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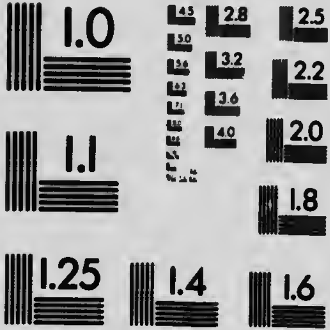

GEOLOGICAL SURVEY OF CANADA
ROBERT BELL, M.D., D.Sc., LL.D., F.R.S.

NOTES ON CERTAIN
ARCHÆAN ROCKS
OF THE
OTTAWA VALLEY

BY

A. OSANN, MULHAUSEN, ALSACE.

(Translated from the German by Nevil Norton Evans.)

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NOTES ON CERTAIN

ARCHÆAN ROCKS

OF THE OTTAWA VALLEY.

By A Osann, Mülhausen, Alsace.

(Translated by Nevil Norton Evans.)

Field of investigation.

In the autumn of 1899, in compliance with a request from the Geological Survey of Canada, I made a series of geological excursions extending over five weeks, in that part of the province of Quebec north and east of Ottawa, and in this I was assisted in the most obliging manner by Dr. Dawson, then director of the Survey. Further, upon many of these excursions I was ably directed by Dr. R. W. Ells and by Mr. E. D. Ingall. It is a pleasure in this place to express my warmest thanks to these gentlemen.

Nature of work.

The object of these excursions was, on the one hand, to become acquainted with some of the principal types of gneisses and their associates, and on the other, and more especially, to study the technically important minerals apatite, mica, and graphite. Naturally, on account of the great variety of the gneisses and the enormous area covered by them as well as on account of the short time at my disposal, it was necessary to select certain characteristic types. Their further geological study, and the determination of their relations, must wait for a special mapping of this highly interesting district. Relatively the longest time was given to the study of the apatite deposits.

CERTAIN GNEISSES FROM THE NEIGHBOURHOOD OF OTTAWA.

Fine section of gneiss.

On the right bank of the Ottawa river, south of Montebello, a station on the Ottawa and Montreal branch of the Canadian Pacific railway, a very fine section has been opened up in the gneiss. The gneiss is here interstratified with quartzite and granular limestone, the gneiss being below and the limestone above the quartzite ; the principal strike is N. 70° E., and the dip 30°-40° to the south. The gneiss is very much bent and folded, as may be easily observed on the surfaces which have been highly polished by ice. The macroscopic character of the gneiss reminds one strongly of the hornfels gneiss in the southern Odenwald and of many so called Rench-gneisses [illegible] the Black Forest ; in hand specimens it is often impossible to distinguish it from these. Characteristic signs are the following : moderately fine and very even grain, great abundance of mica, and a mica-schist habitus caused thereby. Further, lack of flaser or augen structure ; the constituents are very uniformly distributed, the mica plates are all arranged parallel, so that the rock breaks fairly well in this direction. The regularity of the structure is only interfered with by numerous quartz veins and nodules which are frequently as thick as one's finger and thin out to nothing in short distances. The mica of the normal rock is a reddish-brown biotite, but in many of the beds there occurs also a white mica on the schistose surfaces ; this is not uniformly distributed but forms rosette-like aggregations. Many of these latter exhibit a roughly six-sided outline, so that in all probability they are pseudomorphs after staurolite or cordierite. In all other respects the rock seems to be perfectly fresh.

Macroscopic description.

Feldspar and mica abundant constituents.

Under the microscope, the gneiss is seen to be very rich in feldspar. By far the larger number of the sections of feldspar exhibit the crossed twinning of microcline, frequently in one grain the 'cross-hatching' passes over into undulatory extinction and uniform orientation. Sections free from lamellæ do not differ in refraction or micro-structure from the striated [illegible] and belong in all probability to the same feldspar or orthoclase.

Mica occurs in quantities almost equal to the feldspar. In sections parallel to the lamination it exhibits irregularly rounded and ragged forms, and in sections at right angles it is often bent and opened up. The pleochroism is very characteristic, the colours varying between a bright reddish-yellow and dark reddish-brown ; basal sections exhibit no marked differences in absorption. The inclusions in the form of small colourless rounded grains and small crystals of high refractive index and high double refraction are zircons ; around these there is generally a dark non-pleochroitic area.

A further constituent occurring in considerable quantities and which may often be seen with the magnifying glass is tourmaline. It forms short stout columns, 0·1—0.15 mm. in diameter and 0·3—0·4 mm. in length, but the dimensions decrease from this down to extreme smallness. D is brownish-green ; E, colourless with a touch of red.

Colourless mica, as already stated, is confined almost entirely to certain little aggregations ; in the normal rock it is very rare and makes up larger flakes in poikilitic intergrowth with the other constituents of the rock.

Quartz, with the usual fluid inclusions, occurs much more sparingly than feldspar and mica. Apatite and ores are rare ; and rutile as well as graphite and other carbonaceous materials are absent.

Typical hornfels structure.

The structure, especially in those parts poor in mica, is that of a typical hornfels ; in portions rich in mica, especially in sections cut vertical to the schistosity, it is more or less hidden by the parallel arrangement of this mineral. The uniform size of the grain and the extreme freshness of all the constituents of the rock under the microscope is remarkable. The whole macroscopic and microscopic character of the rock is that of a typical paragneiss, that has been formed by the metamorphosis of a sedimentary rock, probably a clay slate. An analysis was made by Dr. Dittrich, and is given under I.

	I.	II.
SiO_2	58·68	57·66
TiO_2	1·39	—
Al_2O_3	16·17	22·83
Fe_2O_3	1·66	—
FeO	5·69	7·74
MgO	3·71	3·56
CaO	0·30	1·16
Na_2O	0·83	0·60
K_2O	8·68	5·72
P_2O_5	0·31	—
CO_2	0·36	—
H_2O	1·65	1·50[*]
Total	99·43	100·77

Analyses compared.

For comparison there is given under II an analysis of a sillimanite-bearing gneiss, rich in biotite, from Trembling [illegible] according to Adams, to whom we owe very valuable invest[illegible] the gneisses from a large area north of Montreal. [illegible] analyses are very similar except in the larger quantity of alum[illegible] smaller quantity of alkalies in No. II, a peculiarity which is expla[illegible] mineralogically by the occurrence of the pure silicate of alumina, sillimanite, in the gneiss from Trembling lake. No. I shows the same percentage of silica, but

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[*] Loss on ignition.

is poorer in alumina and richer in alkalies, corresponding to its content of tourmaline. III gives the molecular proportion of I reduced to 100, excluding the water and carbon dioxide and calculating all iron as protoxide.

	III.	IV	V.	VI.	VII.
$Si O_2$ . . .	67·01	67·60	66·83	83·33	68·55
$Ti O_2$ . . .	1·19	0·35	0·45	0·20	
$Al_2 O_3$ . . .	10·86	9·05	9·61	7·54	14·60
$Fe O$ . . .	6·83	3·74	3·69	1·22	2·49
$Mg O$ . . .	6·35	7·69	5·96	—	0·14
$Ca O$ . . .	0·37	3·51	5·35	0·35	0·48
$Na_2 O$ . . .	0·92	6·40	4·57	3·95	10·15
$K_2 O$ . . .	6·32	1·61	3·12	3·41	3·52
$P_2 O_5$ . . .	0·15	0·05	0·15	—	—

V. with 0·08 Mn O.
0·12 Ba O.
0·07 Sr O.
VII. with 0·07 Mn O.

Characteristic resemblance of analyses.

For both analyses I and II the small quantity of lime in proportion to the large quantity of magnesia and small quantity of silica is characteristic. Further, the total alkalies and lime are far from sufficient to form with the alumina the molecules $(K. Na)_2 Al_2 O_4$ and $Ca Al_2 O_4$. Mineralogically this is explained by the completely unaltered character of the rock, and by the silicates of alumina being free from or poor in alkalies, such as sillimanite and tourmaline. A glance at the analytical tables of plutonic rocks arranged according to molecular proportions (2) shows that such a small content of lime as there is in III only occurs in the case of highly acidic granites and a few elæolite-syenites. In the former case the $Si O_2$ (in molecular proportions) is over 80 , in the latter alumina and alkalies are decidedly higher. For comparison the following are given :—

IV. Analysis of Kammgranite Vogesen.
V. „ Syenite from Yogo Peak, Montana.
VI. „ Granite from Cape Ann, Mass.
VII. „ Elæolite-syenite from Litchfield, Me.

Analyses given for comparison.

Of these, IV. and V. have about the same proportion of $Si O_2$, $Al_2 O_3$, and alkalies as III. ; on the other hand the proportion of lime is considerably higher. VI. has about the same proportion of alkalies and lime ; but alumina, iron and magnesia are lower and silica considerably higher. In VII. silica and lime are as in III., but alumina and alkalies are more plentiful, magnesia and iron much lower. Rosenbusch first pointed out that such a small proportion of lime with relatively large quantities of iron and magnesia are characteristic of normal

Montebello gneiss of sedimentary origin.

clay slates, as is also usually the pronounced preponderance of potash over soda. Provided that during the metamorphosis of such slates, their chemical composition is altered or only slightly changed, as has been observed at least in the case of contact metamorphosis on several occasions, the supposition that the Montebello gneiss has been formed from a clay slate is quite in harmony with its chemical composition. It must not however be forgotten, that as has been often observed in the case of plutonic rocks, by normal decomposition a rapid removal of lime and soda occurs, here also the same chemical character results. Most of the old Paleozoic and Archean clay slates obtained their material mainly from eruptive rocks and eruptive gneisses, so that a leaching out of lime and soda by the weathering during the transport and grinding up of the original material must have taken place, while in the case of plutonic rocks that have not been so mechanically disintegrated, this chemical process will have taken place much more slowly and less completely. The general process is, however, the same in both cases. The above analyses therefore furnish merely a certain probability of the sedimentary character of the Montebello gneiss.

Composition of quartzite from Montebello.

The quartzite from Montebello, consists for the most part of a coarse aggregate of quartz grains, which abut against one another with irregularly angular and toothed margins. No indications whatever of clastic origin or of later orientated growth, &c., can be recognized; a cement is also wanting. Widely distributed, however, are the well known evidences of pressure such as undulose extinction and the breaking up of larger grains into a number of smaller ones of approximately the same optical orientation. Further the streaked appearance, so often described as suggesting twinning lamellæ, is not uncommon. The streaks can be recognized in ordinary light: in part they are as clear as water, in part dull and filled with interpositions looking like dust. Some of these, upon strong magnification are found to be fluid inclusions.

Accessory constituents.

Among accessory constituents may be mentioned some muscovite and graphite, both visible with the magnifying glass, grains of a triclinic feldspar, small quantities of carbonates, probably rich in iron judging from their brown colour, isolated plates of biotite and titanite in rounded grains and elliptical sections.

The granular limestone of the Montebello section is rather coarse in grain, of a dirty grey-green colour and characterized by a considerable content of chlorite. It also contains microscopically some quartz and feldspar, in part microcline.

Not far from Montebello, at a place called Lefaivre, an opening was made a short time ago in granular limestone in the search for graphite. The limestone is here snow-white, much more coarse-grained (grains up to 1 cm.) and contains light brown mica, some muscovite and rounded plates of graphite (up to 2 mm. diameter).

Different type of gneiss.

A type of gneiss entirely different from that already described I found north and north-west of Lachute station (76 miles east of Ottawa). Between Lachute, Lakefield, and the mass of syenite which covers a part of Grenville and Chatham Townships (see geol. map accompanying Annual Report Geol. Surv. Can., vol. VIII., N.S.) this gneiss appears to cover a considerable area. Hand specimens were taken from a number of points and were found to correspond with one another macroscopically as well as microscopically.

Microscopic description.

The uniformly medium-grained rock shows on the cross-fracture a typical stratified structure occasioned by reddish layers composed mainly of potash feldspar and some quartz, alternating with layers rich in hornblende and mica. In other specimens this alternation is more or less indistinct and a granular striped structure appears which passes over one almost completely granular. Under the microscope the rock is seen to be composed essentially of feldspar and hornblende with decreasing quantities of quartz and mica. The hornblende is green and transparent and exhibits in sections parallel to the prism zone a maximum extinction angle ℭ : ℭ, 18–20°. Absorption and pleochroism are strong; 𝔄 is light greenish-yellow, 𝔅 and ℭ approximately equally dark grass-green. The outline is in general irregular, but many grains are much elongated in the direction of the ℭ axis and sometimes rough crystal outlines are observed corresponding, not only to faces of the prism zone but also to terminal faces. The much more rarely occurring brown mica sometimes exhibits six-sided outlines. The allotriomorphic feldspar is to a small extent plagioclase but chiefly orthoclase and microcline. Extremely common and very various in appearance are the microperthitic intergrowths. The orthoclase contains spindle-shaped inclusions or irregular patches of a feldspar characterized by a higher refractive index and double refraction. Further the orthoclase grains are sometimes peripherally surrounded by a narrow edging of more strongly double-refracting feldspar substance which is certainly of later growth. Apatite and zircon occur as accessory constituents in relatively large quantities.

Structure similar to a plutonic rock.

The microscopic structure of the gneiss reminds one strongly of that of a plutonic rock. This impression is produced particularly by the tendency in the amphibole and mica to regular outlines, their frequent bunchy aggregation and the difference in age of these two minerals as compared with that of the feldspar and quartz. On the other hand the ragged development and frequent intergrowth and interpenetration of the contituents so common in other gneisses is entirely wanting. At any rate one may express with great probability the supposition that this Lachute gneiss is of eruptive origin and this is supported by an analysis made by Dr. Dittrich which gave :—

Probably of eruptive origin.

	I.	II.
SiO_2	59·89	67·19
TiO_2	0·96	0·81
Al_2O_3	17·70	11·68
Fe_2O_3	1·95	4·17
FeO	2·71	
MgO	1·56	2·63
CaO	2·53	3·04
Na_2O	5·74	6·23
K_2O	5·83	4·17
P_2O_5	0·17	0·08
H_2O	0·29	
CO_2	0·39	
	99·72	

Under II the corresponding molecular percentages are given, neglecting the water and CO_2 and calculating all iron as FeO. One is struck upon first glance by the distinct difference between this and the Montebello gneiss, although both analyses show almost the same content of silica and alumina. The soda and lime are however quite different. The whole composition of this Lachute gneiss corresponds with that of an eruptive rock, and for it may be give..[2]—

S	A	C	F	a	c	f	n
68·00	10·40	1·28	8·56	10·5	1	8·5	6

This formula fits in very well with those of syenites rich in alkali between the types Umptekite and Hedrumite. There is a remarkable similarity between its composition and that, for example, of the syenite from Red Hill, New Hampshire, (Analysis III) in molecular proportions.

Difference between Montebello and Lachute gneiss.

	III.
SiO_2	66·24
TiO_2	0·68
Al_2O_3	12·00
FeO	4·79
MnO	0·03
MgO	1·76
CaO	2·89
Na_2O	7·64
K_2O	3·83

The high value of Na_2O can here be explained only by microscopic and perhaps also cryptoperthitic intergrowth of orthoclase with a soda feldspar. The average plagioclase has a composition $Ab_4\ An_1$, and is therefore an acidic oligoclase; probably there are present in the rock albite and a basic oligoclase.

Eruptive gneiss from Trembling mountain and Lakefield, P. Q.

Adams, in the investigation above mentioned, gives the analysis of an eruptive gneiss from Trembling mountain. This rock is more acidic to the extent of about 10 per cent of SiO_2, and corresponds in its composition to a granite. At a place called Lakefield, Argenteuil Co., P.Q., a gneiss was collected that does not differ essentially from the one just described. It is decidedly more fine-grained, and contains "Augen" of feldspar, 0 5—1 cm. diameter, whereby the structure is rendered somewhat more "flaserig." The cleavage surfaces of these feldspars are much bent, sometimes are quite crushed. Cleavage plates parallel to oP are in some cases without twinning striæ, and as far as their strong undulose extinction will allow of a determination the extinction is parallel. Other cleavage faces exhibit the cross-hatching of microcline. Under the microscope the grain is seen to be distinctly coarser than that of the gneiss from Lachute. The principal part of the section is made up of a mosaic of little feldspar grains, of which the striated and not striated are present in about equal parts. Quartz is present in much smaller quantity than the feldspar; its quantity may easily be overestimated, as many grains, which on account of their great clearness and high double refraction appear to be quartz, are found upon higher magnification to be covered with fine twinning striæ. This aggregate of colourless grains in large spots shows a quite irregular structure; in other places a parallel structure is clearly seen, all grains being elongated in one direction and arranged parallel to one another. The outlines of the grains are not lenticular but approximately rectangular, resulting in a layer structure.

Microscopic section.

Dark constituents.

The dark constituents are green hornblende, pyroxene, some garnet and ores; mica is apparently entirely absent. These constituents are always aggregated together in narrow bands. The hornblende is apparently the same as in the syenite gneiss. The pyroxene is in part rhombic, as is evidenced by the weak but distinct pleochroism, parallel extinction, lower interference colours, &c. Along with it, and in smaller quantities, there occurs a light greenish-gray monoclinic augite, with scarcely perceptible pleochroism. While the hornblende is always irregularly bounded, the pyroxenes, especially the rhombic ones, are in the form of columnar crystals, sometimes with rounded ends. The garnet is rare; it is transparent, of a very light-red colour, is completely isotropic, and shows rounded or ragged forms; it is always filled with vermiform inclusions of the light-coloured constituents. Frequently a garnet grain will have at its centre an opaque metallic particle, the vermiform inclusions radiating from this. Any regular arrangement of the other constituents around the garnet is not observable. This gneiss also is probably of eruptive origin, and possibly is connected in some way with the neighbouring anorthosites, which in part carry garnet.

Gneiss cut by dyke.

Near the house of Rev. Mr. Pierce this gneiss is cut by a dyke about 0·5 metre thick of a black rock rich in mica. Examined microscopically, it is found to contain a good deal of reddish-brown mica, almost colourless pyroxene in narrow columnar crystals, and serpentine pseudomorphs after olivine. The interspersed mass is too much decomposed to be determined more exactly. In all probability it is a lamprophyre dyke-rock belonging to the Minette-Kersantite class.

Certain other gneisses will be mentioned in the description of the occurrences of apatite and graphite.

ON THE OCCURRENCE OF APATITE AND MICA NORTH OF OTTAWA

First discovery of apatite.

Apatite in large deposits of economic value was known in the district of the Lièvre river as early as 1829, but was soon forgotten. In the year 1847, Dr. Sterry Hunt[*] described similar occurrences in the province of Ontario, between Kingston and Ottawa, in the counties of North and South Burgess, Lanark, Frontenac, Renfrew, Addington and Leeds. A regular exploitation was begun in the sixties and was carried on till the beginning of the nineties. At this time the Canadian apatite industry succumbed to the enormous development of the phosphorite industry in Florida, Alabama and neighbouring states. It was mainly in the two districts indicated, one north of the Ottawa river in the province of Quebec, and one south of the river in Ontario, that the mines were situated. The observations here recorded refer to the first of these districts, and the principal mines on the Lièvre and in the neighbourhood of the Gatineau river were the only ones visited. The area in which apatite occurs and is mined, extends over a large part of the townships of Buckingham, Portland East, Portland West, Templeton, Wakefield, Bowman and neighbouring townships. From the copious literature upon this subject, it may be said that it was very early recognized that the apatite was generally associated with rocks which were entirely or for the most part composed of pyroxene,

Area of apatite-bearing rocks in province of Quebec.

and which Sterry Hunt[3] called 'pyroxenite.' Concerning the origin of this 'pyroxenite' and of the apatite, opinion is still very much divided.

Sterry Hunt on mode of occurrence.

Sterry Hunt[4] described in the year 1863 the apatite as occurring in the Laurentian rocks, both distributed in crystals through carbonate of lime and in 'irregular beds running with the stratification and composed of nearly pure crystalline phosphate of lime.' In North Burgess the mineral occurs in 'several parallel beds interstratified with the gneiss.'

In the year 1866, the same author says[5], 'the presence of apatite seemed characteristic of the interstratified pyroxenic rocks, the apatite marks the stratification.' Simultaneously, 'true apatite vein-stones cutting the bedded rocks of the country' were mentioned. These were 'well-defined veins traversing vertically and nearly at right angles the various rocks.' In the year 1884, Hunt[6] says: 'I have within the past few months examined with some detail many of the apatite workings in Ontario, which have served to confirm the early observations and to give additional importance to the fact that the deposits of apatite are in part bedded or interstratified in the pyroxenic rock of the region, and in part true veins of posterior origin. . . . . The bedded deposits of apatite which are found running and dipping with these (above mentioned gneisses, quartzites, limestones and "pyroxenite layers,") I am disposed to look upon as true beds deposited at the same time with the inclosing rocks. The veins, on the contrary, cut across all these strata, and in some noticeable instances include broken angular masses of the inclosing rocks.' Further, 'in rare cases what appear from their structure and composition to be veins are found coinciding in dip and strike with the inclosing strata.'

Early observations confirmed.

In the year 1885, after another visit to the apatite mines in the Lièvre district, the same author remarks[7]: 'The large mining operations lately undertaken in the Lièvre district show that the crystalline phosphate of lime or apatite belongs to lodes of great size which traverse the ancient gneiss of the region. These lodes include a granitoid feldspathic rock and a pyroxenic rock with large masses of quartz, of carbonate of lime, of pyrites and of apatite. All of these often show a banded structure not unlike that of the gneiss to which they are evidently posterior and of which they often contain fragments.'

J. W. Dawson on mode of occurrence.

J. W. Dawson, in 1876, says[8]: 'It appears from the careful stratigraphical exploration of the Canadian Survey in the districts of Burgess and Ainsley, which are especially rich in apatite, that the mineral occurs largely in beds interstratified with the other members of the series, though deposits of the nature of veins likewise occur. It also appears that the principal beds are confined to certain horizons in the upper part of the Lower Laurentian, above the limestones containing Eozoon, though some less important deposits occur in lower positions.'

Veins a secondary formation.

Further, he says of the veins: 'Since these veins are found principally in the same members of the series in which the beds occur, it is a fair inference that the former are a secondary formation, dependent on the original deposition of apatite in the latter, which must belong to the time when the gneisses and limestones were laid down as sediments and organic accumulations.' Dawson further points out that in the Primordial time animals 'with phosphatic crusts and skeletons' predominated, and the calcium fluoride, contained in the apatite, also occurs in bones especially in many fossils. He lays especial value upon the fact of the occurrence of phosphorite nodules in Cambrian and Silurian strata along the St. Lawrence river and south of the Ottawa river, and which Sterry Hunt, in the Geology of Canada, considered to be coprolites.

Harrington quoted.

Harrington, in 1878, says[9]: 'That many of the apatite deposits of this region (Templeton) are not beds, is plainly shown by the manner in which they cut across the strike of the rocks containing them.' He further mentions the opinion of Brögger and Reusch as to the eruptive origin of the apatite veins of Southern Norway, and remarks: 'This idea of an igneous origin cannot be adopted for our veins,' points out the fact that the 'pyroxenite' often contains grains of apatite, and adds 'no doubt they are the strata from which the apatite of the veins has been chiefly derived.'

J. F. Torrence on occurrence of deposits in Portland and Buckingham.

In 1883, J. F. Torrence[10] expresses the opinion that the apatite deposits of Portland and Buckingham are irregular segregations from the country rock, and that these belong to one or more rock zones more or less strongly impregnated with apatite which follow a N.N.W. direction along the course of the Lièvre river. He further remarks: 'During the past season I often noticed in the same pit, patches of apatite that might easily be taken for the contents of a fissure vein, if ther [illegible] any casing rock on either side of it to separate it from the cou[illegible] rock, and patches of flat-lying apatite that might easily be called bedded, if they were of any great extent or approximately uniform thickness and if the country rock showed any planes of bedding parallel to the longest ones of such patches; or else it might easily be assumed that the country rock had been more or less tilted and overturned since the deposition of the apatite and that the vertical patches were interbedded and the horizontal ones were veins, if their relations to the country rock were such as veins and beds respectively are wont to maintain, but unfortunately I failed to perceive these conditions.' Further: 'In by far the greatest number of cases the containing rock of apatite is pyroxenite; the veins are very irregular, consisting of large bunches or pockets of ore, yielding hundreds of tons, which suddenly pinch out, but soon reappear when followed on their course.'

Other opinions on mode of occurrence.

In 1885, W. B. Dawkins[11] expresses the opinion that apatite occurs 'in veins'. 'They occur in bright crystalline massive schists composed of pyroxene, mica, orthoclase, triclinic feldspar, and apatite, which if not bedded would pass for an eruptive rock'; further, that these accompanying rocks as well as the veins themselves have obtained their material 'from some common deep-seated source of hydrothermal action.'

In the same year, Kinahan says[12]: 'It is possible the present Canadian apatites were originally limestones or allied rocks, the change to apatite being due to paramorphosis, which at present cannot be satisfactorily explained.'

Moreover, in 1884, G. M. Dawson[13] and F. T. Falding[14] are of the opinion that the 'bedded apatite' is of organic origin and that the Laurentian strata in which they occur are altered sediments. The 'vein apatite' has been formed from this by a 'process of segregation.'

On the other hand, in 1886, R. Bell[15] says that the apatite comes principally out of the pyroxenite and there are no indications of organic origin. The pyroxenite is possibly 'derived from igneous sources.'

Supposed clear evidence of eruptive origin.

E. Coste[16], in 1887, attributes the formation of apatite and a part of the iron ores occurring in the Laurentian to eruptive agencies. He says: 'We believe that we have gathered year after year strong and clear evidence to show that our deposits of iron ores in the Archæan rocks are of an eruptive or igneous origin, but also that our deposits of phosphate are exactly similar and have also the same origin.' Further, 'in the region north of Kingston, in the counties of Frontenac, Leeds, Lanark, Renfrew, Pontiac, and Ottawa many deposits of iron ores and many deposits of phosphate were observed also in the same association with igneous rocks, and both cutting through the Archæan rocks. In the case of the phosphate the igneous rock was often the rock termed by Dr. Hunt "pyroxenite," but at other times it was a pegmatite or a mica syenite or a pyroxene syenite.' He further points out that in many localities the iron ores and the apatite occur in the same veins, thus at the Blessington mine in nine different pits; in the summer of 1886, 500–600 tons of iron ore and 1,500 tons of apatite were obtained. 'We should conclude that the iron ores and phosphate to be found in our Archæan rocks are the result of emanations which have accompanied or immediately followed the intrusions through these rocks of many varied kinds of igneous rocks which are no doubt the equivalent of the volcanic rocks of to-day.'

Penrose quoted.

Penrose (1888)[17] verified the frequent vein nature of the apatite deposits. Concerning the 'pyroxenites' he says: 'The pyroxenic rock is never found distinctly bedded, though occasionally a series of parallel lines can be traced through it which, while possibly the remains of stratification are probably often joint planes.' Further, 'the gneiss in some places has no distinct line of separation from the pyroxene but seems to have been impregnated with some of it, forming for a few feet from the line of contact a more or less pyroxenic gneiss.' With respect to the origin of the apatite, Penrose does not give any definite opinion.

A. R. C. Selwyn[18] in 1889 says: 'There is absolutely no evidence whatever of the organic origin of apatite or that the deposits have resulted from ordinary mechanical sedimentation processes; they are clearly connected for the most part with the basic eruptions of Archean date.'

W. B. M. Davidson's views on origin.

W. B. M. Davidson[19] remarks in 1892: 'The pockets of apatite occur in bands or beds of pyroxene of varying thickness, but considerable regularity and which are conformable with the bedding of the gneiss. Most of the ablest Canadian geologists agree that these strata were deposited conformably in the pre-palæozoic sea and that they have been subjected to heat and pressure which has metamorphised the primitive character of the rock. Some writers, however, have considered the pyroxene to constitute lodes or dikes in which the apatite occurs as an accessory mineral, filling the crevices by plutonic action and hence of eruptive origin, which I take to mean that they think the apatite came to its present position through sublimation or through intrusion in a molten state. I am certainly of opinion that this theory is far stretched and without scientific corroboration.' Then he says: 'I believe that the phosphate was more or less regularly deposited in the varying beds in the Laurentian sea and that afterwards during the time of metamorphism phosphate of lime and other minerals crystallized out of the mother-rock in the most convenient positions that they could find.

R. W. Ells quoted.

R. W. Ells[20], who in recent years has examined for the Geological Survey that part of the province of Quebec which contains the apatite deposits along the Lièvre river, comes to the conclusion that the pyroxenites are of eruptive origin and that the occurrence of the apatite is essentially connected with the boundary of the pyroxenite and the gneiss. In connection with this he says: 'From many analyses we know that all pyroxenes contain a very considerable amount of calcium ranging from twenty to nearly thirty per cent. Since then the pyroxene in its intrusion with the gneiss must have ascended along lines of fracture or least resistance, it would be reasonable to infer that vapours charged with phosphoric acid ascended along such lines rather than through the mass of the dike and that in certain positions in proximity to the margins of the dike, these vapours impregnated the softened or heated mass from which as a result of chemical action upon the calcareous portion the phosphate of lime was produced. The mineral would therefore appear to owe its origin to chemical agency rather than to organic.'

Origin due to chemical agency rather than organic.

Rocks from apatite regions examined by Adams.

In closing this reference to the literature of the subject an investigation by Adams[21] must be noticed, which deals with rocks from the apatite region of Quebec and which therefore is of interest. Starting out from the spotted gabbro of Norway as apatite-bearing, Adams has examined certain pyroxenites with respect to their containing scapolite. The specimens came from Lot 35, Range V., of Portland West, from the McLaurin mine, Templeton, and the Emerald mine. In none of these was scapolite found. Further, two rocks collected by E. Coste at the Star Hill mine, Portland West, and the Blessington mine, Ont., were recognized as granular eruptive rocks and designated as mica syenite and augite mica syenite. On the other hand, Adams found in a series of rocks from Arnprior on the Ottawa river, a rock consisting essentially of pyroxene, hornblende and scapolite and which he called scapolite diorite on account of its granular structure. Similarly in the Museum of the Geological Survey there were some scapolite-bearing rocks from Ontario, designated as plagioclase scapolite diorite and plagioclase scapolite amphibolite. Apparently these occurrences, as Adams remarks, are not connected with the apatite deposits. Lacroix later examined the same rock from Arnprior[22].

Diverse opinions held.

Unfortunately I have been unable to consult the greater part of the Canadian literature, but it is evident from what has been quoted above that the views with regard to the Canadian apatite are very diverse.

Davidson and perhaps a few other geologists deny the occurrence of apatite and pyroxenite in true veins. According to them the pyroxenite is of the same age as the gneiss and stratified conformably with it. The apatite has been derived from an original phosphoric acid content of the Laurentian deposits; by their metamorphosis it crystallized out from the 'plastic magma.'

Apatite beds and veins cut the gneiss.

The greater number of Canadian geologists are agreed, however, that both 'beds' and veins of apatite occur, which cut the gneiss strata in all possible directions. They regard the former as derived from phosphoric acid in the rocks due to organic remains, the veins being formed from a leaching out of this material, *i.e.* by lateral secretion. In connection with the organic origin of the phosphoric acid much weight is laid upon the occurrence of graphite in the neighbourhood of the apatite and also [the graphite veins in the neighbourhood of Buckingham on the Lièvre river contain green apatite in compact masses], on the occurrence of Eozoon Canadense in the Laurentian limestones, and of certain iron ores in the Laurentian, the origin of which is also supposed to be connected with the action of organisms.

Genetic relation of apatite and pyroxenite.

Selwyn, Coste, Ells, and also Bell, bring the formation of apatite into genetic relation with that of basic eruptive rocks (*e.g.* pyroxenite). Ells speaks directly of a fumarole action which accompanied or followed their formation and through the action of which upon the lime of the pyroxene the apatite was formed. This view is very similar to the theory put forward by Brögger and Vogt to explain the formation of the apatite veins of southern Norway.

Occurrences now difficult to study.

Unfortunately the opportunities for the study of the occurrences of apatite are very much less advantageous than they were at the time when the industry was in a flourishing condition. Most of the mines are under water and are inaccessible so that one is in many cases confined entirely to the material in the dumps. Further, most of the works are in thick woods, through which it is difficult to travel and in which exposures are rare. Certain favourable opportunities are found where mica occurs in the neighbourhood of the apatite in quantity and quality, sufficient to justify mining operations which are now being carried on. Such a locality is the Vavasour mine, which on account of the very useful opportunities it offers for certain conclusions, will be described somewhat in detail.

Vavasour mine.

The Vavasour mine is situated about 14 miles from Ottawa. It is an old mine which was originally worked for apatite, but at present only for mica (phlogopite.) Both minerals here occur in the same veins and owe their formation undoubtedly to the same process. A number of veins were being worked, which, with a steep dip and a strike almost N. and S., are all so near one another that the whole mine occupies but a very small area. The principal vein has been opened up by cuttings to a length of about 700 feet and in places to a depth of about 50 feet.

Geological relations.

Vein minerals

The best insight into the geological relations is obtained at an opening at the south-east side of the mine property. Here there is a partially exhausted and now abandoned cutting in the gneiss. The gneiss consists of light and dark layers, the former consisting in part of red orthoclase with very much bent cleavage faces and much quartz. In the darker layers the magnifying glass reveals much biotite, some hornblende and quite sporadically a grain of red garnet. The strike of the gneiss is N. and S., the dip 30° W. The apatite vein partially exposed by quarrying has the same strike, but dips, steeply to the east so that the dip of the gneiss layers and of the apatite vein are almost perpendicular to one another. The thickness of the vein is about 1 m. Its borders show up quite sharply against the country rock ; in the gneiss no alterations due to contact were observed. At the bottom of the exhausted cutting and on remaining fragments of the border of the vein one sees that directly upon the border plane pyroxene crystals have formed, prismatically developed up to 5 cm. thick and twice as long. The prism zone is almost perpendicular to the plane of contact. A second vein mineral is reddish-brown phlogopite, also usually well crystallized, but sometimes in scaly aggregates filling out the spaces between the pyroxenes. Everywhere one can discern that the pyroxene is the earlier formed and the phlogopite the later formed mineral. In places the two build a regular net-work the interspaces of which are either empty or filled with a coarse-grained aggregate of reddish-coloured calcite. The central main mass of the vein consists of the same calcite and of green apatite, the relative quantities of the two vary, the former generally predominating. The apatite either exhibits the crystalline form $\infty P \left\{10\bar{1}0\right\}$ $P \left\{1011\right\}$ with rounded edges and corners, or forms large irregular lumps. The richer the vein is in calcite, the better is the apatite crystallized. Calcite crystals are entirely absent. The sequence of the four vein minerals here is therefore : pyroxene, phlogopite, apatite, calcite. The same relations appear on the opposite edge, the vein is laterally symmetrical.

From this vein a narrow vein branches off into the gneiss having a thickness of about 0·5 m. Its edges are also perfectly sharply defined against the gneiss. The vein is symmetrically formed and consists as the accompanying figure shows of two lateral zones *a* and *b* almost equal in thickness and of a central part *c* about 25 cm. thick ; *g* is the gneiss. The two lateral zones consist of a very uniformly granular mixture of pyroxene, phlogopite and apatite. The size of the grains is about 1—2 mm. Pyroxene and mica are present in about equal quantities; the apatite is shown under the microscope to be decidedly less in quantity. Evidently it is a mineral aggregate of similar origin to that of the lateral portions of the vein, only the minerals have been simultaneously and more quickly formed. The central portion consists of coarsely crystalline almost pure reddish and greenish apatite.

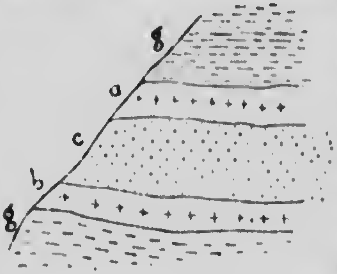

Fig. 1.

Description two lateral zones.

In other parts of the property the apatite-bearing veins do not cut gneiss, but pieces of country rock collected from the dump and also directly from the mine are found to be typical scapolite gabbro. In the case of medium and coarse-grained varieties, it is a rock of typically massive structure and consists of about equal quantities of pyroxene—partially uralitic—and of scapolite. Upon a first glance it is seen to be a basic plutonic rock, and distinctly different from the gneiss. Along with the irregular granular structure there is a streaky structure in many blocks, as is of very frequent occurrence in gabbros. (The petrographical description of these rocks will be given later.) On account of the very few exposures and the short time spent in the district, nothing further can be said with respect to the distribution of the gabbro. It certainly seems to be of no very great extent. It could not be determined whether it formed a little stock or a vein.

The vein consists essentially, as was described above, of the peripheral portions made up of pyroxene and phlogopite, and the central part consisting of apatite and calcite. Mining operations are confined to those portions in which the pyroxene is in smaller quantity and the phlogopite occurs in plates up to a square foot in size, and sometimes in thick crystals.

From the relations observed in the Vavasour mine it may be concluded that :

Apatite occurs in true veins.

1. The apatite here occurs in true veins. That together with other minerals it fills fissures which cut through the gneiss and through a plutonic

Similar relations at MacRae mine.

rock belonging to the family of the gabbros and that it exhibits with respect to the gneiss an intrusive character. This fact has been observed also in many other places as is evident from the literature quoted above. Ells mentions the same relations as occurring at the MacRae mine in Templeton township, at the Little Rapids mine, and says further 'At Crown Hill (mine) the great masses of pyroxene have thrown the gneiss entirely out of its normal strike.' Harrington says: 'As examples of this may be mentioned an important vein on the seventh lot of the first range of Portland, the course of which is N. 15° W., while the strike of the country rock is N. 45° W. On the nineteenth lot of the ninth range of Templeton the rocks strike N. 40° E. and are traversed nearly at right angles to their strike by a vein of apatite. Again on lot fifteen of the eighth range of Templeton are three veins, whose courses are respectively N. 40° W., N. 60° W., and N. 67° W., while that of the county rock is N. 20° W. In some instances deposits which look like interstratified beds in place are here and there seen to give off lateral branches which cut directly across the strike of these rocks. An example of this was noticed at Mud Bay on the twelfth lot of the eleventh range of Templeton, in the case of an apatite vein occurring in garnetiferous gneiss.'

London and Emerald mines.

I myself have observed similar relations in a number of different mines. Above the London mine the garnetiferous gneiss is cut by a large number of pyroxenite veins with very different strikes, forming in fact in some places a perfect net-work. In the lower opening of the London mine the gneiss may be very clearly seen thrown out of its normal position along the apatite vein and bent over nearly at right angles. Here, as Ells pointed out above, in connection with the formation of the cracks there seems to have taken place no inconsiderable disturbance of the position of the gneiss. The fact that the pyroxenite veins cut through the gneiss almost at right angles is also, in the North Star mine, very plainly visible. At the Emerald mine, as will be pointed out later, gneiss and gabbro are cut by pegmatite veins, and these last in their turn undoubtedly by apatite veins.

That similar conditions exist in the apatite region, not visited by me, south of the Ottawa river in Ontario is seen by a profile, given by Penrose, of the Foster mine, Frontenac county. Here also we have cases of apatite veins having dips almost at right angles to that of the gneiss.

Apatite veins always accompanied with pyroxenite.

2. At the Vavasour mine the apatite veins occur along with a scapolitised gabbro. As many authors have stated and as I was also able to prove without exception, the apatite veins are always accom-

panied by so called 'pyroxenite'; they seem to be connected with its ocurrence, and the first question seems to be as to what these 'pyroxenites' are.

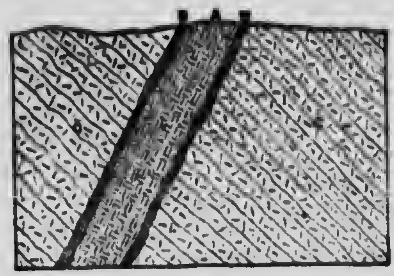

Fig. 2. Section of one of the north-west and north-east veins at Foster's Mine, Loughborough, Frontenac county, Ont.; A, apatite; B, pyroxene; C, country gneiss. Scale 1 inch = 7 feet.

Pyroxenites of plutonic origin.

A portion of them are doubtless intrusive rocks of plutonic origin and belong to the family of the gabbros, norites, diorites, and, in part, to the basic syenites and shonkinites. Adams (see above) has examined two such rocks and designated them as mica syenite and pyroxene mica syenite. In certain cases the rocks exposed in the mines are fresh; generally, however, they are much altered, whereby particularly a new formation of scapolite, at the expense of the feldspar, has taken place. Such scapolite gabbros and related rocks I have collected and examined microscopically from the Vavasour, London, Emerald, North Star, Union, High Rock and Crown Hill mines, and from the Poupore post-office, in short, from almost all the apatite localities visited. They form an analogue to the scapolite gabbro of southern Norway, with which also the occurrence of apatite veins is connected. A conversion of pyroxene into brown hornblende, as is the case in the so-called spotted gabbro from Oedegarden, has not been met with to my knowledge. The pyroxenes are partly altered to green uralite, but the change seems to be independent of the formation of the apatite veins.

Scapolite gabbros examined microscopically.

Mineral aggregates.

Another portion of the 'pyroxenite' has formed in the cracks themselves, and constitutes mineral aggregates, which, in general, are of the same age as the apatite. Such a uniformly granular aggregate of pyroxene, phlogopite and apatite was mentioned in connection with the small vein at the Vavasour mine. The composition and structure of these masses is very varied. In some cases they can be distinguished from the unaltered plutonic rock at a first glance; in other cases they are extraordinarily like these, not only macroscopically, but also microscopically, being rich in scapolite, &c., so that a dividing line between the two classes of 'pyroxenite' can hardly be drawn. This, in the nature of the case, is not surprising. As examples, two cases from the Emerald mine may here be mentioned. In the neighbourhood of the Belleau pit, and underneath the smithy, on the

Pegmatite cut by apatite veins.

Fine examples of pyroxenite at Poupore post office.

boundary of the Squawhill mine, the gabbro, which forms the main mass of the whole hill, is intersected by pegmatite veins, which are widely distributed throughout the whole region. They are granite pegmatites, consisting essentially of quartz and microcline. At both places the pegmatite is cut by narrow apatite veins, which exhibit a symmetrical structure, as in the accompanying figure. The two outer zones about 10-12 cm. thick, sharply defined against the pegmatite, consist of such 'pyroxenite.' The central zone, about 30-40 cm. thick, consists of calcite and apatite. The dividing lines between the 'pyroxenite' and the central zone are not sharp; many crystals of pyroxene, very well formed, penetrate into the calcite, and in some places a gradual transition is found, caused by increase of calcite and decrease of pyroxene. The main part of the 'pyroxenite' is, however, a uniform, rather coarse-grained mineral aggregate, which, under the microscope, is found to consist essentially of augite and scapolite, and is hardly to be distinguished from many altered plutonic rocks. Very beautiful examples of such 'pyroxenite' selvages may be observed in the small opening near the Poupore post-office. The rocks rounded by glacial action show various gneisses, some very rich in garnet, interlaminated with quartzite and cut by a scapolitised gabbro, which contains apatite in lumps and veins. The gneiss also is cut by numerous fissures, often dwindling away to nothing, and each of these is edged with a zone, as thick as one or two fingers, of 'pyroxenite,' consisting of individuals of augite set perpendicular to the edge of the vein. The same pyroxenite zones are seen in the figure on page 21, showing the apatite vein of the Foxton mine, according to Penrose.

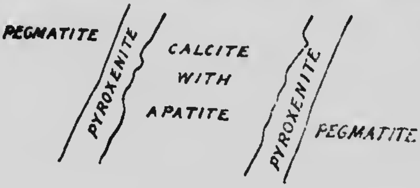

FIG. 3.

From what is said above, it follows that the masses, designated by the general name of 'pyroxenite,' are genetically very different. Whereas in petrography one understands by the name pyroxenite a primary plutonic rock consisting almost exclusively of members of the augite family, we have here to deal mainly with altered gabbros and secondary vein fillings, which are connected with the formation of the apatite.

3. At the Vavasour mine there are essentially four minerals (see Plate I) which constitute the vein material, pyroxene, phlogopite, apa-

tite and calcite, and this order gives their relative time of formation. The pyroxene was the first formed and the calcite the last. This also obtains in the main for the other mines examined by me, although one or other of these minerals is sometimes present in comparatively small quantity or entirely absent. Thus in the dumps of the Cascade mine, I found only traces of apatite, the workings being carried on for mica; in the veins, cutting the diorite gabbro at South March, the pyroxene seems to be absent. The general character of the dikes, however, is so similar that they must surely have the same origin. In many occurrences feldspars play an important part, particularly a gray microcline, which covers whole walls. I have seen nothing of the large quartz masses which many authors mention. Quartz occurs only unimportantly. There are in addition a large number of minerals which will be mentioned later.

Pyroxenites of Upper Lièvre river apatite mines.

In the large apatite mines upon the upper Lièvre river, Union, High Rock, Crown Hill, and in part North Star, the above described vein character occurs less distinctly. The 'pyroxenites' here contain irregular lumps and large pockets of mostly pure apatite and phlogopite, while calcite is much more subordinate. From these, for the most part irregularly bounded masses of apatite, there run off veins which are often filled only with thin plates of mica standing perpendicularly to the walls, widening out here and there and then again carrying apatite. The walls of the mine are here and there penetrated by a perfect network of such little veins, or the whole pyroxenite is fairly impregnated with apatite and mica. Here indeed it is very difficult to determine the boundary between altered plutonic rock and later formed pyroxenite. Penrose gives a number of drawings which illustrate these relations very clearly.

Without going into a special description of the individual occurrences, certain important points bearing upon the genesis of these rocks may be indicated.

Age of pyroxenite and apatite in doubt.

As is evident from the literature already quoted, many authors speak of a 'bedded' pyroxenite and apatite and deduce from this the conclusion that they are both of the same age as the Laurentian strata and belong to a certain division of these. I have been unable in any locality to convince myself of this fact. That many veins are developed as bedded veins (Lagergange), in part filling crevices which in strike and dip correspond with the gneiss, is correct; it is natural that many cracks should be formed in the direction of least resistance. As proof of these deposits being of the same age as the neighbouring gneiss, a certain parallel structure in the pyroxenite and in the apatite masses connected with them has been pointed out, and further the fact that no sharp line of demarkation exists between these latter and the gneiss, that they pass over one into the other.

Pyroxene rock never distinctly bedded.

As far as the parallel structure is concerned, I concur exactly in the view expressed by Penrose: 'The pyroxene rock is never found distinctly bedded,' &c. A parallel structure at all comparable with that of the gneiss I have never found. That many veins exhibit a laterally symmetrical formation has already been pointed out in connection with the Vavaseur mine. A typical example from Mud Bay, Templeton county, as given by Harrington, is here figured. It is a structure which is very well known in the case of ore veins. When such a vein is deposited conformably between gneiss strata its own layers must naturally be parallel with the cleavage planes of the gneiss. Another example from the Grant mine, also by Harrington, exhibits very regular alternations of layers of apatite and pyroxene about $\frac{1}{4}$-inch thick; the structure, as Harrington points out, reminds one strongly of Eozoon. It is expressly stated that the piece comes from a 'vein.' Penrose[17] gives the accompanying sketch of a pit in the neighbourhood of

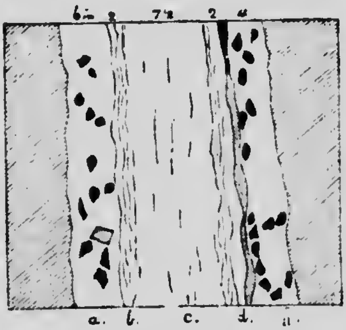

Fig. 4. *a.* Calcite and mica. *b.* Fine grained mica in many lines, with pyroxene and little apatite. *c.* Pyroxene, granular apatite, and a little mica, in fine scales, arranged in wavy lines in the direction of the vein. *d.* Mica-pyroxene and thin layers of apatite, calcite and mica.

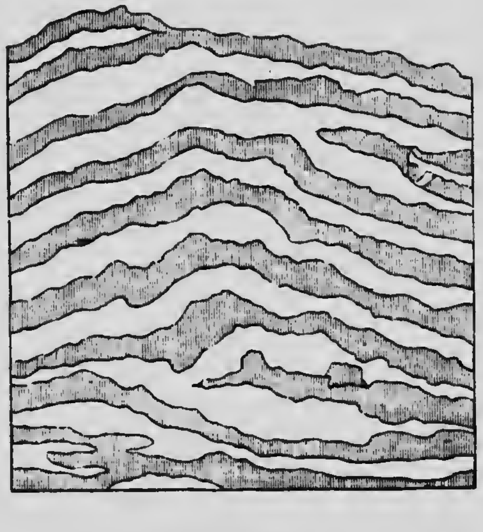

Fig. 5. Veinstone showing alternate layers of apatite and pyroxene.

the Emerald mine. Here evidently there are veins in the pyroxenite which in places dwindle away, and in other places widen out and are

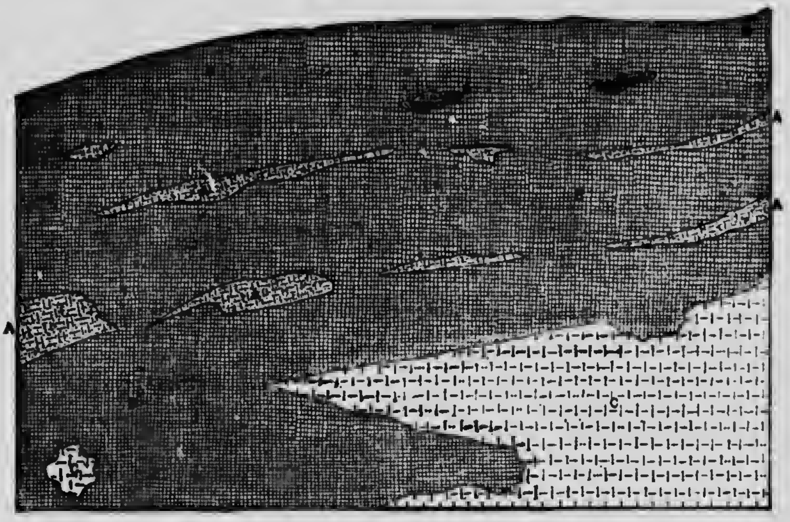

Fig. 6. Section in a pit near the Emerald Mine (looking west), Buckingham, Ottawa County, Quebec. *a.* Apatite; *b.* Pyroxene; *c.* Feldspar; *d.* Pyrite. Scale, 1 inch = 6 feet.

filled with apatite, and are probably connected with a large apatite mass which was mined. The parallel direction of these has nothing to do with a stratified or schistose structure. For comparison another figure by Penrose[17] of a locality at Smith's mine, Frontenac county, is given where such parallel apatite veins cut the syenite. In Plate IV. a piece of vein from the Vavasour mine is shown whose structure at first sight strongly reminds one of the streaky structure of ‘Augen-gneiss.’ From the description on page 19 it follows that it is essentially different from it, however. The quotation from Harrington mentioned on page 20 may be recalled, according to which from such apparent ‘beds,’ fragments and veins run into the gneiss strata.

Apatite veins cutting syenite.

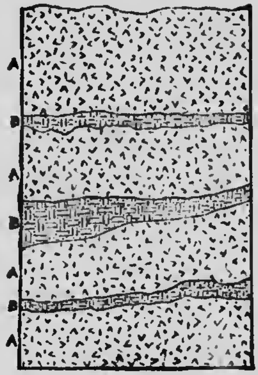

Fig. 7. Opening in west side of a hill near Smith's mine, Oso., Frontenac county, Ont. *a.* Country Syenite; *b.* Apatite, scale, 1 inch = 24 feet.

With respect to the transition of the pyroxenite into the neighbouring gneiss, Transition of pyroxenite into gneiss.

or rather the want of sharp demarcation between the two, the occurrences are very various. At the Vavasour mines there are veins which cut through the gneiss and whose borders are absolutely sharply defined. In other cases, especially where vein formation of the nature of 'pyroxenite' borders on the gneiss, the boundaries are indefinite, and there is an apparent transition. This arises, as Penrose has already pointed out, from impregnation of the gneiss with vein material. Later certain typical examples will be mentioned which leave no doubt that such a process has actually taken place. Plate V shows a vein granite from the London mine upon the spherical planes of jointing of which pyroxene, titanite, pyrite, and apatite have been later deposited. Similar 'leopard granite' is found at Little Rapids and the North Star mine. Plate X fig. II gives the microscopic appearance of a quartzite in which scapolite, pyroxene, apatite, &c. have been deposited in cracks. It is difficult to form an idea as to how far such a process has taken place, as in the mines one sees only that part of the gneiss exposed which was directly in contact with the apatite or the pyroxenite. At the North Star, Union, and High Rock mines, gneisses were collected which were all rich in pyroxene; a very curious gneiss like a granulite and rich in pyroxene, from the London mine, will be described later. How far this content of augite is to be attributed to such secondary impregnation processes can only be determined when these crystalline schists can be followed along their strike to considerable distances from the apatite deposits. In what follows therefore only such cases are introduced as admit of no doubt regarding such a process.

Vein nature of apatite deposits probable.

Still other facts which point to the vein nature of such apatite deposits, have been mentioned by other authors. Thus, angular fragments of the country rock are found in the veins. On the dump of the Murray pit, Emerald mine, I found fragments of gabbro, as large as one's head, entirely encrusted with apatite. The vein minerals themselves also exhibit occasionally such encrustations. Plate II shows a vein fragment from the Emerald mine: a pyroxene crystal about 3 cm. long and 2 cm. thick is surrounded by a coating of apatite about 3–4 mm. thick, the whole being embedded in coarser crystalline reddish calcite. Structures are thus produced such as are frequently found in ore veins and which are called cocarden structure.

Further, drusy hollows occur, the walls of which are lined with well crystallized vein minerals. Harrington[9] gives a series of such occurrences and mentions crystals of apatite a foot in length which were collected from such druses. At the Vavasour mine the workmen showed me a piece of such a druse, the wall of which was lined entirely with little quartz crystals. When Dr. Ells and I were visiting Browns' mine, the owner told us of such a drusy cavity which had been cut into a short time before.

All these peculiarities and the similarity in mineral content of all the deposits of apatite in the province of Quebec known to me, lead to the belief that they are all of the same origin and younger than the associated gneisses. They are accordingly true veins which have been formed in the same way as all other ore veins.

The Vein Minerals.

Vein minerals.

The minerals forming the principal part of the vein filling are pyroxene, mica (phlogopite), apatite, calcite, and some feldspar. Of less importance are amphibole (actinolite), tourmaline, scapolite, titanite, and various metallic sulphides. Further, Harrington gives a long list of other minerals, i.e. fluorspar, quartz, garnet, epidote, idocrase, zirkon, prehnite, cabazite, molybdenite, graphite, &c., of which I only observed a few during my very short visit. Harrington has described all these minerals very thoroughly, and they may therefore here be passed over in a few words.

Pyroxene is the mineral which accompanies the apatite most regularly and in greatest quantity. I saw only one apatite locality in which it seemed to be absent, at least Dr. Ells and I failed to find it, although we made a special search for it. Here there were a series of small veins running through the diorite, near the railway station at South March, not far from Ottawa. An opening was made for the purpose of mining mica, but was soon abandoned as the mica was not very fresh, in consequence of which it had lost its elasticity. In these veins only mica, apatite and calcite were present.

Crystallized pyroxene in apatite veins.

The pyroxene occurs in the apatite veins, partly well crystallized, and partly massive as in the 'pyroxenite.' Here only the former will be dealt with. The crystals are found principally in such deposits as may be said to be typically veins, and which contain much calcite. These veins best exhibit the order of age as given in connection with the Vavasour mine; pyroxene mica, and apatite are the best developed and, being the oldest, are found directly on the border of the vein (the contact). The crystals are usually dark green; the surface is rough and dull; the faces, especially the terminal ones, often appearing as though coroded. On planes of fracture they look very like dark green bottle glass. Almost without exception, they exhibit a very perfect cleavage parallel to oP, in which direction the crystals generally break on being struck. Crystals which I collected at the Cascade mine are about 6 cm. thick and 9–10 cm. long. They exhibit the forms $\infty P \left\{110\right\}\ \infty P \grave{\infty} \left\{010\right\}\ \infty P \bar{\infty} \left\{100\right\} + P \left\{\bar{1}11\right\} + P \bar{\infty} \left\{\bar{1}01\right\} - P \left\{111\right\}$ and $oP \left\{001\right\}$ as in fig. 8.

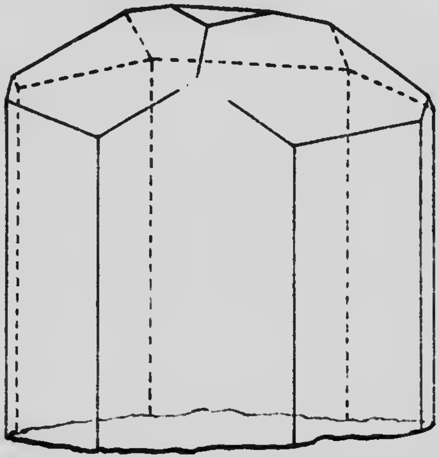
Fig. 8. Pyroxene crystal from the Cascade mine.

Sometimes $+2P\left\{\bar{2}21\right\}$ is also present. The clinopinacoid is always very narrow; the other faces of the prism zone about equally developed, or $\infty P \bar{\infty}$ predominating. At the Emerald mine, there occur also almost black crystals perfectly developed and embedded in calcite. Harrington* mentions also very light coloured grayish-white pyroxene.

Analysis of grey pyroxene from Templeton township.

The analysis of a variety of grey pyroxene from Templeton township gave, according to Harrington, the composition:

	I.	II.
SiO_2	50·87	48·24
Al_2O_3	4·57	2·55
Fe_2O_3	0·97	0·34
FeO	1·96	1·55
MnO	0·15	0·12
MgO	15·37	21·86
CaO	24·44	24·84
Na_2O	0·22	0·20
K_2O	0·50	0·30
Loss on ignition	1·44	
	100·49	100·00

Under II are given the molecular proportions, calculated to 100, and leaving out the loss on ignition. According to these, the proportions are as below:

CaO : (Mg Mn Fe) O   23·53 : 24·84

that is, almost exactly 1 : 1. Further,

$$\begin{aligned}(\mathrm{Ca\ Fe\ Mg\ Mn})\,\mathrm{O} &= 48{\cdot}37\\ (\mathrm{Al\ Fe})_2\,\mathrm{O}_3 &= 2{\cdot}89\\ (\mathrm{K\ Na})_2\,\mathrm{O} &= 0{\cdot}50\end{aligned}$$

and the molecules calculate out as follows :

$$\begin{array}{llll} 1{\cdot}00\ (\mathrm{K\ Na}) & (\mathrm{Fe\ Al}) & \mathrm{Si}_2\,\mathrm{O}_6 & = 3{\cdot}79 \text{ per cent.}\\ 2{\cdot}39\ \mathrm{Mg} & \mathrm{Al}_2 & \mathrm{Si}_2\,\mathrm{O}_6 & = 9{\cdot}06 \quad ''\\ 1{\cdot}55\ \mathrm{Fe} & \mathrm{Ca} & \mathrm{Si}_2\,\mathrm{O}_6 & = 5{\cdot}88 \quad ''\\ 0{\cdot}12\ \mathrm{Mn} & \mathrm{Ca} & \mathrm{Si}_2\,\mathrm{O}_6 & = 0{\cdot}45 \quad ''\\ 19{\cdot}47\ \mathrm{Mg} & \mathrm{Ca} & \mathrm{Si}_2\,\mathrm{O}_6 & = 73{\cdot}81 \quad ''\\ 1{\cdot}85\ \mathrm{Ca} & \mathrm{Ca} & \mathrm{Si}_2\,\mathrm{O}_6 & = 7{\cdot}01 \quad ''\end{array}$$

The silica is for this composition about 2·13 molecular percent too low. This is, perhaps, caused by the fact that titanic acid is present and was weighed with the alumina. At any rate, this pyroxene is very close to diopside, the pure diopside molecule, Mg Ca $\mathrm{Si}_2\ \mathrm{O}_6$, requiring 55·55 SiO_2, 25·93 CaO and 18·52 MgO.

Description of phlogopite accompanying apatite.

Phlogopite is a second mineral almost invariably accompanying the apatite ; many of the mines which were formerly worked for apatite being now worked for mica. The mineral is of several shades of brown, varying from light brownish-yellow, through reddish brown, to dark chestnut-brown : the most common varieties are about the colour of dark amber. Crystals are extremely common and in part of gigantic dimensions (more than 1 foot in diameter). Plates 10–15 cm. in diameter are quite common. The peripheral faces are always very rough and could not be determined with the contact gonimeter with sufficient exactness ; sometimes twining forms are very common. Cleavage lamellæ exhibit no evident pleochroism and in convergent light give a dark cross which in the specimens examined from Vavasour, North Star, Cascade, Union, Browns', Fleury's mines and South March did not open up to hyperbolas, at least the axial angle is very small. Also the inclination of the acute bisectrix to the normal to OP is very small.

Mica examined for fluorine and lithium.

I examined a series of these micas for fluorine and lithium, as these seemed to be important in connection with the question of the origin of these vein minerals. For the recognition of lithium the micas were simply ignited in the Bunsen flame, and the red line of lithium was observed in the spectroscope in the case of the occurrences at Vavasour, Fleury, North Star and Cascade mines. A mica from the Union mine did not give the reaction. For the recognition of fluorine about 1 gram of the mica was fused with sodium-potassium carbonate, the fusion dissolved in hot water and the insoluble material filtered off. In the filtrate the silica and alumina were precipitated with ammonium carbonate, the filtrate acidified with hydrochloric acid, the CO_2 driven off by boiling, the liquid neutralized with ammonia, and the fluorine precipitated as calcium fluoride by means of calcium chloride. From the micas from Vavasour, Union, Fleury and North Star mines a heavy flocculent precipitate was obtained which when burned with the filter and treated with concentrated sulphuric acid gave a strong etching reaction on glass. A mica from the Cascade mine gave, on the contrary, only a slight opalescence. The Cascade mine is at present an abandoned working, that was only worked for mica, while judging from the material on the dump, apatite is entirely absent.

Analysis of phlogopite from South Burgess, Ont.

No analysis of phlogopite from apatite mines north of the Ottawa river is known to me. On the other hand an analysis by Clarke and Schneider[23] is published of the phlogopite from South Burgess, Ont., so well known on account of its inclusions and its beautiful asterism. Under I its composition is given :—

	I.	II.
SiO_2	39·66	40·24
TiO_2	0·56	0·56
Al_2O_3	17·00	12·96
Fe_2O_3	0·27	7·67
FeO	0·20	2·15
MgO	26·49	23·29
BaO	0·62	
CaO		0·35
Na_2O	0·60	
K_2O	9·97	
H_2O	2·99	0·68 (Loss on ig.)
F	2·24	
P_2O_5	trace	
Total	100·60	
—O	0·94	
	99·66	

Under II is the analysis of a phlogopite from the apatite veins of Oedegarden, Southern Norway.[24] Unfortunately it is incomplete, the determination of the alkalies being wanting, but lithia and fluorine are probably absent.

Analysis I is that of a typical phlogopite, but the silica is just a little low. The small quantity of iron and the large quantities of magnesia and of fluorine are, however, characteristic. The last allies the mica closely to the fluor micas, zinnwaldite and lepidolite. Clarke and Schneider calculate for it the formula:

$$Al(SiO_4)_3Mg_3KH_2 + Al_2(SiO_4)_3Mg_4K(MgFe)$$

combining the TiO_2 with the SiO_2, the Fe_2O_3 with the Al_2O_3, the FeO and BaO with the MgO and the Na_2O with the K_2O. The composition calculated from the formula agrees with that found upon analysis very well. A calculation of analyses I and II for purposes of comparison gave, in molecular proportions:

	I.	II.
$SiO_2 + TiO_2$	0·6610	0·6707
$Al_2O_3 + Fe_2O_3$	0·1684	0·1746
(FeMgBaCa) O	0·6391	0·6183

Calculated to molecular percentages the differences are, of course, smaller.

Inclusions in mica.

The much discussed inclusions which cause the beautiful asterism in the mica from South Burgess are excellently seen in the micas from North Star, Union, Fleury and Cascade mines: the mica from the North Star mine in particular contains them with relatively very large dimensions and of great beauty. These inclusions were first described and figured in detail in the mica from South Burgess by G. Rose.[25] The figures given leave no doubt that they are identical with the inclusions in the phlogopite from the North Star mine. Rose originally considered the mineral to be disthene, but subsequently concurred in the opinion of de Cloizeaux that they were a uniaxial mica. Tschermak[26] later described the inclusions and the asterism of a phlogopite from Perth. He remarks that from their refraction and form they could not be a mica, but that he was unable to determine their real nature.

In 1882 Sandberger[27] examined a phlogopite from Ontario. According to him the inclusions were contained only in the decomposed portions of the mica, which were recognized by white spots on the cleavage faces; the bright brown fresh portions of the mica on the other hand did not contain them. 'The chemical analysis showed that the almost colourless needles consisted of pure titanic acid.'

Lacroix[28] described the needle-like inclusions from a black mica from Templeton, which contained neither fluorine nor lithium. For their isolation the mica was treated in a closed glass vessel with concentrated hydrochloric acid at a temperature of 250°, and the remaining skeleton of silica which contained the needles was dissolved in a solution of caustic potash. The inclusions obtained in this way were fused with caustic potash, the mass dissolved in hydrochloric acid, and by warming with zinc a violet colour was obtained which indicated titanium. Further the description of the rectangular and apparently hemimorphic form of certain of these inclusions agrees very well with that of the inclusions observed at the North Star mine.

Rosenbusch[29] mentions in these Canadian micas, rutile and tourmaline needles which in the same way are arranged at angles of 60° and cause asterism.

Secondary nature of inclusions in mica improbable.

It must be especially mentioned that the micas carrying inclusions which I collected, were absolutely fresh and elastic; only such are of commercial value and are mined. It seems to me therefore very improbable that the inclusions are of a secondary nature as many authors consider them to be: I consider them to be of primary formation. Their shapes are very varied. Most of them form fine needles often of astonishing length. In the mica of the North Star mine such needles were observed more than 1 cm. long, and of a thickness which under a magnifying power of 70 appeared to be equal to the cross hairs in the eye piece (eye piece 3, objective 2, Fuess). Sometimes they swell out, especially towards the ends, into a wedge shape, or they attain what Tschermak has called tobacco-pipe shape. Other forms are short and rectangular, six-sided, and then always elongated very much on one side, also eight-sided, often apparently hemimorphic, also quadratic or sharply rhomboidal. Contact twins are not uncommon, the twinning plane being one of the bounding faces, the extinction of both individuals being parallel to the division.

Varying forms of inclusions.

The accompanying sketch, Fig. 3, Plate X, gives an idea of the extraordinary and varying forms. I have measured a large number of angles with the eye piece goniometer of a large Fuess microscope. In spite of the fact of the sharp outlines reducing the errors of observation to a minimum, I hardly found two apparently similar little blades to possess the same values, so that the form gives little indication for the determination of their true character.

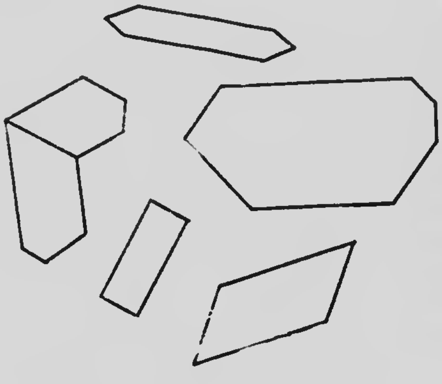

Fig. 3.

The little plates are extraordinarily thin and by illumination with ordinary light they give pale Newtonian colours; isolated and suspended in water, the interference colours are distinctly more brilliant. Needles invariably exhibit parallel extinction, the lesser elasticity coinciding without exception with their long axis. The rectangular, six-sided, and rhomboidal forms also extinguish parallel to one of their edges, generally the longest; sometimes the greater and sometimes the lesser elasticity is in this direction. The bounding lines are extraordinarily sharp, but not very broad, so that the refractive index cannot be much greater than that of the mica. Little needles which by a magnification of 300 (eye piece 3, objective 7, Fuess) appeared hardly thicker than one of the cross hairs, were still transparent. It is therefore very unlikely that they are rutile, as is commonly supposed.

Examination of inclusions by Prof. Jannasch.

The inclusions have the usual regular arrangement, and the asterism of the mica is occasioned by them. They are absolutely unattacked by hydrofluoric acid. Thin plates of mica treated for several hours with dilute HF exhibited regular six-sided etched figures; in places where the mica has been eaten completely through, the needles remained quite unattacked. They may, therefore, be easily isolated with HF. If they are rubbed with the finger on a watch glass they scratch it distinctly. Ignited for a short time in a platinum spoon before the blast lamp they become cloudy and by reflected light dull white, and suspended in water exhibit no effect upon polarised light. Prof. Jannasch in Heidelberg had been good enough to make the following report upon an investigation which he made upon a small quantity of these inclusions isolated by me; 'There was only 0.0466 of a grain so that a quantitative analysis could not be made. Fused with B_2O_3 they gave a clear glass, in which not the smallest quantity of silica could be detected. The mineral is therefore not a silicate. The NH_3 precipitate consisted of white voluminous flocks. For separating Fe and Al the soda fusion was employed. There was no alumina but the mixture consists of a rare earth, traces of iron and some TiO_2 (yellow colouration in the acid solution with H_2O_2). The rare earth gives with soda in excess a completely insoluble white precipitate. From some preliminary reactions it exhibits the greatest resemblance to zirconia. It seems, however, to be a mixture of two rare earths. Besides the above mentioned compounds potash and soda were present in weighable quantities. On heating a sample of the mineral with concentrated H_2SO_4 on the water-bath no reaction takes place, therefore fluorine must be absent. By driving off the SO_3 decomposition takes place. A small quantity tested with $CaF_2 + K_2SO_4$ gave no B_2O_3 colouration. Probably water is also present. The quantity of substance is much too small to characterize the bodies found. Evidently a mineral containing rare earths is present. A more exact investigation with sufficient material I consider to be very important, if you will supply me with this I shall be glad to carry out an analysis.' Upon being further asked whether the rare earth could not be TiO_2 alone, he replied that it could not, as the H_2O_2 reaction was much too weak. I am now busy isolating a larger quantity of inclusions from addititional specimens of mica kindly sent to me by Dr. Dawson.

Description of apatite crystals.

Apatite crystals are generally found in veins rich in calcite: they always exhibit a simple form $\infty P \left\{ 10\bar{1}0 \right\}$ $P \left\{ 10\bar{1}1 \right\}$: the basal end faces I have never seen here, while they seem to be generally present in specimens from Renfrew. The edges and corners are very often rounded, which is referred by many authors to the action of some solvent. I have examined some such crystals without success for etched figures. The colour is generally green, light grass-green to dark blue-green, also brownish-green to brown. The massive portions are in part coarsely crystalline (sparry) and exhibit a fairly perfect cleavage. The crystals sometimes attain a length of several feet: from some pockets in 'pyroxenite,' masses up to 1,000 tons in weight have been found. A curious variety is the sugar-granular apatite: it consists of a fine, almost white, aggregate of apatite grains, in part so soft as to be rubbed off by the hand. Under the microscope a variety from the Little Rapids mine exhibits irregular angular or rounded forms, pretty evenly sized, and among them there is a very little pyroxene and calcite.

Analysis of Canadian apatites.

A series of analysis of Canadian apatites have been published by Hoffmann [30], Carnot [31], and Voelcker [32]:

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
P_2O_5..	40·37	41·08	39·05	41·14	40·87	40·52	40·81	41·50	41·64
F	3·31	3·47	3·79	3·86	3·73	3·38	3·55	1·26	1·17
Cl....	0·44	0·26	0·48	0·23	0·43	0·09	0·04	0·37	0·42
CO_2..	0·03	0·37	0·10	0·22	0·14	0·86	0·52	2·30	2·31
CaO..	47·83	49·16	46·33	49·34	48·48	49·04	49·10	52·90	52·90
Ca....	3·73	3·80	4·26	4·20	4·17	3·60	3·76	—	—
MgO.	0·45	0·16	0·55	0·18	0·16	0·21	0·62	Trace	Trace
Al_2O_3..	0·64	0·71	1·19	0·57	0·84	0·27	0·57		—
Fe_2O_3..	0·15	0·13	1·29	0·09	0·94	0·08	0·13	0·22*	0·30†
Insol...	3·89	0·37	3·49	0·06	1·15	1·63	0·63	0·30	0·37
								$=SiO_2$	SiO_2
Totals..	100·51	99·51	100·53	99·89	100·85	99·68	99·93		

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* with 1·30 FeO. † with 1·20 FeO.

I. Apatite from lot 14, range 6, township of Storrington Hoffmann.
II. " Grant mine, township of Buckingham "
III. " lot 16, range 3, township of North Burgess "
IV. " Ritchie mine, township of Portland "
V. " lot 10, range 10, township of Loughborough "
VI. " Watt's mine, township of Portland "
VII. " 'Doctor' Pit, township of Templeton "
VIII. Inner part of a dark-green crystal from Templeton Carnot.
IX. Outer part of the same crystal. Carnot.

Two analyses of Canadian apatite by Voelcker gave :

	X.	XI
Moisture....	0·01	—
Loss on ignition.	0·25	—
$Ca_3P_2O_8$	89·36	90·31
$CaCO_3$	1·95	
$CaSO_4$	0·54	
$CaCl_2$	0·14	0·75
CaF_2 ...	4·54	5·03
MgO	0·19	
Fe_2O_3	0·41	0·21
Al_2O_3 .. .	0·86	0·99
Insol. res	0·15	0·99
CaO.	1·72	2·27
	100·15	100·58

Evidently all the analyses have not been made upon material free from inclusions. The difference in the amount of fluorine in the first seven analyses to that shown in those following is remarkable. Certainly in these first ones the determinations are too high. Since pure fluorapatite contains only 3·77 F, it is impossible that 3·79 F in analysis III with an insoluble residue of 3·49 can be correct. From the quantities of F and Cl present may be calculated :

Material used in analyses not free from inclusions.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
CaF_2 . . .	6·80	7·13	7·78	7·93	7·66	6·93	7·30	2·58	2·40	4·54	5·03
$CaCl_2$ ...	0·69	0·41	0·74	0·36	0·67	0·13	0·06	0·58	0·66	0·14	0·75
CaF_2 in ..	91	95	91	96	92	98	99	82	80	97	87

The Canadian apatites are therefore distinguished by a very high proportion of fluorine ; in part they are almost pure fluorapatite : the proportion of fluorine molecule to chlorine molecule is always greater than 4:1. The same is true of the apatite in tin ore veins and of the apatite and phosphorite which are also vein formations, partly in granite, in the province of Estremadura, in Spain. In contrast with this are the vein apatites of southern Norway, almost free from fluorine. In twenty crystals from Krageroe, Voelcker could not recognise fluorine.

Calcite is,as has already been stated, always the latest formed mineral in the veins; I have never seen crystals, the mineral forming a coarse-grained mostly reddish-coloured aggregate in the central part of the veins in which the finest apatite crystals occur. It is peculiar that many apatite crystals possess a nucleus of calcite. This may be explained by the former mineral having a sort of skeleton growth and the resulting cavities having been filled up later with calcite.

Feldspars of common occurrence with apatite.

Feldspars are extremely common in many occurrences of apatite. It is especially a grey-coloured microcline, forming coarsely crystalline aggregates which in many places cover large surfaces of the walls of mines. At the Cascade mine I found crystals of a plagioclase exhibiting the faces $0P \{001\}$ $\infty P \breve{\infty} \{010\}$ $\infty P' \{110\}$ $\infty' P \{1\bar{1}0\}$ $\infty P \breve{3} \{130\}$ $\infty' P \breve{3} \{1\bar{3}0\}$ $'P' \bar{\infty} \{\bar{1}01\}$ $P_{,} \{\bar{1}\bar{1}1\}$ $P' \{\bar{1}11\}$ Cleavage plates parallel to 0P and $\infty P \breve{\infty}$ give extinction angles of 3° and 11-12° respectively; it is therefore an andesine of the composition $Ab_4 An_3$. The crystals are elongated in the direction of the a axis. They are about 5 cm long with very rough surfaces, Fig. 10. They are supported partly upon compact pyroxenite, partly upon a network of small pyroxene crystals. At the Vavasour mine I collected masses which consisted of a coarsely crystalline microcline, a light-green plagioclase, and green pyroxene. The single individuals are sometimes over 8 cm in diameter. The plagioclase has on 0P an extinction angle of almost 0°, and

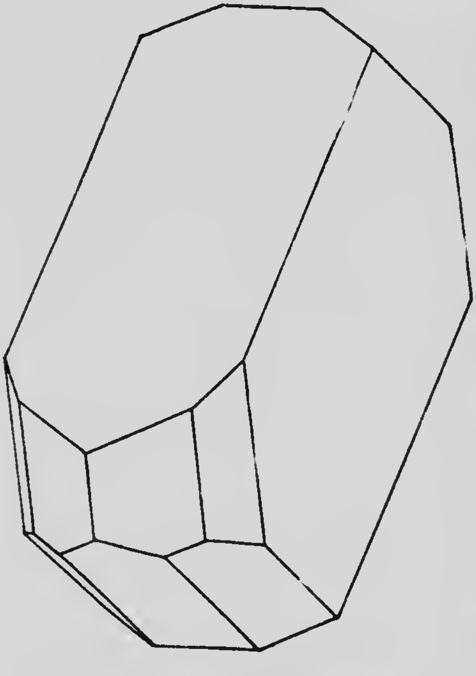

FIG. 10.—Feldspar from the Cascade Mine.

s therefore andesine. Harrington[9] mentions also orthoclase and albite from the apatite veins.

Amphibole was seen principally at the Little Rapids mine in masses composed of little rods and parallel fibres. It is a light-green actinolite. Harrington also describes the change of pyroxene crystals into uralite.

Tourmaline abundant.

Tourmaline is in certain places very plentiful. In one of the pits of the Crown Hill mine a whole wall is covered with black tourmaline. At the Little Rapids mine I found black tourmalines, brown by transmitted light, 0·5 cm long, in calcite, and also on quartz, with the termination $- R \left\{10\bar{1}1\right\} -\frac{1}{2} R \left\{01\bar{1}2\right\}$.

Scapolite crystals.

Scapolite crystals are mentioned by Harrington from various apatite veins; they attain more than a foot in length and in many cases are very rich in faces. I found only parallel-fibrous masses, which, however, were extraordinarily widely distributed in the Crown Hill, Union and High Rock mines where they cover whole walls. Adams has analysed a scapolite from lot 13, range 8, township of Ripon and obtained the following composition :

SiO_2	54·86
Al_2O_3	22·45
Fe_2O_3	0·49
MgO	trace.
CaO	9·09
Na_2O	8·37
K_2O	1·13
Cl	2·41
SO_3	0·80
H_2O (combined)	0·72
H_2O (hygroscopic)	0·14
	100·46
O	0·59
	99·87

This scapolite corresponds pretty closely to the composition Me_1Ma_2, to Me_2Ma_3. Microscopically the mineral is found to be extraordinarily widely distributed in the 'pyroxenite.'

Metallic minerals.

Metallic minerals are represented by pyrite, chalcopyrite and pyrrhotite. In many pits of the Emerald mine the pyroxenite is penetrated through and through with pyrrhotite and pyrite, and the material on the dump is coloured brown by iron.

Titanite in the usual form $\frac{2}{3}P2 \{123\}$ $OP \{001\}$ $\frac{1}{2}P\infty \{102\}$ is found in all the veins. A portion of the vein from the Little Rapids mine consists essentially of grey microcline in which there are green pyroxene crystals and titanite crystals over a centimeter across.

Fluorite seems to occur rarely. Harrington mentions it from several localities, but says also that even in these localities it occurs in small amount. Only at the North Star mine did I see any violet fluorite. The mineral may of course occur also of a green colour and then upon a superficial examination of the dumps be mistaken for apatite.

Quartz not common.

Quartz also is not common. Massive pieces associated with tourmaline and actinolite, I saw at the Little Rapids mine. At the Vavasour mine the workmen showed me a small drusy cavity which was completely lined with quartz crystals and a white lithomarge-like mass; the calcite was at this place unusually coarsely crystalline and contained some chalcopyrite. The quartz crystals, as clear as water, and about 0·5 cm. long, exhibit the simple combination— $\infty R. \{10\bar{1}0\} + R. \{10\bar{1}1\} - R \{01\bar{1}1\}$; Harrington mentions also smoky quartz and amethyst. Crystals appear to be found only upon the walls of cavities, which would justify the conclusion of a relatively younger age.

Other minerals.

The other minerals mentioned [illegible]ngton, of which particularly zircon and garnet appear to be widely distributed, I did not find during my short stay. In Templeton township, zircon crystals are said to occur more than a foot long. The occurrence of molybdenite (lot 12, range 12, township of Templeton) and graphite is interesting, the former because it is the most usual associate of cassiterite in the tin veins, the latter because in the graphite veins north of Ottawa, *e.g.* in Walker's mine, green apatite occurs in large massive pieces. A close relationship of the two kinds of veins is therefore indicated. According to Vogt[33], the apatite of O[illegible]egaarden in Bamle is in places rendered impure by a carbonaceous substance.

Eruptive rocks which accompany the apatite veins (pyroxenite in part). It is characteristic of all the rocks here referred to that they possess the eugranitic granular structure of typical plutonic rocks. As to their mineral composition, most of them consist essentially of a lime-soda feldspar which is either labradorite or a variety closely allied to it, and of members of the pyroxene family (augite, diallage, and a rhombic pyroxene poor in iron), with which some mica and a primary green hornblende are associated. Olivine was never observed, but quartz is present in subordinate quantities. They are therefore in general rocks of the gabbro family, with transitions to norites, diorites, shonkinites, and pyroxenites. What name is to be given to each individual rock cannot be definitely stated on account of the rapid development in petrographic nomenclature and the varying definitions given to such terms as augite-diorite, hornblende-gabbro, mica-gabbro, &c. A real definition of these terms will be possible only when, along with the qualitative mineralogical composition, the quantitative is also taken into consideration, especially the relation of the dark components to the feldspars, the alkali feldspars to the lime feldspars, and the general basicity. These are the factors which in the formulæ of rocks are expressed by the numbers *s a c f*. For such a classification analyses are certainly necessary, but without these a solution of the confusion here existing is impossible. I will therefore here conform to the tables IV. and V, given on page 467 and 468 of my work, and call those rocks which accord with table IV. diorites, mica-diorites, augite-diorites, enstatite-diorites, norite-diorites, and those corresponding to table V. mica-gabbros, hornblende-gabbros, enstatite-gabbros, norite-gabbros. To be sure the lower part of table IV. and the upper part of table V. form transition members which may with equal right be called by either name.

Petrographic nomenclature.

Unaltered Rocks, in part not Scapolitised.

Enstatite-gabbro from the Emerald mine.—At Murray's pit near the top of the hill, along the sides of which the various pits of this mine are located, there are found large blocks of a very fresh plutonic rock which evidently come from the quarry which can no longer be entered. It is a rather coarse, dark-gray, very tough rock, that is seen under the magnifying glass to consist essentially of triclinic feldspar and pyroxene. There is also present a reddish-brown mica, which is, however, not uniformly distributed, but as is well seen in the blocks, is collected into lines which form a network with one another. They are evidently joint planes (Absonderungsklufte) in which the mica has been formed. Running off from these cracks, parallel to which the rock breaks most easily under the hammer, some isolated plates of mica have penetrated the normal rock : large parts of the latter are quite free from mica. Undoubtedly we have here to deal with a later formation ("Neubildung") which is connected in origin

Enstatite-gabbro.

with the apatite and mica in the neighbouring veins. These planes of jointing were the places where the penetration of vapours and solutions would meet with the least resistance, and therefore where secondary minerals would be first expected.

Microscopic description of enstatite-gabbro.

Under the microscope one sees that plagioclase and pyroxene are present in almost equal quantities, the latter, perhaps, predominating to a slight extent. Both generally form irregularly bounded grains.

The plagioclase is very fresh and exhibits the usual twinning striæ, according to the albite law and in part the pericline law. Cleavage plates parallel to oP gave an extinction angle of about 10°, the specific gravity determined by pycnometer was 2·694, and the mineral, therefore a typical labradorite.

Two pyroxenes are present, a monoclinic and a rhombic one. The monoclinic is transparent and of a very light green-gray colour. Pleochroism is hardly perceptible. Besides the cleavage parallel to ∞P, there is a less perfect one parallel to $\infty P\bar{\infty}$; the lamellar structure of diallage, however, is absent. Small leaves of mica have formed in the cleavage cracks of the second order above mentioned. A slight alteration into uralite, beginning at the edges, has taken place.

The rhombic pyroxene is less abundant than the monoclinic. Its sections often have a rude prismatic development. It is colourless and transparent, but in thicker sections exhibits a slight pleochroism between reddish and greenish tones. A high relief, due. perhaps, to its fibrous nature, its very low interference colours, and parallel extinction in sections from the prism zone, enable it to be easily distinguished from the monoclinic augite. An alteration into a green serpentine-like mineral, perhaps bastite, has taken place along rough irregular cross-cracks. Inclusions of little opaque rods are very common, and are arranged in rows parallel to the c. axis of the host.

The mica is transparent with a reddish-brown colour, and in convergent light appears to be uniaxial : the pleochroism is between straw-yellow and red-brown. The detection of fluorine in this mica was of special interest ; if its formation is secondary and connected with that of the apatite and phlogopite of the veins, it was to be expected that it also should contain fluorine. In fact, the carefully purified mineral gave a strong fluorine reaction. Apatite in rounded grains is fairly abundantly present in the rock.

Analysis by Dr. Dittrich.

Dr. Dittrich made an analysis of this enstatite-gabbro. Material was chosen for this purpose which was free from the above-mentioned mica veins, and which, therefore, contained mica only in very small quantities :

	I.	II.	Ia.
SiO_2	49·32	53·76	50·87
TiO_2	0·42	3·70 (impure)	0·32
Al_2O_3	13·33	13·35	8·09
Fe_2O_3	1·28	11·59	
FeO	7·76		7·65
MgO	11·13	7·22	17·22
CaO	11·73	6·92	12·97
Na_2O	2·12	1·70	2·12
K_2O	1·12	0·30	0·71
P_2O_5	0·06	....	0·02
H_2O	0·64	0·71 (loss on ig.)	
CO_2	0·89	....	
	99·82	99·25	

Analysis for comparison.

For comparison the analysis of an olivine hyperite from Lofthus in Snarum has been given under II., as a type of the gabbro accompanying the apatite veins in southern Norway. Ia. gives analysis I. in molecular proportions, calculated to 100. From it may be calculated

s	A	C	F	a	c	f	n
51·19	2·86	5·23	32·61	1·5	2·5	16	7·4

and the formula $s_{51}\ a_{1·5}\ c_{2·5}\ f_{16}\ n_{7·4}$. The rock therefore belongs between the types Molkenhaus Subitelma and Keewenaw, with which the silica agrees in a satisfactory manner. It is on the boundary of the α and β series. As average plagioclase we obtain $Ab_{5·72}\ An_{5·23}$ or almost $Ab_1\ An_1$, which agrees very well with the specific gravity 2·694.

Gabbro from Smithy at Emerald mine.

Another very fresh gabbro was obtained from the smithy, of the Emerald mine, lot 18, range XII. This uniform rather coarse rock also consists of almost equal quantities of very fresh plagioclase and pyroxene, but mica and rhombic pyroxene are entirely wanting. The feldspar commonly exhibits undulose extinction, with bent and cracked twinning lamellæ, probably pressure phenomena. The augite is completely dusted through with tiny inclusions, which by employing an immersion objective are seen to be liquid inclusions with movable bubbles. The formation of uralite has gone somewhat farther than in the gabbro from Murray's pit. Sulphides and apatite are scarce.

A gabbro from the dump of the Squaw Hill mine contains large quantities of red-brown mica : these works are on the same hill as the Emerald mine. It is distributed very evenly through this somewhat fine-grained rock, so that its primary or secondary nature is difficult to determine. The rock is free from rhombic pyroxene, but relatively rich in apatite.

Apatite rare in Cascade mica mine.

The veins of the Cascade mine on the Gatineau river, are distinguished by their poverty in or absolute want of apatite. They are worked only for mica, and apatite is exceedingly rare on the dumps. The principal rock of the hill is also a basic plutonic rock. The typical variety from the railway cutting directly on the river is a uniform medium-grained gabbro of irregular structure, in which may be seen with the unaided eye, fresh feldspar with twinning striæ, some brown mica and a good deal of augite. Plagioclase and augite are present in about equal quantities. The hand specimens which were collected from the mine on the contact against the later-formed 'pyroxenite' and other vein fillings exhibit a somewhat gneiss-like appearance. Augite and plagioclase are arranged in lenticular masses, so that the surface on the main fracture has a light and dark spotted appearance, the cross fracture being somewhat streaky owing to the alternation of the lenticles; the grain is also somewhat finer. At the contact with the pyroxenite the rock is completely penetrated by honey-brown titanite crystals and grains and is very rich in pyrite.

The rock from the railway line shows under the microscope an absolutely irregular structure, neither plagioclase nor pyroxene show crystalline boundaries. Cleavage lamellae of the former give an extinction which on P varies from 3—13° and on M from 7—25°; it therefore belongs to the andesine-labradorite series. Even with the magnifying glass it is seen that many of the cleavage faces are bent. Under the microscope, undulose extinction, bent and broken twinning lamellæ are very common. The rock has certainly suffered great pressure. The pyroxene is transparent, of a light green-gray colour; pleochroism is hardly perceptible. Sections normal to c exhibit, besides the cleavage parallel to the prism, well developed cracks parallel to $\infty P\bar{\infty}$ and very numerous fine cracks, parallel to $\infty P\breve{\infty}$, running only short distances, so that a fibrous appearance is developed. One optic axis is almost perpendicular to this section. Polysynthetic twinning according to oP is very common. The formation of uralite has gone quite far, proceeding from the cracks parallel to $\infty P\bar{\infty}$ and those connected with the formation of the above mentioned twins. Lamellæ converted into uralite often alternate with others of the unaltered mineral. The uralite is green and shows relatively weak differences of absorption, the pleochroism varies from light greenish-yellow to light grass-green. In a section almost parallel to $\infty P\bar{\infty}$ the augite shows an extinction angle of 39—

40°, the uralite 15° and in both c differs from c in the same sense. In the cleavage cracks and the separation cracks parallel to oP the same rod and plate-like inclusions are found as is the case of the hypersthene of St. Pauls island, only here they are scarcer and not so regularly distributed.

Microscopic description of contact rock from Cascade mine.

The mica forms little plates which collect into small knobs or are arranged radially about a large sulphide or pyroxene grain. The mica is undoubtedly younger than the pyroxene. A part of it appears also to have been derived from the uralite. Small plates of mica are grouped as a fringe around the hornblende rods or the hornblende is completely penetrated by them peripherally.

The rock from the contact with the pyroxenite in the Cascade mine is seen under the microscope to be distinctly finer-grained, and the contours of the grains are more rounded. The polysynthetic twinning striæ of the feldspars are replaced more or less by a fibrous appearance which passes over into microperthitic intergrowths. A very common appearance is that the centre of the feldspar grains consists of a cloudy partially decomposed core, which is surrounded by a narrow unaltered edge as clear as water, the optical orientation of the two parts is generally somewhat different. Doubtless a development of secondary feldspar has here taken place. The pyroxene is somewhat darker in colour and more strongly pleochroic than in the rock from the railway cutting. It contains the same opaque or red-brown transparent inclusions. Besides an alteration to hornblende, epidote is also widely distributed. As has already been mentioned in the macroscopic description, titanite occurs very abundantly, the pyroxene slightly predominating over it. It is strongly pleochroic in almost colourless and reddish-yellow tints and frequently shows polysynthetic twinning. The very common pyrite has also been mentioned above. Evidently pyrite and titanite, and perhaps also part of the feldspar, are here alteration products, whose origin is connected with the formation of the 'pyroxenite.'

Gabbro from South March.

Gabbro from South March, about twenty miles west of Ottawa. This rock, which is cut through by a series of apatite mica veins which have here and there been opened up, is also a typical plagioclase augite rock. The absolutely unaltered plagioclase here also shows distinct signs of pressure. Large individuals are frequently broken up: in such places microperthitic intergrowths occur and also some quartz. The plagioclase is extraordinarily rich in hair-like microlites, which are so common in quartz. They are sometimes straight, sometimes bent like trichites, and are arranged absolutely irregularly with respect to one another. Their thickness is so small that they are usually transparent. In isolated thick ones high double refraction and parallel extinction are evident, and it is not improbable that they are rutile. The pyroxene, transparent with very light green-gray colour, is to a large extent converted into uralite; the uralite has, in places, been converted into mica. Opaque metallic grains are surrounded by leucoxene edges and are probably titanic iron ore.

Shonkinite from Crown Hill mine.

Shonkinite from the Crown Hill mine.—This rock which differs chemically considerably from the plutonic rocks already described, is found in a small prospect hole on the river side of the slope on the line of the wire rope tramway, built to transport apatite from the Union mine to the Lièvre river. The uniform, medium to coarse-grained, unaltered rock is very rich in dark-coloured constituents, in which dark-gray pyroxene and to a less extent brown mica can be recognized macroscopically. Feldspar is present in very much smaller quantity. The structure is that of a typical plutonic rock; all parallel structure is completely absent. One would conclude from the macroscopic appearance that it was a micaceous gabbro or basic monzonite.

Microscopic description.

Under the microscope none of the principal constituents exhibit idiomorphic outlines. The feldspar is almost absolutely free from twinning lamellæ and is a typical microperthite; extinction was determined on some cleavage lamellæ, on OP parallel, on $\infty P \grave{\infty}$ as 7°. The little plates between crossed nicols get uniformly dark, probably on account of the extraordinary fineness of the intergrown lamellæ. The optical behaviour, and the strong predominance of potash over soda in the general analysis make it certain that the principal part of the feldspar is orthoclase. On cleavage faces parallel to $\infty P \infty$ the inclination of the very regularly penetrating threads to the cleavage cracks parallel to OP was 74-75°; on oP they lie normal to the cleavage parallel to $\infty P \infty$. The plane of interposition is therefore an orthodome, which, as in murchisonite, corresponds approximately to $7 P \bar{\infty}$. Many feldspar grains upon strong magnification exhibit in their peripheral portions an extremely fine twinning striation; perhaps this is an anorthoclase.

A lime-soda feldspar is present only in very small quantities. It is, unlike the unaltered microperthite, always filled with alteration products in the form of strongly double-refracting threads and plates.

The augite, transparent with a very light green colour, does not exhibit anything remarkable: it is in the first stage of uralitisation. Part of the green weakly pleochroitic hornblende is certainly primary. The mica is frequently intergrown regularly with the hornblende and then no doubt partially derived from it. If a large hornblende section is rotated till it is dark, a number of fine lamellæ, strongly doubly refracting are seen parallel to the cleavage cracks, which may, upon high magnification, be recognized as mica. The mica also surrounds the hornblende and extends into the cleavage cracks and fractures. On the other hand, larger mica plates are certainly primary. As accessory constituents titanite and metallic minerals may be mentioned, the latter on account of their behaviour in reflected light seem to consist essentially of pyrite.

Analysis of shonkinite by Dr. Dittrich.

An analysis of the rock was made by Dr. Dittrich. In spite of the fact that almost all the determinations were made in duplicate with nearly identical results, the total came to 98·66 only. At my request examinations were made for fluorine and chlorine; fluorine was absent, and chlorine present only in traces (not more than 0·1). Where the loss is cannot be guessed.

	I.	II.	III.	IV.
SiO^2	48·60	47·85	46·53	48·98
TiO^2	0·79	......	2·99	1·44
Al^2O^3	13·60	13·24	11·31	12·29
Fe_2O_3	2·30	2·74	3·61	2·88
FeO	4·97	2·65	8·15	5·77
MgO	8·79	5·68	6·56	9·19
CaO	10·00	14·36	12·13	9·65
Na_2O	1·42	3·72	4·95	2·22
K_2O	5·62	5·25	1·58	4·96
P_2O_5	0·19	2·42	.....	0·98
H_2O	0·61	2·74	0·20	0·56
CO_2	1·23	...	MnO 0·22	MnO 0·08
SO_3	0·54	....	.....	BaO 0·13
				SrO 0·08
				F 0·22
	98·66	100·65	101·23	99·73

Analysis for comparison.

No. II, an analysis of nepheline-pyroxene-malignite from Poobah lake, Rainy River district; No. III, theralite from Kunjokthal, Umptek Kola; and No. IV, shonkinite, from Yogo Peak, Little Belt Mountains, Montana, have been introduced for comparison. No. IV agrees best with No. I both in alkalies and the proportion of CaO to MgO and FeO. No. II is poorer in FeO and MgO, but richer in CaO. In III the proportions of alkalies are reversed. Undoubtedly the rock from Crown Hill mine belongs to this family. A reduction to molecular percentages (all iron calculated as FeO) gives:

SiO_2	52·83
TiO_2	0·65
Al_2O_3	8·69
FeO	6·38
MgO	14·33
CaO	11·65
Na_2O	1·49
K_2O	3·90
P_2O_5	0·08
	100·00

Consequently

A = 5·39 ; C = 3·30 ; F = 29·06 ; a = 3 : c = 1·5 : f = 15·5 ; n = 2·4 giving the formula

$$S_{53·5} \quad A_3 \quad C_{1·5} \quad F_{15·5} \quad N_{2·4}.$$

The rock is very similar to the theralite type Kunjokthal, the silica agreeing very well also. The proportion of alkalies places it in the E series. While the rocks described contain much feldspar, veins occur in the gneiss near the London mine which are very poor in feldspar, and which, I believe, in part at least belong to the same category of plutonic rocks. They consist essentially of augite and enstatite and form therefore a transition to *pyroxenites* in the sense of the petrographic nomenclature (*websterite*). The colourless and sometimes also weakly pleochroic enstatite forms roughly outlined prismatic crystals and is always older than the monoclinic augite. It exhibits the usual fibrous texture, parallel to the c axis, across which run irregular wide cracks in which the alteration into a green alteration product begins. The augite does not show any peculiarities worth mentioning. The sparse plagioclase fills up the vacancies between the pyroxenes. The red-brown mica is, judging from the whole manner of its occurrence, a new formation. It develops most readily along the cleavage lines and cracks of the pyroxenes, or in little angular wedges between the other constituents.

Secondary pyroxenites.

Minerals of secondary formation.

The minerals, which in the form of more or less well developed crystals or coarsely crystalline and fibrous masses, occur in the apatite veins, especially those developed in the calcite of the central portions, have been already spoken of. Here we are concerned with mineral aggregates which form preferably upon the edges of the veins and on account of their somewhat uniform grain remind one in their habitus of plutonic rocks. In all these masses pyroxene is the predominating constituent, phlogopite, apatite, scapolite, and metallic minerals also occurring widely distributed. In part they are very difficult to distinguish from altered plutonic rocks; here only typical secondary formations will be described. According to their mineral constitution they may be classed as:

1. Pure pyroxene aggregates.
2. Pyroxene-phlogopite aggregates.
3. Pyroxene-apatite aggregates.
4. Pyroxene-scapolite aggregates.

Pure pyroxene aggregates.

Between these groups there exist, of course, all possible transitions. Here, therefore, only certain types can be dealt with.

Almost *pure pyroxene aggregates* have been obtained from the Brown, Vavasour, Little Rapids and Squaw Hill mines. They are rather coarse, quite irregularly arranged masses of light-green, gray, or reddish-gray colour, which in part (Brown mine) are very richly impregnated with pyrite. Microscopically, they consist of an aggregate of irregularly outlined almost colourless augite grains with which are associated, generally in the form of little patches, calcite, scapolite, and phlogopite in small quantities. The pyroxene has often an exceptionally cracked appearance, or is perforated like a sieve and filled with particles of the above mentioned accessory minerals. Apparently these are not original inclusions but corrosion phenomena. The pyroxene originally formed, was corroded by solutions or vapours and the hollows thus formed were filled with later formed minerals.

I collected a very peculiar "pyroxenite" from the dumps of the Little Rapids mine. It consists entirely of a very loose aggregate of light-gray, highly lustrous rounded pyroxene grains and may be crumbled between the fingers. The grains are about 1 mm. in diameter, and the rock at the first glance does not look unlike a perlite. Massive green apatite is attached directly to the piece.

Pyroxene-phlogopite aggregates.

Pyroxene-phlogopite aggregates have already been described from the Vavasour mine and are found very typically and widely distributed also at the Cascade mine: they contain almost equal quantities of mica and pyroxene. In the specimens from the Vavasour mine, the latter is grass-green, about the colour of chrome diopside, and forms a loose granular mass, partly crumbling between the fingers. In this occur yellow-brown phlogopite plates, mostly arranged in a parallel manner. Contact specimens show that the cleavage planes are normal to the border of the vein. From the gneiss in which the vein occurs, this mass is separated by an aggregate of pure pyroxene about 1 cm. thick, which in part exhibits a fibrous structure; the fibres are placed perpendicularly to the wall of the vein. Upon the first glance one sees that such a banded structure has nothing to do with the parallel structure of the gneiss; further, the contact with the gneiss is absolutely sharp. The size of the grains of this pyroxene phlogopite mixture is very uniform, about 0·5 cm. diameter.

Augite phlogopites

The augite in the specimen from the Cascade mine is somewhat darker, but in sections is almost colourless and transparent. Every where it is seen, from the way the phlogopite plates are wedged in between the pyroxene, that they are younger than the latter.

Other augite phlogophite aggregates from the Vavasour mine exhibit a very peculiar structure. The light grey-green pyroxene forms large, rounded elliptical masses (augen) several centimeters long and generally much elongated in one direction; they possess continuous cleavage, and consist of one individual; between them there is a considerable aggregate of phlogopite, and some fine-grained augite. Plate IV. shows such a vein mass. The lenticular 'augen' are all arranged with their longer axes parallel, so that upon first glance there seems to be a similarity to the structure of a foliated augen-gneiss. The phlogopite plates of the interposed material, however, are arranged almost without exception with their planes normal to the surface of the contiguous pyroxene lenses. The lower part of the figure exhibits a 2-3 cm. thick zone of actinolite; upon it lies, with fairly well defined boundary, the central portion of the vein material rich in calcite.

Another peculiar structure is exhibited by pyroxenites from the Fleury mine. In the main mass consisting of pyroxene, are embedded at distances of 2-3 cm., roundish lumps rich in phlogopite and also containing some calcite.

A transition to the next group is represented by the widely distributed *pyroxene-phlogopite-apatite* aggregates of the Vavasour mine.

Pyroxenite from Union mine.

A type of a 'pyroxenite' consisting of *augite* and *apatite* I obtained from the Union mine. Plate III shows that the pyroxene is without sharp crystallographic outlines, and forms rough prisms arranged parallel, about 0·5 cm. long, among which is a granular aggregate of green apatite; the whole arrangement reminds one of flow structure. In sections, the apatite grains are seen to be penetrated by dark stripes which upon higher magnification are seen to be closely aggregated tube-like fluid inclusions. In what relation the position of the pyroxene stood to the walls of the vein could not be determined, as the piece was taken from the dump.

Pyroxene scapolite aggregates.

Pyroxene-scapolite aggregates.—This group leads over into the altered gabbros. A sharp division between the two is, as has already been pointed out, impossible, as a large portion of the material had to be collected from the dumps. Criteria for such a division might be sought in the method of occurrence and in the microscopical structure of the pyroxene, (if one might postulate that by the scapolitising of the gabbro this mineral had not been essentially changed), and also in the structure of the whole mass. Both considerations, however, lead to no definite results. In most cases augite and scapolite form an irregular granular aggregate, as was the case with the augite and plagioclase in the above mentioned plutonic rocks. Occasionally when scapolite is richly represented there is developed a honeycomb like structure which is so beautifully observed in the 'spotted gabbro' from Oedegaarden. The transition from plagioclase to scapolite is seen in only very few sections, as the material adhering to the walls of the mines and that thrown out upon the dumps is generally completely altered.

Only the two occurrences at the Emerald mine spoken of on p. 21 can be described as certainly secondary formations of this kind. Both form selvages about 5–8 cm. thick to veins whose inner portions consist of pure apatite. In both cases these apatite veins cut pegmatite which in its turn occurs as veins in gabbro and gneiss. The contact of the outer zones against the pegmatite is absolutely sharp.

Description of pyroxene-scapolite aggregates.

Both aggregates possess a light reddish-gray colour and exhibit macroscopically, besides the augite, only some green apatite grains and some pyrite. The scapolite is first seen under the microscope. Here the distribution of the two principal constituents is seen to be very irregular. Some portions of the section consist almost entirely of the colourless transparent augite with little scapolite, in others the latter distinctly predominates. Frequently it forms large rod-like individuals in which augite grains are poikilitically developed. Other portions of the sections exhibit both minerals in almost equal quantities in the form of equally large grains bounded by straight lines, so that a honeycomb pavement-like structure is produced. The scapolite has the opaque rod-like enclosures which are highly characteristic of this mineral and which are arranged parallel to the c axis. In the occurrence at the smithy it is to a great extent altered into an aggregate of colourless strongly doubly refracting little plates which are probably muscovite. The cleavage of the scapolite is always well developed, so that in longitudinal sections it reminds one strongly of muscovite on account of its feeble refraction and high double refraction. Cross sections and the optical orientation of the longitudinal sections enable one to distinguish it easily from this mineral, however. Phlogopite is also found in varying quantities in this augite scapolite mixture.

Altered plutonic rocks and 'pyroxenites,' in part, consisting essentially of augite and scapolite.

Altered plutonic rocks.

To the above described mixtures which on account of their geological occurrence are certainly to be characterized as vein formations, must be added a large number of hand specimens collected at almost all the mines visited. They are dark-gray medium to coarse-grained mixtures of augite and scapolite of completely massive appearance which macroscopically exhibit the greatest similarity to gabbros. Under the magnifying glass one sees that the colourless constituent does not possess the good cleavage and the twinning striæ of plagioclase. The fracture is irregular, often fibrous, the lustre more greasy, so that this is probably the reason why many authors mention the frequent occurrence of quartz in the pyroxenite. Generally, as has already been pointed out, the microscopic examination reveals no traces whatever of the genesis of these masses. As everywhere the same relations are repeated, only certain occurrences, which I hold to be undoubtedly altered plutonic rocks, need be here described.

Scapolite gabbro from Vavasour mine.

Scapolite gabbro from the Vavasour mine.—This is a somewhat coarse-grained rock. Among the darker constituents hornblende may be recognized by its good cleavage. The colourless mineral may without difficulty be distinguished from plagioclase under the magnifying glass. Its poor cleavage, and a somewhat greasy lustre remind one of nepheline; it is frequently fibrous in structure. Pyrite is widely scattered through the rock; brown mica is found only here and there, but in plates nearly a centimetre across. Some epidote can also be seen macroscopically.

Under the microscope the light green-grey transparent pyroxene is seen to form irregular or roughly prismatically outlined grains which, as in gabbro, are often collected together into little lumps. Externally and along the cracks, the augite has become altered into uralite and here and there into epidote. It is also very noticeable here how it is eaten out like a sieve, and everywhere scapolite and phlogopite have been formed in the holes. The latter is seen by fairly high magnification to be wedged in between the augite in the cleavage cracks in long thin plates. Fig. I., Plate X.

The quantity of the scapolite seems much greater under the microscope, because alteration having begun and the mineral having thereby become opaque and dirty-looking it is difficult to distinguish it macroscopically from the augite. Cleavage and optical behaviour in parallel and convergent light, easily prevent its being mistaken for other minerals. In places which are rich in scapolite the above mentioned pavement-like structure is very distinct; see Fig. I., Plate VIII. Cross sections as well as longitudinal ones often exhibit very regular hexagonal contours. The specific gravity of the unaltered scapolite was determined as 2·64 by means of the pyknometer; according to Tschermak's data this corresponds to a mixture of about 36-40% Me to 60-64% Ma. Primary hornblende is entirely wanting.

Similar relations are found in the other hand-specimens examined. The pyroxene is generally very fresh. The scapolite usually exhibits the little rod-like or six-sided opaque inclusions (Fig. 4, Plate X.) which are probably titanic iron. It is much more subject to decomposition than the pyroxene, and thereby becomes fibrous and dark-coloured by a substance, not determinable, being scattered through it like dust. Then it passes over into the laminated aggregate so often referred to. The proportions of pyroxene and scapolite vary very much; usually the former predominates. The pyroxene sometimes shows rough crystallographic outlines, the scapolite never. Phlogopite occurs in many of the rocks, but always exhibits relations which point to its secondary origin, which is certainly connected with the formation of the apatite. The content of metallic minerals is very variable; in most cases it is very small, in others pyrite, pyrrhotite and also some chalcopyrite may be distinguished macroscopically; these are unmistakably impregnations. Apatite is also found abundantly, many sections are completely covered by a network of little veins of it; its formation here is also secondary.

Transition of pyroxenite visible.

A scapolitized gabbro from Poupore post office is very rich in tremolite and epidote. An old apatite opening there is altered into a light-green coloured 'pyroxenite,' which, macroscopically, is seen to contain abundant colourless hornblende. Green actinolite, in company with calcite, forms the filling of veins which traverse the rock in all directions. At one place in the cut, the transition of the 'pyroxenite' into a dark blue-gray, medium to fine-grained rock, is visible, which, with a completely massive habitus, has the appearance of a diorite or gabbro poor in feldspar. It is richly powdered all through with particles of secondary pyrite. Under the microscope, the constituents are seen to be quartz, triclinic feldspar, very abundant green hornblende, epidote and scapolite. The quantities of quartz and feldspar are very different in different specimens; in many they are almost entirely wanting, while in others they constitute almost a quarter of the whole rock. Amphibole and scapolite are poorly outlined crystallographically; they form irregular grains, the former also often rod-like forms. The amphibole is very light-green or quite colourless and transparent, in the former case with weak pleochroism; and, is probably a form intermediate between tremolite and actinolite. Scapolite, with the usual properties, is much altered. The epidote must be a secondary product, and forms crystals elongated parallel to the b axis, and usually well and sharply outlined. Sections perpendicular to b are six-sided bounded by $\infty P \frac{1}{\infty} \left\{ 100 \right\}$ $0 P \left\{ 001 \right\}$ and $+ P \frac{1}{\infty} \left\{ \bar{1}01 \right\}$. Cleavage cracks parallel to OP and $\infty P \frac{+}{\infty}$ are well developed, and twins according to $\infty P \frac{1}{\infty}$ are common. Longitudinal sections with parallel extinction and normal position of the axial plane exhibit very little pleochroism. Strongly pleochroic titanite and pyrite are extraordinarily abundant. In its present condition the rock is best classed as an epidote amphibolite. It has doubtless been derived from a plutonic rock and been impregnated with titanite and pyrite, while scapolite, amphibole and epidote have been derived from feldspar and pyroxene.

The transition into the above-mentioned 'pyroxenite' can be followed microscopically. Quartz and feldspar disappear altogether; conversely colourless pyroxene and phlogopite, in places much whitened, appear in the sections. Scapolite becomes more abundant.

Crystalline Schists from the Apatite Region.

Here again only certain typical rocks will be described.

Squaw Hill
mine
quartzite.

Quartzite from the Squaw Hill mine.—Quartzites similar to those described from the Montebello section, alternate with gneiss in the neighbourhood of the London, Little Rapids and High Rock mines. They generally contain isolated macroscopic feldspar grains. Upon the dumps of the Squaw Hill mine were found pieces of a quartzite which, under the magnifying glass, showed abundant green pyroxene and isolated grains of titanite. Under the microscope, by far the greater part of the rock is seen to consist of an aggregate of quartz with the same structure as the Montebello quartzite. This aggregate is traversed by strings and veins formed of a mixture of light-green augite, dark-green hornblende, abundant scapolite with its characteristic inclusions, titanite, epidote and some calcite. Plate X., Fig. II., shows such a portion moderately magnified. On the right and left sides of the the figure is the colourless quartz; through the middle runs such a vein whose contacts with the quartz are very sharply defined. At other places the quartzite mass in the neighbourhood of such veins is interpenetrated with grains of these minerals. This is doubtless another typical example of secondary formation, caused by impregnation with solutions or vapours. Similar relations are observed in the quartzite from the Crown Hill mine.

Formation of apatite connected with alteration of gneiss.

As to how far gneisses in the neighbourhood of the apatite veins have been altered by such impregnations, or how far in particular the content of pyroxene is to be attributed to such causes, it is difficult to say; on the one hand, because pyroxene-bearing gneisses have been found abundantly in other parts of Canada, *e.g.*, by Adams, east of the apatite region; and on the other hand, because of the short time which I could devote to the examination and the lack of good exposures, it was not possible to follow such augite gneisses to any great distance from the apatite veins. But I certainly believe that such alterations are in many cases connected with the formation of the apatite.

Garnet sillimanite-gneiss.

Garnet-sillimanite-gneiss from Poupore post office.—In the opening already referred to many times, there occur alternating with the 'pyroxenites', gneisses and quartzites. The gneiss strata are cut by pegmatite veins, which consist mainly of feldspar with some quartz. In the neighbourhood of these veins, dislocations and shiftings of the gneiss have taken place. In places the gneiss is completely shattered and cemented by pegmatite. Large pegmatite veins enclose fragments of gneiss, and at the same time off-shoots and apophyses as thick as one's finger have run out between the bands of the latter. The garnet-sillimanite-gneiss forms a band somewhat more than 1 m. thick. It consists of alternate layers rich in light-coloured feldspar and in dark-coloured mica. The light red-garnets, up to 2 mm. in diameter, are distributed irregularly through the rock.

Under the microscope it may be determined that the colourless constituents are essentially feldspar while quartz is distinctly inferior in quantity. Of the feldspars, plagioclase predominates over microcline and unstriated feldspar. Only biotite is present as a dark-coloured constituent. The garnet is of a very light rosy-red colour, and is transparent and optically isotropic. Sillimanite needles are found only in the garnet but literally fill it in places. Rarely there are found in the garnet isotropic grains of dark green colour and stronger refraction which are probably a spinel, very likely hercynite or pleonast. Rutile, in the form of little crystals and twins, is a relatively abundant constituent.

The structure in sections parallel to the schistosity is perfectly irregular. Feldspar and quartz everywhere exhibit marked signs of pressure, which develope an incipient mortar-structure. Large plagioclases are often crushed ; the individual fragments, displaced with respect to one another are still recognizable as belonging to one another: Undulose extinction and the bending and breaking of twinning lamellæ are very common. The biotite exhibits an irregular ragged form. In sections at right angles to the schistosity a parallel structure is developed chiefly by the alternation of layers rich and poor in mica. Quartz and feldspar contribute but little to the parallel structure, a few large quartz grains have been squeezed out in the direction of the schistosity. No regular arrangement of the constituents around the garnet is observable.

In all probability the rock is an altered sediment ; the alternation with quartzite and the mineralogical and chemical composition favour this opinion to a certain extent. On account of the abundance of garnet and of a pure alumina silicate, sillimanite, the chemical composition of the rock must vary greatly from that of an eruptive rock.

North of the London mine garnet gneisses seem to be widely distributed. They are somewhat fine-grained rocks, rich in mica, whose structure is more distinctly foliated. Garnet here occurs in isolated lumps "augen" (up to 5 cm. diameter).

Peculiar crystalline schists in London mine.

A series of very curious crystalline schists are found in the upper and lower workings of the London, mine in contact with the veins carrying apatite. They exhibit an alternation of almost snow-white and dark gray layers ; the individual layers are often only about a centimeter thick. The white layers consist almost entirely of quartz and feldspar. The grain is fine and extraordinarily uniform ; the individual minerals possess the form of rounded grains so that the appearance under the magnifying glass is very similar to that of many aplites or very fine sandstones. In these light-coloured parts there is not a trace of parallel structure. The same is true of portions which on account of the occurrence of hornblende, pyroxene and titanite, are somewhat darker in colour. In the above mentioned perfectly evenly distributed feldspar-quartz aggregate, there are little grains and rods of a light grass-green mineral which under the microscope is seen to be partly hornblende and partly augite. Little grains of titanite are also present in abundance. Here also there is no sign of a parallel structure, or it is exhibited to a very small extent in a tendency to parallel arrangement of the green minerals. Such portions on account of the rapid alternation of layers and their light colour exhibit a great similarity to granulites. If the darker constituents become more abundant they seem to prefer to collect into bunches; the appearance is then similar to the variety known as "Forellen granulit." The very dark layers are very rich in mica.

Constituents and structure of rocks.

Under the microscope the rocks have a well defined honeycomb structure. The feldspar is mainly orthoclase, a little being microcline and plagioclase. Quartz is much less abundant than the feldspar. The very light-coloured hornblende must belong to the tremolite-actinolite series and is in part crystallographically developed in the prism zone. The augite is almost colourless and transparent. Titanite is very abundant in relatively large pleochroic grains; zircon and apatite are common.

The darker bands are rich in a light green-brown, transparent and feebly pleochroic mica. The light green pyroxene is fibrous on account of a parting parallel to $\infty P \grave{\infty}$. This is of course most clearly seen in sections parallel to the prism zone and the extinction is parallel; the plane of the optic axis lies parallel to this. Hornblende is relatively rare but generally well outlined and often enclosed in augite. Sections at right angles to the c axis exhibit only the prism faces on their outline as is often the case with actinolite. Constituents which are very characteristic for granulite, such as garnet and also cyanite, andalusite, and hypersthene, are here entirely wanting. Microperthitic intergrowths also play a very unimportant part. The rocks are perhaps best designated as granulite gneisses. With regard to their origin, it is almost impossible to make a guess. At any rate, a further study of their distribution and their position with regard to the other gneisses is necessary in order to form any opinion upon this point. Moreover, the question as to whether a part of the pyroxene and amphibole, and particularly the abundant titanite and apatite, are not in some way connected genetically with the apatite veins can only be answered when these rocks have been traced out farther along their strike.

Further study necessary.

Hornblende gneisses containing pyroxene were also met with at the High Rock and North Star mines. Here again it must be left to later investigations to show whether the pyroxene is not in some way connected with the apatite veins. They are both medium-grained rocks rich in red orthoclase, and the darker constituents predominate in certain layers without actually producing a distinct schistosity. They may be best described as granular-streaky. The lighter layers contain much microcline, and the only dark coloured constituent present is mica which possesses a strong pleochroism between straw-yellow and dark greenish-brown. This mica can be distinguished at a glance from that of the apatite veins. In the darker layers the mica decreases and green hornblende and green-gray pyroxene increase. Both in hand specimens and under the microscope this gneiss is very similar to that described from the neighbourhood of Lachute and probably possesses the same origin.

Eruptive rocks which occur in the neighbourhood of the apatite veins, but which have nothing to do with their formation.

Eruptive rocks near apatite veins.

Along with coarse-grained pegmatites which are widely distributed in the neighbourhood of the apatite-bearing veins, another type of granite veins occurs, which is characterized by a very even medium to fine grain and an almost complete lack of darker constituents; the rocks consist almost entirely of quartz and feldspar which is mainly microcline. Such a vein about 0·5—1 m. thick has been cut into in the upper workings of the London mine. The normal very light coloured rock is here cut by dark gray-green veins, which often exhibit a regular round or elliptical outline. The rock thus has a very peculiar appearance and is known in Canada as 'leopard granite.' Similar masses were found on the dumps of the Little Rapids, North Star, High Rock and Union mines. A very typical block of this leopard granite was shown at the Paris Exhibition, in 1900. Plate V shows a piece from the London mine. With the magnifying glass one easily sees that these veins are caused by an increased quantity of pyroxene, with which in places much pyrite is associated. Under the microscope they consist of light-green pyroxene, dark sap-green hornblende, epidote, very abundant titanite, apatite, and small quantities of carbonates. Apophyses frequently branch off from the larger veins and after a short course thin out. These minerals have penetrated sparingly in the immediate neighbourhood into the mass of the rock itself.

The whole appearance leaves no doubt that one is dealing with secondary structures, which have been formed upon more or less spherical jointing faces. The identity of the minerals occurring here with the essential ones of the apatite veins makes it certain that impregnation has occurred here and that this process is connected with the formation of the apatite and the minerals accompanying it. It is analagous to the secondary formation of phlogopite on the joint-planes of the gabbro from Murray's pit already described.

Diabase dykes cutting gneiss.

Diabase and augite porphyry both occur in the form of veins. In the neighbourhood of the Little Rapids mine two diabase dykes occur, each at least 10–12 m. in thickness, and having a strike almost east and west; they thus cut the gneisses and quartzites, which here have a strike N.N.E. and S.S.W, almost at right angles. One of these veins is cut by the tramway south of the Little Rapids mine on the slope towards the Lièvre river, and the other north of the main building and the smithy. Both dykes cut not only the gneiss and quartzite but also the pegmatite occurring in them, the northern diabase vein also cuts the pyroxenite, so that they are the youngest dykes in the district.

Both diabases are somewhat coarse-grained, quite fresh, and exhibit macroscopically typical ophitic structure. Under the microscope the plagioclase always exhibits sharply defined forms elongated in the direction of one axis, the interstices being filled with allotriomorphic augite. Not infrequently the latter exhibits for considerabley stretches uniform orientation and is then poikilitically penetrated by the feldspar forms. Sections of the latter normal to P and M gave extinction of 36-38° with the trace of M; the plagioclase belongs therefore to the labradorite series and has approximately the composition Ab_2 An_3. Two such sections with a nearly square outline were observed, which fell into two twin halves along a diagonal. They are probably Baveno twins. The augite is transparent and of a gray-brown colour; it is a typical diabase augite. Some olivines are completely converted into serpentine. Titanic iron in irregular forms is present in abundance.

Augite porphyrite.

An augite porphyrite from the Crown Hill mine is seen in an old opening as a vein 0·5—1 m. thick, cutting pyroxenites and apatite veins. It is a black very fine-grained unaltered rock without any phenocrysts. Under the microscope the feldspars are distinguished from the other constituents by somewhat greater dimensions; they are lath-shaped, but without well defined straight outlines. Between them is a fine-grained mixture of augite grains partially uralitised, some brown mica, ore grains and a very little quartz.

A somewhat different structure is exhibited by an augite porphyrite which forms a vein in the gneiss about 0·5 m. thick with a strike east and west, north of the London mine. The groundmass of this black and almost compact rock has a distinct intersertal structure. In it there are large nodules made up of a collection of irregular augite grains with scattered feldspar particles.

Evidently these diabases and augite porphyrites belong to one and the same younger dyke formation; the thicker dykes are made up of diabases, the thinner of augite porphyrites. The eruption to which they belong occurred after the formation of the apatite veins, and the occurrence of the latter does not stand in any genetic relation to them.

Results of investigations.

The results which have been attained by the examination of the apatite occurrences of the province of Quebec, may be summed up briefly as follows:—

1. The apatite always occurs in true veins, which cut the Laurentian gneisses and associated beds, as well as the so-called 'pyroxenites'. In the first case they are developed in part as bedded veins, i.e, correspond in strike and dip with the neighbouring rocks, in part they cut these rocks at right angles. No reasons whatever have been found for considering these apatite deposits as an integral part of the Laurentian gneiss formation of the same age.

2. The apatite-bearing veins are accompanied by basic plutonic rocks (silica, about 48·50 per cent) which belong to the families of the gabbros, shonkinites, and in part pyroxenites. The 'pyroxenites' of Sterry Hunt are in part such plutonic rocks in an altered condition, in part secondary formations in the veins themselves.

3. The essential alterations which the plutonic rocks have undergone consist in a secondary formation of scapolite (at the expense of the lime soda feldspars), of mica (phlogopite), titanite and sulphides (pyrite, pyrrhotite, and in part chalcopyrite).

4. There is indubitable evidence that the gneisses, quartzites, vein granites and other associated rocks have been impregnated with material from the veins, and that in this way secondary developments of augite, among the minerals mentioned under 3, have been brought about. This process is particularly clearly seen where these secondary developments have been limited to the cracks and crevices of the adjoining rock. The pyroxene of the neighbouring gneisses is perhaps also to be referred to such a cause.

Associated vein minerals.

5. In the veins, a distinct association of minerals is observed. Part of them are distinguished by their containing fluorite or chlorine; to these above all belong apatite, phlogopite, scapolite and tourmaline;

of less importance is, curiously enough, fluorine. Then sulphides are abundant, especially sulphides of iron, pyrite and pyrrhotite, and of less importance, chalcopyrite. Of minerals containing titanium, titanite is abundant, while rutile has not been recognized with certainty. Then a series of pure silicates, especially pyroxene, and less abundantly amphibole and feldspars. Finally, in very large quantities, calcite, which, according to my experience, is always the youngest of the vein minerals. Quartz is rarely found. The occurrence of graphite in several cases mentioned by Harrington, is of great interest from a theoretical standpoint.

Characteristic ore vein structures of apatite.

6. The apatite veins show in some places structures which in the case of ore veins are generally considered characteristic, among them lateral symmetrical structure, cockade structure, and drusy cavities.

These facts show that an extraordinary resemblance exists between the Canadian apatite veins and those of southern Norway, the mode of occurrence of which latter have been described by Brögger, Reusch[24], and recently in great detail by Vogt[33]. There is found the same connection with basic plutonic rocks (gabbros, olivine hyperites, etc.), the same extension of the veins into the neighbouring schists and limestones, 'mostly as bedded veins,' (Vogt) and an association of minerals almost identical with our own if we omit certain unessential points. In Norway the presence of titanic acid has brought about the formation of rutile, here of titanite; in Norway the secondary pyroxene is predominatingly the magnesiarich enstatite, here diopside and malakolite rich in lime; in Norway minerals containing chlorine play an important part, in Canada, on the contrary, those containing fluorine replace them. On all these points Vogt has dwelt at length. When further Vogt says: 'The most important difference is to be found in the fact that in Norway in the case of the apatite veins occurring in olivine hyperite there is a constant alteration of the country rock into scapolite hornblende rock, and into other scapolitised gabbros, while in Canada this has been only exceptionally observed,' it is clear from what has been said above that in this respect also the most far-reaching correspondence exists in both regions.

Apatite veins in Sweden similar to Canadian occurrences.

Also in the most northerly part of Sweden, in the province of Norbotten, the apatite veins which have been discovered during the last few years correspond in mineral content (apatite, mica, augite, scapolite, tourmaline, hornblende, titanite, etc.), in their connection with basic plutonic rocks (gabbros and olivine hyperites) exactly with the Norwegian and Canadian occurrences. Here further the same action upon the neighbouring rock, the same scapolitisation, has been exerted (the 'pneumatolitic metamorphism' of Brogger). Vogt states indeed that the discovery of the scapolite in the altered hyperite by Brogger was the cause which led to the discovery of the apatite.

Origin of apatite veins.

In answering the question as to the origin of the apatite veins, one can safely concur in the view put forth by Brogger, Reusch and Vogt, and for the Canadian occurrences in general outlined by Ells (see References) that the formation of the vein minerals has been caused by a fumarole process which accompanied the eruption of the basic magmas or directly followed it. The material from which the veins were formed, particularly the abundant elements Cl, F, Ti, P, B (in tourmaline), Li (in phlogopite) and sulphur cannot be considered as derived in any way by lateral secretion from the neighbouring gneisses. All the circumstances point to the view that they came up from below and that this phenomenon was connected with the ascent of the basic magmas. Vogt points out rightly the broad chemical and geological analogies between these apatite veins and the tin ore veins.

On the Eozoon Limestone of Côte St. Pierre.

Eozoon limestone.

From Papineauville station (on the line of the Canadian Pacific Railway between Ottawa and Montreal) an excursion was made to Côte St. Pierre, lying about ten miles north, from which place, as is well known, Logan described some of the first specimens of Eozoon Canadense. The exposures examined were on the south-east steep side of a thickly-wooded hill and consist of an old quarry, which was made for the purpose of obtaining serpentine asbestus, and is now abandoned, and several small openings made for the purpose of obtaining Eozoon.

Fig. 11. Eozoon Canadense.

The main rock of which the hill consists is a coarse grained plutonic rock without any indication of parallel structure, rich in dark constituents, mica and pyroxene. The feldspar is seen by the naked eye to be plagioclase, on account of the twinning striæ. In accordance with the analysis given later, the rock is best designated as mica-hypersthene gabbro. The main steep slope of the hill is succeeded by a flatter portion, and in this the contact between the gabbro and the Eozoon limestone lies. There are almost no openings here. There then follows a somewhat steeper portion where the best specimens of Eozoon were found and where the former asbestus mine was situated.

Description of contact rock.

The mica-hypersthene-gabbro is, as already stated, coarse-grained (grains 4-5 mm. in diam.) and shows macroscopically brownish coloured quite unaltered plagioclase, generally in the form of short broad laths, on which account the structure reminds one of that of diabase, abundant black mica and dark pyroxene partly with a bronzey lustre, which is shown by the microscope to be partly rhombic and partly monoclinic. These pyroxenes have lost their lustre along their edges on account of the formation of uralite.

Under the microscope the plagioclase exhibits the usual twinning lamellae according to the albite and, in part, pericline law. It contains many inclusions, as is so frequently the case in basic eruptive rocks, in the form of a fine dust, which, with a high power, is resolved into tiny rods and plates; the latter have hexagonal outlines and are transparent and of a gray-brown colour; they are probably titanic iron. The extinction angle was measured on plates parallel to OP and found to be 2·4½°, on plates parallel to $\infty P \breve{\infty}$, 12·16° : a determination of specific gravity with the picnometer gave 2·675. It is, therefore, a feldspar belonging to the oligoclase andesine series: the specific gravity corresponds very nearly to a mixture $Ab_2 An$, and the extinction angle to a somewhat more basic one. Probably on account of the freshness of the mineral, the specific gravity is a better guide than the few extinction angles.

The monoclinic pyroxene is trasparent and of a light green-gray colour, and exhibits almost no pleochroism. In sections parallel to $\infty P \breve{\infty}$ the extinction $\mathfrak{c}$: c was 42°. Beside the normal cleavage parallel to ∞P there was one parallel to $\infty P \bar{\infty}$ with few cracks but strong and running straight, and a great many short but sharp cracks parallel to $\infty P \breve{\infty}$ causing a fine fibrous structure. These relations are best observed, especially the regular intergrowth with the rhombic pyroxene on sections at right angles to c. The central portion of such a section is formed of rhombic pyroxene with distinct pleochroism between reddish and almost colourless. Beside the cleavage parallel to ∞P there is present a system of fine cracks: the ray undulating parallel to them is reddish in color: in convergent light a bisectrix appears almost normal; the plane of the optic axes is parallel to these fine cracks. It is therefore the cleavage parallel to $\infty P \breve{\infty}$ so common in rhombic pyroxenes. The peripheral portion of the section is composed of augite. In convergent light one axis appears at the edge of the field, the plane of the optic axis is parallel to the above mentioned fibrous cracks, the latter being normal to the cracks parallel to $\infty P \breve{\infty}$ of the rhombic pyroxene. Hence the fibrous cleavage of the augite is parallel to $\infty P \breve{\infty}$. In the same section both pyroxenes pass over into uralite which forms the outer edges and numerous irregularly distributed patches in the interior. All three minerals exhibit simultaneous extinction. The rhombic pyroxene always seems to be older than the monoclinic. Both, especially the former, contain inclusions of little rods and plates similar to those in the plagioclase. The green hornblende, in spite of the fact that it is often quite compact, is in all probability wholly derived from the pyroxenes. It exhibits the usual pleochroism, *a* light yellow-green, *b* and *c* dark grass-green.

The mica collects into bunches with the above mentioned dark constituents, and is mostly certainly primary. A small part seems to have been derived from the uralite.

The dark constituents are irregularly outlined, only the rhombic augite exhibits in part rough prismatic forms, it is undoubtedly the oldest of all.

Besides apatite and isolated metallic grains, there is some quartz in very small grains between the feldspars. Pressure phenomena are hardly present.

An analysis by Dr. Dittrich gave the composition under I; under II the corresponding molecular proportions have been calculated to 100, leaving out the H_2O and CO_2.

SiO_2	52·19	55·92
TiO_2	0·72	0·58
Al_2O_3	14·52	9·15
Fe_2O_3	3·19	8·10 FeO
FeO	6·21	
MnO	trace.	
MgO	6·57	10·56
CaO	8·88	10·20
Na_2O	3·65	3·79
K_2O	1·53	1·05
P_2O_5	1·43	0·65
H_2O	0·53	
CO_2	0·66	
	100·08	

From II may be calculated :

A = 4·84 ; C = 4·31 ; F = 24·55 ; a = 3 ; c = 2·5 ; f = 14·5 n = 7·8 and the formula :

$$\bar{s}_{54.5}\ a_3\ c_{2.5}\ f_{14.5}\ n_{7.8}$$

A glance at the table of plutonic rocks (2) shows that the rock holds about the same position as the mica gabbro from Hurrican Ridge, Yellowstone Park, described by Iddings, and that the mineralogical constitution of both rocks is very similar. The latter contains augite, hypersthene, biotite, plagioclase, some orthoclase, quartz, and olivine. The position of the Canadian rock on the limit of the gabbro and diorite table is also exactly the same. It is best placed in the first vertical series of the gabbros as a type above Molkenhaus (under a = 3). In the diorite table, on account of its a c f ratio it would fit in between the types Montrose and Campo major ; for this position its percentage of silica is a little low. It is therefore designated as mica-hypersthene-gabbro. It is also chemically very similar to the essexite type, Fairview ; here, however, the proportion of alkalies is in general somewhat higher, the value for f distinctly lower. The type point in table VIII (loc. cit.) comes near the points 36 (Montrose) and 67 (Cabo Frio). From the numbers for A and C we obtain an average plagioclase $Ab_{5.8}\ An_{4.3}$. The value for Ab is undoubtedly, on account of the considerable quantity of mica, somewhat high, and in spite of this the value varies but little from that calculated from the specific gravity.

Mica-hypersthene gabbro.

A comparison with the gabbro from Murray's pit shows that the rock from Côte St. Pierre is somewhat more acidic and correspondingly richer in alkalies and alumina, but poorer in bivalent metals ; especially the quantity of magnesia, in spite of the mica content, is distinctly lower. Murray's pit is lower and more to the right in the gabbro table.

In this normal coarse-grained plutonic rock occur abundantly distributed streaky and vein-like masses which are of a very uniform, distinctly finer-grain and without any porphyritic secretions whatever. Under the microscope, they are found to differ from the main rock essentially as follows :—

1. The rhombic pyroxene is entirely absent ; at least in the several sections examined its presence could not be determined.

2. The dark mica is somewhat more abund [illegible] quantity to the augite.

3. Quartz, although still scarce, is more plentiful than in the main rock; further, some orthoclase seems to be present along with the plagioclase.

The structure strongly resembles that of many malchite dyke rocks.

Structure similar to malchite dyke rocks.

Two hand specimens were collected from the 'gneiss portions' on the other side of the road. Both are distinctly more fine-grained than the normal gabbro. One of them is rich in dark-coloured constituents and is similar to a fine-grained gabbro or diorite. The other is somewhat lighter; the feldspar is partly coloured reddish; the mica is arranged in parallel layers, so that there is a gneiss-like appearance. From external characters one would designate the rock as a syenite gneiss. Under the microscope, both rocks contain plagioclase in relatively large regularly outlined grains, with the above mentioned inclusions. Between these plagioclase grains lies a fine-grained irregularly distributed aggregate of unstriated feldspar and quartz. The first contains along with mica abundant monoclinic augite, which is partially uralitized; in the latter, no unaltered augite has been observed, but part of the green hornblende may be uralite. It is also rich in apatite and titanite.

The former seems to me undoubtedly to be a marginal facies of the gabbro, but I am not sure of this. A decision can be made only after a further study of the field relations.

Direct contact not exposed.

As has already been stated, the direct contact between the limestone and the gabbro, b on the profile, is not exposed, but in many places it was possible to uncover rocks which undoubtedly came from very close by it. It is characteristic of the specimens thus collected that feldspar and quartz were completely wanting, and that their coarseness and composition varied very much at points but a little distance apart. One of them is exceedingly tough, fine-grained, of dark greenish-brown colour, and in which may be detected macroscopically isolated large plates of mica and cleavage surfaces of green hornblende up to a centimetre across, irregularly outlined and interpenetrated poikilitically by other minerals. Under the microscope, the main mass of the rock is seen to consist of light-gray transparent augite and green faintly weakly pleochroitic hornblende. Mica is only rarely present, and there is also some calcite, a green transparent spinel and abundant titanite. Feldspars and quartz are altogether absent. The hornblende is very irregularly distributed: in certain portions of the section it forms large shreds which are poikilitically penetrated by other minerals. Where it is wanting, the structure is that of a typical lime silicate hornstone of relatively coarse grain. Plate VIII., fig. 2 gives a representation of this structure.

Another one of these rocks is distinguished by the fact that, macroscopically, besides green pyroxene and very abundant titanite, it contains large grains of a white mineral that, in lustre and cleavage, is similar to the scapolite of the apatite veins. Mica is also very abundant in spots. Under the microscope, this undoubted contact product consists in part of a very uniform mixture of pyroxene, scapolite and titanite. Plate XI., fig. 3, is taken from such a place. Other parts of the same section are made up almost entirely of scapolite, which is coarsely fibrous, the individual fibres having a tendency to arrange themselves radially. Plate XI, Fig. 4.

Massive serpentine from near contact.

From still another place in the neighbourhood of the contact comes a black-green massive serpentine, cut by cracks a centimetre wide, filled with some calcite and large mica crystals. Under the microscope, the serpentine exhibits in some places distinct cross-hatching, caused by two fibrous systems crossing one another at right angles. There are isolated grains of carbonates and mica plates in the serpentine. The mica which fills the cracks has an axial angle of about 30°, and is filled with red-brown inclusions.

At another point near the contact is a very coarse diopside rock. The whole rock consists of coarsely crystalline grains of 2–3 cm. diameter of a light green to almost colourless diopside.

Limestone exhibiting contact metamorphism.

I obtained some hand specimens from Prof. Schmidt in Basel, who had collected them on a former excursion to this place, and which consist of about equal quantities of diopside and calcite. The latter forms a coarsely crystalline marble, in which the diopside is developed as very well formed crystals over a centimetre long. The crystals are short prisms, the two vertical pinacoids occur only as narrow truncations of the prism edges. The terminations consist of OP and various pyramids. The latter are usually very rough and unsuitable for measurements, while the faces of the prism zone and OP give very good reflections. All crystals exhibit a perfect parting parallel to OP probably on account of a fine twinning. The extinction angle in one section parallel to $\infty P \breve{\infty}$, determined with Na light, was 37°.

Undoubtedly we have here a limestone exhibiting contact metamorphism; the whole paragenesis of minerals, the great variety in the grain of the rocks in such a short distance, and the typical contact structure are extraordinarily characteristic. At a somewhat greater distance from the contact the carbonates still prevail, in them the diopside has developed in the form of crystals, and irregular concretionary masses, or with the structure peculiar to Eozoon. Dawson says 'sometimes (not usually) pyroxene is the silicious part of Eozoon.' The diopside is very frequently altered to serpentine. When Dawson says 'Further the white pyroxene of the Laurentian limestones and the loganite and dolomite are all known to have been produced by aqueous deposition,' it certainly does not apply to the augite here: it is in this place a product of contact metamorphism. The normal granular limestones of Canada also very often contain green pyroxene, as has already been pointed out. The rocks here described cannot, however, be mistaken for them; they are recognized as different upon the first glance.

Origin of Eozoon.

With regard to the question as to the organic origin of Eozoon, this is in no way connected with the above facts and their explanation. If Eozoon was an organic being, its hard parts which are still preserved certainly did not consist originally of diopside or serpentine but were first converted to the former by an act of metamorphosis. It may here be pointed out that Johnston-Lavis and Gregory[35] have recently obtained pieces of lime silicate, ejections from Monte Somma, in which the typical structure of Eozoon is present. According to these two authors, this structure is not originally organic, but is produced by metamorphosis. In the Monte Somma specimens augite is subordinate to the basic lime and magnesia silicates olivine and monticellite: there also occur mica and spinels, as is the case at Côte St. Pierre.

TWO CANADIAN OCCURRENCES OF GRAPHITE.

I. *On the occurrence of Graphite at Graphite City, Township of Buckingham.*

Occurrence of graphite widespread.

According to the older reports of the Geological Survey, of which I have been unable to make a through study the occurrence of graphite in Buckingham and the adjoining townships is very widespread. In the first township it is reported from many points in lots 18—28 and ranges V—VIII. In most cases work seems to have been confined to small openings, in only a few has the graphite actually been worked, and even here this has been done very sporadically and witl long delays intervening. In this whole area, as far as is known to me, work is carried on only at Graphite City, and there on a small scale.

In the Report for 1873-74 Mr. Vennor has given some information with respect to the way in which the graphite occurs, and according to this the mineral is found 'in three distinct forms :

1. As disseminated scales or plates in the limestones, gneisses, pyroxenites and quartzites, and even in some of the iron ores, as at Hull.

2. As lenticular or disseminated masses embedded in the limestone, or at the junction of these and the adjoining gneiss and pyroxenite.

3. In the form of true fissure veins cutting the inclosed strata.'

Walker Mining Co.

The workings of Walker Mining Co. lie in lots 19, 20, 21, 22, ranges VII and VIII. There are about 30 openings where graphite has been found, of which several generally lie more or less in a group, they however stretch over a large area, which, on account of the woods and in many places the swamps, is difficult of access. Only in two places does the work seem to have progressed beyond the most primitive stages, at the Main pit where a moderate work is being carried on, and at a group of pits west from this, along the boundary of lots 21 and 22, ranges VII and VIII. Here there are ten pits altogether, of which the largest one is known as Nelly's pit. During the seventies, graphite was mined in considerable quantity by the Dominion of Canada Plumbago Co., as can be seen from the depth of the working and the dumps. What is given below refers for the most part to these two localities. Only a few other openings were visited : many were vainly looked for in the thick woods. On this account, and the short time of my stay, my observations must necessarily be of a very fragmentary character.

Of special interest are the following points :—

Graphite occurs as filling of veins.

1. In all the pits I have seen, with but one exception which will be mentioned later, the graphite occurs as the filling of veins and cracks in gneiss, granular limestone, pegmatite, and granular eruptive rocks. The direction of these veins is independent of the strike of the rocks traversed. Thus in a small opening between the Main pit and Nelly's pit the gneiss has a strike N. 70 E. and a relatively flat dip. It is cut by four graphite veins all parallel and about 4—5 cm. thick, whose strike is N. 20° W. and dip almost perpendicular. Near Nelly's pit there is a pegmatite vein in the gneiss several meters thick. In this, in a relatively small space, there are several graphite veins which have been exposed in openings, and which are as broad as one's hand in places but usually only a few centimetres. In Nelly's pit itself the veins are collected on the boundaries of the granular limestone, the gneiss and a plutonic rock, which, as far as one can see, forms a large dike. Some of these veins have a thickness of over 20 cm. One

can see very well from the abundant material on the dumps how narrow apophyses and branches have run out from the large graphite veins between the layers of gneiss, how these dwindle away, and how along their line of continuation isolated plates and knobs of graphite are deposited. See Plate VII. The granular limestone is strongly impregnated with graphite from the veins. One gets the impression that the loose structure would make the penetration of a foreign substance particularly easy.

Exception to vein formation at Main pit.

The one apparent exception to this vein formation of the graphite is found at the Main pit itself. This is a horizontal tunnel-like working about 20 paces long and on the boundary of the granular limestone and the gneiss. I could not find any graphite veins here, but both rocks are abundantly and very uniformly impregnated with little graphite plates. An opening made about 50 paces above this working in the same hill-side shows a graphite vein about as wide as one's hand on the boundary of the gneiss and granular limestone which is here peculiarly altered (see later).

The complete similarity of these relations shows that the graphite is here a typical vein mineral, that the veins are younger than the pegmatite, and therefore certainly younger than the gneiss and granular limestone cut by the pegmatite. The occurrence at Main pit is really no exception. Here the graphite and even the carbon is no original constituent of the gneiss and limestone but a later impregnation which has proceeded from the graphite veins and which is most closely connected with them.

Mineral content of graphite veins simple.

2. The mineral content of these graphite veins is always very simple, in by far the larger number of cases the graphite itself filling the veins; it then consists usually of parallel fibrous or rod-like aggregates, the direction of the fibres being normal to the walls of the vein, as is very common in Ceylon and in other places. Plate VI shows such a fibrous graphite vein, about two fingers thick, in pegmatite. In rare cases green apatite and scapolite occur with the graphite. Thus, I found near Nelly's pit vein-fragments which contained pieces of pure apatite up to the size of one's fist, while the main mass consisted of a granular aggregate of apatite-quartz, very abundant titanite, graphite, scapolite and pyroxene. Many sections of this aggregate cannot be distinguished in any way from the 'pyroxenite' of the apatite veins. Mr. Walker, the owner of the mines, told me that large pyroxene crystals had been found directly upon the selvage of a vein. The occurrence of apatite appears to be not uncommon, and reminds one of the occurrence of the same mineral on the graphite veins in Ceylon. Thus, Sandberger[36]

found in a lump of graphite from there a core of olive-green apatite as big as an apple, also very abundantly rutile, some titanic iron, feldspar, quartz, a light brown-mica, and sulphides, particularly pyrite. According to the analyses of Jannasch and Locke, this apatite is very rich in fluorine. Grünling[37] describes the occurrence of apatite in graphite in Ceylon in the form of large crystals along with iron-magnesia mica, calcite, quartz and pyrite. Weinschenk[38] mentions also unusually large pyroxenes (ordinary green augite). Coursely crystalline calcite also plays an important role in the Ceylon veins.

Eruptive rocks at Graphite City similar to those with apatite occurrence.

3. The occurrence of graphite at Graphite City is connected with the appearance of massive eruptive rocks which in mineralogical composition are very similar to those described in connection with the apatite occurrencs. One might in part repeat the description here. By Mr. Walker's house there are little cliffs consisting of alternate bands of a dark and light gneiss-like rock—it is a hypersthene biotite gabbro· Similar, though more altered, plutonic rocks consisting essentially of plagioclase, augite, and mica occur at the Main pit and Nelly's pit. Whether they are parts of a large mass or are unrelated could not be determined from the poor exposures. The hand specimens from the two last mentioned localities do not show any evidence of parallel structure and are similar enough to be mistaken for one another.

As far as I could see on my short visit, the occurrence of the graphite is connected with the contact of this eruptive rock with gneiss and granular limestone. The limestone is in these places very much altered; there has been especially a large production of scapolite, pyroxene and titanite. Such altered limestones are so like the scapolite pyroxene rock from the neighbourhood of the apatite veins as to be mistaken for it.

Of the rocks from the neighbourhood of the graphite veins, the eruptive rocks will be now described.

Hypersthene biotite gabbro.

Hypersthene biotite gabbro from the neighbourhood of Walker's house. This rock, as already pointed out, has macroscopically a gneiss-like appearance; microscopically there are seen very strongly developed signs of pressure passing into rudimentary mortar structure. Particularly the feldspar, which is almost entirely plagioclase, exhibits undulose extinction, bending and breaking of twins, and similar pressure phenomena in a wonderfully beautiful manner. Along with a monoclinic augite is less abundantly a strongly pleochroic hypersthene. Both are allotriomorphic, the hypersthene in great part converted into a green alteration product. The monoclinic very faintly pleochroic augite shows in sections at right angles to c along with the prismatic cleavages, short sharp cracks which are visible only by considerable magnification and very good lighting, and which correspond to the orthopinacoid ; the plane of the optic axes is normal to them. Mica is also abundant. The rock must come very close chemically to that from Côte St. Pierre as it does mineralogically, only it is distinctly finer grained.

Another similar rock above Main pit.

A rock which I found above the Main pit in large blocks near the graphite vein already described and which must occur very close by, is very similar to the one just described. The rhombic pyroxene is here much less abundant. Of light-coloured constituents, besides plagioclase, a microperthite is very abundant and also some quartz. The structure is completely irregular and that of a normal plutonic rock. Pressure phenomena are less distinct.

A few paces north of the entrance of the Main pit the same rock occurs again. Macroscopically, it cannot be distinguished from the one last described. Under the microscope, it exhibits very peculiar appearances. Here again by far the greater part of the feldspar is plagioclase. This plagioclase is completely intergrown with quartz. All those phenomena described as *quarz de corrosion, quarz vermicule*, &c., may here be studied in peculiar beauty. From the edges of the feldspar sections there run inwards tube and worm-like developments of quartz which frequently unite and form a regular network. Fig. 2, plate XI., shows a typical example of this latter variety ; the isolated plagioclase particles are much rounded, as though roughly broken up and in part somewhat displaced with regard to one another. In other sections the plagioclase has a sieve-like appearance, caused by numerous inclusions of quartz, generally irregularly outlined but frequently similarly oriented optically. In other cases these quartz inclusions are long and spindle shaped, and are then arranged parallel to one another and to the twinning lamellæ of the albite. Not infrequently, the quartz is replaced by a very fine granophyric intergrowth of feldspar (orthoclase ?) and quartz. Fig. 1, plate XI., shows a place where such an aggregate has eaten its way like a tube into a large plagioclase and which ends at its point in pure quartz. Backstrom* has described and figured very similar appearances in inclusions in Scandinavian diabase, and called them corrosion phenomena. Such an explanation is also applicable here. The occurrence of the dark-coloured constituents is also peculiar. The pyroxene is almost completely urali-

Quartz replaced by intergrowth of feldspar and quartz.

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* H. Bäckström : Über fremde Gesteinseinschlusse in einigen Skandinavisches Diabasen, Medel f. Stockholms, Högskola, No. 108, 1890.

tized ; it is eaten away and filled with little mica plates and particles of quartz, similarly to what was observed in the scapolitized gabbro from the Vavasour mine. The brown mica never forms large plates, but invariably a lot of little spangles and irregularly bounded knobs which group themselves radially, preferably about the pyroxenes and metallic minerals or are arranged in parallel swarms. In a short distance such a group of parallel-arranged micas break up into a sort of soot, so that its arrangement looks like that of the microlites having a fluidal arrangement in glassy rocks. Apatite is not an abundant accessory constituent. Lacroix[22] describes and figures very similar conditions in amphibole pyroxene gneisses from the graphite district of Ceylon and from Salem. It is possible that these corrosion and alteration phenomena are connected with the formation of the graphite veins.

Gneiss near Main pit contains little graphite.

The gneiss which occurs a few paces from the Main pit contains but little graphite. It is a thinly-bedded rock whose cross section is seen to be essentially a granular mixture of reddish feldspar and quartz with some graphite. Mica is much less abundant. On the principal fracture are mainly small plates of light-brown mica.

Under the microscope, the rock consists principally of an allotriomorphic mixture of unstriated feldspar with a little quartz. Plagioclase seems to be extraordinarily scarce. The feldspars are filled with the same hair and needle-like microlites as were described under the gabbro from South March. They are fairly strongly double refracting and have parallel extinction. Whether they are rutile or not cannot be at present decided. They are certainly secondary ; they are sometimes arranged in regular systems for long distances, similar to the needle-like inclusions in the phlogopite ; in polarized light, it is seen that one such system includes several feldspar grains arranged quite irregularly with respect to one another, and that some of the longer of the needles stretch unbroken and undisturbed through several such feldspar grains.

Mica and graphite about equal in hand specimens.

The dark-coloured constituents are represented only by mica, and not very abundantly. All the parallel structure of the rock is brought about by the parallel arrangement of the mica which is collected into certain planes, the bands rich in feldspar are irregularly granular.

In the portions rich in mica, and frequently intimately intergrown with it, there occurs graphite, and in the hand specimens examined these two minerals are about equal in quantity. The graphite forms irregularly bounded ragged masses usually elongated in the direction of the schistosity, and, examined in reflected light, is seen to be intimately associated with sulphides, probably pyrite. The same association is found everywhere in the limestone rich in graphite, which is here mined for graphite. The larger particles of graphite exhibit in reflected light irregularly bounded, often elongated portions rich in sulphides and yellow in colour, while the other portions have the lead-grey colour and lustre of graphite.

The graphite often lies in the form of thin lamellæ in the cleavage of the mica, suggesting primary intergrowth, and surrounds it upon the edges. Again, it is seen along transverse cracks and fissures in the mineral, particularly the spaces caused by the mica crystals opening up along the cleavage lines under mechanical stress are filled by it. Portions poor in mica are avoided by the graphite, but it is sometimes seen here and there invariably on the edges of various feldspar grains in long narrow shreds; it follows all the bends and curves of the outline. This whole method of occurrence of the mica shows that it is the youngest of all the constituents and formed in the rock after its solidification, that it is the product of infiltration.

Mica, the youngest constituent.

The parts of the rock rich in mica are the weakest portions, and along them the rock breaks most easily. The portions poor in mica show, as has already been said, an almost irregular and compact structure. Hence along the former an infiltration of foreign matter would take place more easily and in greater quantity. In the portions rich in mica, the mica itself is the mineral which, on account of its good cleavage and elasticity, would most easily be impregnated with foreign substances. These relations are very beautifully shown in Plate IX.

In those portions of the rocks rich in mica and very often enclosed in mica itself, rutile occurs in small needles and twins. Besides, a mineral was observed in somewhat larger grains and crystals, the latter showing quadratic or orthozonal outlines. It shows a very high refractive index, high double refraction and a brown colour: according to its optical properties it belongs to the tetragonal system and was supposed to be cassiterite. In order to make sure the following test was made: The heaviest constituents of the rock were isolated by heavy solutions and several times treated with hydrofluoric acid; a small quantity of a black powder was obtained. It was dissolved in a borax bead coloured slightly blue by CuO; the bead assumed a ruby colour or became opaque, resembling red sealing wax. This very characteristic reaction proved beyond a doubt, that SnO^2 was present. So that though possibly occuring only sparingly, there can be no doubt as to the presence of cassiterite in this gneiss.

Oxide of tin.

The masses employed for obtaining graphite from the main site do not exhibit macroscopically anything but graphite. Under the microscope they are found to contain abundant calcite in large much twined grains, abundant monoclinic augite in irregularly outlined grains partly passing over into a dirty green serpentine-like alteration product, further quartz grains, abundant titanite with strong pleochroism and a colourless mineral in radiating fibrous aggregates that could not be exactly determined but is perhaps tremolite or wollastonite. The graphite occurs as in the above described gneiss in irregularly outlined much elongated lumps. Its intergrowth with pyrite has already been mentioned. As shown by their composition and by the fact that the transition can be followed, these masses have been derived from the granular limestone.

Occurrence of scapolite at contact of graphite veins.

It has already been mentioned that there has been a developement of scapolite at the contact of these graphite veins, and partly upon them. Two of such rocks may here be mentioned. The first comes directly from the contact with the graphite vein which has been opened about 50 paces above the Main pit. It is medium to fine-grained with pyrite abundantly scattered through it and under the magnifying glass has the greatest similarity to contact metamorphosed lime-silicate rock: its structure is quite irregular and granular. Under the microscope it consists of about equal parts of colourless pyroxene and scapolite which in part has undergone the alteration described above. Apatite in large grains and titanite are relatively abundant: quartz is scarce.

The hand specimen of the other rock, also indistinguishable macroscopically from a coarse-grained lime-silicate hornstone, and cut by graphite veins, comes from Nelly's pit. Here too the principal constituents are augite and scapolite, with microcline and a little red brown mica. None of the constituents exhibit crystalline form. The structure is irregular granular, in part distinctly honeycombed.

II.—*On an occurrence of Graphite in Grenville Township.*

Graphite in Grenville Township.

This graphite mine lies about two miles north of the Grenville railway station. On the geological map accompanying a 'Report on the Geology of a portion of the Laurentian area lying to the North of the Island of Montreal,' (Annual Report Geol. Surv. Can., Part J. Vol. VII. (N. S.) there is in the south-west corner a large syenite area covering about thirty-six square miles in the townships of Grenville, Chatham and Wentworth. According to Ells, the graphite mine lies about one mile west of this syenite just at the limit of the map. A glance at the map shows that the Laurentian gneiss at this place contains a series of bands of granular limestone, and the graphite mine is in the granular limestone.

First mention of graphite in Geological Survey reports.

In 1845-46 graphite from the granular limestone of Grenville was mentioned by Logan in the Report of the Geological Survey. The graphite was said to occur on lot 10, range V., together with feldspar, quartz, pyroxene and titanite in a vein which cut the granular limestone. Other occurrences were known at various points in this and the neighbouring townships. The occurrence on lot 10, range V. was worked and abandoned at various times. In the Catalogue of the Collection of Economic Minerals of Canada prepared for the Exhibition in Philadelphia, 1876, it is referred to as follows: 'On this lot five beds or veins of more or less pure graphite occur in a belt varying from five to eight feet in width. They range from five to twenty-two inches in thickness and are inclosed in a gangue from which the graphite may be readily separated. This gangue consists of pyroxene, wollastonite, feldspar and quartz with smaller quantities of sphene, phlogopite, zircon, garnet and idocrase. The country rock consists of white limestone. The deposit has been opened to a depth of thirty feet along sixty feet of its course and some of the graphite has been exported, etc Some of the blocks broken up for shipping were estimated to weigh from 700 to 1,500 lbs.' Recently work seems to have been taken up again actively. At the time of my visit new buildings were being put up and new stamps were being introduced. The whole of the work is carried on in open cuts.

Mode of occurrence

As can be seen from the foregoing description, the graphite occurs filling fissures, *i.e.* as veins in the granular limestone. With respect to the extent of the latter and eventual interbedding with gneisses and quartzites I know nothing. The mine is situated in the thick woods.

The normal granular limestone from an experimental pit is a medium-grained rock which exhibits macroscopically along with a snow-white calcite, rounded grains of a green pyroxene which look almost as though they had been fused, and some graphite in small plates of about 1 mm. diameter. These two minerals are locally concentrated into individual bands of the limestone, causing an alternation of lighter and darker bands. These are indeed the two accessory constituents which are most widely distributed in the granular limestones of Canada. Under the microscope it is further seen that feldspar and quartz are present in spots in no very small quantities, and moreover some colourless transparent garnet and titanite must be mentioned.

For comparison with this limestone, a large quantity of the granular limestone from Lachute Station about ten miles east of Grenville, was dissolved in dilute hydrochloric acid. The limestone is distinctly coarser grained and contains along with pyroxene a light red-brown phlogopite, also some graphite, and a red-brown mineral not further investigated, which looked like garnet but was strongly doubly refracting; possibly it is a member of the humite chondrodite series. Upon dissolving this limestone there frequently remains a coherent skeleton which consists of abundant quartz and a triclinic feldspar along with the minerals already named. All possess a more or less rounded surface as though fused. The feldspar exhibits polysynthetic twinning lamellæ, and on cleavage surfaces parallel to 0P almost parallel extinction, so that it must be an oligoclase. Thus, the normal limestone from the Grenville graphite mines shows no unusual composition.

Vein graphite of economic value.

The graphite which is worth mining occurs in the limestone as undoubted filling of fissures and veins, which occur together locally with almost parallel strike. Few of these veins are more than 1 decim. in thickness. The limestone between the graphite veins is very much altered, and particularly rich in quartz. This forms grains of over 2 mm. diameter, and becomes in places so abundant as to impart to the rock the appearance of a quartzitic sandstone; in other places a large part of the calcite grains have become altered to fibrous wollastonite. At the same time there has occurred a strong impregnation of graphite, so that in the neighbourhood of the cracks the rock has become almost black. These alterations decrease in intensity with the distance from the graphite veins. In the veins themselves and in places upon them there are masses of pure fibrous wollastonite, green pyroxene, and titanite, a cubic foot in size. Here also graphite occurs in hexagonal plates more than a centimeter across. If on the other hand a crack is filled completely with graphite it forms apparently a structureless mass or a fibrous aggregate. Frequently the calcite in the neighborhood of the veins has become coarsely crystalline and of a blue colour, as is the case in contact rocks from Monzoni and the Banat.

Wollastonite.

The wollastonite of the veins and their immediate neighbourhood consists either of snow-white parallel fibrous aggregates of 10—20 cm. length of fibre, and then generally almost quite pure, or an irregular coarsely columnar aggregate and is then abundantly intergrown with pyroxene and titanite. Microscopically the apparently pure mineral contains small augite lamellæ. The c axis of the latter is parallel to the fibres or b axis of the former. Graphite and pyrite frequently occur in irregular cross cracks, and they are therefore in part younger than the wollastonite.

An analysis by Bunce (Dana's Mineralogy, 1850) gave :

	I.	II.
SiO_2	53·03	0·8838
FeO	1·20	0·0167
CaO	45·74	0·8168
	99·99	

Under II. the molecular proportions are given. The composition is :

$$0{\cdot}8168 = 90{\cdot}71 \quad CaSiO_3$$
$$0{\cdot}0167 = 1{\cdot}85 \quad FeSiO_3$$

There remains an excess of 0·0670 SiO_2 which is perhaps caused by quartz inclusions.

The augite has a dark bottle-green colour and exhibits along with the cleavage cracks parallel to ∞P, a parting parallel to oP. Parallel to these faces of parting microscopic liquid inclusions are arranged in bands.

Titanite abundant.

Titanite is also very abundant in pieces up to the size of one's head. Busz (40) describes two crystals from here which were about 1 cm. thick and 4 cm. long. The habitus is exactly that of the well known crystals from Renfrew, the observed faces being $P\bar{\infty}\ \{\bar{1}01\}$ $P\breve{\infty}\ \{011\}$ $\frac{2}{3}P\grave{2}\ \{\bar{1}23\}$ and $-2P\grave{2}\ \{121\}$ according to Naumann's orientation. I found only massive pieces of a resin brown colour.

A parting parallel to two faces is very characteristic and complete and gives with the goniometer very good reflections from surfaces making an angle of 54° 29′. This is almost identical with those found by Busz for the titanite from Renfrew (54° 30′). From these he calculates a parting parallel to $\frac{1}{3}P4$. In consequence of this parting the mineral is very crumbly and fragile.

Zircon is decidedly more scarce than the three minerals described above. I was able to find only two small crystals in the material collected, and these were somewhat over 0·5 cm. long and about 1 mm. thick. They exhibit the forms $\infty P\ \{110\}$ $3P\ \{331\}$ $3P3\ \{311\}$ and $P\ \{111\}$ The termination of the crystal is sharp, as in the accompanying figure, on account of the preponderance of 3 P and 3 P 3. The colour is light violet gray.

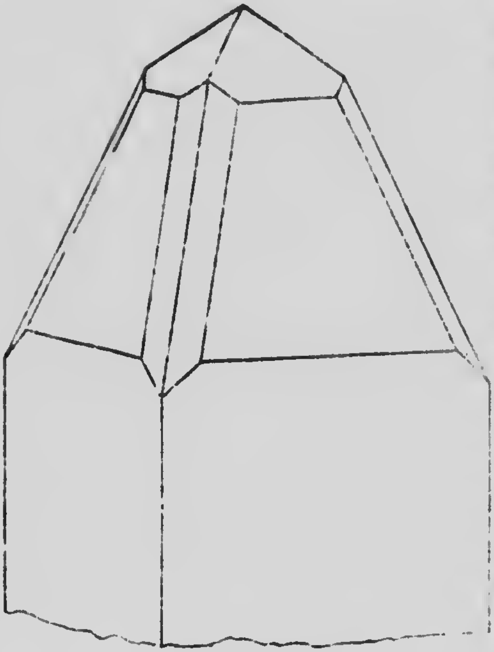

FIG. 12. Zircon from Grenville.

Hoffmann (11) gives vesuvianite and garnet as minerals accompanying the graphite at Grenville: during the short time of my stay I was unable to find these.

Limestone cut by eruptive rock.

In one of the openings the granular limestone is cut by a vein of eruptive rock. It is compact, of green violet gray-colour with a few lath-shaped little feldspar phenocrysts. The rock is about 0·5 m. thick and becomes finer in grain along the edges. Under the microscope it is seen to be much altered, only a few large plagioclase crystals being quite fresh. In the groundmass one recognizes very much altered plagioclase and sections of a prismatically developed mineral that is completely decomposed. On the contact with the limestone the feldspars of the groundmass exhibit fluidal arrangement and form a brown mass which consists for the most part of tiny [illegible] refracting grains which are probably alteration products of a glass. Probably the rock is closely related to the augite porphyrites already described from the neighbouring apatite region.

Analysis of graphite by Hoffmann.

Hoffmann (12) has made a series of analyses of graphite, both from various localities in the townships of Grenville and Buckingham, the results of which are given in the report here referred to. The most important results which have been derived from the investigation of the occurrences of graphite at Grenville and Graphite City, may be summed up as follows:

1. In both occurrences the graphite appears as matter filling veins and cracks, and is therefore younger than the containing rock. The strike of these veins is independent of that of the crystalline schists cut

by them. In many of the veins graphite is the only vein mineral, as at Graphite City. In other cases pyroxene, green apatite, scapolite, titanite, and wollastonite are also present; these with the exception of wollastonite, are the most abundant minerals of the apatite veins.

Country rock impregnated with graphite.

2. From these veins the country rock has been impregnated with graphite, particularly in the case of the crystalline limestones which, no doubt, on account of their somewhat loose structure, have shown themselves most susceptible to this influence. In the case of the gneisses this impregnation has been confined essentially to the layers richest in mica, along which also the rock breaks most easily. Particularly at the Main pit in Graphite City these impregnations have gone so far that the granular limestone is mined for graphite.

3. Along the contacts of the graphite veins, the neighbouring rocks have suffered alteration into scapolite and pyroxene, as is characteristic in the case of the apatite veins. There have thus been formed masses which cannot be distinguished from many of the 'pyroxenites' of the apatite regions (Graphite city). At Grenville, the granular limestone has been converted into a mixture of pyroxene, wollastonite, and titanite. In places they are so strongly impregnated with silica that a rock similar to quartzite has been formed.

In both cases minerals have been formed which are essentially the same as one is accustomed to observe in limestones which have undergone contact metamorphism. This contact metamorphism of the limestone can be explained only by the assumption that the limestone has been penetrated by gases and vapours from the neighbouring eruptive magma, and upon further cooling perhaps also by solutions, and that in this way the materials foreign to the limestone, especially the silica, have been introduced.

Further discoveries of graphite at Grenville probable.

The assumption of a similar process in the formation of the graphite veins is most probable. At Graphite City plutonic rocks have been recognized at several places close to the graphite veins. At Grenville this was not possible (the augite porphyrite there occurring in veins certainly has nothing to do with such a process); however it must not be forgotten that nothing is known geologically of the region even immediately around the graphite works. Perhaps the immense mass of syenite whose boundary is only about a mile to the east should be considered in this connection. I am thoroughly convinced that the graphite veins at Grenville are not of isolated occurrence, as is the case at Graphite City, but that the wooded character of the country has prevented further discoveries of graphite in the neighbourhood.

In one respect these two occurrences differ, for in that at Graphite City the plutonic rock itself is cut by graphite veins. One must, therefore, here suppose a process conditioned, as in the case of the tin ore and apatite veins, by fumarole action after the cooling or solidifying of the eruptive rock. The occurrence of apatite and graphite veins in such close proximity in the province of Quebec and exhibiting so much in common mineralogically and geologically shows that they have had a similar or analogous origin. One needs only to be reminded of the occurrence of graphite in apatite veins, and conversely of apatite in graphite veins. The latter is reported from Ceylon in all geological descriptions.

Origin of graphite in granular limestone.

Graphite is widely distributed in the granular limestone of Canada, but is as far as my knowledge goes, however, present only in small quantities. That this graphite has been derived from carbon originally present in the limestone and probably of organic origin, seems to me to be without doubt. By the same process of metamorphism by which the limestone was converted into marble, this graphite has also been formed. The graphite of the veins which have been described has, however, certainly nothing to do genetically with this other graphite sparsely and evenly distributed. A short time ago Weinschenk (37) came to the same conclusion in regard to the graphite veins of Ceylon.

According to this theory the source of the carbon forming the graphite must be sought deep down in the earth. As to the chemical form in which it was present as a constituent of volcanic fumaroles, we know at present very little. Weinschenk supposes that it was in the form of cyanogen compounds. It may be pointed out that quite recently Cohen has found in the nickel-iron of Ovifak and Niakomak, which is now supposed by all to be of terrestrial origin, the same iron carbide which under the name of cohenite has been known for a long time as a constituent of meteoric iron. Further the inclusions of liquid carbon dioxide especially in the quartz of eruptive rocks, can only be supposed to have originate from an original content of carbon in the fused masses of the earth's crust.

C. H. Gordon's paper on syenite gneiss.

'It was only while correcting this report that I became aware of Mr. C. H. Gordon's paper on the syenite gneiss (leopardrock) from the apatite region of Ottawa county, Canada.* The investigations of the author are essentially confined to the occurences at the High Rock mine. The results of his work which have for us a particular interest for us are as follows :—

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* Bull. Geol. Soc. Am., Vol. VII., 1896.

Intrusive nature of syenite gneiss certain.

(*a.*) The syenite gneiss occurs in dyke form in pyroxenite, gneiss and quartzite and cuts across the latter in part at right angles to the strike. There can therefore be no doubt as to its intrusive nature, and its younger age in relation to the later rocks.

(*b.*) The syenite gneiss occurs in three structurally different modifications, which are united to one another, sometimes in one and the same rock mass, by transition forms, as coarse-grained syenite gneiss, as ellipsoidal syenite gneiss, and as streaked syenite gneiss.

1. The coarse-grained modification is made up of irregular shaped angular blocks of coarse-grained rock (sometimes as much as two inches in diameter) which are separated from one another by a network of fine-grained mineral aggregates.

2. In the ellipsoidal syenite gneiss these coarse-grained blocks are no longer irregular but are rounded ellipsoidal, or egg-shaped.

3. Through the latter becoming flatter and ovoid, transition forms to the streaked syenite gneiss (Modification 3) are developed. In this last, these are so flat that a lenticular structure with an alteration of coarse and fine-grained bands results although the difference in the grain is not so marked as in Modifications 1 and 2.

Accessory minerals.

(*c.*) Mineralogically all these modifications are of like composition. Feldspar (in greater part microcline), green pyroxene, and quartz are the essential constituents. Accessory to these are titanite, apatite (in places in masses of over one foot in diameter), pyrite, mica, hornblende (in part alteration product from pyroxene) calcite, and sparingly also rutile and tourmaline. The coarse-grained blocks consist essentially of feldspar, with subordinate quartz and isolated well-formed pyroxene crystals. The fine-grained network lying between is coloured more o less intensely green and in it the augite, titanite, pyrite, and the othe accessory minerals are more strongly developed. The pyroxene prism and needles are here in part regularly arranged ; they lie with thei long axis normal to their contact with the enclosed coarse masses

(*d.*) The whole rock shows pressure effects which are particularl intense in Modification 3, the streaked syenite gneiss. Accordin to the whole description, the lenticular structure has been produce through the crushing together with perhaps also the rolling out of th coarse constituents of Modifications 1 and 2. The greatest extrem of pressure is in the network whose structure is to be directl designated as mortar (mortel) structure.

(c.) With respect to the origin of these peculiar structural relationships, the author discusses different possibilities and sets forth the following hypothesis as the most probable :—

Structure of leopard rock.

(1.) The structure characterizing the leopard rock is due to orographic agencies and represents an intermediate stage in the development of a streaked augite-syenite gneiss out of an augite-syenite which was distinguished by a coarsely crystallized structure and by a somewhat irregular aggregation of pyroxene. The character of the original magma may have been modified somewhat by the absorption of included fragments of pyroxenite.

(2.) The distribution of the pyroxene has been effected presumably by the solution of portions of the original constituents and their crystallization along lines marking the location of cracks.

(3.) With continued pressure these lumps (the coarse-grained blocks) have been more and more drawn out, the process being accompanied by recrystallization until the rock assumed the streaked gneissoid form."

The rocks which I had an opportunity of studying belong to Gordon's Mod. 2, the coarse-grained blocks being in part completely spherical. The boundary between these and the fine-grained material is seen to be conditioned through original more or less spherical jointing. If such rocks are strongly squeezed these spherical masses become more and more flattened and consequently a lenticular structure is induced. At the same time effects of pressure, such as the crushing of the constituents, the production of a mortar structure, &c., are more pronounced along joint planes in which the cementing is weaker and more open than in compact coarse blocks, therefore the pressure effects are more pronounced in the network. So far one can completely agree with points 1 and 3 of the author. On the other hand I am convinced that the unequal distribution of the minerals, particularly the strong enrichment in pyroxene, apatite and pyrite, as also the occurrence of rutile and tourmaline, in the fine-grained network, is not as the author believes a sort of lateral secretion in the syenite gneiss itself, but originates from an impregnation along these joint fractures of materials from without, which work their way into the coarse-grained blocks. This impregnation phenomenon took place contemporaneously with the formation of the apatite veins.

Reason of unequal distribution of minerals.

The whole process was developed in the following way :—First of all came the intrusion of stock and dyke formed masses of gabbro and a part of the pyroxenite, in the gneiss and quartzite. Probably soon after came the formation of the syenite gneiss dykes, in which were formed both spherical and more or less irregular joint-planes. Then followed the development of the apatite veins and a part of the pyroxenite (newly formed from the apatite veins themselves), and at the same time impregnation of the neighbouring rock through solutions and pneumatolitic action. Lastly came the pressure effects which gave to the syenite the structure of a lenticular (flaser) gneiss.

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APATITE CRYSTALS IN COARSE SPATHIC CALCITE.—VAVASOUR MINE.

AUGITE-CRYSTAL ENCRUSTED WITH APATITE IN COARSELY CRYSTALLINE CALCITE.—*A*, AUGITE; *B*, APATITE BORDER.
(SEE PAGE 26).

Pyroxene [Apatite] "Pyroxenite."—The lighter portion consists of Green Apatite, the darker of rudely prismatic Augite.—Union mine. (See page 48).

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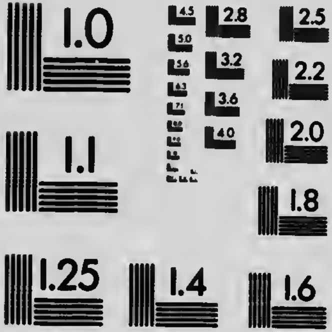

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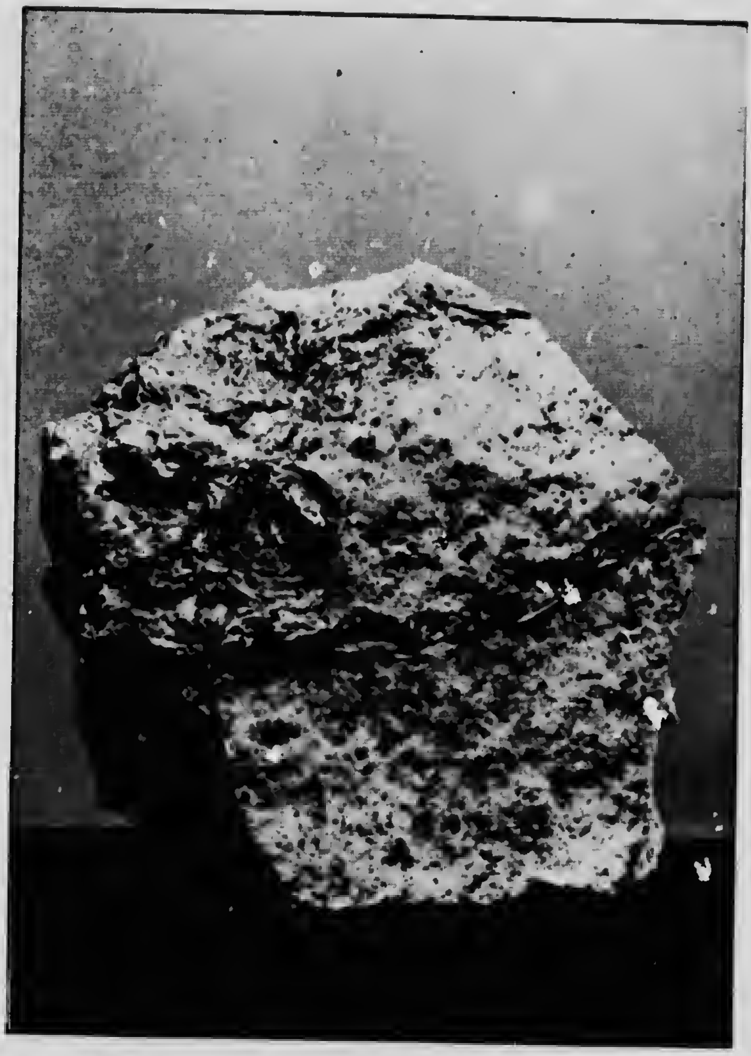
'Pyroxenite.'—'Eyes' of Pyroxene lie in an aggregate of Pyroxene and Phlogopite.—Vavasour mine. (See page 48).

Leopard Granite.—The large dark portion in the lower right hand quarter is very rich in pyrite. (See pages 26 & 56).

STRINGER OF COLUMNAR GRAPHITE IN PEGMATITE. NELLY'S PIT, GRAPHITE CITY.



GRAPHITE STRINGERS PINCHING OUT IN GRANULAR GNEISS FROM A GRAPHITE VEIN.—
NELLY'S PIT, GRAPHITE CITY.

FIG. I. SCAPOLITE GABBRO. VAVASOUR MINE. SCAPOLITE AND AUGITE IN PART URALITIZED. (SEE PAGE 50).

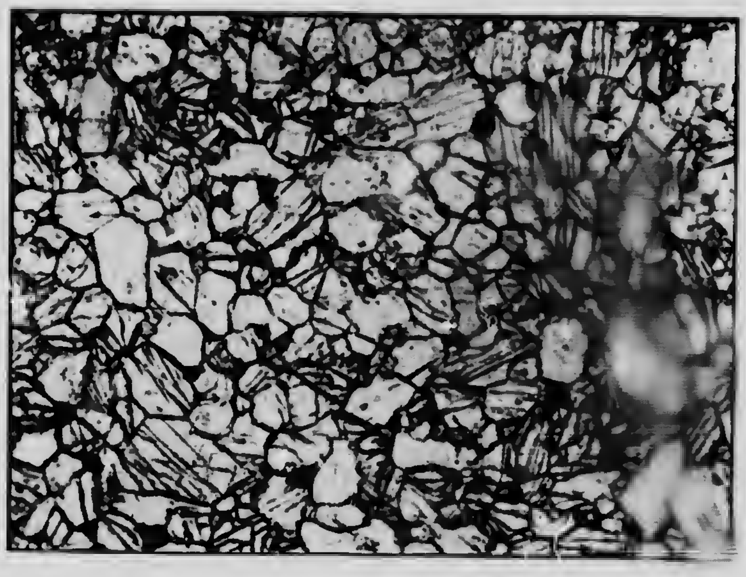
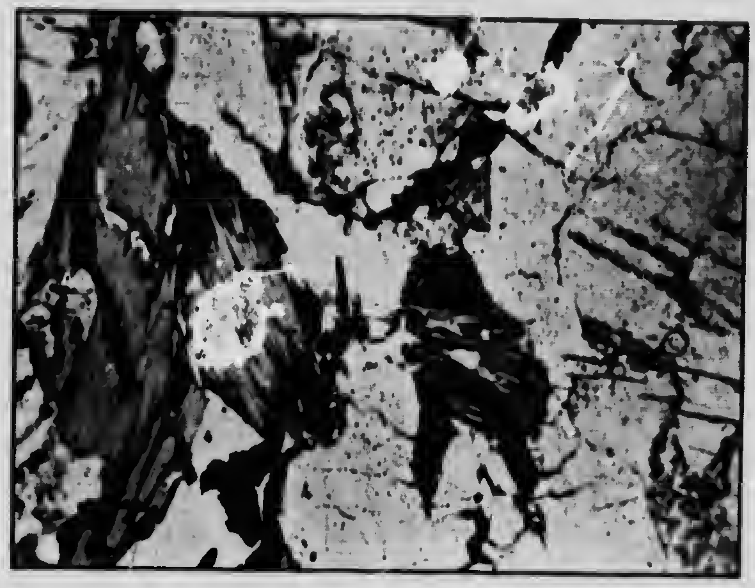


FIG. II.—LIME SILICATE-HORNFELS, CONSISTING OF PYROXENE, SOME AMPHIBOLE [illegible] TITANITE.



FIGS. I. AND II. GRAPHITE GNEISS FROM MAIN PIT., GRAPHITE CITY. (SEE PAGE 72).

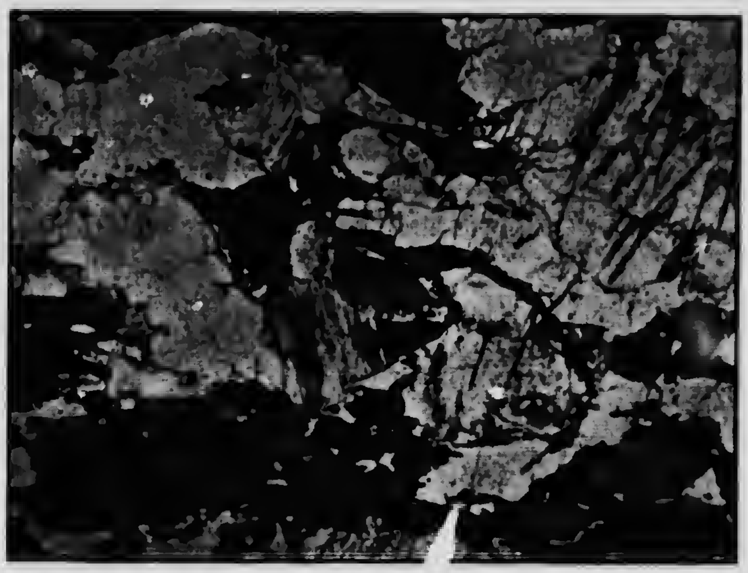


FIG. II.

Fig. I.—Pyroxene from Scapolite gabbro, Vavasour mine. (See page 21).

Fig. II.—Quartzite from the Squaw Hill mine with vein consisting of Pyroxene, Scapolite, Titanite, etc. (See page 26).

Fig. III.—Phlogopite with inclusions, North Star mine. (See page 32).

Fig. IV.—Scapolite with characteristic inclusions.

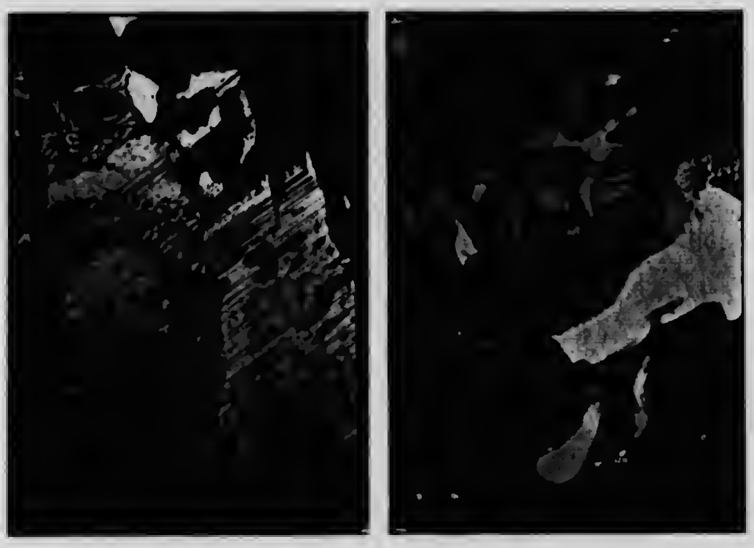


Fig. I. Fig. II.

Plagioclase with granophyric corrosion vein, Graphite City. (See page 70).

Fig. III.—Scapolite Pyroxene, contact rock, Côte St. Pierre. (See page 65).

Fig. IV.—Scapolite spherulite, contact rock of Côte St. Pierre. (See page 65).

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