmenite, titanite, and apatite are quite abundant and epidote has formed by alteration of pyroxene.

## CONCLUSIONS

The earliest rocks to be intruded are dark green, fine-grained to porphyritic, and, in some cases, have a trachytic texture. These rocks are characterized by large amounts of pyroxene, augite, and aegirine-augite; and by considerable biotite. Quartz is usually present in small amount. Albite, or, in the porphyritic types, potassium feldspars, or both, form up to 75 per cent of the rock. Areas of this type of rock are scattered throughout the whole igneous mass; they are not confined to the edges as they would be if the edges represented the original, basic, and more quickly chilled parts of the intrusion.

Succeeding phases are lighter coloured. The ferromagnesian constituents are less and the feldspar and quartz more abundant. The feldspar phenocrysts are predominantly potash varieties, but albite is concentrated in the groundmass and in many cases replaces the phenocrysts and even some of the larger quartz crystals.

The final, fine-grained dyke rocks are nearly pure albite and quartz and within them and in the neighbouring rocks, a considerable amount of blue, soda-rich amphibole has been produced. In some cases small stringers of blue-green amphibole cut intermediate types of the syenite porphyry in areas where many of the late acid dykes occur.

The rocks grade from basic types, the earliest to be intruded and which seem to correspond roughly with nordmarkite porphyry, through coarse quartz syenite porphyries to fine-grained alkali syenites. Some of the later phases that are particularly rich in quartz verge on granite porphyries.

The igneous body presents highly femic phases in abundance. Feldspathoid types, as far as known, are lacking. This may be due to several causes. The prevalence of trachytic textures among the larger masses of the more basic varieties is taken to indicate the action of differential pressure which would probably lead, as Bowen<sup>1</sup> suggests, to squeezing out of residual liquid from the parts of the magma that were already partly solidified. These residual liquids, judging from the nature of the later phases of intrusion, were rich in quartz and the alkalis, particularly soda. The relatively large amount of quartz in some of the more acid varieties may be due to a cessation of the differential pressure on the magma and the resultant intrusion of the residual material en masse. The great extent to which the original potash feldspars and much of the ferromagnesian material have been corroded points to a high concentration of volatile constituents in the residual liquids of the magma. Sodium appears to have played a major part in these final reactions. Additions of sodium after crystallization of the late phases of the intrusion, which are themselves very rich in albite, is evidenced by a peculiar blue, soda-rich amphibole which cuts across, in very irregular fashion, the feldspar crystals that form the most acid varieties of the syenite porphyry. It also forms by alteration of green hornblende, pyroxene, or biotite where rocks containing these minerals have been cut by more acid dykes. These facts indicate that the whole mass of igneous rock has, after solidification, been acted upon by the volatile constituents which accumulated at that time, as a final end point of differentiation, and which were exceptionally rich in

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<sup>1</sup>Bowen, N. L.: *Jour. Geol.*, Supplement, vol. 23, p. 56 (1915).

sodium. This conception is adequately expressed by Colony,<sup>1</sup> who says: "The effects produced within the igneous rock itself are due . . . . . in part to reactions due to adjustments of equilibrium between the extreme end-stage, highly concentrated 'mother liquid' which, by selective freezing, has been enriched with the more volatile gases usually termed 'mineralizers', among which water plays an important part, and the now almost wholly consolidated igneous rock." He goes on to say: "At this stage much of the quartz and some of the alkalis, especially soda in such form as to appear ultimately as albite, seem to be concentrated in the form of a liquid consolidation-residuum, which, from such evidence as is presented in the rocks themselves, must possess an extremely low viscosity, great penetrating power, and considerable chemical activity." From the study herein described, and especially from the widespread occurrence of the blue soda-amphibole, the writer suggests that this "consolidation residuum" may more closely approach, in some cases, a gaseous or pneumatolytic state than the liquid condition assigned to it by Colony.

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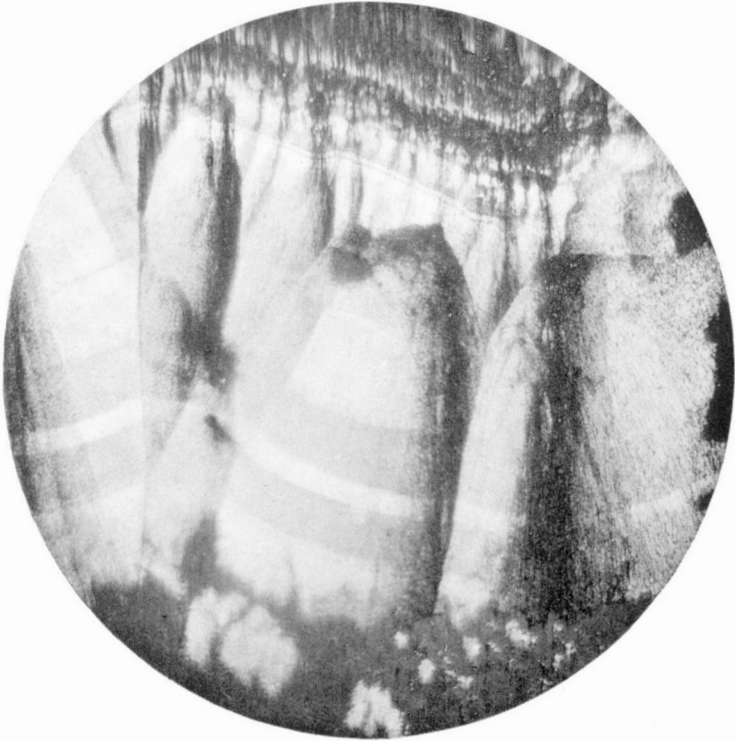
<sup>1</sup>Colony, R. J.: "The Final Consolidation Phenomena in the Crystallization of Igneous Rock"; Jour. Geol., vol. 31, p. 169 (1923).



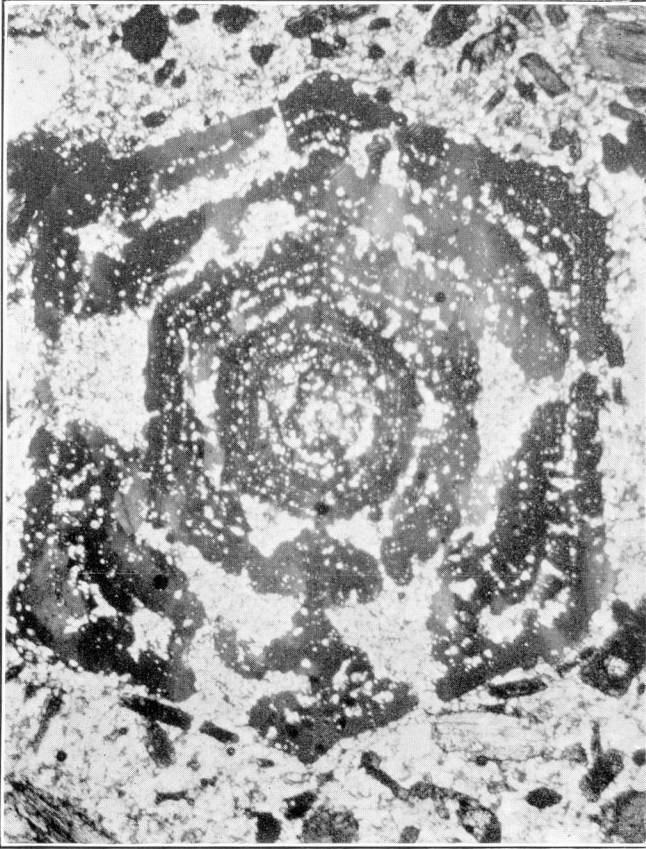


Specimen showing nodular bodies of collinsite and quercyite enclosing fragments of andesite.  
Specimen about 20 in. long. (Page 3.)





Microphotograph of conical quereyite spherulites from lake François, B.C. Polarized light. 40 diameters. (Page 9.)



Section of quartz crystal showing concentric arrangement of fine-grained groundmass, 33 diameters. (Page 34.)