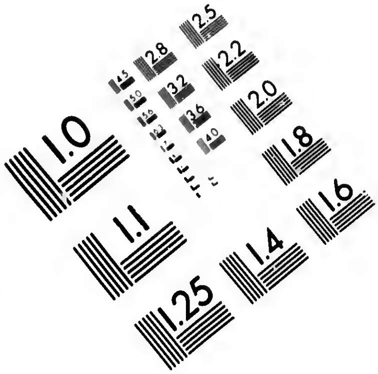

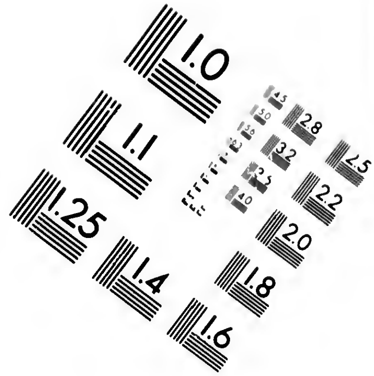

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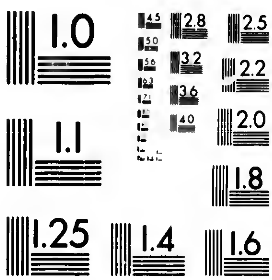

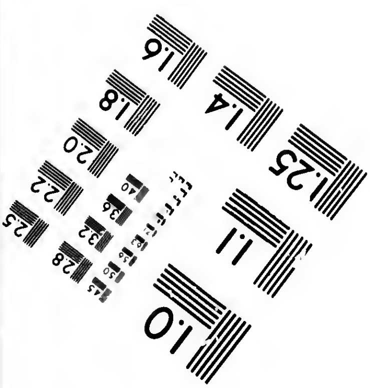

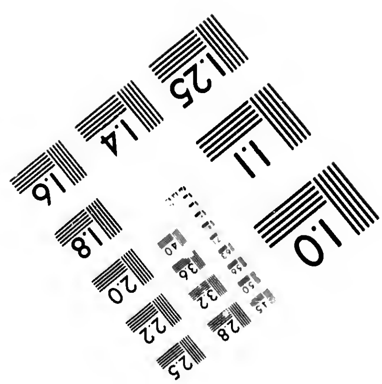

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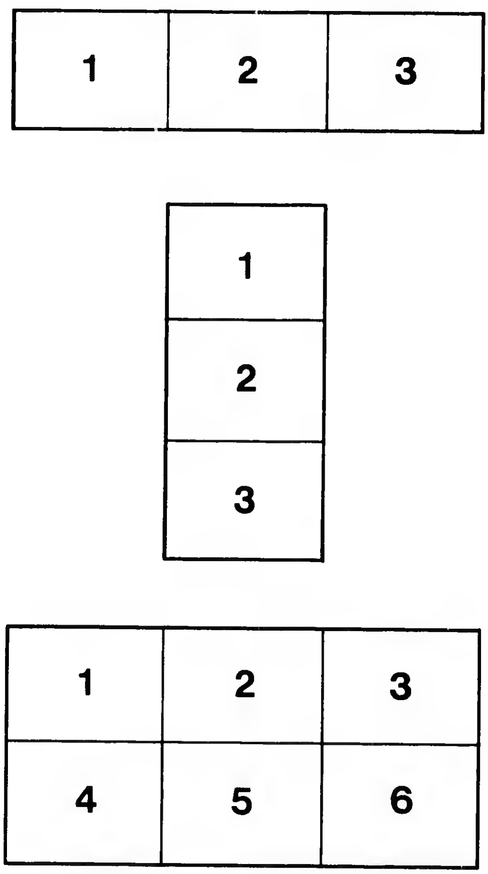
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Plate I.—CONTACT OF THE ANORTHOSITE AND GRENVILLE SERIES, AS SEEN FROM PIEDMONT, AUGMENTATION OF MILLE ISLES.

GEOLOGICAL SURVEY OF CANADA

G. M. DAWSON, C.M.G., LL.D., F.R.S., Director

REPORT

ON THE

GEOLOGY OF A PORTION OF THE LAURENTIAN AREA

LYING TO THE

NORTH OF THE ISLAND OF MONTREAL

BY

FRANK D. ADAMS, Ph.D., F.G.S., F.R.S.C.

OTTAWA
PRINTED BY S. E. DAWSON, PRINTER TO THE QUEEN'S MOST
EXCELLENT MAJESTY
1896

To GEORGE M. DAWSON, C.M.G., LL.D., F.R.S.,

Director of the Geological Survey of Canada.

SIR,—I beg herewith to submit to you a Report upon the Geology and Economic Resources of that portion of the Laurentian region lying to the north of the Island of Montreal, together with a geological map of the same.

In the spring of 1885 I was instructed by Dr. A. R. C. Selwyn, then Director of the Survey, to undertake a detailed geological examination of this district, with a view to ascertaining the true character and relations of the great masses of anorthosite which occur in it and which had been supposed by Sir William Logan to constitute an upper member of the Laurentian system. These rocks, which are also very extensively developed in several other parts of the Laurentian, had attracted much attention on account of the large deposits of iron ore which they contain, but their true relation it was believed could best be ascertained in this district, which is for the most part comparatively easy of access, while forming as it does an eastward continuation of the Grenville district, previously mapped by Sir William Logan, it also promised to afford important additions to our knowledge of the Laurentian system as a whole. These expectations have, it is hoped, been in a measure realized.

The field work was carried out during portions of the summers of 1885, 1887, 1888 and 1889, and was completed in 1891 after the severance of my connection with the Geological Survey, to accept the Logan Professorship of Geology in McGill University.

The south-western corner of the area I have not studied, as no anorthosites occur there, and that portion of the sheet was carefully examined by Logan, being embraced in his map of the Grenville district, which appears in the Atlas accompanying the "Geology of Canada," and published in 1865. It has also quite recently been re-examined by Dr. Ells, to whom I am indebted for information concerning the distribution of the crystalline limestones in this portion of the area.

The north-west and south-west sheets of the "Eastern Townships" map, issued by the Geological Survey, and the Sectional Map of the Province of Quebec, published in 1894 by the Crown Lands Department of the province, have been taken as a basis for the topography of the accompanying map. It has, however, been corrected and supplemented by the more recent government surveys, as well as by extensive surveys of my own. The issue of a separate map to accompany the present report, is necessitated by the fact that the area described is unfortunately situated at the meeting of four sheets of the geological map of the Province of Quebec, now in course of preparation, two of which sheets cannot be completed for publication for some years yet.

The petrographical work in connection with the Report has been carried out in part at the University of Heidelberg and in part in the petrographical laboratory of McGill University.

Previous to the commencement of my survey, a certain amount of work had been done in this district, by various members of the Geological Survey, at different times. Short visits to certain parts of it had been made by Sir William Logan, Dr. Sterry Hunt and Mr. John Lowe, a number of localities being referred to by them in the early reports of the Survey. In the summer of 1880, Mr. R. G. McConnell mapped an area of considerable size lying to the southern portion of the counties of Berthier, Maskinongé and St. Maurice, a small portion of which is included in the present map. Mr. H. G. Vennor and Mr. Lewis R. Ord also examined portions of the district in 1879-80. A short statement concerning the work of these three gentlemen is contained in the Summary Report of the Operations of the Geological Corps, by Dr. A. R. C. Selwyn, 1879-80, pp. 3-5.

My warmest thanks are due to Prof. Rosenbusch of Heidelberg for aid and advice on many points connected with the petrography of this district; also to Prof. Carlyle, formerly of McGill University, now Provincial Mineralogist for British Columbia, who ably assisted me during the seasons of 1885 and 1887, as well as to Mr. Walter C. Adams, B.A.Sc., Mr. Nevil Norton Evans, M.A.Sc., and Dr. B. J. Harrington, for chemical analyses of rocks, and to Mr. G. H. Garden, C.E., and several other gentlemen who have assisted me in various ways.

I have the honour to be, sir,

Your obedient servant,

FRANK D. ADAMS.

MONTREAL, 25th June, 1896.

TABLE OF CONTENTS.

NOTE.—*The bearings given in this report are all referred to the true meridian.*

REPORT

ON THE

GEOLOGY OF A PORTION OF THE LAURENTIAN AREA

LYING TO THE

NORTH OF THE ISLAND OF MONTREAL.

Physical Features.

The continent of North America, as is well known, has been gradually built up by the accumulation of sediments, about certain very ancient land areas which now form the skeleton of the continent and are termed its Protaxes. Of these by far the largest and most important is the great Northern Protaxis, which forms the hilly and mountainous country bounding the plains of central Canada on the north, its southerly limit extending from Lake Superior in a nor'heasterly direction to the coast of Labrador, while in a north westerly direction from that lake it runs nearly to the shores of the Arctic Sea.

Northern Protaxis.

This great core or nucleus of the American continent, lying almost entirely within the Dominion of Canada and embracing as exposed an area of some 2,001,250 square miles,* constitutes what the distinguished Austrian geologist Suess, has termed "The Canadian Shield" or "Boss," of the earth's crust, as well as the more mountainous stretch of country along the Labrador coast, and is composed exclusively of very ancient crystalline rocks.

The district covered by the present Report forms a portion of this Protaxis, being situated at its southern edge, which here runs nearly parallel to the course of the River St. Lawrence and is about twenty miles north of the Island of Montreal, as shown in the accompanying map, which comprises an area of 3258 square miles, situated in the counties of Argenteuil, Terrebonne, Montcalm, Joliette, L'Assomption, Berthier and Maskinongé, in the province of Quebec.

* This does not include the outlying and separated Archæan areas, occurring in Newfoundland, and in the States of New York and Michigan, and is based on the supposition that the limits assigned to the nucleus in the imperfectly explored regions of the far north by Dr. G. M. Dawson are correct. *See* G. M. Dawson, Notes to accompany a Geological Map of the Northern Portion of the Dominion of Canada, Annual Report, Geol. Surv. Can., vol. II. (N.S.), 1886.

Aspect of its relief.

In the aspect of its relief, the district embraced by the accompanying map presents a well marked division into a great plain which stretches across its southern portion, occupying the valley of the St. Lawrence, and which is underlain by Palæozoic strata of Cambro-Silurian age, and a hilly or mountainous district composed of Archæan rocks to the north.

From the St. Lawrence the plain gradually rises to the north-west, attaining in the present area at its northern limit, a height of about 300 feet above the St. Lawrence at Montreal. It is usually covered with a heavy mantle of drift, so that over large areas no exposures can be found, and is well watered, fertile and thickly settled by an industrious and thriving agricultural population.

Rising abruptly from this plain, the Archæan appears as a line of hills, stretching across the country and forming a very well marked topographic feature. These hills are distinctly visible from "Mount Royal," on the slopes of which lies the city of Montreal in the extreme south-east corner of the sheet, as one looks to the north on a clear day.

The appearance which they present when seen from the plain at a distance of a few miles is shown in the accompanying sketch, taken from near the southern corner of the township of Brandon (Plate II).

These hills really constitute the edge or southerly limit of a great uneven plateau, which, however, like the plain, rises gradually to the north-west.

Elevation of plateau.

Roughly speaking it may be said that, if a line be drawn across the plateau, parallel to the northern edge of the plains, and about half way between the plain and the north-west corner of the sheet, the district to the south of this line would have an average elevation of about 1000 feet, while to the north of it the country frequently attains an elevation of 1500 feet, or to the extreme north-west, of 1900 feet. Isolated hills rise still higher, as, for instance, Trembling Mountain (Plate II.), which is probably the highest point in the district, and which attains a height of 2380 feet above sea level. Logan in 1858 measured trigonometrically the height of Trembling Mountain above Trembling Lake and found it to be 1713 feet. A barometic determination by Dr. Ells and myself gave the height as 1720 feet Logan's estimate of the total height of this mountain as "about 2061 feet above Lake St. Peter," is, however, too low, as the railway at Chute aux Iroquois is 726 feet above Montreal and Trembling Lake is 90 feet below Chute aux Iroquois.

Trembling Mountain.

The hills about Ste. Agricole also, on a moderate computation, must attain a height of 2100 feet, the central portion of the township of

FIG. 1.—LAURENTIAN HILLS, FORMING THE EDGE OF THE NORTHERN PROTAXIS, NEAR SOUTHERN CORNER OF THE TOWNSHIP OF BRANDON.

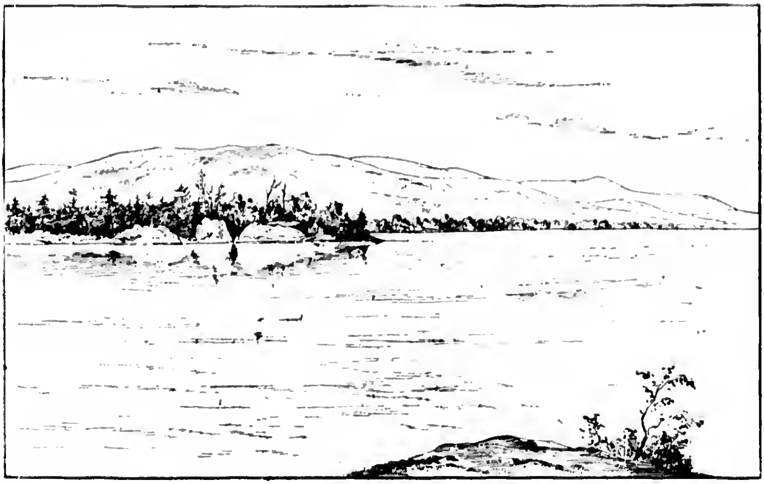

FIG. 2.—TREMBLING MOUNTAIN, AS SEEN FROM SOUTH-WEST SIDE OF TREMBLING LAKE.

PLATE II.

Archambault, in which this place is situated, being occupied by the "Montagne Noire," which is so rugged that in laying out the township, it was left entirely unsurveyed.

This Archæan plateau has a remarkable mammillated or undulating surface, the depressions being generally filled in with drift, forming extensive flats which are studded with numerous lakes, great and small, filled with clear water and forming one of the most characteristic features of the country. Rounded, ice-worn bosses or hills, protrude through the drift in every direction. These seldom rise to a height of more than three or four hundred feet above the average level of the country, and present, especially where the district has been traversed by forest fires, great faces or whole summits of bare rock. The lakes are drained by several rivers tributary to the St. Lawrence, that run through drifted valleys of which the sides are usually beautifully terraced.

Character of country.

The landscape in this Laurentian country is of a very pronounced type, which, while lacking on one hand the grandeur and sublimity of the great mountain regions of the world, and on the other, the tranquil beauty of well cultivated lowlands, has a certain rugged beauty of its own, and when clothed with the autumn foliage, a remarkable brilliance. Although the slopes of the hills are often cultivated, it is principally the depressions and river-valleys that afford land capable of settlement and suitable for agricultural purposes. The settlements therefore are, and must of necessity always be, more scattered than those on the plain, and the land although producing excellent crops in many places, is generally sandy and less fertile than that of the plains. The country, however, now supports a hardy and contented population of farmers, which, except in the south-west corner of the district is almost exclusively of French extraction, and settlements are, year by year, extending further back into the hitherto unreclaimed forests of the north.

Heights of important points.

The following is a list of the heights of some of the more important points in the area. These, with the exception of that of Trembling Mountain, before referred to, have been determined by instrumental levelling, carried out in connection with the construction of the Canadian Pacific, the Montreal and Western, and the Great Northern railways. The datum line adopted is that of the Canadian Pacific Railway, which is 19 feet above the old lock-sill at the entrance of the Lachine Canal in Montreal Harbour. This datum line is 30·61 feet above Steckel's mean level of the Gulf of St. Lawrence. In the following table this correction has been applied, 31 feet being added in each case to the height of the point as given by the railways.

Altitude of various Points on the lines of the Canadian Pacific, the Montreal and Western, and the Great Northern Railways above Steckel's mean level of the Ocean in the Gulf of St. Lawrence:—

Grenville	221	feet.
Lachute	241	"
Ste. Thérèse	126	"
St. Jérôme	314	"
Shawbridge	605	"
Montfort Junction	531	"
Piedmont	555	"
Ste. Adèle	641	"
Ste. Marguerite	911	"
Deep Rock Cut (M. & W. R. R.)	1031	"
Lac la Fourche	1014	"
Ste. Agathe	1243	"
Summit near St. Faustin	1406	"
St. Faustin	1261	"
St. Jovite	711	"
Lake Sam (surface)	750	"
Chute aux Iroquois (rail level)	757	"
Three Sisters' Rapids (low water)	728	"
Trembling Mountain	2380	"
Ste. Sophie	274	"
New Glasgow	367	"
Bank of River Ouareau, 300 feet above the bridge—McLaren's Mills, Grande Ligne	266	"

Archæan Geology.

GENERAL STATEMENT.

General statement.

That portion of the area occupied by the Archæan, is underlain for the most part by a series of gneisses, presenting great variations in both structure and composition, and with which are associated crystalline limestones, quartzites, &c. These belong to the *Grenville Series* of Sir William Logan,* and are of Laurentian age. In certain parts of the area, however, there are great stretches of orthoclase-gneiss much more uniform in character and without limestones and quartzites. These are referable, in some cases at least, to the *Fundamental Gneiss* of Logan, which was by him believed to underlie the Grenville series and to form the basal member of the Laurentian system.

* Geology of Canada, 1863, p. 839.

Breaking through these gneisses and in some cases interbanded or interstratified with them, are several anorthosite masses, by far the largest of these being that which for purposes of convenience may be termed the Morin anorthosite, and which comprises an area of 990 square miles. Two important intrusions of acid rocks, one of granite and the other of syenite also occur in the district.

In the present report the anorthosites are shown to be intrusions, and are separated from the Laurentian proper. The name Laurentian is therefore made to embrace the Fundamental Gneiss, which, although, so far as can be ascertained at present, essentially igneous in origin, may possibly contain some sedimentary material, and the Grenville Series, which is composed of altered sediments associated with much injected igneous matter.

The Laurentian Gneisses and their Associated Rocks.

STRATIGRAPHICAL RELATIONS.

Grenville Series.

The rocks composing the Laurentian in this portion of the Protaxis, usually possess a more or less distinct arrangement in the form of bands, layers or beds which alternate with one another. That a purely objective attitude may be preserved the term band rather than bed will be employed, the latter term being usually associated with the idea of a sedimentary origin which in the present case should not thus be taken for granted.

Banding of the rocks.

This banding is frequently replaced by a foliation caused by the parallel arrangement of the individual grains of the several constituents of the rock, without any distinct arrangement of these latter in bands. In any district where banding and foliation occur together they usually coincide in direction, and are often found in the same rock.

In the eastern portion of the area, in the townships of Joliette, Brandon, Peterborough and Chapleau, as well as in the country to the north of these townships, these Laurentian rocks lie flat or nearly so. Further west, as shown in the sections accompanying the map, a series of low undulations appear, while in the western portion of the area they are thrown into a series of sharp folds with nearly vertical dips, the strike varying in different places from north-east to north-west.

Flat-lying gneisses.

The eastern area of flat-lying gneisses, with occasional intercalated bands of crystalline limestone and quartzite, extends far beyond the limits of the map to the north-east, occupying in this direction a very large district traversed by the River Mattawin, the Rivière du Loup and other smaller streams, which cut their way down these nearly horizontal rocks, and along whose banks, from time to time, as well as in the cliffs bordering many of the little lakes drained by these streams, good sections, often representing a vertical thickness of from two to three hundred feet, are obtained. On the more level surface of the country on the other hand, the rocks exposed are of course comparatively uniform in character. Over this tract of country, embracing an area of at least 750 square miles, the gneisses often lie quite flat, while low dips seldom exceeding 30° everywhere prevail. In several localities the direction of dip varies rapidly from place to place, low undulations in the flat gneisses being observed, running now in one direction and now in another. The whole area gives the impression of a comparatively thin crust, which has rested upon or has been sustained by an underlying molten or fluid mass.

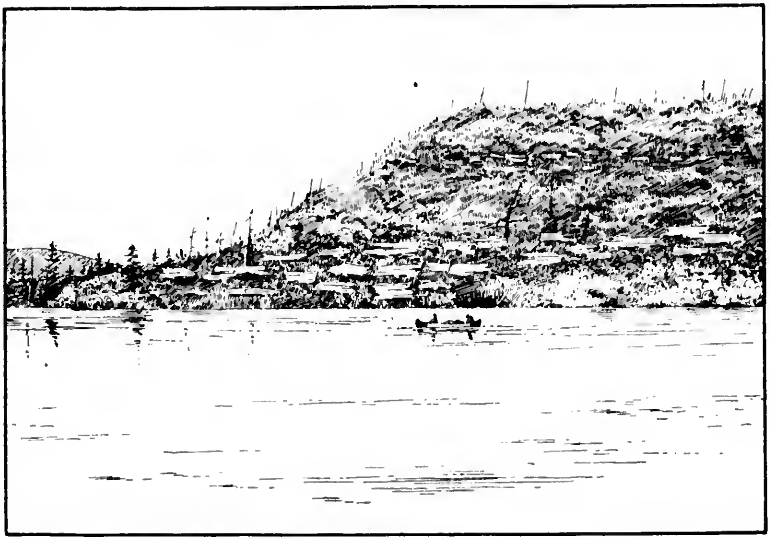

Figure 1.—Horizontal Gneiss, near Cedar Rapids, River Mattawin, Que.

Granite batholite.

That this in all probability was really the case, is shown by the appearance from under the gneisses, in the southern part of this district, of a great area of granite, a portion of which is seen in the north-east corner of the map. This would seem to represent a very extensive batholitic mass of granite underlying the district in question at no very great depth beneath the surface, and here partially exposed by erosion.

PLATE III.—CLIFF OF WHITE GARNETIFEROUS QUARTZITE, INTERSTRATIFIED WITH GARNETIFEROUS AND RUSTY-WEATHERING GNEISS—2 MILES N.W. OF ST. JEAN DE MATHA.

Figu e I. represents a sketch, showing a cliff of these nearly horizontal gneisses just below the Cedar Rapids, on the River Mattawin, about 20 miles beyond the northern limit of the accompanying map.

Plate III. is a photograph of an other cliff, consisting in this case of white garnetiferous quartzite, interbanded with garnetiferous sillimanite gnei ses, within the limits of the map, about 2 miles north-west of St. Jean de Matha.

In the area embraced by the map, limestones have not been found in the Laurentian to the east of Ste. Emilie or Ste. Beatrix, but in the extension of this district to the north beyond the limits of the map, bands of crystalline limestone have been found at a number of widely separated points in the flat-lying gneisses along the River Mattawin and about the head-waters of the Rivière du Loup. At one locality three miles north-west of the Lacroix Rapids, on the Mattawin River, reddish and grayish gneisses with interstratified quartzites occur in horizontal layers with bands of white crystalline limestone, in some places quite pure and elsewhere holding grains of serpentine and scales of mica. At one place, in a cliff by the side of a lake, several limestone bands were observed, one above the other in the same exposure. Three of these had thicknesses of three, four and eight feet, respectively. At another point half a mile distant, two bands of limestone were seen in a similar exposure, the upper being six feet thick, while the lower was exposed for a thickness of twenty feet, the lower limit not being seen. These bands could be traced horizontally in the face of the cliff for a distance of half a mile. Crystalline limestones.

Between Ste. Emilie, Ste. Beatrix and Radstock on the east and the Morin anorthosite on the west, the Laurentian is thrown into a series of folds, which toward the south are overturned, and in this district crystalline limestone is exposed at a number of points. Most of the exposures, however, seem to be parts of a single band repeatedly brought up by the folding, and coinciding in strike with the surrounding gneiss. (See the sections accompanying the map). Some large bands of anorthosite also occur in this district. Toward its southern limit along the edge of the Palæozoic, in the townships of Rawdon and Kildare, the gneiss strikes nearly north-and-south, but going north along the eastern limit of the Morin anorthosite, the strike gradually turns more and more to the west; the gneiss wrapping itself around the anorthosite mass, until at Lac des Iles it strikes N. 75° W. Strike of gneiss conforms to anorthosite boundary.

In the great block of gneiss which extends into the anorthosite from the north, and in which lie the valleys of Lake Archambault, Lake Ouareau and a number of smaller sheets of water, a similar coincidence between the strike of the gneiss and the direction of the anorthosite boundery is observed. North-east of Lake Croche and on the north-east arm of Lake Ouareau the strike averages about N. 20° E., while on the west side of Lake Ouareau north of St. Donat and about Lake Lafronay, which is situated about the middle of the township of Lussier, it averages about N. 55° W. This strike to the east of north is confined to the immediate westerly margin of the anorthosite, as on the north-west of Lake Croche it has already veered around to the west again.

Determines course of streams.

The influence of the strike of the gneiss on the shape and position of the lakes and on the course of the streams is also very marked in this district, being especially well seen as determining the course of the River L'Assomption and the shape of Lac des Iles, Lake Croche, Lake Lafronay and Lake Pembina. Also in the forking of Lake Ouareau, corresponding to a change of strike, in the course of the River Ouareau between Lake Archambault and Lake Ouareau and in the position of Lake Archambault itself.

In the north-west corner of the map the strike of the gneiss continues to follow the outline of the Morin anorthosite mass, being N. 20° E. on the Devil's River, just north of the anorthosite contact, and N. 5° W. in exposures about two miles from the forks of the river, further south in the township of Grandison.

Further south in the township of Wolfe, the gneiss is more masive, so that it is difficult to ascertain the strike, but at Lac Gauthier, on the line between Grandison and Wolfe, it is N. 20° E., still following the line of contact. Over the greater portion of the Augmentation of Mille Isles, further south, there is a general north-easterly strike, which, however, in the vicinity of the Lakefield anorthosite mass, veers around to the north-west, following the course of the mass in question.

Between St. Jérôme and New Glasgow the strike, which is at first north-easterly, swings around to the north as the latter place is approached, while to the east of New Glasgow, a wedge of gneiss striking to the north runs up into the Morin anorthosite for a distance of fifteen miles, splitting it in two just before it disappears beneath the Palæozoic strata of the plains.

Foliation induced by pressure.

In certain parts of the Morin anorthosite mass, as will be explained, a foliation has also been induced by pressure in the anorthosite itself, which can be shown to have been originally a coarse-grained massive rock. This foliation also runs parallel to the limits of the mass, except along its southern boundary about St. Sauveur, where the anorthosite cuts across the gneisses and limestones of the Grenville series, the strike of the foliation being continuous across the boundary from the gneiss into the anorthosite.

It thus becomes evident that, with the one exception just mentioned, the foliation of the gneiss runs around the anorthosite mass, following the windings of the boundary, and that it is not entirely an original structure, in consequence of which the anorthosite mass took its present outline, but it is in part at least secondary, having been caused by the great pressure to which both rocks have been subjected subsequent to the intrusion of the anorthosite mass, which pressure has induced a certain amount of motion in both rocks. This motion has been accompanied by a certain stretching, dragging, or flowing of the gneissic series along the edge of the anorthosite, as seen especially well in the abrupt change in strike of the gneisses along the immediate margin of the anorthosite mass about Lake Croche and to the north-east of Lake Ouareau.

That a stretching of the gneissic series has taken place is also clearly proved in many places where the ordinary quartzose orthoclase-gneiss alternates with bands of dark pyroxene-granulite or amphibolite. In such cases the dark bands are often seen to have been pulled apart, the disconnected pieces being arranged in lines following the strike of the rock, and can be plainly seen by the fact that the ends of adjacent pieces match one another, to have originally formed parts of the same band. The accompanying sketch taken from an exposure on the Cypress River, a short distance beyond the northerly limit of the map, shows this excellently. Here there are large exposures of fine-grained reddish quartz-orthoclase-gneiss, with bands of a dark pyroxene-amphibolite, the whole series being much stretched owing to a great curve or sweep in the strike of the gneisses of this district, whereby they are bent back upon themselves. By this stretching the amphibolite bands have been torn apart as seen in Figure 2, while the quartz-orthoclase-gneiss possessing a certain degree of plasticity, not only stretches, but fills up the spaces between the disconnected fragments of the amphibolite bands.

Stretching of the gneissic series.

Figure 2.—Bands of Pyroxene-Amphibolite in Quartz-Orthoclase-Gneiss, torn apart by the stretching of the series. Cypress River. Scale, 1 inch to two feet.

The same phenomenon has been observed in hundreds of cases, not only in the area at present under consideration, but elsewhere in widely separated parts of the Laurentian. If the pressure is so intense that any member of the series is torn apart, it is always the basic rock which shows itself to be the less plastic, while the highly quartzose rocks accommodate themselves to the strain by plastic movements. Sometimes, however, these basic rocks themselves suffer a very considerable amount of stretching before they break. This stretching can be observed occasionally in the nearly flat gneisses of the eastern part of the district embraced by the map, the fragments here moving apart in a horizontal direction as from a horizontal disrupting force, such as might be exercised if the gneisses had been stretched over the underlying granite batholite, either by a downward pressure due to a great weight of overlying rock, since removed, or by an upward force exerted by the rise of the granite magma.

Tearing apart of basic bands.

In the folded portion of the district further to the sout' west, this tearing apart of the basic bands becomes more marked and very striking and seems to be the invariable rule whenever rocks of this character are associated with quartzose gneisses and the whole series is bent or twisted.

The same phenomenon is very well seen in the case of the thin bands of gneiss, so frequently found interstratified with the limestone bands. Here the limestone under the influence of pressure is the more plastic of the two rocks, and the gneiss, also plastic to a lesser extent, is bent into curiously complicated forms, but when the movements become too great is torn apart into curved and crumpled fragments, which, standing out from the weathered surface, give the rock a very remarkable and characteristic appearance.

Faults.

It may appear somewhat remarkable, in view of the folding to which these rocks have been subjected, that faults are not more numerous. They seem, however, to be rare, although in such areas of contorted crystalline rocks, their existence is not easily determined. Only two were noted, although the existence of others was conjectured. The first of these is at the dam on the River Ouareau, where it flows out of Lake Ouareau. Here, two masses of red orthoclase-gneiss, with interstratified quartzite bands, come together, one set striking N. 10° W. and the other N. 40° E., both having a high south dip. This it will be noted is a portion of the area where the compression of the gneiss must have been especially severe, the ordinary north-westerly strike of the country-rock being changed to a north-easterly strike along the margin of the anorthosite mass. The second fault which was noted is on the road between New Glasgow and St. Calixte de Kilkenny, about six miles in a straight line from the former place, and at the contact between the gneiss and the anorthosite, where a fault probably occupies the bed of the River Achigan, one conspicuous band of gabbro running up to the river and there disappearing.

The fact that these rocks have been folded rather than faulted, does not seem so remarkable when it is remembered that the movements to which they were subjected were brought about when the rocks were deeply buried and hence heavily loaded. Heim has shown folding rather than faulting to be the result of such conditions in the Alps. The fact that the rocks, when subjected to these movements, were in a highly heated condition, as will be shown in treating of the anorthosites, probably contributed to the same result.

Conditions of faulting.

The alternation of the various varieties of orthoclase-gneiss with one another is especially well displayed in the township of Brandon where also there are very numerous and heavy bands of pyroxene-granulite, as well as several bands of anorthosite (p. 126 J) conforming to the general strike. The township, therefore, merits a short, special description.

The first ten ranges are for the most part cleared and settled, while the last two ranges are still largely under forest, the country rising to the north and being there more rugged. Unfortunately much of the south eastern part is heavily drifted so that over considerable areas no exposures can be seen. A striking feature of the eastern part of the township is the beautiful stretch of water known as Lake Maskinongé, with its extensive valley of flat drift extending northward through the 8th and 9th ranges and indicating a much greater extension of the lake in this direction in post-glacial times. Lac Corbeau and Lac Noir have also, as seen in the presence of similar drifted valleys, been much larger sheets of water in former times. The township is traversed by numerous roads which afford means of access to almost every part of it, and owing to the way in which it is laid out, the ranges running north-east and south-west, while the rocks strike north-west, the roads running between the ranges afford a series of lines of section directly across the strike.

In geological structure the township may be divided into two parts, one consisting of the north-west two-thirds and the other of the south-east portion comprising the remaining one-third. The north-west portion is occupied by a flat syncline, the rocks striking north-west, those of the eastern half of the township dipping at low angles, averaging about 25°, to the south-west, while those in the western half dip to the north-east at angles of about 15° (see accompanying section, Fig. 3.) In the two upper ranges, the strata over considerable areas are quite flat, and no dip exceeding 15° was anywhere observed. In addition to the regular north-east and south-west dips above mentioned,

Township of Brandon.

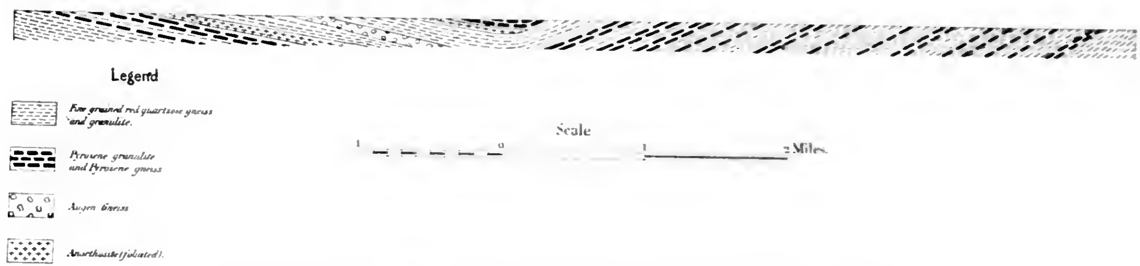

Figure 3. Section across Township of Brandon on line between Ranges VIII. and IX

slight undulations of the strata in the direction of the strike are often seen, so that in isolated exposures dips to the north west or south-east can occasionally be observed.

The rocks occupying this syncline consist of gneisses in great variety, fine grained granulites and leaf-gneisses, augen-gneisses, garnetiferous gneisses of various kinds, with occasional sillimanite-gneisses. Also heavy bands of pyroxene-granulite and pyroxene-amphibolite, with bands of quartzite and three bands of anorthosite. A section across the township along the line between ranges VIII and IX, a distance of eight miles, is seen in Figure 3, and detailed petrographical descriptions of the several rocks are given on pages 38 J, 76 J. These various rocks have the form of distinct bands which are usually sharply defined. No limestone occurs in this township. The rocks, as for instance granulite and pyroxene-granulite, often alternate in bands much too thin to be separately mapped, and the individual masses, even if of large size, frequently pinch out or alter their character in the direction of the strike, and the drifted character of the basin of Lake Maskinongé renders it impossible to ascertain whether the several groups of rocks recognized in the western half of the section reappear in regular order to the east of the synclinal axis. The anorthosites, however, were nowhere observed on this side, which indicates that they are not interstratified layers but rather squeezed out intrusive masses and the exposures which are seen on the eastern half of the section indicate that the rocks here present fewer varieties. It is probable, however, that the fact that certain well-defined bands which appear in the western half of the section do not reappear to the east of the synclinal axis is due to the series being essentially a rolled out complex of igneous masses. Rocks occupying syncline.

The exact thickness of the "strata" represented in this north-west portion of the township is not known, but, as has been mentioned, the country gradually rises to the north, and it was ascertained by direct measurement (aneroid), that starting from the edge of the drift-filled basin of Lake Maskinongé, at lot 6 on the concession line between ranges IX. and X., and going north to a point about the middle of lot 1 of range XII., the ascent is made over 540 feet of nearly horizontal strata; if the average dip of these be taken at 15° this alone would represent a thickness of 522 feet.

The evidence here, as in other parts of the area where the gneisses are approximately horizontal, goes to show that although the bands are not flexed and contorted they have been subject to great vertical compression. The various rocks are quite as highly crystalline as in the more contorted districts, the anorthosites show evidence of very great crushing since they were injected, and the gneisses themselves under the microscope show very marked cataclastic structure.

Granite mass

The south-east portion of the township is quite different in structure At the extreme south-east corner is a small area occupied by a portion of the great granite mass which occurs along the eastern side of the sheet. It is coarse in grain and sometimes possesses an indistinct foliation.

Limiting this granite on the west is a band of fine-grained granite about a mile and a half wide. It is quartzose and reddish in colour, almost free from mica or other iron-magnesia silicates, and nearly uniform in grain and composition.

In many places one can observe little local irregularities in grain such as are often seen in granite apophyses, and it frequently holds large orthoclase phenocrysts like the coarse granite to the east. In many places an indistinct foliation can be seen, and it often holds little strings and sometimes apparent fragments of white quartzite and of a dark basic rock, usually coinciding in direction with the indistinct foliation above mentioned, which is about N. 5° W. and parallel to the limit of the coarse-grained granite. This fine-grained granite is apparently a contact phase of the coarse granite, the transition, however, being very rapid, since on lot 1 of range III. the two can be seen within a few yards of one another. An actual contact or passage between them was nowhere observed. The western limit of this fine-grained granite, on the line between ranges I. and II., is about the east half of lot 8. To the west of this the fine-grained granite is succeeded in the following lot by a well-banded grayish gneiss, striking N. 10° W. and dipping to the east at an angle of 65°. In this area are many dykes, veins or bands of granite, often very coarsely grained as is so generally the case in pegmatite apophyses, sometimes running parallel to the banding of the gneiss and elsewhere across it and anastomosing with one another. This gneiss is exposed at frequent intervals along the road for a distance of rather over three miles from the fine-grained granite, but is usually reddish in colour and holds bands of quartzose and hornblendic gneiss, frequently broken up into fragments, which, although in many cases evidently having formed parts of the same band, now lie in the reddish gneiss separated from one another. This reddish gneiss in many places resembles the fine-grained granite and is almost free from iron-magnesia minerals. The strike of the gneiss varies very much in different places, and even in the same exposure. It, however, always dips in an easterly direction or towards the granite, and always at very high angles of from 65° to vertical. From the last exposure of the gneiss on lot 17 to the western limit of the township, there are no other exposures, the country being heavily drifted.

In the south-east corner of the township, therefore, we have the edge of a great mass of granite flanked by a band of much finer grained granite, and beyond this a series of highly tilted gneisses, which have been much disturbed, and penetrated by granite veins or dykes apparently apophyses from the main mass, the series being entirely different both in character and attitude from the well-banded gneisses of the flat syncline occupying the north-western portion of the township. Between these two areas the township is under heavy drift, so that the actual relation of the two sets of gneisses to one another is obscured. It would seem, however, that they must be separated by some stratigraphical break, either a fault or an unconformity. It may be noted that if a line be drawn from the most westerly exposure of these south-eastern gneisses, on lot 17, to the northern point of Lake Maskinongé, it will divide the two series from one another, and such a line would also run nearly parallel to the limits of the granite mass.

The north-western gneisses belong to the Grenville series; whether the south-eastern gneisses should be referred to the "fundamental gneiss" or not is uncertain.

Among the most important constituents of the Grenville series, not so much on account of their volume as owing to their economic value and the genetic considerations attached to them, as well as to the aid which they afford in working out the stratigraphical relations of the series, are the crystalline limestones. The existence of bands of crystalline limestone in the flat-lying gneisses, beyond the north-eastern limit of the map, has already been referred to, but within the area embraced by the map, although not observed in the nearly horizontal gneisses of the north-eastern district, crystalline limestone is repeatedly exposed elsewhere, as will be seen by consulting the map, being brought up by the folding of the gneisses in the more contorted parts of the area. Crystalline limestones.

The south-western portion of the area embraced by the map, as has already been mentioned, was included in a "Map Showing the Distribution of the Laurentian Rocks in Parts of the Counties of Ottawa, Terrebonne, Argenteuil and Two Mountains," by Sir William Logan, published in the Atlas accompanying the "Geology of Canada," which appeared in 1865. In the map accompanying the present Report, the distribution of the limestones in Montcalm, In south-western portion of area.

Morin, the Augmentation of Mille Isles, and in the district to the south-west has been taken from this map. In the area worked out by Logan, which, howe.., c, lay principally beyond the western limits of the present map, he believed that the existence of either three or f ar distinct limestone bands of considerable size, at widely separated horizons, could be established with tolerable certainty. Dr. Ells, however, who has recently re-examined this district, and whose report will appear shortly, doubts the correctness of these views, and believes that the limestones are concentrated towards the summit of the series. The character and distribution of the limestones in this portion of the area being described in the reports of Logan and Ells, need not here be further referred to.

In the north-west corner of the area, the Laurentian is represented by reddish and gray gneisses, often rich in quartz and well foliated, which on the Devil's River are occasionally garnetiferous and associated with quartzites. This district is a good deal drift-covered, and no crystalline limestone was observed in place, but a large angular block of this rock found by the side of the Devil's River, about the northern limit of the map, indicates that bands of this rock do occur here associated with the gneiss.

Crystalline limestone of Trembling Lake.

A heavy band of limestone runs through Trembling Lake, which lies immediately west of Trembling Mountain, being exposed on the islands in the lake as well as at its outlet. Crystalline limestone is also exposed at several points in the vicinity of St. Jovite, in the township of De Salaberry, but the heavy drift which mantles this portion of the country renders it impossible to ascertain the extent and distribution of the rock.

In that portion of the district to the east of the Morin anorthosite, it was also believed at first that some five or six different bands of limestone existed, but the result of a detailed study goes to show that the three principal bands at least are probably repetitions of one and the same horizon, being related to one another as shown in the sections accompanying the map.

The course of the several lines of outcrop of these eastern limestones may be briefly indicated.

Crystalline limestone near St. Jérôme.

There is firs. a small and comparatively unimportant occurrence on the west side of the North River, near St. Jérôme. Exposures of the limestone are seen crossing the road, and blocks of it may be found at intervals in the fields to the south of the road. Logan states that it can be traced for about a mile and a half, running in a direction

N. 12° E. Although the surrounding country was carefully examined, no actual exposures of this limestone could be found, except those above-mentioned. In the direction of its strike to the south, it would cross the North River and be covered up by the Cambro-Silurian rocks within the next half mile. It does not appear on the banks of the river, however, neither could any continuation of it be found to the north.

Near New Glasgow.

A more important occurrence of limestone, although still comparatively thin and impure, is found a short distance to the west of the village of New Glasgow, being exposed in the bed of the River Jordan and near the Cambro-Silurian contact. From this point it can be traced in a direction a little east of north, skirting along the edge of the great anorthosite arm, as far as range III. of Kilkenny, a distance of about six miles, where it is lost sight of.

An isolated exposure of a pure white crystalline limestone occurs on lot 10, range VII., of Kilkenny, where it forms a low ridge about a hundred yards wide. This, however, is probably distinct from the New Glasgow band, which, if it holds its course as above described, would be cut off by the anorthosite a short distance to the north of the point where it is last exposed. It certainly is cut off by the anorthosite eventually, for the latter on the north passes across the strike of the gneissic series. What may be a continuation of this same limestone band, however, appears on the other side of the anorthosite mass, at Lake Ouareau. The most northerly point at which the limestone is here exposed, is a slight elevation rising above the drift on the Couture Road, on lot 20, range II., of Lussier. Following the prevailing strike, it appears again to the south-east, in Lake Ouareau, forming a series of little islands, which lie along the west shore of the lake. On one of these, which is composed exclusively of white crystalline limestone, with many little inclusions of gneiss produced by the tearing apart of narrow bands in the manner already described, the strike is about N. 75° W., and the limestone is exposed for a width of 275 yards across the strike. This is not the whole width of the band as the exposure is bounded by the waters of the lake on either side. The band then appears on the east shore of the lake, near its southern extremity, where it has a width of about 200 yards. The southern portion of the lake is, in fact, excavated in a band of limestone, interstratified with white quartzite and certain gneisses which are almost invariably found associated with the limestones, which band, being very near the border of the anorthosite mass is, at many places all about the lake, invaded by and mixed up with anorthosite, which is

At Lake Ouareau.

often intruded parallel to the foliation of the gneiss, and often has a more or less distinct foliation accompanied by excellent cataclastic structure (section 370). The fact that it was possible to point out the existence of limestone in this remote district was of considerable importance to the settlers there, who had been obliged previously to haul all their lime from St. Jérôme, a distance of forty miles over rough roads.

The strike, wherever this can be observed, indicates a sharp bending of the strata back upon themselves at the southern portion of the lake, corresponding to the outline of the lake. The foliation is probably largely a secondary one, induced by pressure, as shown by the fact that it is shared by the intruded anorthosite. The limestone with its associated gneisses is limited on three sides by the anorthosite, and here again is evidently cut off by it.

Crystalline limestone in Cathcart.

A second limestone band occurring to the east of the Morin anorthosite, is seen in the bed of the Black River, on the line between ranges VIII. and IX. of the township of Rawdon; then in large exposures on ranges IX., X. and XI. of the same township, crossing into ranges III. and IV. of the Augmentation of Kildare, on the western corner of that township. Going still further north, it is seen on lot 11 of range IV. of Cathcart, crossing range VII. of Cathcart and running under a little lake on range VIII., appears again near St. Come, and is then exposed on lots 27 and 28 of the last range of the township of Cathcart. To the north of this point the country is unsettled, and covered with a dense growth of forest, so that the continuous tracing out of a small band of limestone is impossible. Continuing on the same strike, however, limestone was observed on the front of lot 28 of range II. of Cartier, on the line between II. and III. of Cartier, also about lot 28, and then at two points on two little lakes lying a short distance to the east of Lac des Ilets on the stream issuing from that lake. Limestone was also observed protruding through the drift by the shore of the River L'Assomption, about four miles from Lake L'Assomption. It is here exposed for a width of fifteen feet across the strike, but the limit of the band is seen only on one side, the water concealing its contact with the gneisses on the other. The petrographical character of this limestone is described on page 66 J. This occurrence, however, is not on the same strike and may not belong to the band above described.

It was impossible to follow this band with certainty in its southerly extension. This is owing to the fact that the southern part of the township of Rawdon is heavily drift-covered, comparatively little rock being exposed. Mr. Carlyle carefully examined the River Ouareau, from Rawdon to the Cambro-Silurian contact, and was unable to find any limestone. Above the village, the river runs through drift, until the exposure of anorthosite at the upper bridge is reached. Small exposures of the limestone were, however, found protruding through the drift, on range IV. of Rawdon, about lot 13, which may possibly mark a continuation of the band in this direction, but if so, the limestone band is greatly diminished in size to the south.

This band, which may be called the Rawdon band, is most extensively exposed on range IX. of Rawdon, and in the vicinity of St. Come. At the former locality, several years ago, it was extensively burned for lime, and at the latter place it is now being burned at two different points. Rawdon band.

A noteworthy fact in connection with this limestone band, is that it occupies the summit of an anticline, the dip being from it on either side.

A third band is seen in considerable exposures about a mile and a half west of St. Alphonse, on range I. of Cathcart, where it is burned for lime, and to the south on the adjoining range of the Augmentation of Kildare. It is then seen near the road, about lot 38 of range VI. of Cathcart, and then at a number of places lying in a direction west of north from the last exposure and running through ranges VII., VIII. and IX. of the same township, it passes into the forest covered township of Tracy.

The fourth band is thin and impure. A few exposures about a mile to the south-west of St. Ambroise de Kildare may probably be referred to it, but it is well exposed first, on range VII. of Kildare, near the cheese factory, then about the rear of this township, then in the village of Ste. Beatrix, and again about a mile further north, at the bend of the River L'Assomption. Then in the Seigniory of the D'Aillebout, about three miles south of Ste. Emilie, and again on the Mattawin road, about the line between ranges III. and IV. of Joliette.

A fifth band, still further to the east, is exposed on lot 2, of range VII. of Kildare, and is then covered with drift until it reappears about three miles further north, in D'Argenteuil, at a point one mile east of the town-line of Kildare. Crystalline limestone in Kildare.

These several bands, together with those described in the south-eastern portion of the area by Sir William Logan, embrace all the limestones which occur in it, with the exception of four small isolated occurrences. The first of these has been already mentioned, and is Other occurrences.

situated on lot 10 of range VII. of Kilkenny. The second was found on lot 22 of range IX. of Rawdon. It is about twenty feet wide, and is associated with a band of nearly pure, coarsely-granular, pyroxene rock, which is described on page 85 J. Its mode of occurrence is that of a lenticular mass. The third is on lot 20 of range V. of Rawdon. The fourth occurrence is found near the line between lots 8 and 9 of range VI. of Cathcart. This has been opened as a marble quarry, and partakes rather of the nature of a vein deposit. It is described on page 152 J, in the section treating of the Economic Geology of the district.

Continuity of the limestone

The question as to whether the Laurentian limestones form continuous bands or are merely a series of disconnected lenticular masses has been frequently discussed. Their softness and the ease with which they are eroded makes these limestones appear less continuous than they really are, for glacial and pre-glacial decay and erosion acted far more vigorously on the limestone bands and the strata immediately associated with them than on the harder gneiss of the series, and as a result the former almost invariably occupy depressions, and very frequently river-valleys or lake beds. In such places, of course, the drift is thickest and most persistent. When, therefore, the strata underlying such a drifted area are contorted and only protrude at intervals through the gneiss, or even when they are not contorted but exposed only at considerable intervals, it becomes a matter of great difficulty to decide whether the occurrences of limestone form a continuous band of limestone or a series of disconnected patches. It becomes, however, necessary in this connection to define what is meant by the term "limestone band." Pure crystalline limestone or marble, ten, twenty to sometimes 100 or more feet in thickness, is often found, but in the majority of cases the bands consist of the limestone interstratified with many thin bands of gneiss. This was true of all the limestone bands described by Sir William Logan in the "Geology of Canada," the gneiss often constituting half or more than half of the whole thickness. When by squeezing or stretching these gneiss bands have been torn apart or pulled out into fragments, the gneiss and limestone become irregularly mingled together; subordinate masses of limestone may disappear along the strike and gneiss may come in, to be succeeded again by limestones. The limestone also being very plastic under pressure, the relative amounts of the two rocks may vary in different parts of the band.

The band as a whole may thus be continuous for a long distance, while its individual component masses may and do thin out, disappear, and become succeeded by others. It is thus by no means uncommon to find a limestone band which, at one part of its course, is represented by a thick development of nearly pure limestone, further on represented by a number of thin layers of limestone interstratified with bands of gneiss. A limestone band thus becomes a certain horizon more or less thick in which limestone is abundant, while it is absent from the rocks on either side.

Accepting the term "limestone band" in this sense, investigations in this area go to show that when the country is favourable for study, limestone bands are found to be continuous for long distances following the strike of the associated rocks, and that they are at least as continuous as the bands of any other kind of rock making up the series. But, as before mentioned, their very nature causes them to be more easily hidden or drift-covered, than the bands of the harder associated rocks, and they are thus sometimes apparently less continuous than these.

There is reason to believe that the limestone bands sometimes act as lines of least resistance along which motion is especially pronounced under the differential strains incident to folding. An excellent example of this, on a small scale, was seen in an exposure about one mile south-east of a point two miles below the Ox-bow Rapids, on the River Mattawin, in the region of flat-lying gneisses beyond the northern limit of the map. Here the gneiss is usually medium in grain and is to all appearance as well bedded as any sedimentary series. Several little bands of crystalline limestone, from a few inches to two feet in thickness, together with a few small bands of quartzite, are interstratified with the gneiss. An excellent section is presented in the cliff by the side of a little brook, and the effects of a thrust in a direction parallel to the bedding, consequent on the stretching to which the rocks in this district have been subjected, is well displayed. The upper beds can be plainly seen to have moved for a few feet over the lower beds, along the plane of a thin limestone band, which, with its interstratified gneiss layers, is quite undisturbed in the northern end of the section, while further south it has been broken off, folded on itself, and puckered up in a most complicated manner by the horizontal motion. Movements along limestone bands.

The thickest body of limestone exposed in the area is probably that on the islands of Lake Ouareau, which, as above mentioned, has a width 275 yards across the strike, with neither wall seen. The largest occurrence of pure limestone, unmixed with gneiss, uncontorted and dipping regularly, so that its true thickness can be ascertained, is a portion of the Rawdon band, on lots 27 and 28 of range X. of Raw- Thickest body of limestone.

don, in the valley of a branch of the River Rouge. Hills of gneiss rise on either side of the river at this point, those to the west also holding some limestone, and between them is a nearly level interval through which the river runs. This strip or interval is 225 yards wide, and is in all probability entirely occupied by the limestone band, which, in that case, would here be about double its ordinary thickness, as it is bent back on itself, occupying, as it does, the summit of an anticline (see Section No. 1, on the map). Over the greater part of the flat valley-bottom, however, the underlying rock is concealed by drift, but on the east of the river coarsely crystalline limestone, for the most part nearly pure but in some places rich in serpentine, lying in regular beds or bands striking N. 20° W. and dipping to the east at an angle of about 60°, is exposed for a width of 155 feet across the strike. This would give as a minimum an actual thickness of limestone unmixed with gneiss of 134 feet, while the thickness is probably much greater.

The petrographical character of this limestone is described on page 65 J.

Fundamental Gneiss.

Fundamental gneiss.

Trembling Mountain (Plate II.), which was taken by Sir William Logan as the typical development of the Fundamental Gneiss, is composed of a fine-grained, pale red, orthoclase-gneiss, with a foliation which is generally distinct and with occasional bands differing slightly in character or coarseness of grain. It contains a very few thin bands of a nearly black pyroxene-amphibolite. The petrographical character of these rocks will be considered in detail on pages 42 J, 77 J, where it will be shown that the gneiss is really a crushed or granulated granite. The mountain is flanked on the south-west by the limestones and their associated sedimentary gneisses, of the Grenville series, occupying the greater part of the bed of Trembling Lake, and described on page 49 J.

In the south-western portion of the map, to the west of the great Morin anorthosite, considerable masses of more or less indistinctly foliated gneiss, without banding and often passing into augen-gneiss, are seen. These are also in great part crushed igneous rocks, and may be intrusive, but on account of the folding and squeezing to which the district has been subjected, it is difficult to separate them from the limestone-bearing series.

Along the southern portion of the township of Brandon also, as has been mentioned, there occurs a somewhat similar set of gneisses quite distinct in character and attitude from those in the northern portion of the same township (p. 20 J.)

Whether all these gneisses really form a portion of a floor on which the Grenville series was deposited, since brought up by folding and erosion, and thus entitled to the appellation "fundamental gneiss," or whether they are intrusive masses, foliated by the pressure to which the whole region has been submitted, cannot be determined.

Acid Intrusions.

Two large and important intrusions of acid plutonic rock break through the gneisses, one in the south-western and the other in the north-eastern corner of the area. The former, which was examined many years ago by Sir William Logan, is referred to by him as follows:—"This mass of intrusive syenite occupies an area of about thirty-six square miles in the townships of Grenville, Chatham and Wentworth. In its lithological character the rock is very uniform, being composed for the most part of orthoclase, either of some tinge of flesh-red or a dull white with black hornblende and a rather sparing quantity of grayish vitreous quartz. The red tinge prevails more on the west side, the white on the east. In the spur which runs into Wentworth, mica is occasionally found accompanying the hornblende. The rock is rather coarse-grained in the main body, but dykes of it are sometimes observed cutting the limestone and gneiss, in which the grain is finer. These have not been traced as yet to any great distance from the nucleus."*

Intrusive syenite.

The granite occurring in the north-east corner of the map occupies a much larger area, but the mass lies for the most part outside the limits of the sheet. It is very coarse in grain, red in colour, and usually contains but little quartz and iron-magnesia constituents. The orthoclase usually occurs in very large individuals giving a porphyritic appearance to the rock, while in certain parts of the area, and especially towards the outer limits of the mass, the rock takes the form of a well defined augen-gneiss. This variety is well seen about St. Didace, where a microscopical examination shows that some of the augen are plagioclase and that the iron-magnesia constituent is biotite (section 357). The felspar augen, both in the massive and gneissic varieties, usually have an approximation to a good crystalline form.

The relation of this granite to the gneissic series in the township of Brandon, has already been described (p. 20 J). Mr. R. G. McConnell who mapped a portion of it in 1880, refers to it as cutting off the gneissic series at one point where the direct contact could be seen.†

Granite of St. Didace.

* Geology of Canada, 1863, p. 39.

† Report of Progress, Geol. Surv. Can., 1879-80, p. 5.

In the district south-east of St. Didace, the granite also appears to break through the gneiss. An examination of that district shows that at the junction there is a zone of rocks which have been much crushed and twisted and which show no distinct strike, while the strike of the gneiss beyond this zone follows the line of contact, the gneiss, however, having been apparently submitted to great pressure, as if shoved against the granite and forced or dragged along its edge. The granite beyond the eastern limit of the sheet is cut by a small area of anorthosite, so that if the anorthosite intrusions within the map are of the same age, the granite was intruded before them.

On the upturned edges of these deeply eroded Archaean rocks, with their anorthosite and granite intrusions, the Potsdam sandstone and succeeding Cambro-Silurian rocks repose in flat undisturbed beds. At some points along the edge of the Protaxis, as at St. Canute, to the west of St. Jérôme, and on the River L'Assomption, the Potsdam sandstone is observed resting on the gneiss, while elsewhere the strata in closest proximity to the gneiss consists of a magnesian limestone, probably Calciferous in age, as to the south of St. Jérôme, or of a highly fossiliferous limestone of Trenton age, as between New Glasgow and Ste. Julienne.

Palaeozoic outlier.

An outlier of those Palaeozoic rocks, almost circular in form and about two miles in diameter, occurs about nine miles north of the edge of the Protaxis, on ranges III. and IV. of the township of Abercrombie, showing that the Palaeozoic covering once extended at least as far north as this.

These strata cover up the gneisses, anorthosites and granites alike, and are evidently of much more recent age, being separated from the Laurentian and its associates by a long interval occupied in the upheaval and erosion of the Laurentian area.

How long before Upper Cambrian time this folding and erosion took place cannot be determined from a study of this area, but further west along the edge of the Protaxis in the Lake Superior district, we find that the Keweenawan and Animikie series also repose in flat undisturbed beds on the eroded remnants of a series of crystalline rocks which have the petrographical character of the fundamental gneiss. This makes it at least very probable that in this eastern area also, the erosion took place in pre-Cambrian times.

Pre-Cambrian erosion.

It is a very remarkable fact that the roche moutonnée character possessed by the eroded Laurentian rocks and which is usually attributed to the glaciation undergone by them in the Pleistocene, was really impressed upon them in the first instance in these pre-Cambrian times, for all along the edge of the nucleus from Lake Superior to the Saguenay, the Palæozoic strata, often in little patches, can be seen to overlie and cover up a mammillated and roche moutonnée surface showing no traces of decay and similar to that exposed over the uncovered part of the area. The conclusion therefore seems inevitable that not only were these Laurentian rocks sharply folded and subjected to enormous erosion, but that they had given to them in pre-Cambrian times their peculiar hummocky contours so suggestive of ice action.* The pre-Palæozoic surface of the fundamental gneiss of Scotland, as Sir Archibald Geikie has shown, also presents the same hummocky character.†

Petrography.

The Laurentian of this area consists of orthoclase-gneiss in almost endless variety, alternating or interstratified with pyroxene-gneisses, amphibolites, crystalline limestones, quartzites, garnet rocks, etc., which also present a great variety of forms and are connected by many transitional members. Thus bands of quartzite, while usually forming well defined stratigraphical units, frequently hold more or less orthoclase, and thus pass into quartzose gneisses, or crystalline limestones in certain places become very impure owing to the presence of various silicates, and might thus be classed as calcareous gneisses, and so on. Orthoclase gneiss.

The orthoclase-gneisses preponderate largely and might, if the crystalline schists were classified in the same detail as intrusive masses, be separated into a number of petrographical species, each with its distinctive name, representing the mineralogical equivalents, not only of the granites and syenites, but also of all the various transitional forms standing between these and the gabbros and diorites, which latter find their equivalents in the true plagioclase-gneisses and amphibolites. The one essential character of the gneisses is the possession of a certain banding or foliation, which on one hand may and often is as well pronounced as the lamination in any sedimentary rock or, on the other hand, may be so indistinct that its existence can only be detected by the examination of large weathered surfaces.

It is not, however, advisable in all cases to attempt to separate, classify and map these numerous varieties of gneiss, owing to the fact that they occur in smaller masses and are much more intimately associated with one another than is the case with their intrusive equivalents. Mineralogical varieties.

* A. C. Lawson,—Notes on the pre-Palæozoic surface of the Archæan Terranes of Canada—Bull. Geol. Soc. Am., vol. I., 1890.

† A Fragment of Primeval Europe—Nature, Aug. 26, 1888.

The classification of these gneisses is further complicated by the fact that each mineralogical variety may present great and important diversities of structure in different places.

Rocks of the Laurentian.

From a mineralogical standpoint, the rocks of the Laurentian in this region might be arranged in the following classes: –

Gneisses—

Quartz-Orthoclase-Gneiss (Granulite in part) Quartz-Orthoclase-Biotite-Gneiss. Quartz-Orthoclase-Hornblende-Gneiss.	Granite-Gneiss, or when poor in quartz or free from that constituent Syenite-Gneiss.	
Orthoclase-Plagioclase-Hornblende-Gneiss.	Syenitic-Diorite-Gneiss.	
Orthoclase-Plagioclase-Pyroxene-Gneiss.	Syenite-Gabbro Gneiss	Pyroxene granulite in part.
Plagioclase-Pyroxene-Hornblende-Gneiss.	Gabbro Diorite-Gneiss	
Plagioclase-Pyroxene-Gneiss.	Gabbro Gneiss.	
Plagioclase-Hornblende-Gneiss.	Diorite-Gneiss (Amphibolite in part).	
Garnet-Sillimanite-Gneiss. Orthoclase-Scapolite-Pyroxene-Gneiss, &c.	No mineralogical equivalent in the igneous series.	

Quartzite.

Garnet Rock.

Pyroxene Rock.

Crystalline Limestone.

The gneisses, especially in the basic varieties, are often rich in garnets, pink or red in colour, and frequently of large size. Such garnetiferous gneisses are an important element in many parts of the series, and especially in the vicinity of the limestone bands. Many of the plagioclase-pyroxene-gneisses are of course closely related to the foliated anorthosites. Muscovite is seldom or never found, while in the pyroxene-gneisses, rhombic as well as monoclinic pyroxenes frequently occur. In addition to the certain constituents of the gneisses, as given in the above table, accessary constituents are frequently present, although these are neither abundant nor numerous. Of these accessary constituents the most important are, magnetite, ilmenite, pyrite, apatite, zircon, rutile, graphite, tourmaline, orthite, monazite and spinel. In some parts of the district the gneiss over large areas is very uniform and regular in structure and composition. This is especially true in those areas which may be referred to the lower or fundamental gneiss. Elsewhere, there is a great variation in composition and character in different bands within comparatively limited areas. This is particularly marked in the vicinity of the limestone bands, where the gneisses are usually garnetiferous and more frequently contain sillimanite, graphite, rutile, pyrite and other accessary minerals.

A peculiar, very rusty-weathering gneiss usually, rather fine-grained and often nearly white on the fresh fracture, seldom occurs except in association with the limestone bands, and it is the exception to find crystalline limestone unaccompanied by this gneiss. It occurs not only in many parts of the area at present under discussion, but in every other part of Canada and the United States where the Grenville series with its characteristic limestones is found. It is especially well developed in central Ontario* and about Port Henry in the State of New York.

Rusty weathering gneiss.

The quartzite, often garnetiferous, also occurs, chiefly in association with the limestones.

A noticeable feature in those Laurentian gneisses which have quartz and orthoclase as the chief constituents, is the small proportion of iron-magnesia minerals which they contain. It is rare to find such a gneiss rich in these constituents, and very frequently they are entirely absent. On the whole, hornblende is more common than biotite.

The colour of the ordinary gneiss on a fresh fracture is reddish or grayish. The more basic varieties are dark-gray or even brown in colour, while in the acid gneisses, reddish and light-gray tints prevail. The gneisses weather white, gray, reddish, or brown, according to their composition. They are occasionally very coarse-grained, especially in the case of the augen gneisses, which sometimes hold masses of felspar, an inch or more in diameter. They are generally however medium in grain, often fine-grained, but seldom so fine that the chief constituents cannot be distinguished by the unaided eye, especially when the weathered surface is examined.

As has been stated above, the distinctive characteristic of all these gneisses is the possession of a more or less decided foliation or banded structure. By foliation is understood a laminated structure, produced in a rock by the parallel arrangement of certain or all of its constituent minerals. Thus a granite would become foliated if all the little biotite individuals were caused to assume a parallel position, and the foliation would become still more pronounced if the other constituents were also arranged in parallel strings. By banding is understood the alternation in the form of bands, of gneisses differing more or less in composition or structure, which gneisses may or may not be foliated as well. The origin of this foliated or banded structure in the case of the Archaean is one of the most difficult problems presented in the study of these ancient rocks. It was formerly supposed to represent the

Foliation and banding.

*F. D. Adams,—Report on the Geology of a portion of Central Ontario, Annual Report, Geol. Surv. Can., Vol. VI. (N.S.), 1892-93.

remains of an original bedding, due to sedimentation, but now almost obliterated, the gneiss thus being comparable to certain indistinctly foliated rocks found in contact zones about great eruptive masses of granite. In recent years, however, the study by many able investigators* of the effects produced in rocks when deeply buried in the earth's crust and subjected to great pressure during the process of mountain making, have clearly shown that perfectly foliated rocks may be and are produced from massive igneous rocks, by such processes, so that the existence of a foliated structure in a rock can no longer be regarded as evidence of sedimentary origin. Any rock when subjected to deformation under the influence of pressure, will tend to assume a foliated character. If these movements have been very pronounced, the foliation will be correspondingly distinct; while, if the pressure has acted on a complicated series of rocks of diverse character, as for instance igneous and sedimentary rocks penetrated by later intrusions, or on a great body of igneous rock which has undergone magmatic differentiation, a petrographical series composed of alternating bands of very different varieties of gneissic rocks may result.

Its origin.

The great irregularities in composition which of recent years have been shown to exist in many large eruptive masses, make the intimate association of different varieties of gneiss, and their passage into one another, much more intelligible than formerly, since such associations and gradual transitions would certainly be presented in any gneissic series formed by the squeezing or stretching of differentiated masses of this kind. Thus, in several districts of ancient crystalline rocks which in recent years have been made the subject of very careful study, as for instance the granulite region of Saxony and the southern portion of the Grand Duchy of Baden, a great weight of evidence has been accumulated which goes to show that certain rocks which have been classed as Archaean gneisses or schists are altered sedimentary rocks, while other gneisses in the same districts can be shown to be squeezed or crushed rocks of igneous origin.

Altered sediments.

Crushed igneous rocks.

The separation and recognition of these two classes of rocks will probably become more easy and certain as investigation advances, but it remains to be ascertained whether it will be possible eventually to bring all gneisses under one or other of these two heads.

* A. Heim.—Geologie der Hochalpen zwischen Reuss und Rhein.-Beiträge zur Geol. Karte der Schweiz. vol. XXV. Bern, 1891.

C. Schmidt.—Beiträge zur Kenntniss der auftretenden Gesteine. *Ib.*

B. Milch.—Beiträge zur Kenntniss des Verrucano. Erster Theil. Leipzig, 1892, and many others.

The criteria for the determination of gneisses which consist of metamorphosed sediments are not as yet thoroughly worked out, but the following are three lines of evidence by which it would seem that such rocks may be recognized :—

Criteria for discrimination.

1. Their Chemical Composition.—Modern investigation goes to show more and more clearly that in their composition igneous rocks do not present and exhaust all possible combinations of silica with the common bases present in them. Certain combinations of silica and bases are found in igneous rocks; others are not. Igneous rocks, furthermore, do not commonly occur indiscriminately associated with one another, but are found in certain family groups, constituting what are known as "petrographical provinces." If therefore, certain gneisses forming thick, well defined bands in any district of crystalline rocks, have a composition which is not that of any igneous rock but which is identical with that of the ordinary sediment laid down in the present seas, this is a strong argument in favour of the sedimentary origin of the gneiss in question. In the case of granitic rocks undergoing atmospheric disintegration, the chemical processes at work consist chiefly of the partial removal of the alkalies with a certain amount of the silica and a portion of the lime, the rock at the same time taking up a certain amount of water. If the rock becomes thoroughly decomposed, as in the case of the decomposed granites from which china-clay, a material almost free from alkali, is obtained (but in the great majority of cases the decomposition is not so complete), the partial decomposition serves to disintegrate the rock, which, falling to a loose, earthy mass, may then be washed away, and eventually deposited as sediment. If the chemical action has been but slight, an arkose may in this way be produced which will differ but little from the original granite. If, on the other hand, the decomposition, although not complete, is well advanced, a fine mixture of sand and clay will result, which will be distinctly different in composition from the original granite.

By chemical composition.

This mixture, speaking generally, will be richer in alumina and poorer in alkalis than the granite, and will contain proportionately more magnesia and less lime than the original rock ; and, although granites differing in composition necessarily yield products having corresponding differences, yet when these chemical changes have gone beyond a certain point, a decomposition product results which possesses a composition distinctly different from that of any igneous rock, and the most intense baking or re-crystallization cannot again produce a granite from it. If, therefore, gneisses were produced by the metamorphism of such granitic decomposition products, it might not be possible, from their composition, to recognize them as altered sediments in all or perhaps even in the majority of cases, but in certain instances it would be possible.

Then again, the composition of certain other rocks, such as quartzites and crystalline limestones, mark them as of aqueous origin. Such rocks, if their mode of occurrence precludes the possibility of their being of the nature of vein deposits or residual products, must be altered sediments, as sedimentation is the only other process with which we are acquainted by which such rocks are produced.

Again, the presence of free carbon in the form of graphite or any graphitic mineral, disseminated through a gneiss or schist, points to a sedimentary origin, as such substances do not occur in igneous rocks.

If several of these indications of a sedimentary origin are combined in the same series of rocks, as, for instance, if bands of limestone are found interstratified with bands of quartzite and with a gneiss having the composition of a shale, some or all of the bands holding graphite, the evidence of a sedimentary origin becomes proportionately stronger.

By resemblance to contact rocks.

2. *The Resemblance of such Gneisses to the Metamorphosed Rocks of Contact Zones.*—Undoubted sedimentary rocks, such as shales or slates, are in many cases invaded by great bodies of molten granite, which bring about certain alterations in these sedimentary rocks, which alterations consist essentially of a re-crystallization of the sediment. This re-crystallization becomes progressively more complete as the contact with the granite is approached, until immediately along the contact a so-called hornstone is produced. This hornstone, as the name implies, is usually fine in grain, but in other cases, as in the Granulite region of Saxony, the most altered portion of the shale is represented by a coarsely crystalline rock resembling a gneiss, through which there runs an immense number of little strings and streaks of the granite. These products of intense metamorphism, although consisting essentially of quartz, biotite, muscovite, felspar and other minerals found in granite rocks, have these minerals arranged in quite a different manner, giving rise, especially in the case of the finer grained varieties, to what is known as a hornstone structure; while certain other minerals not found in granitic rocks but characteristic of these contact zones also occur in them. If, therefore, in any gneissic series, certain rocks are found which present the spotted and other structures of the less altered portions of contact zones, or the hornstone structure of the more altered portions, with or without a swarm of little strings or streaks of granitic material passing through

them, the evidence again points to their being altered sediments. Such rocks have been found extensively developed in certain Archaean districts, where these have been carefully examined, as, for instance, in the Black Forest.*

3. The Survival in such Gneisses of Structures peculiar to Sedimentary Rocks.—Undoubtedly sedimentary products, as, for instance, rounded, water-worn pebbles, or angular clastic quartz grains, when recognized in any crystalline rock, also determine it to have been of sedimentary origin. In this way, certain rocks in Norway and Saxony formerly classed as Archaean crystalline schists have been recognized as altered conglomerates. Clastic quartz grains are in some cases rendered possible of recognition by the fact that in the processes of alteration secondary silica is deposited about them, and in this way the form of the original grain marked by its coating of iron oxide or other adhering impurity, is preserved and can be recognized, notwithstanding the complete alteration and crystallization of the rock. This process is especially well seen in the case of sandstones changing into quartzites, but can also be recognized in the metamorphism of certain arkoses into felspathic quartzites, which in composition would be identical with the more acid gneisses of the Archaean. By survival of original structure.

Applying these tests in the district at present under consideration, it has been found possible to place in one class certain rocks which all lines of evidence indicate as of sedimentary origin. To these belong the crystalline limestones, the quartzites, and certain associated gneisses usually containing sillimanite, garnet, and graphite.

Another class can be recognized as consisting of rocks of igneous origin which have been squeezed or crushed. To this class, in addition to the anorthosites which are treated by themselves under another heading, are a whole series of quartzose orthoclase-gneisses, usually poor in iron-magnesia constituents, and possessing a variety of structures. Rocks of doubtful origin.

A third class consists of rocks whose origin is as yet doubtful. This is due in part to the fact that, it has been impossible to subject them to an exhaustive examination, including chemical analysis. Possibly, however, their origin could not in many cases be ascertained even if such an examination were made. This class includes a considerable proportion of the ordinary orthoclase-gneisses of the district, as well as most of the pyroxene-gneisses and amphibolites.

* Geologische Specialkarte des Grossherzogthums Baden—Erlauterungen zu Blatt Gengenbach von A. Sauer—Heidelberg, 1894, page 8.

In the following pages these three classes of rocks will be considered separately, beginning with the gneisses of igneous origin.

Instead of endeavouring to describe every member of the large suite of specimens which has been studied microscopically in the course of this investigation, which would entail the presentation and repetition of an immense mass of petrographical detail, a number of typical occurrences from each class will be selected for description, as it is believed in this way a knowledge of the petrography of the district may be more clearly conveyed.

Class I.—Gneisses of Igneous Origin.

In these gneisses, orthoclase felspar preponderates largely, which is itself evidence against a sedimentary origin. Quartz is almost always present, though frequently in small amount. Its presence and proportion can be best ascertained in the field, by an examination of the weathered surface of the rock, on which the contrast of the quartz and orthoclase is much more marked than on a fresh fracture. These two minerals frequently make up almost the entire rock (quartz-orthoclase-gneisses), but they are usually associated with small quantities of biotite and hornblende, occurring either separately or together. Graphite, which is abundant in rocks of class 2, is never found in these gneisses. Three structural varieties are especially worthy of mention: (*a*) Augen-gneiss; (*b*) Ordinary granulated gneiss; (*c*) Leaf-gneiss.

These are connected by transitional forms.

Augen-Gneiss (Quartz-Orthoclase-Hornblende-Gneiss)—Township of Brandon, Lots 16 and 17, Range IX. (Section 555).

Augen-gneiss. The rock is of a reddish colour and quite uniform in character over large exposures. In hand specimens, it shows a distinct foliation caused by the presence of slightly undulating but nearly parallel narrow black lines of hornblende, alternating with thicker streaks and layers of reddish orthoclase.

These minerals occur for the most part in the form of fine grains, but in this finely granular mass cores or remnants of large individuals of hornblende and orthoclase respectively are abundant, from the granulation of which the finer grained portion of the rock has been produced. These cores have not a good crystalline form, but are rounded, lenticular, or tear-shaped, with trails of the granulated material running off from them in the direction of the foliation on either side, the foliation curving around them. The orthoclase cores are often large, sometimes over an inch in diameter, frequently presenting curved or twisted faces, and can be seen to be in the very act of breaking up into smaller fragments. The hornblende remnants are identical in shape with those of the orthoclase, but are smaller in size.

Granulated structure.

Under the microscope the rock is seen to be composed essentially of orthoclase, quartz and hornblende. As accessary minerals, biotite, diallage, apatite, zircon and iron ore are present in very small amount. Orthoclase preponderates largely, partly as large augen and partly as granulated material. The augen show an uneven extinction, although this is not always very pronounced, and between crossed nicols show a finely mottled or spotted structure due to a fine microperthitic intergrowth. They have an irregular oblong, often more or less rounded shape, and lie with their longer axis in the direction of the foliation of the rock, or more or less inclined to it. When considerably magnified they can be seen to possess a finely serrated edge as if jagged from the breaking away of little fragments. The augen can, in fact, be observed in the very act of breaking down into the finely granular material which surrounds them by a process of peripheral granulation, as described in the case of the anorthosites. The groundmass, so to speak, in which these orthoclase augen are embedded, consists principally of small grains of the same mineral. These generally show the same mottled appearance as the augen, and differ but little from one another in size. The larger ones often exhibit an uneven extinction and can frequently be seen to be in the act of breaking up into smaller grains. All these smaller orthoclase grains are very irregular in shape. In one of the sections a very few small grains of plagioclase were present. The quartz occurs chiefly in more or less elongated grains. These are often greatly elongated, forming the "leaves" of quartz so abundant in the "leaf-gneiss." These are distributed through the granulated orthoclase lying in the direction of, and in fact in part causing, the foliation of the rock. These grains have an almost uniform extinction, and are not broken or granulated, even if they are many times as long as they are wide. On very careful examination, however, they can usually be seen to exhibit a slightly uneven extinction suggestive, as will be shown in describing the "leaf gneisses" of a smearing of the mineral out in one plane. They sometimes fork at the extremities or at the sides. These quartz individuals can often be observed sweeping around the partially granulated augen of orthoclase in long curved grains or lines of grains.

The hornblende, which is green in colour and is present in comparatively small amount, occurs as strings of very irregular-shaped grains, resulting from the granulation of large individuals the cores or remnants of which remain as small augen. A grain or two of biotite is occasionally associated with the hornblende. In one slide a single grain of diallage was present, but in all the slides there are a few grains of a yellowish aggregate, which is apparently a decomposition product of diallage. Even if this be the true explanation of their origin, the diallage would be very subordinate to the hornblende in amount. There is no evidence that the latter has been derived from the former. A few small irregular-shaped individuals of apatite, and small zircon prisms, as well as a small amount of magnetite occurring in elongated grains or long narrow strings like the quartz, complete the list of constituents.

Mode of occurrence.

This augen-gneiss occurs as a very irregular-shaped mass, in the township of Brandon, intercalated in the gneissic series, with the strike of which its foliation coincides. (Fig. 3.) It forms large roche moutonnée exposures, very uniform in character, and is succeeded to the east by a large development of nearly black pyroxene granulite. Augen-gneiss, identical in character, was found in about a dozen different localities in the same township, in long narrow masses running parallel to the strike of the series. Augen-gneiss, closely related in character, occurs abundantly in many other parts of the area. It is found, for instance, in large exposures at a number of places along the southern edge of the area, between New Glasgow and St. Jérôme, and between the latter place and St. Canute, also to the north of this district towards Shawbridge and St. Sauveur, as well as in the extreme north-west corner of the area, on the Devil's River, the River Macaza, and about the lakes lying to the north of Trembling Lake.

Origin.

With regard to the origin of this augen-gneiss, there can be no doubt but that it is produced by the squeezing of a coarse-grained, in some places perhaps porphyritic, granite. In the case of the Brandon rock, this granite was a basic hornblende variety, probably with large porphyritically developed orthoclase crystals, similar in structure to the great granite mass on the east side of the township of Brandon, well seen about St. Didace, a mass which at many parts of its periphery is developed as an augen-gneiss, closely resembling the one in question. In other cases the original granite has been more acid in character and of the nature of a pegmatite, as in the township of Wolfe, where the line between ranges VIII. and IX. is crossed by the line between lots 34 and 35. Here, the extremely contorted gneiss is cut by a number of pegmatite veins, having a distinct augen-gneiss structure. (Section 567.) In many other parts of the Laurentian, both in this district and in Central Ontario, pegmatite dykes have been observed cutting across the gneissic strata, in which dykes an augen-gneiss structure has been developed, which are in fact augen-gneisses in certain places, or throughout their whole mass. The foliation of this augen-gneiss, moreover, coincides with that of the surrounding gneisses, but is quite independent of the direction of the dyke.

A good example selected from many similar ones is seen on lot 17 of range VI. of Brandon, and is shown in the accompanying figure:— Pegmatite crushed to augen-gneiss.

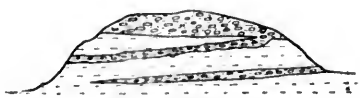

Figure 4.—Pegmatite dykes converted by pressure into Augen-Gneiss, the foliation of which coincides with the foliation and banding of the gneisses through which they cut. This exposure is 8 feet in width. (Range VI., Lot 17, Township of Brandon.)

At this locality there is a series of large roche moutonnée exposures made up of an alternation of fine-grained, reddish, orthoclase-gneiss, coarse augen-gneiss, dark pyroxene-granulite, and vitreous quarztite, the whole dipping to the east at a low angle. Although the several rocks seem at the first glance to succeed one another in pretty regular bands, careful examination shows that in certain places the augen-gneiss cuts across the other bands, as shown in the figure, the foliation in the transverse arm running parallel to the regular foliation and banding of the whole exposure, but not coinciding with the direction of the arm itself. In the thinner apophyses the granulation is more advanced and the augen less abundant than in the heavier bands from which it proceeds.

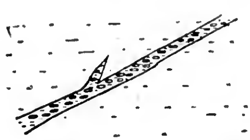

Figure 5.—Dyke of Pegmatite crushed to Augen-Gneiss, the foliation of which coincides with that of the Anorthosite through which it cuts. (Range VIII., Lot 19, Township of Brandon.)

Figure 5 shows a similar case where a pegmatite dyke crushed to an augen-gneiss cuts obliquely across the foliation of the anorthosite in the township of Brandon.

It is thus evident that in these cases, and probably in the cases of all the augen-gneisses, we have to do with granitic intrusions into earlier rocks, which intrusions certainly date from a time before the development of the foliation of the gneisses, or at least before the foliating forces had ceased to act.

Granulated Gneiss (Quartz-Orthoclase-Hornblende-Gneiss)—Trembling Mountain, Township of Joly (Sections 528, 530, 533, 534).

This mountain, which, as is well known, is the highest point in the whole Laurentian range of this part of Canada, rises 2380 feet above sea-level and 1720 feet above the waters of Trembling Lake, which lie along its foot. (Plate II.) It is sculptured out of a great mass of gneiss, uniform in character from base to summit, and has an especial interest in that it was cited by Sir William Logan as the typical occurrence of the Fundamental Gneiss, which he believed to lie at the base of the whole Laurentian system.

Trembling Mountain gneiss.

This gneiss is rather fine in grain, and has a distinct though not very striking foliation, marked by the presence of a series of thin, interrupted black lines, seen on surfaces broken at right angles to the foliation. On large weathered surfaces a slight variation in size of grain can occasionally be seen in thin bands parallel to the foliation, and at long intervals, thin bands of a black pyroxenic amphibolite are met with. The gneiss has a pale reddish colour when fresh, and weathers brownish-gray.

Under the microscope it is seen to be composed essentially of orthoclase, quartz and hornblende, the first-mentioned mineral preponderating largely. As accessary constituents, magnetite, probably containing a certain amount of titanium as in one case it was observed associated with a substance resembling leucoxene, and in some slides a few grains of plagioclase and biotite, are found. A few little zircons and a few irregular grains of a mineral probably apatite are always present, and in one of the specimens a not inconsiderable quantity of a rhombic pyroxene was associated with the hornblende in little irregular grains, without however affording any evidence of having been derived from this latter mineral.

Structure.

The structure of the rock is remarkable. (Plate IV., Fig. 1.) No more typical example of a cataclastic or "mörtel" structure could be found. Large, very irregular-shaped, often more or less rounded individuals of orthoclase, presenting a fibrous appearance, due to a very fine, microperthitic intergrowth and showing excellent strain-shadows, lie

FIG. 1.

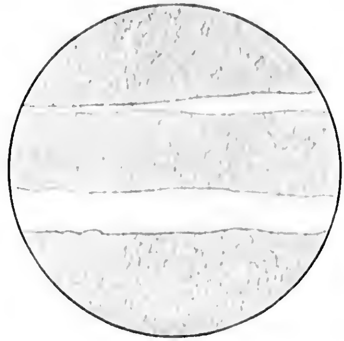

FIG. 2.

FIG. 3.

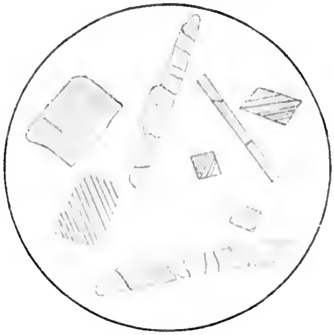

FIG. 4.

PLATE IV.

FIG. 1. "FUNDAMENTAL GNEISS," TREMBLING MOUNTAIN—Hornblende, Orthoclase and Quartz. × 10.

FIG. 2.—LEAF GNEISS, 3½ MILES NORTH-EAST OF ST. JÉRÔME—Orthoclase and Quartz. × 10.

FIG. 3.—GARNETIFEROUS SILLIMANITE-GNEISS, 1 MILE WEST OF ST. JEAN DE MATHA—Garnet, Sillimanite, Quartz, Orthoclase and Pyrite. × 10.

FIG. 4.—SILLIMANITE CRYSTALS IN GNEISS FROM WEST SHORE OF TREMBLING LAKE.

imbedded in a very finely granulated mass, making up the greater part of the rock, composed also of orthoclase, and which can be plainly seen to have been derived from the breaking down of the larger orthoclases, the process being actually observed in all its stages in the sections. The process consists partly in peripheral granulation and partly in the subdivision of the larger individuals into smaller ones, by the development of lines of this broken material across them in the direction of greatest stress.

The quartz, the larger individuals of which frequently contain little rows of the minute dark inclusions often seen in the quartz of granite, though present in smaller amount, presents the same phenomena. This is also true of the hornblende, the large individuals of which are for the most part broken into fragments which are arranged in rudely parallel lines, forming the interrupted black lines above mentioned as marking the foliation of the rock. The origin of the gneissic structure in the case of this rock admits of no question. It is not an original structure, nor a survival of bedding indicating a sedimentary origin, but it has been produced by movements in the rock brought about by crushing, the original rock having been a hornblende-granite.

Chemical composition.

In order to ascertain whether the chemical composition of this rock would bear out the conclusions derived from its study in the field and under the microscope, an analysis of it was made for me by Mr. Walter C. Adams, B.A.Sc. The results of this analysis are given below under I., while under II. the results of the analysis of a granite from the Carlingford District, in Ireland, by Haughton, are presented for purposes of comparison :—

	I. GNEISS. Trembling Mt.	II. GRANITE. Carlingford.
Silica....	69·24	70·48
Alumina ...	14·85	14·24
Ferric oxide .	2·62	3·72
Manganous o' ..	·45	
Lime....	2·10	1·48
Magnesia..	·97	·40
Soda....	4·30	3·66
Potassa.. ..	4·33	4·26
Loss on ignition ...	·70	1·59
	99·56	99·83
Total alkalies.....	8·63	7·92

The composition is that of a typical granite, and is entirely different from that of the gneisses of Class II., of which the analyses are discussed on pages 59 J to 61 J. The points of distinction, and those which mark it as of igneous origin, are high silica combined with low alumina, and high percentage of alkalies. The lime also, as is usually the case in granites, is in excess of the magnesia.

For a description of the bands or stratiform masses of pyroxene-amphibolite which are intercalated in this gneiss, see page 77 J.

Leaf-Gneiss—(Quartz-Orthoclase-Gneiss)—3½ miles North-east of St. Jérôme (Sections 334, 665).

Leaf gneiss.

As a typical locality for this important and interesting variety of gneiss, certain large exposures protruding through the drift near the southern edge of the protaxis, and about 3½ miles from St. Jérôme, by the side of the Great Northern Railway between this place and New Glasgow, may be taken.

The rock is pink in colour, fine in grain, excellently foliated, and practically free from all iron-magnesia constituents. In the hand specimen it appears to consist of very thin alternate layers of quartz and orthoclase. The quartz, however, can scarcely be said to occur in layers, but rather in long narrow leaves, presenting the appearance of layers, when the specimen is broken at right angles to the foliation in one direction, but appearing as much shorter layers or dashes when the rock is broken in the other direction, at right angles to the foliation. When, on the other hand, the rock is broken in a direction parallel to the foliation, the quartz presents the appearance of having been smeared over the felspar surface, in long, narrow streaks, very much as butter might be thinly spread on bread.

Under the microscope, in a section cut at right angles to the foliation the rock (Plate IV., Fig. 2) is seen to be composed of a uniform mosaic of felspar grains, through which the quartz runs in narrow, sharply defined bands. These quartz bands in polarized light resolve themselves into a series of individuals, each having a long rectangular section, and placed end to end, the bands being remarkably uniform in width and sharply defined against the felspar mosaic on either side. The quartz individuals are sometimes as much as ten times as long as they are wide, and yet have an almost absolutely even extinction. The orthoclase which constitutes the greater part of the rock, forms, as has been mentioned, a mosaic of much smaller grains, showing, as a general rule, between crossed nicols the wavy lines, due to fine microperthitic intergrowths, so often seen in gneisses. These grains fit into one another along very serrated boundaries; they do

Structure.

not show any very pronounced strain-shadows, neither are there any augen or remnants of larger grains to be seen. Smaller and larger grains are present, but there is no distinct evidence of the larger breaking up into the smaller. A grain or two of plagioclase is seen in each slide, as well as one or two very small decomposed remnants of what may have originally been minute mica scales.

Complete granulation.

The structure suggests a completely granulated rock, in which the granulation has, perhaps, been effected in part, at least, by re-crystallization.

Distribution of the gneiss.

Gneisses presenting this leaf structure with its accompanying microscopic characters are abundant and occur in many widely separated parts of the area embraced in this report. They are for instance, very extensively developed in the last range of the township of Cartier, being excellently exposured on the shores and islands of the typical little Laurentian lakes which lie between the two branches of the River L'Assomption, one of which runs out of Lac des Ilets, and the other out of Lake L'Assomption. Several of these lakes are rock-basins which have been excavated out of this gneiss. The gneiss from this locality (section 318), closely resembles that above described, although the quartz leaves are not so sharp and regular, and plagioclase, in clear, brightly polarizing grains, is more abundant. There are also a number of little scales of biotite scattered through the rock as well as a few very small isotropic red garnets. As before, the appearance under the microscope is suggestive of granulation with at least partial re-crystallization, although no absolute proof of this can be obtained. At many places in the township of Brandon also leaf-gneiss occurs interbanded with pyroxene-granulite, quartzite, &c., consisting as before of quartz and orthoclase, iron-magnesia constituents being absent or represented by a few grains of iron ore. One of these localities is lot 13 of range VI. (section 685), by the side of the road which crosses this lot, where the gneiss is interbanded with pyroxene-granulite and often cut by irregular-shaped masses of augen-gneiss, running now with and now across the direction of foliation as above described.

On lots 18 of range V. and 15 of range IX. (section 576), of the same township, this same variety of gneiss is also well exposed, the latter locality being at the westerly contact of the most eastwardly of the anorthosite masses which occur in this township. In the very fine-grained felspar groundmass of these rocks, however, occasional larger grains of orthoclase can be seen which are much twisted, show a very uneven extinction, and can in some cases be seen to be undergoing a process of peripheral granulation, giving rise to smaller grains like those of the groundmass. In the rock from the latter locality also, sections show distinctly that a movement in the direction of the foliation has taken place in the felspar mosaic, during or subsequent to its formation.

Transitional Forms.

Between augen-gneiss and leaf-gneiss all possible intermediate varieties are found in various parts of the area. Such intermediate forms present leaves or thin layers of quartz alternating with layers of finely granular orthoclase, in which the augen or remnants of large orthoclase individuals are more or less abundant. When these augen are large and abundant the rock approaches an augen-gneiss on one hand; when the granulating process has so far advanced that they have become greatly reduced in number and size, or have almost disappeared, the rock passes gradually over into a leaf-gneiss on the other. Gneisses are often found which would be classed as leaf-gneiss but which on careful examination show a few minute twisted remnants of orthoclase augen, here and there, indicating the true character of the rock.

Transitional forms.

The great granite mass occupying the eastern side of the township of Brandon, along its northern limits assumes first the form of an augen-gneiss, and then passes over into such a leaf-gneiss (section 660), which, however, is poor in quartz, the transition being excellently seen on the shores of Lake Sacacomie, which lies just beyond the eastern limits of the map. Many similar cases of pegmatites passing into augen-gneiss and then into leaf-gneiss have been observed, and even when the transition cannot be seen, transitional forms are so common as to render the conclusion inevitable that many at least if not all the typical leaf-gneisses have been derived from the crushing or foliation of coarse granite rocks, having passed through the intermediate stage of augen-gneiss. In a similar manner those forms of leaf-gneiss in which the quartz individuals are smaller, occurring in the form of little dashes or scales rather than leaves, have probably been formed from finer grained rocks of similar character, passing through an intermediate stage such as that described in the Trembling Mountain gneiss, which, after all, is a species of microscopic augen-gneiss. In the movements which have taken place in these rocks, resulting in the development of a foliated structure, the processes at work are, it is believed, chiefly mechanical.

The structure of mechanical origin.

In certain districts which have been made the subjects of careful study elsewhere, structures resembling closely those above described have been thought to have been produced by the breaking down and re-crystallization of the original constituents. This does not seem to be true in these Laurentian gneisses—for in the case of the felspar and hornblende the granulated material is exactly the same to all appearances as the larger augen. Even when the latter consist of microperthite the granulated material has also the same character, which would hardly be expected if a re-crystallization had taken place. Sericite and the various other minerals so often produced during the re-crystallization of rocks under the influence of pressure are also absent.

The effect of the pressure on the quartz is especially remarkable, for, as has been stated, the individuals of this mineral are not granulated or broken up into smaller grains, but take upon themselves the form of thin leaves or laths, often eight or ten times as long as they are wide, and in the case of the augen-gneiss often following curved courses.

These leaves do not show, as a general rule, the intense strain-shadows often observed in the felspar augen, but almost always show evidences of strain at intervals along the length of the leaf, dividing the latter in this way into certain ill-defined areas with slightly different orientation. The leaves also, as has been stated, can be observed to bend around large orthoclase remnants and sometimes to fork at their extremities. A very long lath of quartz will al in some instances break across, giving several elongated fragments arranged in a line.

Like that of quartz-porphyry at Thal.

That these phenomena are the result of a purely mechanical rolling out of quartz individuals cannot be positively asserted, but they are to all appearance so produced. There is no evidence of any breaking with a restoration of continuity by the deposition of secondary quartz. The process therefore appears to be quite different from that described by Lehmann in the Saxon granulites* but is identical with that seen in the squeezed dykes of quartz-porphyry at Thal, near Eisenach, in Thuringia,† and elsewhere. These dykes, which cut through a series of mica-schists, have had a well marked foliation induced in them parallel to that of the country-rock but often transverse to their own length. The phenocrysts consist of orthoclase, plagioclase and quartz, which are arranged in the groundmass with their longer axes in the direction of the foliation. The felspars and especially the plagioclases have broken into fragments under the pressure to

* Entstehung der altkrystallinen Schiefer Gesteine, S. 250.

† Futterer.—Die Ganggranite von Grossachsen u. d. Quartzphorphyre von Thal im Thuringen. (Inaug Diss. Heidelberg, 1890.)

which the rock has been subjected, which fragments are arranged in lines in the direction of the foliation resembling in that respect the Belemnite fragments in the Bündner Schiefer of the Alps. The spaces between the broken fragments are filled not with the groundmass squeezed into the cavity but with grains of quartz and sometimes felspar, coarser in grain than the groundmass, and which although probably secondary is not derived from the broken phenocrysts, since it can be seen that the several portions of these if brought together would fit closely into one another.

The quartz phenocrysts, on the other hand, are drawn out into cigar-like forms, often eight times as long as they are wide. These are not broken or granulated but are sharply defined against the groundmass and sometimes have a curved form. Occasionally little elongated strings resembling the groundmass are seen within the quartz phenocrysts, which were in all probability inclusions of the groundmass in the original phenocrysts that became rolled out with the phenocrysts themselves. All these elongated quartz phenocrysts present remarkable extinction phenomena. Each individual extinguishes nearly simultaneously over its whole surface, but when carefully examined is seen to divide up into a number of little fields extinguishing in succession, not however sharply separated but merging into one another so that the shadow sweeps over the field with a peculiar twinkling effect.

Plastic deformation of quartz.

This appearance is identical with that seen in the quartz of many gneisses. There is no evidence of breaking and re-cementing, as there is no interruption in optical continuity in the individual as there must be if this had taken place. The phenomenon is probably the same as that exhibited in the plastic deformation of ice crystals recently studied by Mügge.* It is thus evident that under certain conditions when felspar is crushed or granulated, quartz undergoes a rolling out or elongation without breaking, molecular movements taking place in some peculiar way, which result in an entire change in form while the individual still retains an approximately uniform extinction. In this way, in the Laurentian system, granitic rocks became gneisses. It is extremely rare in these rocks to find quartz grains which have been broken or granulated, and although as investigation proceeds it may be found that the granulation of the felspar and bisilicates is in part a chemical process, the evidence at present available tends to the belief that, as in the case of the anorthosites, to be referred to later on, the process is chiefly mechanical. In other rocks of this system, how-

* Ueber die Plasticität der Eiskrystalle. Neues Jahrbuch für Mineralogie &c. 5, H. 3, p. 212.

ever, as well as in other districts of crystalline schists, re-crystallization and chemical re-arrangement have undoubtedly played a chief part.

Class II.—Gneisses, Limestones, Quartzites, &c., of Sedimentary Origin.

Another class of gneisses, quite different in composition and structure from those above described, occurs abundantly in many widely separated parts of the area at present under discussion, as well as in all other parts of Canada where the Grenville series is found. Intimately associated with these gneisses are other rocks whose composition also makes it impossible to class them with rocks of igneous origin: these are the crystalline limestones and quartzites which form such a prominent petrographical feature of the Grenville series. Rocks of sedimentary origin.

The criteria by which gneisses having a sedimentary origin may in many cases be recognized have already been indicated, and the very fact that the rocks just mentioned and included in the present class are almost invariably closely associated with one another, is in itself additional evidence of their common sedimentary origin.

The gneisses of this class, while under the microscope still seen to contain a certain amount of quartz and orthoclase, are made up very largely of garnet and sillimanite, which are their most important constituents. These and other differences in their composition are accompanied by differences in structure as well. One set of these rocks is characterized by a rapid disintegration when exposed to the weather, giving rise to a sand-like product very rusty in colour and which is very characteristic. A second set are very similar in composition, but do not weather in the same rusty manner. Gneisses.

As typical of these rusty-weathering gneisses, the following occurrence may be taken:—

Garnetiferous Sillimanite-Gneiss—About one mile west of the Church of St. Jean de Matha, Seigniory of De Ramsay. (Sections 648, 649).

This gneiss occurs in thick bands, interstratified with and overlain by the white garnetiferous quartzite described on page 62 J, the whole lying very nearly horizontal. The gneiss weathers exceedingly rusty, but on the fresh surface is seen to be fine in grain and dark-gray in colour, small garnets and graphite scales being readily recognized in it. It is more uniform in character than is usual in gneisses, the strike St. Jean de Matha.

being marked by bands somewhat richer or poorer in garnet, or by other slight differences in composition.

Under the microscope the rock is seen to consist of garnet, sillimanite and quartz in large amount, with some orthoclase and iron pyrite, and a little biotite, rutile and graphite. (Plate IV., Fig. 3.)

The garnet individuals, which are usually large, are more or less rounded in form, but frequently elongated in the direction of the foliation, and, as is usually the case in these Laurentian gneisses, are perfectly isotr[illegible]. They frequently hold inclusions of quartz, sillimanite and rutile, and present the appearance of having grown in the rock and inclosed these other older constituents.

Sillimanite.

The sillimanite occurs in colourless elongated prisms from ·05 to ·25 millimetres in diameter, the longest individuals being somewhat over 1·1 millimetres in length, and often slightly curved, apparently by pressure. It has a rather high index of refraction, as well as a rather high double refraction. The longitudinal sections show the cleavage parallel to the macropinacoid as a series of fine lines parallel to the longer axis, except when cut parallel to this face. They also show the transverse cracks usually seen in long and slender prisms. When tested by means of the quartz wedge it is found that $c = \mathfrak{c}$. Terminal faces cannot be recognized. In transverse sections the prisms are seen to have the nearly square cross section of the prism $\infty P\frac{3}{2}$. The cleavage crosses these sections diagonally, and in the direction of this cleavage lies the plane of the optic axes, the axial angle being small. These properties serve to identify the mineral and to distinguish it from wollastonite or andalusite, which in certain respects it resembles. (Plate IV., Fig. 4.)

The quartz, which is uniaxial and positive, contains, as is very frequently the case in these gneisses, many minute straight hair-like inclusions, which are dark in colour. In the great majority of cases, it shows a more or less pronounced uneven extinction, and the grains are often long and narrow, the longer axes lying in the direction of the foliation.

Pyrite and graphite.

The orthoclase possesses the usual characters, and between crossed nicols sometimes has the faintly fibrous appearance often seen in the orthoclase of gneisses, the larger grains showing strain-shadows as in the case of the quartz. The biotite occurs in very small amount, and in small individuals of a deep brown colour, here and there slightly twisted. The rutile appears as a few irregular-shaped, nearly opaque, little grains. The pyrite, the presence of which gives rise to the rusty weathering of the rock, and which occurs in considerable amount, is in the form of little irregular-shaped strings and masses scattered through the rock. It frequently occupies little cracks running through the various other minerals or surrounding them. It sometimes occurs well crystallized, but is often very fine-grained and in little masses having a concentric banded structure like that seen in agate, the mineral having evidently been deposited in little cavities subsequent to the crystallization of the rock and being frequently related to the graphite in such a way as to suggest that the pyrite had been deposited owing to a reducing action on the part of the carbon. The graphite, which in the hand specimens seems to be somewhat abundant, is seen in the thin sections to occur in the form of small elongated individuals, black and quite opaque.

A study of the thin sections also shows the rock to be quite different from the quartz-orthoclase-gneisses already described, not only in mineralogical composition but also in structure. The elongated individuals of sillimanite, quartz, etc., lying in one direction, mark the foliation of the rock, though this is not very pronounced.

No evidence of granulation, however, is to be seen, the pressure which granulated the gneisses of the last class, having, to all appearances, crystallized these *in situ*, the constituents being, in the nomenclature of Milch, "eleutheromorphic."* The uneven extinction of the sillimanite, quartz, and orthoclase would, however, seem to indicate that the rock had been subjected to some pressure since their development; but on the other hand, the garnet, which was developed later being quite isotropic, would seem to have been produced during the final compression of the rock. No evidence of granulation.

Another locality at which a gneiss almost identical in character occurs is in the front of lot 4 of range X. of the township of Brandon. (Section 680). Where the road crosses this lot there are large exposures of gneiss consisting of an alternation of small bands of augen-gneiss and leaf-gneiss holding little augen, with other rocks of the nature of amphibolite or pyroxene-granulites often holding quartz; as well as with a few bands of this rusty garnetiferous sillimanite-gneiss and some calcareous gneiss or very impure limestone. Both the augen-gneiss and the amphibolite-gneiss occasionally hold garnets. The rusty-weathering gneiss is seen under the microscope to be composed essentially of garnet, sillimanite, orthoclase and quartz, with pyrite, rutile and biotite in very subordinate amount. The garnet, as before, Garnet.

* Beiträge zur Lehre von der Regionalmetamorphose—Neues Jahrbuch für Mineralogie, IX Beilage Band. S. 107.

is in the form of irregular-shaped masses, having a sponge-like character owing to the numerous inclusions of biotite, felspar, sillimanite and rutile which it contains, it is as in the rock last described quite isotropic. The pyrite occurs filling little cracks and was apparently infiltrated after the crystallization of the rock. No graphite is to be seen in the specimen or slide. This rock, like that from near St. Jean de Matha, shows no evidence of cataclastic structure, but has apparently resulted from an entire re-crystallization *in situ* under pressure. The same is true of the quartzose garnetiferous gneiss interbanded with this rusty gneiss.

There can be no doubt in the case of these exposures, that the augen-gneiss and the leaf-gneiss produced from it, are of igneous origin.

Two other occurrences of this peculiar rusty-weathering gneiss may also be referred to; in these, however, the orthoclase has a granulated appearance, although no absolute proof of its cataclastic origin can be obtained.

Garnetiferous Sillimanite-Gneiss—Road between the Township of Kildare and Lake Rocher—Seigniory of D'Argenteuil. (Section 302.)

Kildare.

At this locality there are a series of exposures representing a very considerable thickness of strata made up of an alternation of grayish quartzose gneiss, with thick bands of white garnetiferous quartzite and of this rusty-weathering gneiss. There is also in one place a band of white crystalline limestone, holding grains of dark-green serpentine. This is exposed for a width of twenty feet, and occurs interstratified between a band of white quartzite and one of the rusty gneiss. All these rocks frequently hold a little graphite. The rusty-weathering gneiss as before consists of garnet, orthoclase, quartz and sillimanite with pyrite and a little rutile and graphite. The contrast between the very rusty weathered surface of this gneiss and the pale-gray almost white colour of its surface on a fresh fracture is very striking.

Garnetiferous Sillimanite-Gneiss—Township of Kildare, near the line between Ranges XI. and XII. (Section 436.)

This locality is just to the west of Lake Français, and on a continuation of the same section as that in which the last-mentioned rock occurs, but about three miles further west. It is the first exposure on the road, to the west of the anorthosite band which passes under the lake. The rock consists essentially of garnet, sillimanite, quartz and orthoclase, the garnet often inclosing the sillimanite. It is almost identical in character with the rusty-weathering gneiss of the other localities described above.

As examples of the second set of these rocks before mentioned, which, while very similar to those just described, do not contain pyrite, and consequently are not distinguished in the field by the rusty sand-like disintegration product, the following may be selected:—

Garnetiferous Sillimanite-Gneiss—3 miles north-west of St. Jean de Matha—Seigniory of De Ramsay. (Section 563.)

This rock occurs three miles in a straight line north-west of St. Jean de Matha, at the bridge where the road from this place to Ste. Emilie crosses the Black River. The gneisses here lie practically horizontal. The rock is red in colour, and highly garnetiferous. North-west of St. Jean de Matha.

Under the microscope the rock is seen to be composed of garnet, sillimanite, quartz and orthoclase, with smaller amounts of rutile, serpentine, pyrite, graphite and biotite. The general characters of these minerals are the same as those which they present in the rocks of the last set just described.

The garnet is perfectly isotropic. The sillimanite is present in considerable amount, in prisms whose long axes lie parallel to the foliation of the rock. The quartz contains a great abundance of minute, black, hair-like inclusions, quite straight and arranged in several intersecting series. The orthoclase has a distinctly fibrous appearance, owing, in part at least, to the presence of little, rod-like inclusions, some black and nearly opaque, others transparent and nearly colourless. The rutile is present in deep brown, nearly opaque grains, sometimes having a tolerably good prismatic form, but generally more or less rounded. The serpentine occurs in a few large grains derived from the alteration of some mineral, which has now entirely disappeared. Graphite is scattered through the rock in numerous little flakes. The biotite occurs in very small amount, often inclosed in the garnet. Only a very few small grains of pyrite are present.

The rock, as has been stated, is very highly garnetiferous, the garnet occurring in lumps of a pink colour, making up a large part of the rock, the other constituents of the rock being much more fine in grain and flowing round the large garnet lumps, thus giving rise to an indistinct foliation in the direction of the motion. The structure, however, is quite different from that of augen- or leaf-gneiss, for the study of the thin sections affords no indication of granulation. The large garnet lumps crystallized *in situ* and are uncrushed. They are not remnants of larger masses which have escaped complete granulation. The sillimanite appears to be somewhat broken in places, but this is not certain, and a study of the thin sections proves that at least some, if not all, the constituents of the rock have been produced by a process of re-crystallization.

Sillimanite-Gneiss.—West shore of Trembling Lake. (Section 591.)

Trembling Lake gneiss

The geology of Trembling Lake, which large sheet of water lies near the north-west corner of the accompanying map, is of especial interest. Along the eastern shore of the lake rises Trembling Mountain, the highest point in this part of the Dominion, and which, as already stated, is cited by Logan as the typical occurrence of his fundamental gneiss. The gneiss composing Trembling Mountain is very uniform in character and, as has been shown on page 43 J, consists of a great mass of squeezed igneous rock. Running up through the lake, and exposed at its southern extremity, as well as on the islands in the lake, is a heavy band of white crystalline limestone. Associated with this, and well exposed on the shores of the southern portion of the lake, especially on the western side, are garnetiferous and sillimanite gneisses in considerable variety. On the eastern side these form a narrow border, in some places graphitic and holding interstratified bands of quartzite, which is succeeded by the Trembling Mountain gneiss a short distance inland. At the north-western end of the lake coarse granite-gneiss, with scarcely perceptible foliation and no banding, comes in.

One variety of the gneiss, occurring on the west shore of the lake and about a quarter of the way up the lake from the southern extremity, was selected for examination.

The rock, which weathers somewhat rusty, is fine-grained and dark purplish-gray in colour on fresh fracture, looking somewhat like a fine mixture of pepper and salt. It consists essentially of orthoclase and quartz with a large amount of biotite in little flakes. Running through the rock are little interrupted wavy streaks, white in colour, and apparently parts of what were once continuous little bands. These consist essentially of sillimanite in minute acicular crystals (Plate IV., Fig. 4) and, ha ng a rudely parallel direction, give to the rock, which is otherwise massive, an indistinctly foliated appearance.

Figure 6.—Sillimanite-Gneiss, west shore of Trembling Lake. Sillimanite, Quartz, Orthoclase, Biotite and Pyrite. × 38.

The accompanying figure (No. 6) shows the appearance of the rock under the microscope, portions of two bands rich in sillimanite with an intervening band rich in biotite being shown. As accessary constituents present in small amount, the rock contains garnet, titaniferous iron ore, a few grains of pyrite and of a mineral which has the characters of allanite, pleochroic in pale brownish and green tints and deeper in colour in the interior of the grain. These constituents are bounded by well defined, sharp lines; there is no granulation, and no twisting of the grains. The rock has the appearance of having been entirely re-crystallized, and resembles certain altered rocks found in the contact zones about great granite masses.

It bears as strong a resemblance to a metamorphosed sediment on one hand as the rock of Trembling Mountain does to an igneous mass on the other—resemblances which in each case are emphasized by the chemical composition of the rock. Resemblance to altered sedimentary rocks.

Garnetiferous Sillimanite-Gneiss.—Darwin's Falls on River Ouareau, near Village of Rawdon, Township of Rawdon. (Sections 637, 638.)

At Darwin's Falls, which are about a quarter of a mile below the lower bridge at Rawdon, the river cuts its way through a gorge of Laurentian rocks which are well banded and dip to the west at a high angle, the attitude being nearly vertical. The gneiss is in most places highly garnetiferous, the pink garnets occurring in lumps sometimes as much as an inch in diameter, and is interstratified with bands of white quartzite (described on page 62 J), some of which are highly garnetiferous, while others are nearly free from garnet. There are also bands of felspathic quartzite. The bands of these various rocks, which have all the appearance of beds, are from a few inches to several feet in thickness.

Darwin's Falls

In one place a little string of crystalline limestone about an inch wide was found, but no larger band could be discovered: to the north, however, nearly on the strike of these exposures, a heavy band of crystalline limestone appears, which may possibly cross the river just above the village, where the banks are heavily drift-covered. This locality has already been referred to in describing the distribution of the limestone bands on page 25 J. The microscopic character of the quartzite interbanded with the gneiss, is described on page 62 J.

The gneiss contains much garnet and sillimanite, but differs from the gneisses of the class before described, in that it is much more highly quartzose.

The garnet occurs in numerous irregular-shaped grains with the peculiar arm-like extensions running out into the web of the rock in all directions and inclosing individuals of the other constituents. Orthoclase, quartz, sillimanite, biotite, rutile and iron ore have been observed thus inclosed in the garnet, so that the latter mineral would appear to

Figure 7.—Garnet holding inclusions of other constituents of the rock—Garnetiferous Sillimanite-Gneiss—Darwin's Falls, near Rawdon.

Garnet with inclusions.

have been developed later than any of the other constituents of the rock. This peculiar mode of growth on the part of the garnet is seen almost invariably in the garnetiferous gneiss of the Laurentian, as well as in the highly altered sedimentary strata folded into the Alps

(Bundner Schiefer) and elsewhere, and has already been noted as occurring in some of the rocks described above. The mineral appears to add to its substance in all directions in which material which will yield garnet can be reached, and even seems to be assimilating or in some way getting rid of grains of the most diverse minerals which it has inclosed, minute irregularly rounded remnants of many of these alone remaining in the interior of the garnet individuals, while the peripheral portions are often still full of inclusions. How this is accomplished it must be left for future investigation to decide, for, in the manner in which these garnets and other minerals developed by metamorphic processes grow in solid rocks, there is much which is as yet mysterious and not by any means thoroughly understood. The garnet filled with inclusions, in its want of continuity often resembles a sponge, or a great Amœba whose substance is barely sufficient to inclose the miscellaneous collections of objects on which it is feeding. In addition to the garnets and quartz, orthoclase and sillimanite are abundant, while biotite, rutile, iron ore, pyrite, and zircon (?) are present in small amount, all these minerals presenting the normal characters of the several species.

The rock has an indistinct foliation, due in part to the arrangement of the various minerals with their longer axes in one plane, and in part to a certain variation in relative abundance of the different minerals in different planes. The quartz and orthoclase show effects of pressure, but no undoubted granulation or distant cataclastic structure is seen in the slides, neither are there any augen. The garnet and sillimanite are certainly due to re crystallization, and the evidence goes to show that the rock as a whole has resulted from this process. It has, however, since re-crystallization, been subjected to a certain amount of pressure, for although in some cases the quartz and orthoclase show slight evidences of pressure this has not affected the garnet at all.

Chemical Composition of the Gneisses of Class II.

In order to ascertain whether the gneisses of Class II., which differ so distinctly in mineralogical composition and structure from those of Class I., present differences in the chemical composition of the rock as a whole, three of the most typical gneisses of the class were selected from those described and were analyzed. The results of these analyses are given below. No. III. was made for me by Mr. Nevil Norton Evans, of McGill University, and Nos. IV. and VII. by Mrs. Chemical composition of gneisses of Class II.

Walter C. Adams, B.A.Sc. To both gentlemen I desire to acknowledge my great indebtedness.

	III. GNEISS. — St. Jean de M.	IV. GNEISS. — Trembling Lake.	V. SLATE. — Wales.	VI. SLATE. — Melbourne.	VII. GNEISS. — Rawdon.	VIII. SLATE. — Tinzen.
Silica	61·96	57·66	60·50	64·20	74·70	79·97
Titanic oxide	1·66	.....	.....	.....	.....	.....
Alumina	19·73	22·83	19·70	16·80	8·88	8·62
Ferric oxide	.....	.....	.....	.....	9·64	6·63
Ferrous oxide	4·60	7·71	7·83	4·23	.....	.....
Ferric sulphide	4·33	.....	.....	.....	.....	.....
Manganous oxide	trace.	trace.	trace.	.....	·50	.....
Lime	·35	1·16	1·12	·73	1·07	·76
Magnesia	1·81	3·56	2·20	3·94	1·87	1·52
Soda	·79	·60	2·20	3·07	·42	·64
Potassa	2·50	5·72	3·18	3·26	·95	2·30
Loss on ignition	1·82*	1·50	3·30	3·42	1·05	.....
	99·55	100·77	100·03	99·65	99·08	100·44
Total alkalies	3·29	6·32	5.38	6·33	1·37	2·94

* Water.

III. Gneiss from about one mile west of St. Jean de Matha. A fine-grained garnetiferous sillimanite-gneiss, containing much quartz and orthoclase. Graphite and pyrite are also present, the latter causing the gneiss to weather to a very rusty colour. It occurs in thick bands interstratified with white garnetiferous quartzite, the whole lying nearly flat. (See page 49 J).

IV. Gneiss from the west shore of Trembling Lake. A fine-grained dark gray gneiss, composed of quartz and orthoclase, with much biotite and sillimanite. It occurs near a band of crystalline limestone which occupies the bed of Trembling Lake. (See page 51 J).

V. An ordinary roofing slate from Wales. Analysed by T. Sterry Hunt. (Phil. Mag., 1854, p. 237.)

VI. A similar roofing slate of Cambrian age from the large quarries in the Township of Melbourne, in the southern portion of the province of Quebec. Analysed by T. Sterry Hunt. (Geology of Canada, 1863, p. 600.)

VII. Gneiss from Darwin's Falls, near the village of Rawdon, province of Quebec. It is a highly quartzose garnetiferous gneiss, and occurs in well defined bands interstratified with quartzite, which is often highly garnetiferous, the bands being from a few inches to several feet in thickness. (See page 56 J).

VIII. Red slate from near Tinzen, in the district north of the Engadine, Switzerland. Highly siliceous, containing 9·12 per cent of silica as quartz. (Vom Rath, Z. D. G. G., 1857, p. 242.)

Different in composition from any igneous rock.

It will be seen, on comparing the analyses of these three gneisses (III., IV. and VII.) with the analysis of the Trembling Mountain gneiss, given on page 43 J, that they are quite different in composition. They are, in fact, quite different in composition from any igneous rock. On the other hand, the high content in alumina (in III. and

IV.), the low percentage of alkalies, and the great preponderance of magnesia over lime, characteristic of shales and slates, will be noted. The rocks thus present chemical evidence of having undergone a leaching process. (See page 35 J.)

The high percentage of alumina with low alkalies is due to the presence of sillimanite, a mineral very common in the crystalline schists, but seldom or never found in large amount in unaltered igneous rocks.

Composition of granites and shales.

The marked difference in composition between granites and shales or slates is distinctly seen on comparing the analyses of a series of granites with those of a series of slates, as, for instance, those given in Roth's "Gesteins Analyzen." The latter are seen to be on an average considerably higher in alumina and much lower in alkalies, while at the same time they are lower in silica, which has been separated both as sand and in combination with the alkalies which have gone into solution, and in most cases contain more magnesia than lime instead of more lime than magnesia, as is usual in granites.

The average percentage of alkalies in the thirty-seven analyses of granites from various parts of the world given by Roth in his work above mentioned is 7·35 per cent, while twenty-three primitive clay-slates (Urthonschiefer) contain on an average only 4·70 per cent and twenty-five slates of Silurian age 4·82 per cent of alkalies. The slates thus contain on an average about two-thirds of the amount of alkali present in the average granite.

Effects of decomposition of granites.

The changes which a granite undergoes when it is decomposed by the action of the weather have been well brought out by an excellent study of the chemical composition of the fresh and the decomposed granite of the district of Columbia, by Prof. Merrill, in which the decomposed rock was found to have lost 25·21 per cent of lime, 28·62 per cent of soda, 31·98 per cent of potassa and 14·89 per cent of silica, but only 3·23 per cent of alumina, and 1·49 per cent of magnesia.* A result which, so far as the alkalies are concerned, agrees very closely with the average loss indicated in the case of the forty-eight slates referred to above.

A typical slate is thus distinctly different in chemical composition from an ordinary granite, although sediments having an intermediate composition are frequently produced by the disintegration of granite

* Referred to in a paper entitled Disintegration and Decomposition of Diabase at Medford, Mass., Bull. Geol. Soc. of America, 1896, p. 357.

without complete decay, giving rise to such rocks as arkose, grauwacke felspathic sandstones and so on.

The strongly marked resemblance in composition to slates on the part of the gneisses from St. Jean de Matha and Trembling Lake is seen when their analyses are compared with those of the two slates Nos. V. and VI. They have, in fact, the composition of ordinary roofing slate.

No. VII., which is a gneiss so highly quartzose that it might almost be termed an impure quartzite, also has a composition differing from that of any igneous rock, but one which is identical with many siliceous slates. No. VIII. is the analysis of such a slate from the Engadine district in Switzerland, and is, as will be seen, almost identical with No. VII. Siliceous bands from some of the Canadian slate quarries, also have a similar composition. The alumina in this case is low on account of the preponderance of quartz, which also lowers the alkalies. The magnesia, as before, preponderates over the lime. No. VIII. lost 1·92 per cent on ignition before analysis, and these figures do not, therefore, appear in the analysis as given above.

Analyses of slates.

That there is nothing remarkable in the interstratification of bands of gneiss differing greatly in composition in the same series of exposures as at Darwin's Falls, supposing them to be highly altered sediments, is well shown by the following analyses of two varieties of slate taken from different bands in the same quarry, in rocks of Cambrian age, at the Danville Slate Quarry, in the province of Quebec, south of the St. Lawrence. They were made by Dr. J. B. Harrington, and have not hitherto been published.

	IX. Slate. Danville.	X. Slate. Danville.
Silica	55·75	67·85
Alumina	17·87	9·10
Ferrous oxide	9·07	11·14
Manganous oxide	·70	·79
Lime	1·14	·98
Magnesia	5·81	3·23
Soda	1·12	1·80
Potassa	2·97	·44
Loss on ignition	5·26	4·55
	99·69	99·88
Total alkalies	4·09	2·24

Amount of carbon present.

The amount of carbon present was determined in No. IX. and found to be ·26 per cent; all the iron was found to be present in the ferrous state. These two slates, as will be seen, contain the proper relative proportion of constituents for the formation of gneisses like these just described. No. IX. might, if submitted to the proper conditions for its metamorphosis, produce a gneiss similar, in a general way, to that from Trembling Lake, but poorer in sillimanite, while No. X. would crystallize into a gneiss like that from Darwin's Falls (No. VII.), but less quartzose.

In these gneisses which have been classed as of sedimentary origin, we have therefore rocks which have the chemical composition of shales or slates, a mineralogical composition quite different from that of the gneisses of Class I., and a structure which shows that they have been produced essentially by a process of re-crystallization. These facts, it is believed, taken together, establish the right of these rocks to be considered as altered sediments. The effects produced by the dynamic metamorphism are along the same lines as those observed by Heim in the Alps, the same force which crushes the highly crystalline rocks into finely granular schists, re-crystallizes the sedimentary rocks, often developing large individuals of various new minerals in them. It is not, however, claimed that all granulated rocks in the Laurentian are of igneous origin or that all re-crystallized gneisses are altered sediments.* If any arkoses or coarse felspathic sandstones were deposited with the shales, those being very similar to granite in character would probably be altered by crushing and granulation to gneisses almost identical in appearance, and under the microscope with those produced from granites; futher study may indeed show this to be the origin of some of the quartzose orthoclase-gneisses associated with the garnetiferous sillimanite-gneisses above described. It is also possible that certain igneous rocks have undergone a complete re-crystallization during metamorphism. It is desired in the present contribution to our knowledge of these rocks merely to show that certain of these gneisses have had a sedimentary origin, and that certain others can be recognized as altered igneous rocks, while very many still remain whose origin is, as yet, undetermined.

All granulated rocks not igneous.

Distinct from the little strings and veins of quartz which are often found cutting the rocks of this as of all other great districts of crystalline strata, are the well defined and often very thick bands of quartzite which occur regularly interbanded or interstratified with the gneiss and crystalline limestones of the district. Of these the following three occurrences may be selected as typical:—

Quartzites.

* See C. J. Smyth, Jr., Metamorphism of a Gabbro occurring in St. Lawrence County, N.Y. Am. Jour. Sci., April, 1896, p. 280.

Garnetiferous Quartzite—About one mile west of the Church of St. Jean de Matha, Seigniory of De Ramsay. (Sections 573, 661).

Garnetiferous quartzite.

This rock occurs interstratified with and overlying the garnetiferous sillimanite-gneiss described on page 49 J, forming great exposures extending off to the north-west. One great cliff of these rocks, interstratified with garnetiferous quartzose gneiss, is represented in the photograph reproduced in Plate III. The beds, as will be seen in the photograph, are practically horizontal.

The quartzite is of medium grain and brownish-gray colour, and holds numerous garnets, often as much as an inch in diameter. Bands richer or poorer in garnet or showing other slight differences in character alternate with one another. Under the microscope the rock is seen to consist essentially of quartz and garnet. Sillimanite is present in considerable amount with accessary orthoclase, plagioclase, biotite, and rutile. The indistinct foliation of the rock is caused by the arrangement of the various constituents with their long axes in one direction.

St. Jean de Matha.

The quartz consists of larger grains with streams of little ones running between them, almost every large grain showing well marked strain shadows. It presents the appearance of having been crushed or granulated, the broken material often sweeping in curves around the large garnets. The garnets are isotropic and hold many inclusions of quartz, sillimanite, and rutile. The sillimanite occurs in the long and slender individuals, with parallel extinction and small axial angle already described from the associated gneisses. The rutile is brown in colour, a single elongated individual often penetrating several grains of quartz. The felspars and biotite do not occur in all sections.

Although no augen of quartz are seen, for this mineral, as has been shown, does not usually develop augen on crushing—the rock presents the appearance of having been greatly crushed.

Quartzite—Darwin's Falls, near the Village of Rawdon, Township of Rawdon. (Sections 633, 635.)

Darwin's Falls.

The rock occurs in beds or bands, from a few inches to several feet in thickness, regularly interstratified with the garnetiferous sillimanite-gneiss described on page 56 J. Some of the bands are highly garnetiferous, others are free from garnet, while others again contain a considerable amount of felspar. Under the microscope the rock closely resembles that just described from west of St. Jean de Matha. It consists of quartz, with small quantities of orthoclase and garnet and accessary biotite, rutile, zircon, ilmenite, leucoxene and pyrite. The rock is seen to be foliated owing to the presence of a few little lines of felspar grains running through it in one direction, and it may be considered as a very quartzose variety of the associated gneiss above referred to.

The quartz consists of larger grains, surrounding which and running into them in irregular bays and arms, are areas consisting of much smaller quartz grains. The large grains show strongly marked pressure phenomena when examined between crossed nicols, being divided into areas differing slightly in orientation, although the continuity of the grains is preserved. It contains great numbers of minute black hair-like and dust-like bodies, the former quite straight, which traverse the rock in somewhat wavy lines and in a direction nearly at right angles to the foliation, passing from one grain into another without deviating from their course, and were evidently developed after the rock had its present texture. The orthoclase is present in small amount, and frequently shows strain shadows. Its appearance suggests granulation, although there are no augen remaining to prove this. The garnet is present in the form of more or less rounded grains, often somewhat elongated in the direction of the foliation. It is isotropic, and as usual holds a few inclusions consisting of the other minerals of the rock. The other constituents possess the usual characters. On the whole the evidence, while not conclusive, goes to show that the rock has undergone a granulation previous to the crystallization of the garnet, or in which the garnet was not broken. Professor Rosenbusch believes that in some of these Rawdon quartzites original clastic quartz grains with enlargements due to the deposition of secondary silica can be detected.

Quartzite—Pont de Dalles, River L'Assomption (Section 667).

This locality is rather over a mile to the east of Ste. Béatrix. The rock occurs interstratified with several varieties of gneiss, some of them holding raspberry-red garnets as much as two inches in diameter. It is composed almost exclusively of quartz in elongated grains, giving a foliation to the rock. A few grains of garnet and a few scales of graphite can be detected by the unaided eye. While under the microscope, orthoclase, sillimanite, rutile and zircon are seen to be present in small amount as accessary constituents. The weathered surface exhibits numerous scolithus-like holes, which, however, are not continuous for any considerable distance, and are found on examination to be due to the weathering out of garnets. The flattened quartz

Pont de Dalles.

grains have as a general rule an extinction making an angle of 40° to 45° with their long axes, and contain the same dark inclusions described in the quartzite from Darwin's Falls, similarly arranged. The grains come together along irregular serrated lines and show a marked uneven extinction, although little or nothing in the way of actual granulation can be detected.

Crystalline limestone.

The petrography of the Laurentian limestones, so far as these can be studied macroscopically, has been exhaustively treated by Sterry Hunt in his Report on the Laurentian Limestones of North America.* The limestones of the district at present under consideration differ in no way from those of other Laurentian districts described in the report in question. They are usually comparatively pure and only a few of the fifty-four minerals described by Hunt as occurring in the Laurentian limestones have been recognized in them. Of these graphite, mica, pyroxene, serpentine and quartz are most frequently seen. They are usually rather coarse in grain, never very fine-grained or compact and where exposed to the weather disintegrate into masses of calcite grains resembling coarse white salt in appearance, or else are dissolved away by the rain leaving smooth undulating surfaces. Considerable quantities of the disintegrated limestone occurs on some of the islands in Trembling Lake. Although white or nearly white on a fresh fracture, these limestones, like those of other parts of the Laurentian, often weather black, apparently owing to the growth upon exposed surfaces of a very minute black lichen.

Effect of weathering

The limestone usually possess a more or less distinct banding due to the presence in varying quantities of one or more of the accessary minerals present, and are, as has been before mentioned, usually associated or interstratified with bands of rusty-weathering garnetiferous or sillimanite-gneiss having the composition of ordinary argillaceous sediments, or with bands of quartzite.

Associated sedimentary gneisses.

Serpentine is not usually abundant in the limestones of this area, and no trace of Eozoon has been found.

The limestone from two localities was submitted to microscopical examination.

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* Report of Progress, Geol. Surv. Can., 1863-66, reprinted in the Report of the Regents of the University on the New York State Cabinet of Natural History for 1867, Appendix E.

Crystalline Limestone—Township of Rawdon, Range X., Lots 27 and 28 (near lime-kiln)—(Sections 632, 636).

These exposures are among the largest in the whole area and have already been referred to on page 27 J. The rock is well banded, some bands consisting of a white and almost pure limestone containing only a few scales of mica, while other bands are filled with grains of dark-green serpentine. In some of these serpentinous bands the serpentine is present in the form of large lumps, and on breaking open a number of these some were found to contain rounded cores of white pyroxene. These cores are readily detached from the inclosing serpentine by the tap of a hammer and fall out leaving hemispherical depressions. They are precisely like those described by Merrill* in the serpentine of Montville, New Jersey, and clearly show that the serpentine in the limestone has originated from the alteration of grains and lumps of pyroxene originally present in it. The vexed question of the origin of the Laurentian serpentines is, therefore, so far as this occurrence is concerned, clearly answered. Rawdon. Serpentine altered pyroxene.

Under the microscope (Plate V., Fig. 4) the rock is seen to consist of calcite, with serpentine in rounded grains, varying in amount in the different sections, and a few scales of mica. The calcite forms a mosaic of grains of uniform size, having sharp well defined boundaries, with no intervening lines of smaller grains or other evidences of granulation. It presents the usual optical characters of the species, with the rhombohedral cleavage and often the twinning according to $-\frac{1}{2}$ R. The grains possess a uniform extinction. The serpentine is very pale green, almost colourless, in the sections, and occurs in rounded forms showing aggregate polarization. It contains, however, no cores of pyroxene, the alteration being complete in the case of these small grains. The serpentine is sharply bounded against the calcite, but the serpentine grains do not possess crystalline outlines, their borders being always curved and their outline sometimes nearly circular. A serpentine grain is often completely inclosed in a single calcite individual. In No. 632, the serpentine grains are for the most part small and are arranged in the form of little rings embedded in the calcite and filled with grains of the same mineral. These evidently result from the alteration of groups of pyroxene grains similar to those described below in the limestone from the River L'Assomption. The mica, which does not appear in all the sections and is never abundant, occurs in rather large leaves, which are almost colourless, the light passing Microscopic character.

*Proceedings of the United States National Museum, 1888, p. 105.

through parallel to the cleavage having a faint brown tint It is uniaxial and negative and polarizes in brilliant colours, resembling closely the bleached biotites often seen in altered rocks. The extinction is occasionally slightly uneven. One striking fact in connection with the sections is that some of the calcite grains are clear and quite transparent while others are somewhat turbid owing to the presence of very minute dust-like inclusions. The same calcite individual is even in some cases clear in some parts and more or less turbid in others. This turbidity, when studied in connection with that exhibited by the calcite of comparatively unaltered limestones, such as certain beds of the Trenton, in which it is clearly seen to be derived from fragments of crinoids and other fossils about which clear calcite has been deposited in optical continuity, the outlines of the fossil fragments being frequently by no means sharp, is very suggestive of the derivation of this limestone from fossil fragments also. Against this supposition is the fact that the clearness or turbidity is usually confined to the special grain which exhibits it, instead of the grain possessing a turbid core with a clear margin, but it is nevertheless a phenomenon which merits a much more extended study than it has been possible to give it at this time.

Crystalline Limestone, River L'Assomption, about 4 miles from Lake L'Assomption. (Section 655.)

River L'Assomption

This occurrence which is exposed by the side of the River L'Assomption near the northern limit of the map has already been referred to on page 24 J. Under the microscope it closely resembles the limestone just described and consists of calcite in large grains showing no evidence of breaking, twisting or granulation, with a little pyroxene, serpentine and mica. While in places somewhat turbid, the calcite shows but little of that suggestive arrangement of the turbidity referred to in the case of the Rawdon rock. The pyroxene, which is colourless in the thin sections and pale green in the specimens, is arranged in little irregular groups or strings of small grains, much smaller than the calcite grains and which occasionally show crystalline outlines but are usually rounded in form. These groups are often completely inclosed in a single calcite individual. The pyroxene is biaxial, and shows the usual cleavages, and inclined extinction and is frequently partially altered to serpentine.

Class III.—Gneisses, &c., of doubtful origin.

In addition to the gneisses, etc., of classes I. and II., whose origin can be determined with a high degree of probability, there is a third class, comprising a large proportion of all the gneisses of the area whose origin is doubtful. Some of these resemble more or less closely the rocks of class I., while others bear a marked resemblance to those of cla s II. Chemical analysis would in the case of many of these gneisses, &c., throw much light on the question of the origin of the rock. Gneisses of doubtful origin.

A few of these rocks, representative of extended and widespread occurrences in various parts of the area, have been selected for description.

Quartz-Orthoclase-Biotite-Gneiss.—Township of Kildare, front of Range VII. (Section No. 352.)

This is a gneiss, gray in colour weathering white, which possesses a distinct foliation and occurs interstratified or interbanded with reddish orthoclase-gneiss, often in thin layers, forming large exposures where the road, running south-west from St. Ambroise de Kildare, crosses range VII. It is a very common variety of gneiss, occurring extensively in many parts of the area embraced by the present report.

Under the microscope, the rock is seen to consist chiefly of quartz and orthoclase. Biotite in small amount and a few grains of plagioclase are also present in each section. The orthoclase, which is present in large amount, is in the form of large grains separated by little strings or streams of smaller grains of orthoclase, all of which, instead of coming together along straight lines, have a crenulated outline. The large grains almost invariably show strain shadows, and the parallel position of the lines of smaller grains, is one of the elements which gives rise to the foliation of the rock. The quartz, in its mode of occurrence strongly resembles that described in the leaf-gneiss and in some augen-gneisses of class I., having for the most part the form of long and narrow leaves or laths much larger than the felspar grains, and whose position being parallel to that of the strings of small orthoclase grains above mentioned also serves to mark the foliation of the rock. These quartz laths, although running through the granulated orthoclase, show no signs of granulation, but consist of single individuals, occasionally broken across but showing no signs of pressure other than a slightly uneven extinction. Some of Kildare.

them are as much as sixteen times as long as they are wide, and sweep in curves around the larger felspars, while others consisting of single individuals have curiously irregular and even forked outlines. The leaves or laths are not elongated parallel to the vertical axis, their extinction generally making an angle of about 30° or 40° with the direction of their greatest length. The biotite occurs in the forms of small leaves, usually associated with the felspar, but sometimes embedded in the clear quartz laths, and arranged parallel to the foliation. It is the only iron-magnesia constituent present, with the exception of a little chlorite which in places results from its decomposition.

Miniature augen-gneiss.

The rock is thus a species of miniature augen-gneiss, and has evidently resulted from movements in a rock having the mineralogical composition of a granite or arkose.

Garnetiferous Quartz-Orthoclase-Biotite-Gneiss—Township of Brandon, Range X., Lot 4. (Section 662.)

Brandon.

The rock is rather fine grained and gray in colour, containing numerous rounded pink garnets up to a pea in size, pretty uniformly scattered through it. Under the microscope, it is seen to be composed essentially of quartz, orthoclase, biotite and garnet, the biotite being subordinate in amount, with plagioclase, sphene, iron ore and pyrite as accessary constituents. The foliation is due to the parallel arrangement of the little biotite leaves and to the existence of little strings of quartz running through the rock in a direction parallel to these.

The quartz has the form of irregular-shaped individuals, often in leaves, more or less curved and running with the foliation. These leaves sometimes consist of a single individual, sometimes of several individuals, but never of granulated material. Some small grains of quartz are also seen embedded in the felspar. The orthoclase, which is abundant, never exhibits more pronounced evidence of pressure than a slightly uneven extinction, even this is often absent, and the extinction is quite uniform. No evidence of granulation is seen, the several individuals coming together as in a mosaic, suggestive of re-crystallization. The biotite is in little leaves or rather large bunches. It does not sweep around the garnets, as is so often the case in similar rocks, but is often inclosed in grains of this mineral, which is evidently younger. It is deep brown in colour and pretty uniformly distributed throughout the rock.

Microscopical character.

The garnet, which is rather abundant, occurs in grains which are usually rounded, but sometimes sub-angular, and is quite isotropic.

It holds inclusions not only of the biotite, but also of orthoclase, quartz, sphene and other constituents, and presents the appearance of having grown around and inclosed them. The plagioclase is present in small amount, the twin lines not being bent or twisted. The rock shows no cataclastic structure or other marked evidence of pressure, either in the hand specimen or in the section, with the exception of a small eye of felspar associated with some apparently granulated material, indistinctly seen in the hand specimen, and which seems to be connected with a little pegmatite vein running parallel to the foliation.

Associated with this gneiss in the same series of exposures, which occur along the road between ranges IX. and X., are a variety of other gneisses and allied rocks, interbanded with one another and lying nearly flat. Some of these gneisses are highly quartzose, others are more basic, having the composition of a garnetiferous hornblende-gneiss. Some are the typical garnetiferous sillimanite-gneisses (Section 680) describedon page 51 J. Others again resemble amphibolites, while a few thin bands of a calcareous gneiss or very impure limestone, as well as a few of quartzite, are also present. Associated rocks.

These rocks, like that of section 662, while free from cataclastic structure and presenting an appearance suggestive of a highly altered sedimentary series, have nevertheless been submitted to great pressure, and have been rolled out like a plastic mass, for associated and intercalated with them are many small bands of augen-gneiss, and leaf-gneiss occasionally holding little augen, which belong to the first class of gneisses already described and which are undoubtedly squeezed and crushed, possibly intrusive, granites.

Garnetiferous Hornblende-Gneiss—Township of Rawdon, Range VI., Lot 24. (Section 439.)

This gneiss, which is dark in colour and contains an abundance of rounded pink garnets scattered through it, occurs in large exposures interstratified or interbanded with a series of pyritiferous gneisses rich in garnet and often holding graphite, which, having been supposed to contain gold, are referred to in the section treating of Economic Geology, on page 148 J. Garnetiferous gneiss.

Under the microscope, the rock is seen to consist essentially of hornblende, garnet, orthoclase and plagioclase, with accessary pyroxene, biotite, pyrite, iron ore and apatite. Rawdon.

The hornblende, which with the garnet makes up most of the rock, is brown in colour and pleochroic in brown and yellow tints. The garnet is quite isotropic and holds inclusions of the hornblende, plagioclase, pyroxene, pyrite, iron ore and apatite. The orthoclase and plagioclase are present in about equal amount, and taken together are present in about the same proportion as the hornblende. The pale-green pyroxene occurs in small quantities associated with the hornblende, and is in part monoclinic and apparently in part rhombic. The rhombic pyroxene is partially altered to serpentine.

The felspar individuals are smaller than those of most of the other constituents, and often form a mosaic showing no very pronounced pressure effects, but elsewhere occur as lines of smaller grains about and between larger ones, in a way suggestive of granulation, actual "augen," however, are not seen. It is difficult to determine whether the hornblende and pyroxene have been produced by re-crystallization or not: they certainly have not undergone much granulation, while the garnet which makes up a large part of the rock is certainly a product of re-crystallization. The comparative absence of pressure effects, in the case of the iron magnesia constituents, as compared with the felspars, may indicate that the former in their present form originated during the pressure, or that during the movements induced by the pressure, the felspars gave way more readily, allowing the movements to be effected chiefly through their disruption. Gneisses containing such a large proportion of hornblende are not common in the Laurentian of this area.

Quartz-Orthoclase-Gneiss (Granulite)—Township of Brandon, Range VIII., Lot 22. (Section 574.)

Granite.

Another variety of gneiss which is very common in this region, and which is seen in many parts of the township of Brandon and elsewhere, resembles in many respects certain of the Saxon granulites, being reddish, fine-grained and nearly free from iron-magnesia constituents. It is, however, as a general rule, free from garnet, which is so characteristic as an accessary constituent to the Saxon granulites. The minute structure is different from, but perhaps related to, that of the gneiss of Trembling Mountain described on page 42 J. As a typical locality, lot 22 of range VIII. of Brandon, may be selected.

Brandon.

The rock here occurs in bed-like masses interstratified with thin bands of quartzite and with some thick bands of the pyroxene-amphibolite described on page 73 J. The exposures are large and the beds or bands lie nearly flat. The rock is fine in grain and of a pale reddish or pinkish colour. It has a somewhat indistinct foliation and is uniform in character over large exposures.

Under the microscope it is found to consist, for the most part, of microperthite, the individuals of which are sometimes seen to be twisted, but not in a very marked manner. Quartz, sometimes in leaf-like forms, is present in smaller amount and shows similar though less marked evidences of pressure. A few grains of black iron ore, probably magnetite, a small amount of a chloritic decomposition-product derived from some bisilicate which has entirely disappeared, with a few little colourless rounded grains of zircon or possibly monazite, are the only other constituents of the rock. The minute structure differs from that of the Trembling Mountain rock in being fine in grain throughout, the larger individuals described in that rock being absent. It resembles, in fact, the fine groundmass of the Trembling Mountain rock, consisting of minute angular and more or less rounded fragments indiscriminately mixed together. Probably a crushed granite.

From a study of the sections, no decided proof can be obtained that this is cataclastic structure, but it is just the structure which would be produced if the process of granulation, described in the case of the Trembling Mountain gneiss as in progress, were completed, the original structure being entirely destroyed. If the banded character of the rocks of the district has been produced by a process of stretching or rolling out, the movements and concomitant granulation must have been very much more intense than was necessary to produce merely an indistinct foliation as in the Trembling Mountain rock; or the original rock may have been finer in grain. The evidence of pressure in the case of the orthoclase would, as has been shown in the case of the Trembling Mountain rock, be less marked in the finely granulated material than in the larger remnants, if any remained.

Therefore, although the rock may have been produced in some other manner, its minute structure is just such as would be caused by the intense crushing of a granite rock, and Professor Rosenbusch believes it to be merely a crushed granite.

Another class of rocks found associated with the orthoclase-gneisses in all parts of the area, but very abundantly in the township of Brandon and the adjacent parts of the eastern portion of the area, are pyroxene-gneisses and pyroxene-granulites. Pyroxene-gneisses and pyroxene-granulites.

These rocks differ from the orthoclase-gneiss in colour, being usually yellowish, brownish or black on the fresh fracture. Although usually indistinctly foliated, they are frequently nearly massive and uniform in character over large exposures, in this way differing from the usual run of the associated acid gneisses. Their constituent minerals cannot as a general rule be determined from the study of a hand specimen, but under the microscope the rocks are found to have a composition which varies but little.

Rhombic and monoclinic pyroxenes.

Pyroxene is always present as an essential constituent, both rhombic and monoclinic varieties usually occurring together. Hornblende, usually green but sometimes brown in colour, is sometimes but by no means always present. Biotite when present at all is very subordinate in amount. Plagioclase is usually the predominating felspar, but orthoclase is very often present as well, and is sometimes as abundant as the plagioclase. Magnetite, apatite and a few other accessary constituents occur in small amount.

Character of the rocks.

These rocks are very seldom coarse in grain, being generally rather fine-grained to nearly compact. They may be separated into two classes which, however, have no sharp dividing line and pass into one another by imperceptible gradations. One class would embrace the coarser grained varieties, which are usually somewhat poorer in the iron magnesia constituents and occur in large bodies, and which may be called pyroxene-gneisses. The other class comprises the fine-grained and nearly black varieties, which occur very frequently interbanded with granulite and other forms of orthoclase gneiss, in all parts of the area, and which from their resemblance in character and mode of occurrence to the "trap-granulites" or "pyroxene-granulites" of the Saxon granulite gebirge may be called pyroxene-granulites.

Quite distinct from normal granulites.

This latter name has certain disadvantages,* among others the fact that the rock bears no resemblance to true granulite, but as the name already has a status in petrographical nomenclature from the thorough description which has been given of the petrographical character and mode of occurrence of the rock in the Saxon granulite gebirge, as well as owing to the circumstance that every other name already in use and which might be applied is attended with equally great objections, it will here be employed to designate the rocks in question. These pyroxene-granulites when they become rich in hornblende and poor in orthoclase might be termed pyroxene-amphibolites.

As typical examples of these pyroxene granulites and pyroxene amphibolites the following rocks may be taken.

* See Zirkel, Lehrbuch der Petrographie, vol. III., p. 251.

Pyroxene-Amphibolite—Range VIII., Lot 22, Township of Brandon. (Section 571.)

In the hand specimen, the rock is seen to be rather fine in grain, nearly black in colour, and to possess an indistinct foliation, with occasional narrow bands in which one or other constituent predominates. Pyroxene-amphibolite, Brandon.

It occurs in thick bands interbanded or interstratified with the granulite described on page 70 J.

Under the microscope, the rock is found to consist essentially of hornblende, pyroxene and plagioclase felspar, with a small amount of orthoclase felspar and a little magnetite, apatite, and probably a few grains of quartz. The hornblende is deep brown in colour and strongly pleochroic, and is present in large amount. There is no evidence that it has been derived from the pyroxene and it often occurs in comparatively large individuals. The pyroxene, which is also present in large amount, is in part hypersthene, showing the usual pleochroism in yellow, red and green tints and a parallel extinction. Some monoclinic pyroxene is also present. None of the constituents have even an approximately idiomorphic development. All are in irregular-shaped grains.

The foliation, which is parallel to the banding, is indistinctly seen in the thin sections, but there is a development all through the sections of granulated material in little strings or streaks running in one direction. This is composed largely of plagioclase, but hornblende and pyroxene are also seen in a granulated condition, mixed with the plagioclase. Almost every one of the larger grains of plagioclase shows the effects of intense pressure, in well marked strain shadows, twisting of twin lamellæ and breaking into smaller grains. It is a fact of interest that, in this as in many similar cases, the hornblende and pyroxene, although in places granulated, do not when in large grains show uneven extinction, while what in ordinary light appear to be grains of plagioclase of similar size, invariably, when examined between crossed nicols, are seen to be crushed aggregate of small plagioclase grains. Microscopical character.

The examination of this rock under the microscope makes it certain that whatever the origin of the banding may be, the foliated structure is not original, but has been produced by movements in the rock which were accompanied by a granulation of its constituents. The hornblende may possibly be a secondary product.

Chemical composition.

A specimen of the rock analysed for me by Mr. Walter C. Adams, B.A.Sc., was found to have the following composition :—

XI.

Pyroxene-Amphibolite—Township of Brandon.

	Per cent.
Silica	49·76
Alumina	17·53
Ferric oxide*	10·62
Manganous oxide	·36
Lime	10·57
Magnesia	7·96
Soda	3·05
Potassa	·80
Loss on ignition	·34
	100·99

It is thus identical in composition with many gabbros and diabases.

This rock passes over on lot 19 of range VII. into a pyroxene-granulite (section 561) free from hornblende, and consisting of pyroxene, plagioclase and orthoclase, with a considerable amount of iron ore scattered through the rock, and usually associated with the pyroxene. It is nearly massive, a foliation being merely indicated by the presence of a few parallel strings somewhat coarser in grain than the rest of the rock. In this rock also the constituents show evidence of much twisting and present an uneven extinction. The felspar has undergone a certain amount of granulation. The sections show that the rock has been subjected to a certain amount of motion as a result of pressure ; but whether this motion has been very great, cannot be decided from their study alone.

Pyroxene-Granulite—Range VI., Lot 13, Township of Brandon. (Section 684.)

Pyroxene-granulite Brandon.

Occurs interstratified with granulite, the whole being cut transversely by pegmatite masses which have been crushed to an augen-gneiss, the foliation of which coincides with the banding of the series (see Figs. 4 and 5).

The rock has an indistinct foliation when seen in large exposures, but no foliation can be noticed in hand specimens. It is dark in colour and rather fine-grained.

*All the iron is calculated as ferric oxide.

FIG. 1.

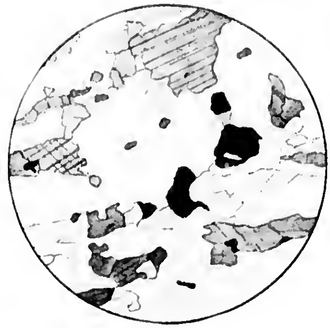


FIG. 2.

FIG. 3.

FIG. 4.

PLATE V.

FIG. 1.—PYROXENE-GRANULITE, RANGE VI., LOT 13, TOWNSHIP OF BRANDON—Plagioclase, Pyroxene and Iron Ore. × 29.

FIG. 2.—PYROXENE-AMPHIBOLITE, TREMBLING MOUNTAIN—Hornblende, Pyroxene, Plagioclase and Iron Ore. × 29.

FIG. 3.—PYROXENE-GNEISS, ST. JEAN DE MATHA—Pyroxene, Felspar and Iron Ore. × 30.

FIG. 4.—SERPENTINE-LIMESTONE, RANGE X., LOT 27, TOWNSHIP OF RAWDON—Calcite (in places twinne[illegible] and Serpentine. × 11.

It is composed of pyroxene, which is for the most part augite, pale-green in colour and with barely perceptible pleochroism, together with plagioclase and a good deal of iron ore. There are also a very few grains of pyrite. The rock contains no hornblende, biotite or orthoclase. The structure is allotriomorphic, and although the felspar shows faint indications of strain the pyroxene is never granulated, and the rock looks as if it had been crystallized *in situ* (Plate V., Fig. 1).

The granulite (Section 685), which is interstratified with it does not form continuous bands, but thins away when followed along the strike. It is composed of quartz and orthoclase, and has an appearance which is highly suggestive of extensive granulation, for although all the grains are small, there are often smaller ones which appear to have been formed by the breaking down of the larger, and in a few places the peripheral granulation of the orthoclase could be observed. That both rocks must have undergone a decided rolling out under pressure, in the direction of the bands, is proved by the conversion of the inclosed pegmatite veins into an augen-gneiss with a foliation in this direction.

Pyroxene-Granulite—Range VIII., Lot 12, Township of Brandon, (Section 683),

Forms a large mass which is the northerly continuation of the occurrence last described. It shows, however, distinct differences in mineralogical character, proving that the rocks of this class vary somewhat in their nature from place to place, even in the same masses. The augen-gneiss and granulite are here absent.

The pyroxene is pale-green in colour as before, but most of it is rhombic in character, with strong pleochroism in reddish and greenish tints and parallel extinction. An untwinned felspar which is probably orthoclase is also present, and is more abundant than the plagioclase. Very small amounts of hornblende, biotite, pyrite and zircon are also found, as well as a considerable amount of apatite in rather large individuals. Iron ore occurs in rather large amount, often partly inclosing the pyroxene, as is frequent in these rocks. The appearance of the rock under the microscope, is suggestive of granulation.

Pyroxene-Granulite—Range VIII., Lots 9 and 10, Township of Brandon (Section 356).

This rock forms large exposures about one mile to the east of the occurrence last described. The rock is here fine grained, very uniform and nearly massive. It is never banded, and in places no foliation

Other pyroxene-granulites from Brandon.

can be detected. Between these exposures and those last described the pyroxene granulite is associated with granulite plainly derived from a granite by crushing, as it frequently contains remnants or augen of as yet uncrushed orthoclase. The rock is composed of rhombic pyroxene and plagioclase with some orthoclase (untwinned), but also contains much hornblende and biotite. A small amount of augite may also be present. Iron ore, pyrite and apatite are accessary constituents. The hornblende, which is green in colour, is about equal to the pyroxene in amount, and the biotite to about one-half the amount of either. All three minerals are intimately associated. There is no evidence that the hornblende or mica are secondary, although the mode of occurrence of the latter suggests that seen in certain contact rocks such as hornstones. The plagioclase is broken and twisted in places and the rock looks like a granulated one, but if so there are no large remnants left.

Pyroxene-Granulite—Range IX, Lot 16, Township of Brandon, (Section 682).

Other pyroxene-granulites from Brandon.

This rock, which in the field closely resembles the last two, occurs rather over a mile to the west of No. 683, which it closely resembles also in composition and microscopical character, and from which it is separated by bands of granulite and other varieties of gneiss. It contains large intercalated masses of augen gneiss, whose foliation coincides in direction with the banding of the whole series.

The pyroxene is chiefly rhombic, but monoclinic pyroxene is also present. Both minerals are pale-green in colour, and can be distinguished only by their optical properties. The rhombic pyroxene (probably hypersthene) shows the regular pyroxene cleavages with parallel extraction in sections parallel to the vertical axis. Prismatic sections exhibiting the cleavage parallel to $\infty P\bar{\infty}$, when examined in convergent light show this to be the plane of the optic axes. The mineral is distinctly trichroic. $\mathfrak{a}$ = red, $\mathfrak{b}$ = yellow, $\mathfrak{c}$ = green. The monoclinic pyroxene is not pleochroic, has a higher double refraction and shows an inclined extinction.

The plagioclase and an untwinned felspar, probably orthoclase, are present in about equal amount. Biotite and green hornblende occur in very small quantity, associated with the pyroxenes. A few grains of pyrite and apatite are present in each section, as well as some iron ore, which usually incloses grains of pyroxene—a peculiar mode of occurrence often found, however, in these rocks. (See page 79 J.)

None of the constituents have good crystalline form. The foliation is produced by the arrangement of the pyroxene grains with their longer axes in one direction. Almost every grain of felspar shows strain-shadows or fractures. It is difficult to say whether the peculiar granular character of the rock has been produced by movements or not. The pyroxene does not show any evidence of granulation although it occasionally shows strain-shadows. Under a low power, however, the sections exhibit an appearance of extensive granulation and suggestive of the possibility of the rock having been deformed by the granulation of the felspar with a certain movement of the pyroxene individuals through the granulated mass. Origin of structure.

Separated from the pyroxene-granulite on the east by a mass of very rusty-weathering gneiss, and associated with granulite proper, is another rock resembling the one here described in appearance, but which is, in places, rich in garnet. A section (No. 686) of the garnetiferous variety, however, showed the rock to be composed essentially of red garnet and dark green hornblende with some pyroxene. The garnet is quite isotropic and felspar is absent.

Pyroxene-Amphibolite—Trembling Mountain. (Section 536.)

In describing the geology of Trembling Mountain (see page 42 J) it was mentioned that the existence of thin bands or stratiform masses of a black pyroxene-amphibolite at long intervals interrupted the uniformity of this great mountain-mass of granulated gneiss. Pyroxene-amphibolite. Trembling Mountain.

This pyroxene-amphibolite is identical in character with some of the pyroxene granulites just described. It consists essentially of hornblende, pyroxene and plagioclase, with very small amounts of iron ore, apatite and biotite as accessary constituents. The hornblende is green or sometimes brownish-green in colour and strongly pleochroic, as in the associated gneiss. The pyroxene, which is chiefly rhombic in crystallization, is not quite so abundant as the hornblende. The plagioclase is present in large amount and in well twinned grains. There is no evidence that the hornblende has been derived from the pyroxene.

Although in the hand specimens the rock looks more massive than the associated gneiss, when examined in thin sections under the microscope it is seen to possess a distinctly foliated structure (Plate V., Fig. 2). None of the constituents have any approximation to an idiomorphic form, the rocks consisting of a mosaic of irregular-shaped grains. The felspar grains, while irregular in shape are about equal Microscopical character.

in all dimensions, and form a sort of groundmass, in which the hornblende and pyroxene, which have a tendency to assume elongated forms, are distributed as irregular, discontinuous, anastomosing strings.

This rock, although, from its existence in the foliated gneiss shown to have been submitted to enormous pressure and probably squeezed out by this into its present band-like form, affords no absolute proof of the granulation so well seen in the gneiss which incloses it. The felspar grains, nevertheless, may have been produced by granulation. The bisilicates often occur in little granules like those seen in the granulated anorthosites, although they usually assume the rather elongated forms, above referred to. It is in fact in all probability a granulated rock, although the absence of large remnants makes proof of this impossible.

It is probable that these occasional interrupted bands or elongated masses of pyroxene-amphibolite in the crushed granite represent basic secretions in the original rock, such as are found in granites in all parts of the world.

Pyroxene-Gneiss—St. Jean de Matha, near the church. (Section 358.)

Pyroxene-gneiss.—St. Jean de Matha.

The rock is dark-gray in colour and while distinctly foliated has a pretty uniform character over large exposures. In the thin sections it is seen to consist essentially of pyroxene, felspar and iron ore. Biotite and hornblende are present, but in very subordinate amount, together with a few grains of pyrite and apatite.

The pyroxene is in part hypersthene and in part augite, the relative proportion of the two varying in different sections, but the hypersthene on the whole preponderating. The hypersthene shows the usual trichroism in reddish, greenish and yellowish tints and is free from all schillerization inclusions. The augite closely resembles the hypersthene in appearance, but has an inclined extinction and is not pleochroic. The two pyroxenes are intimately associated.

Two felspars.

Two felspars are present in about equal amount. One is a well twinned plagioclase, presenting the usual characters; the other is an untwinned felspar, which is frequently observed in these rocks and which is in all probability orthoclase, its most noticeable characteristic being the appearance of pale bluish and brownish tints respectively, when between crossed nicols the section is turned slightly on either side from the direction of maximum extinction. The phenomenon appears to result from a slight dispersion of the bisectrices.

The iron ore, which is, after the pyroxenes and felspars, the most abundant constituent, is black and opaque, and when examined by reflected light often presents certain bands and spots differing slightly in lustre from the rest of the grain, which indicates the intergrowth of two sorts of iron ore probably differing in content of titanium, as described in the case of the Morin anorthosite. Its mode of occurrence, however, is very peculiar, being found in between the bisilicates generally in long, narrow grains, and often nearly or completely surrounding the latter (see Plate V., Fig. 3). It was in one case observed to have the form of a narrow band cutting across a pyroxene grain and continuous with a mass of iron ore on either side. It was evidently formed after the bisilicates had crystallized. The same phenomenon was observed in the case of certain anorthosites very rich in iron ore (see page 100 J). Distinct evidence of crushing, in the existence of augen or marked twisting of constituents, is absent, but the rock nevertheless looks as if it might have undergone a thorough granulation. Traces of this are, as usual, much more marked in the felspars than in the pyroxenes.

Intergrowth of iron ores.

Iron ore crystallized later than bisilicates.

A pyroxene-gneiss (Section 305), almost identical with that just described, forms large exposures in lot 16 of range XI. of the township of Brandon, between the Lac Corbeau and the second anorthosite band.

Pyroxene-Gneiss—Seigniory of D'Aillebout, about one mile N.E. o Range III. of the Township of Cathcart. (Section 299.)

This rock was chosen as a typical representative, not only of large exposures in the immediate district, but of the basic gneiss, intimately associated and interbanded with the red quartzose orthoclase gneiss, in very many widely separated parts of the area covered by this report. The rock is bluish on the fresh fracture, but weathers gray, and has an indistinct foliation coinciding with that of the associated quartzose orthoclase-gneiss.

Pyroxene-gneiss. D'Aillebout.

Under the microscope it is found to consist essentially of pyroxene and plagioclase. A considerable amount of untwinned felspar, some of it probably orthoclase, is also present, as well as a little hornblende, biotite, iron ore, pyrite, apatite and calcite. The pyroxene is for the most part hypersthene, identical with that in the rock last described. The hornblende, which is green in colour, is apparently derived, in part at least, from the alteration of this pyroxene. The iron ore, as before, is often found partially inclosing the pyroxene. The occasional presence of leucoxene as an alteration product indicates that it is a titaniferous variety. The calcite is secondary. In addition to the plagioclase, presenting the ordinary characters as seen in those gneisses, there are a number of individuals which are very clear and polarize brightly, resembling the secondary plagioclase often developed in crushed rocks.

Evidence of granulation.

As in the case of the pyroxene-gneiss just described from St. Jean de Matha, although there is no absolute proof of granulation, it is almost certain that the rock has been subjected to this process; strings of fine grains are everywhere seen in and about the larger grains, and the appearance is that of a granulated rock. Here again the evidence is principally seen in the felspars.

Pyroxene-gneiss in in Saguenay region.

Pyroxene-gneisses identical in character with those just described, as has been mentioned, are very abundant in the area embraced by the accompanying map, but especially in that part of it lying to the east of the Morin anorthosite. They are also found widely distributed in the Laurentian elsewhere, as, for instance, in the Saguenay district. They differ from the associated acid gneisses not only in composition but in having a darker colour (never red like the orthoclase gneisses), a more uniform character, and more massive appearance. They never contain quartz.

Common in Lower Archaean.

These pyroxene-gneisses and pyroxene-granulites, formerly thought to be very uncommon rocks, have in recent years been described from a great number of localities in all parts of the world, and will probably be found to be one of the constant elements of the lower Archaean wherever that is extensively developed. A brief review of these various occurrences, with full references to their literature, is given in a recent paper by Professor Judd.*

Origin of pyroxene.

The origin of these rocks is a question concerning which, even in the localities where they have been most thoroughly investigated, there have been great diversities of opinion. In the district in which pyroxene granulites were originally described, for instance, the granulite region of Saxony, Nauman believed them to be eruptive, Stelzner and others consider them to be metamorphic products, while Lehmann, who has made a more recent and very thorough study of them, considers the question of their origin as still an open one. The mode of occurrence of the pyroxene-granulite in Saxony and the intimate rela-

*The Rubies of Burma and Associated Minerals, their mode of occurrence, origin and metamorphoses. Phil. Trans., 1896, p. 192.

Also A. Lacroix—Contributions à l'étude des Gneiss à Pyroxene—Bull. Soc. Min., France, April, 1889.

tion which it bears to the normal granulite, the two rocks being connected by a complete series of intermediate varieties, points very strongly, in the case of the Saxon occurrences, to the origination of both rocks in the differentiation of an original igneous magma. The chief difficulty in considering the pyroxene-granulites of Saxony as differentiation products from the same magma that gave rise to the normal granulite, is the fact that they are practically massive and have been considered to show no evidence of crushing, while the accompanying granulite is seen to have been crushed and granulated in a very marked manner. Gneisses and granulites.

The pyroxene-granulites of the district embraced in the present Report, differ from those of Saxony chiefly in being a little coarser in grain and in possessing, as a general rule, a more or less indistinct schistose structure. Garnet also is a less frequent constituent. Saxon occurrences.

That these Canadian rocks, whatever be their origin, have been greatly compressed and rolled out like plastic masses (although no conclusive evidence of the fact can be seen in the minute structure of the rock) is placed beyond a doubt by the presence in them of sharply folded, crushed and foliated masses of pegmatite converted into augen-gneiss and leaf-gneiss by the pressure, the foliation running in one plane through the whole body of the rock and being quite independent of the position of the pegmatite masses. That the present attitude of the rocks was not their original one, is also plainly shown in Figure 8, where a dark-coloured pyroxene-gneiss, containing a good deal of quartz, is seen to lie as a series of sharp folds in a mass of leaf-gneiss. The axis of these folds is now the strike of the rock, but it is evident that the pyroxene-gneiss originally formed a band, dyke or arm in the lighter coloured quartzose orthoclase rock, running Crushed pegmatite masses.

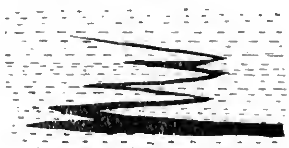


Figure 8.—Dark Pyroxene-Gneiss folded in a mass of Leaf-Gneiss, Range VIII., Lot 18, Township of Brandon. Scale 8 feet to 1 inch.

in a direction highly inclined or possibly at right angles to the present strike. This is by no means an isolated case or confined to this locality; the same phenomenon can be observed in very many places in this as well as in other Laurentian areas in various parts of the Dominion, and when the folds are longer and more compressed their resemblance to interstratified bands, especially in small exposures, is much more marked.

Microscopical character unlike that of gabbro.

The microscopic structure of the pyroxene-granulites, as a class, is quite distinct from that of the undoubted igneous rocks having the same mineralogical composition (the gabbros), but after the study of a large number of sections of these rocks from various parts of Canada, as well as from the Saxon granulite region, I am unable to see that their structure precludes them from being considered as granulated rocks, although no direct evidence of crushing may be afforded by them. The indications of granulation in the case of the Canadian rocks have already been referred to in the description of the sections.

Much light might be thrown on the origin of these peculiar rocks by a thorough study of their chemical composition, with a view to ascertaining whether they all, like the pyroxene-amphibolite from Brandon (No. 571), have the composition of gabbros and diabases, or whether some of them have a composition different from that of igneous rocks.

At present the origin of these Canadian occurrences must remain a matter of doubt, although the argument in favour of a metamorphic origin in the case of the Saxon rocks, from alleged absence of granulation and other pressure phenomena, does not, as has been shown, apply with equal force to the pyroxene-granulites of Canada.

Orthoclase-Scapolite-Pyroxene-Gneiss—Township of Rawdon, Range VII., Lot 20. (Sections 597, 630.)

Scapolite-gneiss.

This gneiss, which weathers to an exceedingly rusty colour, occurs in bands interstratified with a grayish-weathering, garnetiferous gneiss, traversed by many little veins of quartz. Across the road on the same lot is the band of garnet rock described on page 84 J. It is fine-grained, greenish-white in colour, and on a fresh fracture presents a finely-speckled appearance. As has been mentioned, it weathers very rusty and disintegrates so readily that it is difficult to obtain specimens which are really fresh. It has a very indistinct foliation.

Rawdon.

Under the microscope, it is seen to be composed essentially of orthoclase, pyroxene and scapolite, with accessary pyrite, pyrrhotite, graphite and sphene. The pyroxene, which is very pale green in colour, has the characters of malacolite. The scapolite is colourless, uniaxial and negative, with cleavages crossing at right angles on basal section, and parallel extinction in sections in the plane of the vertical axis. The sulphur, if calculated as pyrite, would show the presence of nearly four and a half per cent of that mineral, but, although much pyrite is present, there is a good deal of pyrrhotite present as well, the two minerals being intimately associated. These two minerals almost certainly represent a later impregnation, occurring, as they do, in little irregular-shaped masses, with minutely banded structure parallel to their sides, as if filling cavities. They are sometimes decomposed to hæmatite, the pseudomorphs being often remarkable in that they consist of a single individual. The ferric hydrate which stains the weathered surface of the rock is also derived from their decomposition.

Microscopical character.

The graphite occurs as little flakes, and is often intimately associated with the pyrite, suggesting some genetic connection in the case of the two minerals; as, for instance, the formation of the sulphides from the reduction of iron-bearing solutions through the agency of organic matter, a portion of which still remains as graphite. The sphene, which is seen in every slide, is pale brownish in colour, and occurs in more or less elongated grains lying in the direction of the foliation. It has the usual high index of refraction and high double refraction, with an extinction generally inclined at a small angle to the longer axis of the grain, and is often twinned. The rock presents the appearance of having been produced by a complete crystallization or re-crystallization of the various constituents *in situ*, the grains of felspar having sharp polygonal outlines, and the individuals of the several minerals fitting together like the pieces of a mosaic, no signs of granulation being visible.

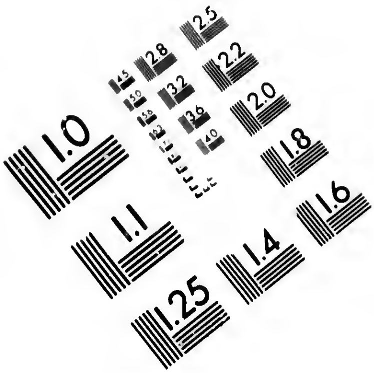
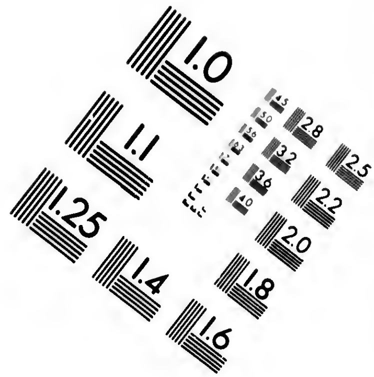
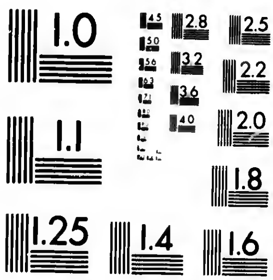
Chemical composition.

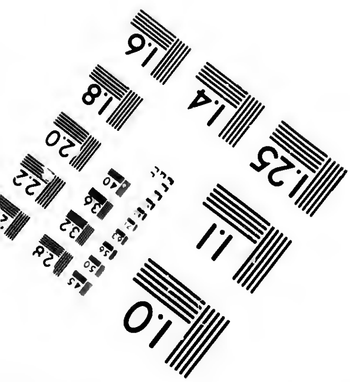
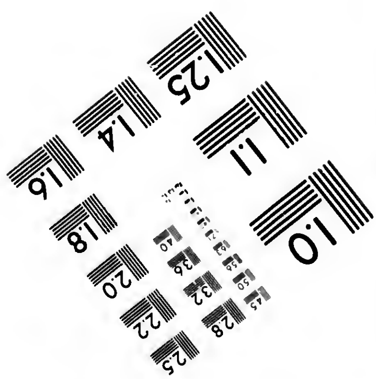
A specimen of this gneiss was analysed by Mr. Walter C. Adams, B.A.Sc., and was found to have the following composition:—

XII.—Orthoclase-Scapolite-Pyroxene-Gneiss—Township of Rawdon, Range VII., Lot 20.

	Per cent.
Silica	54·89
Titanic oxide	1·66
Alumina	13·67
Ferric oxide	1·35
Ferric sulphide	4·43
Manganous oxide	·62
Lime	5·63
Magnesia	4·70
Soda	1·95
Potassa	8·34
Water and graphite (by difference)	2·76
	100·00
Total alkalies	10·29

IMAGE EVALUATION
TEST TARGET (MT-3)

This gneiss, as will be seen, differs entirely in composition from any of those of which the analyses have already been given. The low content of alumina, combined with low silica, the high alkalies and the preponderance of lime over magnesia, mark it off as quite distinct from the slates and sedimentary gneisses before considered. If it be an altered sediment, it is one which has suffered very little leaching during deposition, and must have been of the nature of a tuffaceous deposit, or one formed from the rapid disintegration of an igneous rock having the composition of a basic trachyte or syenite. It is, therefore, a rock which, so far as its composition is concerned, might be either an altered sediment or an altered igneous rock; and it is impossible, consequently, to draw from its chemical composition any definite conclusions as to its origin. The graphite, however, points to a sedimentary origin.

Specimens of another band of gneiss (Section 385) similar in general appearance to that just described, and occurring near it, were found upon microscopic examination to differ from it in holding a considerable amount of garnet and plagioclase, as well as some quartz, but no scapolite. The pyroxene is very pale brown in colour, and the garnet, which as usual in the Laurentian gneisses is quite isotropic, holds as inclusions grains of the various other constituents of the rock.

Garnet rock

Intimately associated with the garnetiferous gneisses, and probably representing an extremely garnetiferous variety of them, are the bands of garnet rock described from two localities under the heading of Economic Geology (p. 150 J.)

At the first of these localities—the rear of lot 20 of Range VII. of the township of Rawdon—several bands of the garnet rock are found, the widest being about two feet thick. They occur interstratified with fine-grained garnetiferous gneiss and white quartzite. In some parts of the bed the garnet rock is almost pure, while in others it is seen to contain a little quartz, biotite or felspar. The purer portions (Sections 440, 654) when examined under the microscope are seen to consist almost exclusively of pink garnet. Some iron ore, with a little biotite, and in one section a grain of green spinel, are the only other constituents. The garnet occurs in very large individuals, which are isotropic and almost free from inclusions, with the exception of a few grains of biotite. The iron ore is black and opaque and occurs chiefly in the form of large angular grains. The surfaces of the garnet grains are often stained with a little ferric hydrate. The biotite and iron ore are inclosed in the garnet and have the appearance of having originated contemporaneously with it. In some sections (No. 654) a little plagioclase is present.

On lot 22, of range IX., of the township of Rawdon, a heavy band of granular brown pyroxene rock occurs, associated with garnetiferous graphitic gneiss and crystalline limestone. Owing to the fact that the exposures are not continuous, it is impossible to ascertain the precise width of the band, but it is probably about twenty feet wide. Pyroxene rock.

Under the microscope (Section 366) the rock is seen to be made up almost exclusively of a pyroxene, very pale pinkish brown in thin sections. The cleavage is imperfect and the mineral shows a very faint pleochroism, and in sections at right angles to an optic axis is seen to be biaxial, the axial angle being large. With this pyroxene is associated a colourless uniaxial and negative mineral, probably a scapolite, and a very few grains of pyrrhotite.

An analysis of the pyroxene gave the following results:—

XIII.—Pyroxene—Rawdon, Range IX., Lot 22.

	Per cent.
Silica	49·289
Alumina	8·388
Ferrous oxide	4·611
Manganous oxide	undet.
Lime	25·376
Magnesia	12·723
	100·387

The Anorthosites.

THE MORIN ANORTHOSITE.

Stratigraphical Relations.

As shown in the accompanying map, there is, in the region under consideration, one large area of anorthosite, constituting its chief geological feature, and several smaller occurrences of the same rock quite subordinate in extent. This large area will be referred to as the Morin anorthosite mass, from the township of Morin, which for the most part lies within it, while the smaller areas will be distinguished by similar local names, as the Lakefield area, the St. Jérôme area and so on. Morin anorthosite.

The Morin area consists of an almost circular mass of anorthosite, from the south-western side of which there proceeds a long arm-like extension. The mass has a diameter of about 37 miles, and, with the arm-like extension just mentioned, an area of 990 square miles. It is surrounded on all sides by the gneisses and associated rocks of Size.

Laurentian age, with the exception of the extremity of the arm, which extending much farther to the south than the rest of the area, runs underneath and becomes covered up by much more recent strata of Cambro-Silurian age (Potsdam and Calciferous) bounding the protaxis in this direction. The limits of the mass have been carefully traced out by myself, except where it crosses the townships of Howard and Montcalm, where the boundary had already been determined by Sir William Logan (See Atlas accompanying Geology of Canada, 1865), and in the southern part of Wolfe, where it had been traced out by Mr. Vennor. Along this portion of its course the boundary is a well marked topographic feature, the anorthosite rising as a cliff or abrupt line of hills from the rolling country underlain by the Grenville series. (See Plate I.) The exact course of the boundary across the very wild, unsurveyed and unsettled township lying to the north-west of the township of Lussier is uncertain. Its direction as laid down on the map, however, must be a near approximation to the correct one, as the country immediately to the north of it has been examined and found to be underlain entirely by gneiss.

Boundaries.

Character of anorthosite country.

The country underlain by this anorthosite, leaving out of consideration the arm-like extension above mentioned, is very hilly, the hills seldom rising to such height as to be properly designated as mountains, and while often rugged and precipitous still preserving the smooth flowing contours seen everywhere in the Laurentian in this part of Canada. Between these hills are valleys or plains, generally of no great size, occupied by drift, which valleys as well as the hill sides are year by year being cleared of their forest growth and converted into farms supporting a hardy population.

Scattered through these valleys are a great number of lakes, some of considerable size, where the North River and other streams take their rise, the waters of which eventually find their way into the Ottawa or St. Lawrence.

The highest hills in the area are those about Duck Lake in the township of Cartier, and those in the district about the Montagne Noire in the township of Archambault. On the whole, this anorthosite area is rather more rugged than that underlain by the surrounding gneiss.

Arm-like extension of anorthosite.

As has been shown on page 13 J, and as will be seen by consulting the map, the gneissic series through which this anorthosite has been intruded, is, so to speak, closely wrapped around the anorthosite mass, its strike for the most part following the sinuosities and curves of the contact; the most notable exception to this being along a portion of the southern boundary. Its foliation is thus evidently, in part at least, a secondary structure, induced subsequent to the intrusion of the anorthosite by great pressure, which pressure has affected the anorthosite as well—for the anorthosite, especially near the contact on the eastern side, possesses a distinct foliation coinciding in direction with that of the gneiss. The arm-like extension of the anorthosite through the gneiss to the south-east becomes somewhat wider as the plains underlain by the Palæozoic are approached, being divided longitudinally by a wedge of gneiss which runs into it from the south, and which with the anorthosite becomes covered up by the overlying Palæozoic rocks. The anorthosite of this arm, like the gneiss itself, dips to the west, being therefore on the western side overlain by gneiss. The angle of dip, however, varies much in different places.

Although in many parts of the circumference of the area, the anorthosite comes against the gneiss without producing any perceptible alteration, yet in some places, and especially between Shawbridge and Chertsey, a dark heavy rather massive rock, rich in bisilicates and often holding a little quartz and some untwinned felspar, borders the area and may possibly be a contact product of some kind. The boundary of the typical anorthosite against this intervening rock is usually pretty sharp, while the latter passes over gradually into the gneiss of the district. It is, however, difficult to decide whether this rock is to be considered as a peculiar and abnormal (possibly altered) variety of gneiss, or as a contact phase of the anorthosite. What is apparently the same rock, or a very similar one, occurs largely developed at the north-west corner of the area, between the typical anorthosite and the gneiss. Stratigraphical as well as microscopical evidence indicates that here it is a peculiar variety of gabbro, nearly or quite massive, but sometimes showing a *schlieren* structure. This breaks through the gneiss, but is apparently continuous with the rest of the anorthosite mass. Continuous exposures from one rock into the other, enabling the relations to be determined, have, however, nowhere been found, but the evidence goes to show that this gabbro forms part of the anorthosite area and is not a separate intrusion, although the transition is rather abrupt. Contact phase.

At a number of places near the limits of the area, especially about the dividing line between the rear ranges of Wexford and Chertsey, near the road to St. Donat, very large masses of orthoclase gneiss occur inclosed in the anorthosite, and afford additional proof, if any be required, of the intrusive character of the latter. Those occurring about the line between Wexford and Chertsey, lie approximately in the direction of the prolongation of the strike of the great tongue of gneiss which runs Gneiss inclusions.

up between the main mass of the anorthosite and the arm-like protrusion from it, and probably represent a former extension of the gneiss in this direction, shattered and invaded by the anorthosite.

Similar inclusions of gneiss are also seen near the margin of the Morin area in the rear of the township of Doncaster, being exposed on the road running south from Lake Archambault to Ste. Lucie, and along the River Ouareau where it crosses range VIII. of Chilton.

Pegmatite veins.

A very large mass of gneiss, some five miles long and two miles wide, is also inclosed by the anorthosite near the east side-line of the township of Chertsey.

The anorthosite is in many places penetrated by coarse pegmatite veins. These are especially abundant near the edge of the area, cutting both gneiss and anorthosite, so much so, that an approach to the boundary may often be surmised from their appearance in large numbers. These pegmatite veins, however, are by no means restricted to the margins of the area but are abundant in places near its centre. They are composed of quartz and orthoclase, often with a little iron ore, and are thus quite different from and apparently uninfluenced by, the composition of the anorthosite through which they cut. A number of other occurrences in the township of Wexford, which are probably of the same nature, were found to hold the same bisilicates as the anorthosite. None of the rarer minerals frequently found in such veins were observed, except one which occurs in the thin sections of a single specimen, and which resembles allanite

In the township of Wexford, along the road which runs south-west from Lac des Iles between ranges VIII. and IX., there is a great body of highly quartzose rock, much of it an almost pure quartzite, inclosed in the anorthosite. It extends along the road for about two miles, varying considerably in width, but near the lake being over a quarter of a mile wide. This mass may be an inclusion of gneiss, such as those referred to above, but much of the quartzite has an appearance suggestive rather of vein origin (Section 437).

Both the anorthosite and the gneiss are cut by numerous dykes of diabase and augite porphyrite.

In order to understand why Logan, and other good observers following him, regarded these anorthosites as constituting a distinct overlying series, a brief review of the grounds on which he based this view may here be presented.

Sir William Logan's views.

On working out the geological structure of the Grenville district, which district lies immediately to the west of that embraced in the present report, the two overlapping somewhat, Logan recognized three principal bands of crystalline limestone which he called the Trembling Lake band, the Green Lake band, and the Grenville band respectively. The limestone above mentioned as abutting against the anorthosite at St. Sauveur, was believed to be a portion of the Green Lake band, Sir William referring to the band as having been "interrupted" by the Morin anorthosite. Further to the north, in the township of DeSalaberry, he found that two of the limestone bands again came in contact with this anorthosite mass, one of them being this same Green Lake band and the other the Trembling Lake band. Sir William refers to this occurrence as follows (Geology of Canada, 1863, p. 838): "The higher of the two bands * * * is interrupted by a mass of anorthosite or labradorite rock which apparently covers it up. A similar phenomenon appears to occur in Morin (St. Sauveur), where the limit of the labradorite rock * * * immediately flanks the limestone band on the north," and goes on to say: "If, on exploration to the eastward of the Trembling Mountain, it should be farther ascertained that the two inferior limestone bands of the Grenville series disappear on reaching the margin of the anorthosite, it may be considered as conclusive evidence of the existence in the Laurentian system of two immense sedimentary formations, the one superimposed unconformably on the other, with probably a great difference in time between them."

A careful examination of this district in company with Dr. Ells, of the Geological Survey, has since shown, however, that one of the supposed interruptions really is not seen, the anorthosite mass mapped on the first range of the township of Grandison, and which was probably reported to Sir William by one of his assistants, having no existence, and that the drift is so heavy in this region that even if the other limestone bands did come against the anorthosite the contact could not be observed. A careful examination of the contact on the south-west corner of the area in the neighbourhood of the village of St. Sauveur, leaves little doubt that the limestone is really cut off by the anorthosite at this point. The limestone underlies a plain, protruding here and there in large exposures through the drift, whilst the anorthosite rises from this plain as a steep wall or cliff. The limestone is exposed 200 yards from the foot of the anorthosite wall, but the drift covering then becomes so thick that the character of the contact itself cannot be determined. Both to the east and to the west the associated gneiss is cut off in a similar manner.

Limestones are cut off by the anorthosite at St. Sauveur.

On the north-east side of the anorthosite area there was found, moreover, another limestone band which runs through Lake Ouareau, and

At Lake Ouareau.

forms in it a number of small islands. It is also well exposed on the south shore of this sheet of water. This bed disappears at the edge of the anorthosite a short distance from the south end of the lake, and no further traces of it are seen until what is probably its continuation appears again interstratified with the gneiss at the south-east corner of the anorthosite area.

In order to understand why Logan regarded the anorthosites as belonging to a sedimentary series, a fact must be borne in mind which will be referred to at greater length in considering the structure of these rocks, namely, that in places the anorthosite shows a more or less distinctly foliated structure, which structure was believed in accordance with the views generally accepted at that time to represent a partially obliterated bedding.

Sections from St. Jérôme to New Glasgow.

This is especially true of the anorthosite near its contact with the gneiss and is especially well marked in the long arm-like protrusion from the south-east corner of the area, which, as above mentioned, runs into the gneiss in the direction of its foliation, and finally, with it, becomes covered up by the overlying Palæozoic to the south. There is, moreover, at St. Jérôme a smaller isolated area of a more or less foliated anorthosite intercalated in the gneiss, and this was supposed by Logan, who from lack of time was unable to examine the whole area carefully, to form part of the great Morin area, which really terminates many miles to the north. Starting from a point to the west of St. Jérôme and going in an easterly direction across the strike of the rocks to New Glasgow, he passed from gneiss over the St. Jérôme anorthosite and then over a series of gneisses interstratified with quartzites and a band of crystalline limestone to the arm-like protrusion of the Morin anorthosite referred to above, which has a foliation parallel to the strike of the gneiss, and over it to gneiss once more. Misled by this section, which is here a most deceptive one, he concluded that the whole consisted of a great sedimentary series of anorthosites with interstratified quartzites limestones and gneisses, which series formed the southerly development of the anorthosites that he had observed interrupting the Grenville series in DeSalaberry and the other townships to the north. Accordingly, in Section No. 6 of the Atlas accompanying the Geology of Canada, this "Upper Laurentian" is made to include the limestone at St. Jérôme and to underlie the whole stretch of country from the supposed contact with the Grenville series at the River Gagnon to the west of St. Jérôme, south-eastward to the state of Vermont, although for the most part covered by newer strata. Instead of this we really have the

Grenville series with certain areas of the fundamental gneiss, continuous throughout the whole district embraced by the map accompanying the present Report, except where it is interrupted by intrusive masses of anorthosite. The foliation of the anorthosite, therefore, being now recognized as a distinctly dynamic phenomenon, and there being no evidence of any series of gneisses except the Grenville series and the fundamental gneiss in the district, this "Upper Laurentian" series of Logan passes out of existence.

Logan's "Upper Laurentian" has no existence.

Petrography of the Morin Anorthosite.

The earlier geologists who first explored the great stretches of Laurentian rocks underlying various parts of the Dominion, in many widely separated districts met with enormous masses of a rock differing entirely from the common orthoclase rocks which make up the greater part of the Laurentian system. This rock was composed principally and sometimes exclusively of plagioclase felspar, but often varied considerably in structure from place to place, being sometimes massive, sometimes schistose, sometimes coarse and sometimes fine in grain.

Petrography of Morin anorthosite.

These rocks they called anorthosite. In the Geology of Canada, (p. 22) Sterry Hunt refers to the rock in the following words: "Since all these varying triclinic felspars are anorthic in crystallization, and approach more or less to anorthite in their composition, Delesse thus proposed to designate them by the common name of anorthose, as distinguished from orthose or orthoclase, and the rocks characterized by their presence as anorthosite. In accordance with this we have adopted the generic name of anorthosite for these rocks."

The name anorthosite.

This term anorthosite has often been misunderstood, having been confused with anorthite and supposed to designate a rock consisting of anorthite, a felspar which rarely occurs in these rocks. The word "anorthose" suggested by Delesse, is synonymous with the word plagioclase, which has now supplanted it in common usage, and consequently the term anorthosite simply means "plagioclase rock," a designation which serves both to define its composition and to emphasize the difference between these anorthosites and the predominating orthoclase rocks of the rest of the Laurentian region.

The place of this anorthosite is in the family of the gabbros, where it occupies a position at one extremity of the series corresponding to that of the pyroxenites at the other extremity. An ordinary gabbro when it becomes very rich in felspar passes into an anorthosite; when, on the other hand, the felspar decreases in amount, so that the

Composition of anorthosite.

pyroxene predominates largely, a pyroxenite results, while if in the case of an olivine gabbro the pyroxene decreases in amount, leaving plagioclase and olivine as the essential constituents, a troctolite results.

Almost pure plagioclase.

Hunt has estimated that three-quarters of the anorthosites of Canada do not contain over five per cent of minerals other than plagioclase.

This anorthosite, which occurs not only in Canada, but in Norway, Russia and other countries, constitutes a well defined rock type, and one which, not only on account of its peculiar composition, but also owing to the enormous size of the masses in which it occurs and the constancy of its character, occupies an important position in the petrographical series.

The anorthosite of this Morin area exhibits a great variation in structure and colour and in certain places even a considerable variation in composition, but is in mineralogical composition a gabbro or norite free from olivine and very rich in plagioclase. Hand specimens from about fifty different places in the area have been sliced and microscopically examined, and the following description of these rocks is based on the results thus obtained. The number of minerals which the rock contains is not large, the variations in composition resulting principally from their irregular distribution. The following minerals have been observed in the rock :—

Minerals occurring in Morin anorthosite.

Plagioclase	Muscovite and Paragonite	Epidote
Augite	Bastite	Zoisite
Hypersthene	Chlorite	Garnet
Ilmenite	Quartz	Zircon
Orthoclase	Magnetite	Spinel
Hornblende	Apatite	
Biotite	Calcite	

Of these plagioclase, augite, hypersthene and ilmenite are by far the most important.

Plagioclase.

As above mentioned, Hunt adopted the name anorthosite for these rocks on account of the great preponderance in them of plagioclase or anorthose. He considered the type which contains only felspar as the true anorthosite and estimated that three-fourths of the anorthosites in the Dominion did not contain over five per cent of other minerals.*

Like the other constituents of the rock, the plagioclase is quite fresh, showing but very rarely any traces of decomposition, and when it is not granulated (that is protoclastic or cataclastic in structure) presents

*T. Sterry Hunt—On Norite or Labradorite Rock, Am. Journ. Sc., Nov., 1869.

in hand specimens, almost without exception, a dark violet, but more rarely a reddish colour. This colour is still plainly visible in thin sections, although naturally much fainter, and is seen to be caused by the presence of an immense quantity of minute opaque black rods and extremely small opaque dark points, which give the mineral in thin sections a peculiar turbid appearance. The latter probably represent in part cross-sections of the rods, but are more usually round or slightly elongated individuals of the same substance as the rods and occurring with them. Vogelsang* estimated, in connection with his studies of the anorthosite of Labrador, that these inclusions amount to from one to three per cent of the volume of the mineral, and goes so far as to say: "Le nombre des microlites contenus dans un volume déterminé est susceptible d'être apprécié avec plus de précision; les résultats toutefois s'écarteront beaucoup entre eux, suivant l'échantillon qu'on aura choisi et le point dans lequel on l'aura examiné. Dans le labradorite violet figuré le nombre de microlites s'élève au minimum à 10,000 par millimètre cube; mais pour autres variétés jaunes et gris foncées le calcul m'a donné un nombre au moins dix fois plus considérable de sorte qu'il y avait ici, dans l'espace borné d'un centimètre cube plus de cent millions de petits cristaux étrangers." The larger rods are surrounded by a zone of clear felspar. Some inclusions are transparent, and have a reddish-brown colour resembling hæmatite; these appear in small scales which often show a somewhat distorted hexagonal outline. Objects which closely resemble the above mentioned rods are often seen, when very highly magnified, to be cavities, partly filled up by the dark material of the rods. These inclusions are pretty uniformly scattered through the felspar individuals, and not confined to certain places, nor present more abundantly in some places than in others, as is the case with the gabbros described by Williams† or by Judd.‡ Minute fluid inclusions may often be observed arranged in rows; in these there appears now and then a moving bubble. In one or two cases small cubes were perceived in them, and in one case it was thought that a double bubble could be recognized. In two or three localities the otherwise normal felspar contained but few of these inclusions, and consequently was almost white in colour. The nature and origin of these dark inclusions, which occur so frequently in the felspar and

Minute inclusions.

* Vogelsang—Archives Néerlandaise, T. III., 1868.

† G. H. Williams—Gabbro and associated Hornblende Rocks in the neighbourhood of Baltimore, Md.—Bull. U. S. Geol. Surv. 28, p. 21.

‡ J. Judd—Gabbros, Dolerites and Basalts of Tertiary age in Scotland and Ireland—Q. J. G. S., 1886, p. 82.

other constituents of the gabbro, in the most widely separated localities of the globe, have been frequently discussed.

Their character.

The inclusions are so minute that they cannot be isolated and chemically examined. Their form is not defined with sufficient sharpness and constancy to enable their crystallographic character to be determined. Some investigators have endeavoured to gain some information as to the nature of these minute bodies by observing their deportment when treated with concentrated acids, but the results obtained are contradictory. Judd (l. c.) found that they resist concentrated hydrochloric acid. Vogelsang (l. c.) treated a small piece of felspar from Paul's Island, Labrador, which contained them, with hot hydrochloric acid for four days. He found that the acid had strongly attacked the felspar, but could perceive no alteration in the needles, except that they had become slightly paler. Hagge,* however, found that in the same rock from Labrador all the brown scales were dissolved when treated with the acid for a time too short to effect a decomposition of the felspar. He considered that they were probably göthite.

Prof. Judd's examination.

Probably titaniferous iron ore.

They are evidently some iron compound, and the peculiar colour of the transparent individuals, taken in connection with the fact that, as will be shown under certain conditions, they unite to form small masses of titanic iron, leads to the belief that the view of Professor Rosenbusch is correct, namely, that they consist principally of titanic iron ore or ilmenite. The transparent ones have the form of the mineral known as micaceous titanic iron ore, which Lattermann† found intergrown with magnetite in the nephelinite of the Katzenbuckel. The peculiar colour of this mineral, moreover, resembles perfectly that of these inclusions. The diverse results which the several investigators have obtained in the matter of the solubility of these inclusions may perhaps be explained by the titaniferous iron ore in some hand specimens being richer in titanic acid than in that of others.

In this connection it must be mentioned that titanic iron ore is a mineral which is constantly found in these anorthosites in Canada, often in enormous quantities, so that it is considered as particularly characteristic of them, while in the Laurentian proper the iron ores, in the greater number of cases, contain no titanic acid. Lacroix,‡

* Hagge, Microskopiche Untersuchung über Gabbro and verwandte Gesteine, Kiel, 1871, S. 46.

† Lattermann in Rosenbusch Mass. Gest, p. 786.

‡ Lacroix—Contributions à l'étude des gneiss à Pyroxene, p. 141—Bull. Soc. Min. France, April, 1889.

who has investigated somewhat similar inclusions in certain Norwegian gabbros, which, however, are double refracting, thinks that they are pyroxene, especially as they frequently appear to be grouped together, forming larger grains which may be determined as belonging to this species: "Les grains en question semblent avoir attiré à eux les particules pyroxéniques en suspension dans le feldspath et les avoir incorporées à leur masse." It is quite possible that these inclusions so often found in gabbros and allied rocks, consist of the heavier minerals of the rock, in some cases pyroxene and in others iron ore, which were finely disseminated through the magma while the rock was crystallizing, or which, perhaps, separated, but as the several constituents crystallized. My best thanks are due to Professor Judd for a small collection of thin sections of typical gabbros and peridotites from the north of Scotland, which he has described and on which he has principally established his theory of "schillerisation." An examination of these revealed the fact that nowhere in them are the inclusions in the plagioclase so numerous and well defined as in the Canadian anorthosites. The peculiar arrangement of these inclusions in the Scottish rocks along cracks, fissures, &c., which Professor Judd has described, and which especially supports his theory of their secondary origin, is not observed in these Canadian rocks. Their inclusions are on the contrary distributed thickly and pretty uniformly through the whole felspar individual, generally indeed throughout the felspar of the whole rock. They disappear, as above mentioned, only when it has been granulated. This remarkable fact will be referred to again.

Schillerisation.

The uniform distribution of these inclusions does not prove that they are not schillerization products, for if the rock were completely schillerized these products might be quite evenly distributed in it. Only in a few places in this Morin area does the plagioclase exhibit that play of colours which is produced by these inclusions in the felspar from Labrador and elsewhere.

The plagioclase is almost invariably excellently twinned, according to both the albite and pericline laws, the two sets of twin lamellæ crossing one another at right angles in the thin sections. This twinning is apparently sometimes secondary and produced by pressure, as for instance when the lamellæ appear along a certain line or crack, or when they appear in places where the plagioclase individual is twisted.

In most cases, however, they are of primary origin. Frequently in the sections there are a few untwinned individuals of plagioclase which are probably cut parallel to $\infty P \breve{\infty}$ (010). But in certain hand-specimens there is a considerable percentage of untwinned felspar,

Twinning plagioclase.

resembling in all other respects the plagioclase which shows a well defined twin structure. In order to determine whether in these cases two felspars were really present, separations by means of heavy solutions were made, on material from three hand specimens from different localities, in the thin sections of which these untwinned felspars occurred in considerable quantity. Since, however, in a solution having a specific gravity of 2·67 all the constituents sank, these untwinned individuals cannot be more acid than labradorite, to which variety the remaining felspar likewise belongs. Similar occurrences of untwinned plagioclase have been often observed. Hawes*, who investigated some of them, gives an analysis† of an ordinary specimen of typical labradorite of St. Paul's Island and adds: "Some of the anorthosites described by T. Sterry Hunt in the Geology of Canada, 1863, were proved by his analyses to be composed of pure labradorite, and some sections of the same which he submitted me for examination were found to be composed of a multitude of small grains, none of which were twinned."

Composition of the plagioclase.

An examination was made of the well twinned plagioclase from two other localities. The first was a hand specimen of a typical anorthosite which is found five miles north-west of Ste. Adèle in the Morin district. Its specific gravity was between 2·65 and 2·67, and it had, therefore, also the composition of an acid labradorite, a fact confirmed by the values of the extinction-angle measured on a small fragment separated by means of Thoulet's solution. The second was from the village of Ste. Adèle itself, which lies at the corner of the Morin area. Here the anorthosite is porphyritically developed with large plagioclase crystals which are sometimes as much as four inches long. These had the following extinction angles: on $\infty P \breve{\infty}$ (010) $24\frac{1}{2}°$ to 26°, on O P (001) = 6°. An analysis of the bluish opalescent plagioclase from the Morin district will be found in the table of analyses given on page 130 J; here again the felspar is a labradorite.

The plagioclase of the anorthosite from these six different localities is, therefore, in all cases labradorite, and there is every reason to believe that the felspar throughout the whole area belongs to this variety. Although it is generally quite fresh, yet a partial decomposition was observed in one or two cases, where it is altered to a mixture of calcite, epidote and zoisite, as mentioned in the description of these minerals. A peculiar variety of the rock, having a saussuritic habitus, was observed at New Glasgow. This is an entirely local

* Hawes—On the determination of Felspar in thin Sections of Rocks. Proc. Nat Mus., Washington, 1881, p. 134.

† See table of analyses, p. 130 J.

occurrence connected with the small zones of disturbance which here run through the anorthosite. In thin sections of this rock, which is almost entirely composed of plagioclase, mixed only with a few small grains of iron ore, the plagioclase is seen to have undergone a peculiar alteration. The alteration product is a mineral usually having a fibrous structure, and occurs in the plagioclase in little spots. It has the optical character of a bastite or pseudophite, and the decomposed felspar resembles, therefore, to a certain extent that of Waldheim in Saxony, described as pyknotrope by Breithaupt. In another hand specimen of the same rock from New Glasgow, the felspar is changed into a colourless mineral which forms small feather-like clusters. It shows magnificent polarization-colours and has a distinct cleavage to which the extinction is parallel. The mineral possesses the optical properties of muscovite but may be paragonite, which cannot be distinguished from muscovite under the microscope, and is a more probable alteration product of plagioclase. Alteration product.

The augite is, with a few exceptions, generally present in much smaller quantity than the plagioclase, but is next to it the most abundant constituent. Rhombic pyroxene is present, however, in nearly, if not quite equal amount. The augite occurs in irregularly shaped grains of a light-green colour, which are either non-pleochroic or exhibit a scarcely perceptible pleochroism in greenish tints. In sections which are nearly parallel to the base, the typical cleavages characteristic of pyroxene are seen cutting each other almost at right angles. They are often intersected by a third more perfect cleavage which is parallel to $\infty P \infty$ (100) as shown by its position relative to the plane of the optical axes. In the prismatic zone the mineral shows an extinction-angle from 0° to 45°. Augite.

In many sections of the pyroxene, there are brownish-black tables or small black rods which resemble very much the inclusions in the plagioclase, above described. Where these occur they are frequently parallel to $\infty P \bar{\infty}$ (100); in other cases instead of being scattered throughout the whole individual they are confined to certain spots. The augite can often be observed to have grown around grains of iron ore. It is generally quite fresh, but in many hand specimens is decomposed. The products of decomposition consist sometimes of a finely granular mixture of chlorite, and a rhombohedral carbonate with occasional quartz grains, the whole constituting a gray almost opaque mass. In other specimens, the augite is changed into a yellowish bastite, which then fills up not only the space originally occupied by the augite, but also penetrates into the small fissures of the rock and forms thread-like veins and scales even in the felspar grains. In some specimens again it is converted into a mineral resembling serpentine. When both pyroxenes occur together in the rock, the augite is generally intimately associated with the rhombic pyroxene.

Rhombic pyroxene. Hypersthene. The rhombic pyroxene, which occurs so often in association with the augite, does not essentially differ from the latter as far as can be ascertained from its thin sections, either in index of refraction, in double refraction or in colour. It is however strongly pleochroic with the following colours:

$\mathfrak{a}$ = red, $\mathfrak{b}$ = yellowish green, $\mathfrak{c}$ = green.

The absorption is $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$, the difference between $\mathfrak{a}$ and $\mathfrak{b}$ being very small.

Its rhombic character, was established by the following observations in the case of a hand specimen from the township of Chilton, in which the mineral occurred in fresh condition and in larger quantity than usual. Sections parallel to the base showed the two cleavages of the prism which intersected almost at right angles, as well as a third more perfect set of cleavages, to which small black rods were often parallel. Since the direction of the extinction was also parallel to this latter cleavage, it must be in the direction of a pinacoid. In convergent light, there was seen on the basal section a bisectrix, but not an optic axis as n the case of a monoclinic pyroxene. When a section in which an optic axis appears was examined, the above-mentioned pinacoidal cleavage was found to be parallel to the plane of the optic axes. The pinacoid in question was therefore $\infty P \breve{\infty}$, that is to say it cuts off the acute prismatic angle as $\infty P \bar{\infty}$ does in the case of diallage. In sections which showed an optic axis and only one set of cleavages to which the small rods lay parallel, the cleavage was seen to be parallel to the plane of the optic axes.

In all sections which contain the mineral, many grains are found which show only one good cleavage to which the extinction is parallel.

In general it is like the augite quite fresh, in a few sections it appears, however, changed into bastite, and in a few others into a serpentine-like mineral. It sometimes contains the dark scales and rods so often found in hypersthene, but very often these are entirely absent. It is indeed a remarkable fact that in these Canadian rocks, the iron-magnesia minerals contain but a few of these inclusions, while the associated felspar is filled with them, the exact opposite being true in the case of the gabbros and associated rocks of the Scottish Highlands, which have been described by Prof. Judd.

Hornblende does not occur in the anorthosite of Morin except in a few places near the contact with the gneiss. In these cases it is always found in intimate association with the pyroxenes, in the form of irregularly defined grains generally about the border of the granulated masses of the pyroxene. It occurs as a general rule only in very small quantity. It is usually green in colour, but is often brown. It shows the cleavages, the small extinction angle, and the characteristic pleochroism of the species. In a hand specimen from the neighbourhood of the contact on Lake l'Achigan, the maximum extinction-angle was found to be 15° and the following pleochroism was observed : Hornblende

$\mathfrak{a}$ = greenish yellow, $\mathfrak{b}$ = yellowish green, $\mathfrak{c}$ = green.

The absorption was $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

In another hand specimen, quite close to the contact, about six miles north of New Glasgow, a brown hornblende was likewise found in small amount. The extinction-angle was 18°, with the following pleochroism :

$\mathfrak{a}$ = light brownish yellow, $\mathfrak{b}$ = deep brown, $\mathfrak{c}$ = deep brown, with the absorption as before, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

It also occurs in the peculiar rock which has been referred to above as a gabbro, which was found in a number of places between the true anorthosite and the gneiss.

Biotite never occurs in large amount, but is present rather frequently in very small amount as an accessary constituent. It is usually found with the iron ore or with the hypersthene, and shows characteristic brown colour, strong pleochroism and parallel extinction. Biotite.

The occurrence of muscovite or paragonite has been referred to in describing the plagioclase. Muscovite or paragonite

Chlorite occurs occasionally in small quantity as a decomposition product of pyroxene or biotite. Chlorite.

It is doubtful whether quartz ever occurs in the anorthosite as a primary constituent. It occurs, however, in small amount in the form of little grains scattered through the anorthosite on lot 36 of range VI. of the township of Wolfe, near the contact of the anorthosite with the surrounding gneiss. Again on the west side of the Achigan River, near New Glasgow, it is occasionally found in the anorthosite, and has the appearance of a primary constituent. Here again, however, the occurrence is near the contact with the gneiss, and it is certain that some secondary quartz is present as a decomposition pro- Quartz.

duct of the pyroxene, so that the quartz which has the appearance of a primary constituent may also be of secondary origin.

In the gabbro which occurs as above stated in many places between the typical anorthosite and the gneiss, quartz is quite frequent. But in this rock many facts point to the secondary origin of the quartz. It often occurs, for instance, in more or less sharply defined veins, made up of large individuals. When it occurs in the form of separate irregular grains, those extinguish uniformly, although they are often more or less fissured, but they are by no means so much broken as might be expected if they were primary ingredients in view of the extremely broken condition of the felspar and the other constituents of the rock.

Ilmenite and magnetite.

In nearly every section of anorthosite, some irregularly shaped grains of an opaque black iron ore are seen. These are usually few in number. The quantity of iron ore is considerable only in a few places, and as in these the percentage of pyroxene increases in the same proportion, the rock here assumes a very dark colour, so that it is often taken for an iron ore. These portions of the anorthosite rich in iron ores are only few and local, and they pass over into the normal gabbro of the area, which, as above mentioned, is very poor in iron ore.

If these iron ore grains are examined by reflected light, they are found to be black, and in a few cases they can be seen to be partly changed into a gray decomposition product, evidently a variety of leucoxene. This circumstance proves that the mineral contains titanic acid in considerable amount.

In three hand specimens from widely separated parts of the area, an intermingling of two iron ores was distinctly seen. In that from the township of Wexford, lot 7, range I., one of the above-mentioned localities where the anorthosite is rich in iron ore (Section No. 398), careful observation in reflected light showed the iron ore to occur partly as a bluish-black coarse-grained variety, and partly as a brownish black finely granular variety, both being irregularly intermingled and distinguishable only by reflected light.

When the section was treated for about half an hour on a water-bath with warm concentrated hydrochloric acid, the coarsely granular variety was entirely dissolved and the acid became strongly coloured with iron, while the finely granular variety was apparently not at all affected. There is here evidently an intergrowth of magnetite with ilmenite or at least with a titaniferous iron ore.

In another hand specimen (from the neighbourhood of Lake Ouareau) a similar intergrowth was observed; the grains had a banded appearance in reflected light, one variety crossing the other in a single or double set of interrupted bands. When the section was treated with cold concentrated hydrochloric acid for 48 hours, no effect was produced; but when treated with warm concentrated acid in a water-bath, one variety of iron ore was dissolved as before, while the other again remained undissolved. In this case the intergrowth is probably parallel to the face of an octahedron or rhombohedron. A similar intergrowth has been described in the iron ore of the Carrock Fell gabbro, and in the nephelinite of the Katzenbuckel,* except that in the latter case, the titanic iron ore occurs in the form of micaceous titanic iron ore, not as the coarse and opaque variety found in the above-mentioned rocks.

Intergrowth of different iron ores.

It has been the invariable experience in Canada, that the large iron ore deposits common in these anorthosite rocks, contain so much titanic acid, that it has been impossible hitherto to work them profitably. Recent experiments, however, lead to the hope that in the future some of them at least may be smelted with profit. (Appendix II.) In order to determine whether the iron ore which is disseminated in small grains throughout the whole rock was also rich in titanic acid, the iron ore of three hand specimens of the anorthosite from different parts of the area was separated and tested. In every case the mineral was but faintly magnetic and gave a strong titanic acid reaction.

Two specimens of iron ore from the pegmatite veins, which cut through the anorthosite and the gneiss at the contact of the two formations, west of St. Faustin, and therefore do not belong to the anorthosite, showed strong magnetism and gave only a faint reaction for titanic acid. The iron ore bed, a short distance west of St. Jérôme, in the orthoclase gneiss, also consists of magnetite and contains no titanic acid. We therefore find that these investigations confirm the conclusion that the iron ore of the anorthosite is very rich in titanic acid, while the iron ore of the Laurentian gneiss generally contains no notable quantity of this substance.

Titanium in iron ores of anorthosites.

In the variety of anorthosite very rich in iron ore from lot 7, range I., of Wexford, the evidence obtained from the thin sections, shows that the iron ore crystallized later than the pyroxene, as it can be observed frequently completely inclosing individuals of this mineral. The same fact was noted in the case of the pyroxene granulites. (See page 79 J).

Iron ores of gneisses usually free from titanium.

* Latterman, in Rosenbusch, Physiographie der Massigen Gesteine, p. 786.

Pyrite. A few small grains of pyrite often occur in the thin sections of the anorthosite. They are generally found associated with the iron ore.

Apatite. Apatite is seldom observed in the anorthosite. When it does occur it is in the form of more or less rounded grains. It is more frequently found in the varieties rich in iron ore in the township of Wexford and other localities, than in the normal anorthosite.

Calcite. Calcite was found in but two hand specimens. One of these was fresh, and contained a small amount of calcite which might possibly be a primary constituent. The other was from New Glasgow, and in this the calcite appears together with zoisite, epidote, etc., as a decomposition product of the plagioclase.

Epidote. The only locality where epidote occurs is also near the village of New Glasgow. It is found in several sections of the anorthosite from this place, along with chlorite and quartz, as a product of the alteration of the pyroxene, and as above mentioned with calcite and zoisite as a product of alteration of the plagioclase. In one or two places it also occurs in small bands, cutting diagonally across the anorthosite, following the line of small faults. The epidote is everywhere secondary.

Garnet. Garnet does not occur as a constituent of the normal anorthosite, but is often found near its contact with the surrounding gneiss. It has a pinkish colour, and is seen under the microscope in small irregular masses, which are often mixed with or completely surround the grains of iron ore. In the sections of the variety of anorthosite rich in iron ore from the township of Wexford, lot 7, range I. (and from other places above mentioned), a pale-pink garnet occurs forming a small zone of uniform breadth around every grain of iron ore or pyroxene where these would otherwise come in contact with the plagioclase. Between the pyroxene and the iron ore there is however no garnet. It is quite isotropic and has grown out from the iron ore or pyroxene into the felspar, against which it is bounded by sharp crystalline outlines. These zones of garnet are analogous to the zones of actinolite and hypersthene around the olivine of the anorthosite from the Saguenay River, and those which have also been described in olivine gabbros of many other localities.

Zircon. Zircon is not found in the normal anorthosite, but it occasionally occurs in this rock near its contact with the gneiss. It is seen only in small quantity, and especially in the peculiar contact variety which occurs, as above mentioned, in some places between the anorthosite and the gneiss. It was observed in this in many localities. It has the form of small stout prisms, always with more or less rounded edges, which are characterized by a parallel extinction, high refractive index and strong double refraction.

Spinel was observed in a single hand specimen, in the form of small rounded isotropic grains, deep green in colour, occurring as inclusions in plagioclase and pyroxene. Spinel.

The Structure of the Morin Anorthosite.

The macroscopic structure of these anorthosites, as well as that of most of the crystalline rocks forming the Laurentian system, is best studied on the great glaciated surfaces of the roches moutonnées, which protrude through the drift in all directions. On a freshly fractured surface, or even on a smoothly glaciated surface which has been protected from the weather, comparatively little of the structure may be seen; but when the glaciated surface has been exposed, during the interval which has elapsed since the disappearance of the ice, to the etching action of the weather and the dilute solution of carbonic acid known as rain water, the structure of the rock is brought out in a wonderfully clear and striking manner, just as the structure of wrought iron or of various alloys is brought out by the treatment of their polished surfaces with the stronger acids. Such weathered surfaces, moreover, being many square yards in extent, enable the structure of considerable masses of the rock to be determined and the relations of different structures to one another to be clearly seen. Structure of Morin anorthosite.

If any large weathered surface of the anorthosite, such as is found in the roches moutonnées anywhere within the Morin area, be examined (leaving out of consideration for the present the arm-like extension and that part of the main area adjoining it), it will be noticed that the rock, which is coarse-grained and of a deep violet colour, has not that regularity of structure which we see in a typical granite, but presents a more or less irregular structure. This irregularity is sometimes scarcely noticeable, but is at other times striking, and is due to the presence of the bisilicates and iron ore in larger amount in some parts of the rock than in other parts. The portions richer in bisilicates may take the form of large irregular-shaped patches occurring at intervals through the rock, or of many small patches occurring abundantly in certain parts of the rock which elsewhere is nearly free from them. In some cases these are arranged so as to form irregular wavy streaks instead of patches, which sometimes take a rudely parallel direction, giving a sort of strike to the rock, but which in other places are quite irregular in Glaciated surfaces. Irregular structure arrangement. Between these patches or streaks rich in bisilicates, and rather badly defined against them, are portions of the rock which are very poor in or often quite free from bisilicates. The structure is well represented in Plate VI., which is a photograph of a large anorthosite boulder on lot 5 of the ninth range of Chertsey. Here the iron ore and bisilicates are aggregated together in irregular-shaped more or less rounded portions of the rock, while the remainder of the rock is almost absolutely free from iron-magnesia constituents. Of these portions containing the bisilicates and iron ore, these constituents form about one-third of the rock, the rest being plagioclase. Large individuals of plagioclase, irregular in shape and which will be referred to again, occur quite abundantly in the parts of the rock free from bisilicates, but are very rarely found in the patches containing the bisilicates. With the exception of the larger individuals of plagioclase, the rock is uniform in grain throughout. The portions containing the bisilicates weather more readily than the rest of the rock, and thus leave hollows on the weathered surfaces, while when the patches are elongated, as is usually the case, irregular sausage-shaped cavities result. In the occurrence represented on Plate VI. it will be noticed that one of the masses rich in bisilicates and much larger than the others, forms a rude band across the lower portion of the boulder. In such cases, the bisilicate individuals are arranged with their larger axes in a direction rudely parallel to the band.

Variation in relative amount of constituents

Often in connection with this irregularity in the relative proportion of the several constituents present in the rock, but often quite independent of it, there is a rapid and frequently abrupt variation in size of grain from place to place, certain spots or streaks being, as before, finer or coarser than the mass of the rock. More or less well pronounced irregularities, due to one or both of the causes above mentioned, are met with in all the anorthosite areas of Canada which have been examined, but are not peculiar to them, being found in gabbros and allied basic plutonic rocks in various other parts of the world. Thus Dr. George H. Williams in his paper entitled The Gabbros and Associated Hornblende Rocks occurring in the neighbourhood of Baltimore, Md., says on page 25: "The most striking feature in the texture of the unaltered gabbro is the repeated and abrupt change in the coarseness of the grain which is seen at some localities. It was undoubtedly caused by some irregularity in the cooling of the original magma from a molten state, for which it is now difficult to find a satisfactory explanation. The coarsest grained varieties of the Baltimore gabbro occur in the neighbourhood of Wetheredville and there these sudden changes in texture are most apparent. Irregular patches of the coarsest

Plate VI.—Anorthosite, showing segregation of the dark coloured constituents in certain portions of the rock.

kinds lie embedded in those of the finest grain without any regard to order. In other cases a more or less pronounced banded structure is produced by an alteration of layers of different grain or by such as have one constituent developed more abundantly than the others. Such bands, are not, however, parallel, but vary considerably in direction and show a tendency to merge into one another as though they had been produced by a motion in a liquid or plastic mass."*

Similar coarse-grained patches are sometimes seen in the gabbro diorite quarried at Kuhlengrund, near Eberstadt, in Hessen, in a rock which is otherwise perfectly massive and pretty regular in grain. Other similar cases might be cited. Similar elsewhere.

One of the most remarkable occurrences, and one especially noteworthy as showing how a transition takes place from a perfectly normal and massive rock, through one in which these irregular coarse-grained patches are developed, into one showing an imperfect banding such as is sometimes seen in anorthosite, was observed in the great Saguenay anorthosite area, along the course of the River Shipshaw, which runs into the Saguenay from the north about seven miles above the town of Chicoutimi. Along the stream there are at frequent intervals immense smooth roche moutonnée exposures of anorthosite, etched by the weather and burnt clear of all vegetation by forest fires, thus presenting excellent surfaces for the study of the rock. The series of exposures in question is bounded on the north by a great dyke of gabbro, about a half a mile wide, which cuts across the anorthosite, and extends down the Shipshaw a distance of eight miles in a straight line to a point three miles from its union with the River Saguenay. River Shipshaw.

At the first-mentioned point the rock is coarse-grained, absolutely massive over large exposures and regular in grain. This continues for about half a mile, when ill defined patches which are very coarse in grain appear in the rock. In the coarse-grained portions the individuals composing the rock measure an inch or even more across, while in the mass of the rock they are much smaller. Both show a well marked ophitic or diabase structure, in which the plagioclase occurs in lath-shaped individuals, the augite filling in the intervening spaces, a structure which is occasionally seen, but is very unusual, in the anorthosite. This continues for rather over four miles, with in places a further irregularity due to a great variation in the amount of the several constituents present in different parts of the rock, the rock over considerable exposures being all plagioclase, while elsewhere it is Change in structure.

*G. H. Williams, Bulletin No. 28, U. S. Geol. Survey.

rich in diallage, which sometimes occurs in masses as much as a foot and a half in diameter. Large masses of almost pure plagioclase or diallage are thus found in the rock.

Streaked or banded rocks

After an interval of a mile, where the rock is concealed, there is another series of exposures, extending over a mile along the river, in which, as before, the ophitic structure is well developed, but in which the rock is irregularly streaked or banded owing to the fact that the want of uniformity in grain and composition, described above, is no longer displayed in the shape of irregular patches, these having been pulled out into long wavy streaks, similar to those described above by Dr. Williams. Further down the river these streaks begin to assume a rudely parallel direction, giving the rock a determinable strike, while the ophitic structure gradually disappears. A case is thus presented, where an undoubtedly eruptive rock, quite massive and with well pronounced ophitic structure, gradually passes over into one which is banded, the bands being marked by great variations in size of grain and in relative proportions of constituents; and it thus becomes evident, that the rude banding which is a common structure in certain anorthosite areas, and which was formerly supposed to represent a more or less obliterated stratification, is really a structure developed by movements in a truly igneous and massive rock.

Granulation of constituents.

But another structure is also presented by the anorthosites. When any of the anorthosites in the area embraced by the present report are carefully examined, this streaked or irregularly banded structure is seen to be accompanied in most, if not in all cases, by a peculiar breaking or granulation of the constituent minerals of the rock. This is often beautifully displaced by the large weathered surfaces. The accompanying sketch (Figure 9), taken from an exposure in the Morin area near Ste. Marguerite, shows the appearance presented in one of these cases. Here the banding is distinct, but in many parts of the area, even where no banding is seen, the rock presents this peculiar brecciated structure, fragments of plagioclase and of other constituents of the rock being imbedded in a species of groundmass made up of smaller grains. As plagioclase in most cases preponderates almost to the exclusion of the other constituents, the fragments are usually of this mineral, and, although occasionally showing an approximation to good crystalline form, they are almost invariably quite irregular in shape, often possessing absolutely tattered outlines. The groundmass of smaller grains also consists of plagioclase. In some places these fragments constitute the greater part of the rock; elsewhere they are present very sparingly and the groundmass preponderates. The larger individuals can, moreover, be frequently seen in the very act of breaking up, the several fragments having shifted their position but very slightly; and in such cases it is often evident that the breaking is not of the nature of a simple crushing, for from the same individual pieces will be found breaking off in various directions quite at haphazard.

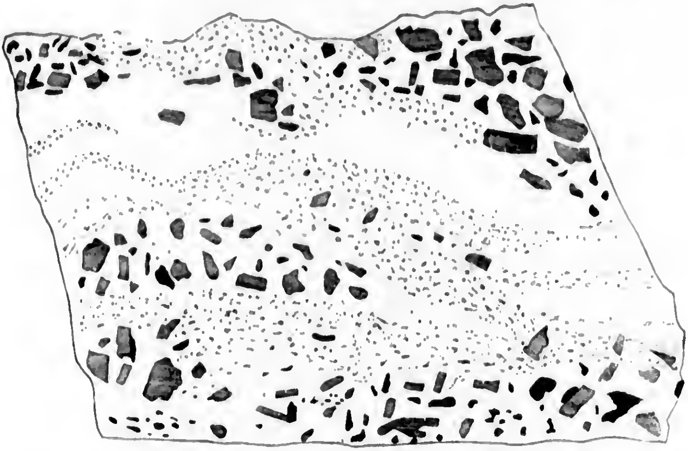


Figure 9.—Anorthosite showing a brecciated structure, near Ste. Marguerite, Township of Wexford. Fragments of Plagioclase and Hypersthene in a groundmass of the same minerals in a granulated condition. The sketch represents a width of 9 feet.

When examined under the microscope in thin sections, hardly a specimen of any coarse-grained variety can be obtained from any part of the area which does not show at least traces of this clastic or granulated structure; and if a series of specimens is studied, every step can be traced in the passage from the massive rock, showing the merest traces of this structure through intermediate breccia-like stages, to anorthosite consisting entirely of broken grains, perhaps with mere remnants of the original large individuals. The three accompanying micro-photographs illustrate successive stages in this granulation. (Plate VII.) They are taken from three thin sections of anorthosite from different parts of the Morin area, photographed in polarized light between crossed nicols and equally magnified, the enlargement in each case being 22 diameters.

Microscopical character.

(A.) This section, from the large exposures about five miles north-west of the village of Ste. Adèle, in the township of Morin, before

Photographs of thin sections of anorthosite.

referred to (p. 96 J), represents the massive anorthosite, showing only the merest traces of granulation on the left of the field. The size and shape of the constituent individuals of plagioclase and their polysynthetic twinning are well seen. The rock is composed almost exclusively of this mineral, the individuals of which are neither bent nor twisted, and no strain shadows are to be observed.

(B.) In this section, which was prepared from a specimen collected about three and a half miles north-east of White Lake, in the front of the township of Chilton, a distinct breaking or granulation of the plagioclase can be observed, especially in the lower portion of the slide, while the same process can be elsewhere seen, though less well marked. The large plagioclase individuals no longer meet along clear well defined boundary lines, but are irregular in shape, cracked, and separated from one another by a mosaic of broken grains. Strain-shadows, twisted twin lamellæ and other evidences of pressure are well shown. The rock shows no distinct foliation or banding.

(C.) The third section shows the appearance presented by a highly granulated variety of the anorthosite under the microscope. This specimen was obtained from the arm-like extension of the anorthosite mass before mentioned, near its western contact with the gneiss, on range XI. of the township of Rawdon. In this section, about one-half of the field is occupied by broken grains of plagioclase, while in the middle is a large plagioclase individual in process of destruction. A line of granulated material is being developed in a longitudinal direction through the large crystal, making, as is usual, an angle of about 20° with the lines of twinning, and which would, if continued, cut it in two; while about its edge little fragments of the plagioclase can be seen in the very act of breaking off—first a strain-shadow (excellently seen on the upper edge of the large individual) appearing, then a curved crack extending in from the edge of the crystal, and finally the breaking away of a small piece of the mineral, leaving an irregular indentation. The appearance is precisely that which the mineral would present if by means of a pair of small pincers little pieces were being broken off the edge. The strain having been relieved by fracture, all evidence of pressure disappears in the broken grain. And if a thin section were composed of broken grains alone, it would in most cases be impossible to determine that these had resulted from the breaking down of larger individuals. This rock is excellently foliated, owing to the finely granulated material, resulting from the breaking up of each large individual, arranging itself in the shape of a very flat lens about the crystal remnant from which it

Show stages of granulation.

FIGURE A.

FIGURE B

FIGURE C.

PLATE VII.—MICROPHOTOGRAPHS, SHOWING THE PROGRESSIVE GRANULATION OF THE MORIN ANORTHOSITE UNDER THE INFLUENCE OF PRESSURE. × 22.

was derived, which lens, of course, lies in a plane at right angles to the pressure, and in section appears as a long slender tail of broken grains extending from the remnant in either direction. (Fig. 10.)

The pyroxenes, rhombic or monoclinic, when present in the rock, undergo a precisely similar process of granulation with the formation of similar tails of broken grains.

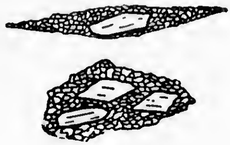


Figure 10.

Sometimes large individuals can be observed which have broken into two or more pieces during the process of granulation, the lens of broken grains thus inclosing several fragments more or less separated from one another, which from their respective outlines can be seen to have been originally one. (Fig. 10.)

A very remarkable fact in this connection, which has already been briefly referred to in describing the mineralogical composition of the anorthosite, is that the large crystal fragments of plagioclase have a deep violet colour, while the granulated plagioclase is white. This contrast is excellently seen either on the weathered surface (Plate VIII.) or when a thin section is placed on a sheet of white paper, and is due to the fact that the minute dark-coloured or black inclusions, which abound in the large individuals, are absent in the broken material. They seem to have aggregated themselves together into little grains of titanic iron ore, which occur in the granulated plagioclase, but which on the other hand are absent in the large individuals. So distinctive is this contrast of colour, that when a thin section containing plagioclase in both forms is placed under the microscope, it is possible at once to predict from the colour alone, just what portions will show granulation and what portions will not, before the actual structure has been revealed by the agency of polarized light. This might seem at first sight to indicate a recrystallization in the case of the granulated portions of the plagioclase, but the facts do not seem to support this supposition. The felspar, during the process of granulation, does not at any rate alter in composition, but merely breaks, and through the loss of the dark inclusions becomes lighter in colour.

Plagioclase changes colour when granulated.

No investigations bearing on this particular point have been made on the anorthosite of the Morin area, but the fact has been established

No change in composition of the ... plagioclase when granulated.

by the study of precisely similar anorthosites from several other areas. Thus it was found in the case of the anorthosite of Mount Williams, on the River Shipshaw, in the Saguenay area, that the large dark-coloured individuals and the white granulated plagioclase, were both labradorite, differing in specific gravity by only ·015, the dark felspar being naturally a trifle heavier on account of the inclusions. Again, in analyses XIV., XV., XVI. (see p. 130 J) are given the results of an examination by Dr. Sterry Hunt, of the large plagioclase individuals and the finely granulated base of an anorthosite from the Château Richer area. Both are in this case more acid, approaching andesine in composition; but here again in composition they are identical. The same circumstance has been confirmed by Leeds in the case of the anorthosite of Essex County, New York, and by Sachsse in a flasergabbro from Rosswein in Saxony*, although in these two latter cases the material analyzed was not quite pure.

Frequently, as has been stated, the production of the granulated material from the large individuals can be actually observed; and in such cases it can be seen that so soon as the fragment is separated from the large individual its colour disappears. The granulation, it would appear, in some way gives freer play to the forces which bring about the concentration of the material of the dark inclusions. When the anorthosite is composed entirely of the finely granular material, if it be almost entirely plagioclase as is usually the case, the rock can hardly be distinguished, especially on the weathered surface, from a white crystalline limestone.

White anorthosite.

This peculiar variety of white granular anorthosite, with comparatively few of the large individuals remaining, is also largely developed in the Saguenay and other of the anorthosite areas in the province of Quebec, and is described from the area in Essex County, New York, by Leeds, and from Labrador, by Vogelsang, as well as by other observers, it being found apparently to some extent, in most of the localities where anorthosite is largely developed.

Granulated varieties on sides of intrusion.

In the Morin anorthosite, and the same is true of the Saguenay area, the most granulated varieties are found near the sides of the intrusion, especially on the east side, as if the pressure had been exerted from that direction, but more or less distinct evidences of granulation can be seen throughout the entire area. The white granulated anorthosite forms the greater part of the arm-like extension of the Morin mass,

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* Ueber den Feldspathgemengtheil des Flasergabbros von Rosswein i. S.—Ber. d. naturf. Ges. i. Leipzig, 1883.

PLATE VIII.—GRANULATED ANORTHOSITE, WITH INCLUDED REMNANTS OF THE ORIGINAL ROCK, RIVIÈRE AUX SABLES, TOWNSHIP OF JONQUIÈRE, QUE.
(REDUCED ONE-HALF.)

protruding through the drift in all directions in the form of hundred of smooth white hummocks giving a striking appearance to the landscape, as for instance, about the village of New Glasgow; and this district being easily accessible by roads and railways, the structure and character of the rock can here be studied with comparative ease. Further, it can be observed that everywhere in this arm-like extension and in almost all its occurrences elsewhere, this white granulated anorthosite is more or less distinctly foliated, owing to the arrangement of the bisilicates and iron ores in more or less distinctly parallel lines or streaks. It is often quite evident that these are nothing more than the rounded patches, rich in bisilicates, described on p. 104 J, as occurring in the massive anorthosite and represented in Plate VI., which, owing to a movement in the rock, have been drawn out in one direction. The irregular-shaped patches, differing greatly in size of grain, described as occurring in the massive rock, are also here represented by elongated streaks of similar character. This foliation is best seen where bisilicates and iron ore are comparatively abundant. When, as is sometimes the case, the rock is almost free from these constituents and all the plagioclase fragments have been destroyed, it assumes a nearly uniform granular character, and no trace of foliation can be observed. The foliation, however, is usually distinctly seen, and in the arm-like extension runs parallel to the direction of the arm itself, that is to the strike of the gneiss, which it penetrates. Along the western border of the arm, the strike is exceedingly regular and remarkably well developed, as at New Glasgow, but is especially well seen along the same contact further north on range XI. of the township of Rawdon, on the road between the villages of Chertsey and Rawdon. Here the rock is seen to have a remarkably regular schistose structure, due to the alternation of thin layers of pure plagioclase with still thinner ones of pyroxene. The pyroxene bands might more properly be called leaves, as they are very thin, being frequently represented by mere parallel lines in transverse sections. When examined under the microscope, in thin sections or weathered surfaces, both they and the plagioclase layers are found to contain small cores or remnants of large individuals with trails of grains extending from them in either direction as before described. These give rise to the perfect foliation and the progress of the granulation is seen in a most astonishingly perfect manner, the cores being in the very act of breaking up (Plate VII.). These cores can occasionally be seen to be the remnants of very large individuals, which have sheared almost in the direction of the foliation. They are thus often long and narrow, some having been observed as much as twelve times as long as they are wide.

Foliated anorthosite.

Origin of several structures.

The question of the origin of the several structures described next presents itself. There is every reason to believe that those structures which have been described as occurring in the massive anorthosite, namely the irregularity in size of grain and the more or less irregular distribution of the several constituents through the rock, are original structures produced before or during its solidification. These irregularities, frequently seen in intrusive rocks, are certainly not the results of pressure; and the circumstance that the streaks or irregular bands, when present in the otherwise massive rock, assume no definite direction, but twist about as if owing to the movements in the rock while in a pasty condition, indicates that they have been produced by movements before the rock became solid. The unequal distribution of the constituent minerals in the rock, must have resulted either from irregularities in the composition of the original magma, or from processes of segregation at work in the magma during cooling and crystallization. The irregularities in the size of grain may be due to differences in the rate of cooling, differences in amount of mineralizer present, or to other causes with which we are at present unacquainted. The angular character of certain of the coarse-grained portions of the rock which are found embedded in the anorthosite of normal grain, would seem to indicate that these had crystallized where circumstances were favourable to the development of coarseness of grain, and had been subsequently broken up and imbedded in a portion of the magma which crystallized in more fine-grained form.

Movements subsequent to solidification.

On the other hand, the granulation of the coarsely crystalline massive anorthosite, usually with the concomitant development of a more or less distinctly foliated or schistose structure in the way described, is undoubtedly due to movements in the rock, resulting from pressure which acted subsequent to its solidification, for, as has been shown, the granulation begins to make its appearance in the massive crystalline rock itself. Under the influence of pressure, the massive rock gradually gave way, and, in the movements which resulted, attrition gave rise to granulation. Moreover, wherever these movements continued longest this granulation became most complete, until finally the last remnants of the larger individuals disappeared, and in the case of a pure anorthosite, a more or less evenly granular rock resulted. In the anorthosite, however, the remnants of larger individuals are seldom or never entirely absent, and in the great majority of cases the amount of interstitial material is quite small. Even when the granulation was most complete, the rock did not crumble into an incoherent powder, but remained as hard and tough as ever, the grains, being unable to separate from one another on account of the great pressure to which they were subjected, rolled over one another, remaining always within the sphere of cohesion.

In this way, any portions of the originally massive rock differing in grain or composition from the rest, would be represented by bands, streaks or even lines in the resulting granulated anorthosite; very coarse-grained portions being represented by bands or streaks containing large plagioclase remnants, fine-grained portions being represented by bands or streaks where these are very small or even absent, while corresponding differences would appear in the case of areas differing in mineralogical composition.

These foliated or schistose anorthosites then, were produced by movement in a massive igneous rock, and are not altered sediments, the structure which they present being, as has been shown, a cataclastic structure. Schistose anorthosites not altered sediments.

But although this granulation and its accompanying phenomena are certainly the results of pressure to which the rock has been subjected, the effects of this pressure are in certain respects quite different from those usually observed. As a general rule, in the case of schistose structures produced by shearing, of which so many excellent examples have been described by Lehmann and others, the breaking up of the constituents takes place principally along certain definite lines. Along these lines or bands, which are sometimes quite wide but which at other times sink to almost microscopic dimensions, the rock is reduced to a comminuted state, forming, if not subsequently compacted, the so-called "rutschmehl" of Heim. Between these shearing planes the rock presents comparatively little evidence of pressure. Where, moreover, great movements accompany dynamic action, and especially along lines of motion, or if these be not present, then throughout the whole rock, certain peculiar alterations in the minerals constituting the rock are found. Of these may be especially mentioned the alteration of pyroxene to hornblende, and of plagioclase into a mixture of zoisite, albite and other minerals known by the name of saussurite.

So far as can be ascertained, no undoubted occurrence of a sheared gabbro or allied rock has been recorded, where hornblende either compact or in the form of uralite and saussurite have not been formed. In a paper on the sheared gabbros of the Lizard in Cornwall,* in which a perfect foliation has been induced by pressure, giving rise to rocks closely resembling the foliated anorthosites of the Morin area, except that the mineralogical changes above mentioned have taken

*Geological Magazine, November, 1886.

place, Teall says "there is no reason to believe that foliation of the kind referred to in this communication can take place without molecular re-arrangement."

Peculiarities in structure of granulated anorthosites.

On the other hand, the anorthosites possessing this cataclastic structure present the following peculiarities :—

1. The cataclastic structure is not developed along certain lines, but may be observed more or less distinctly throughout the rock, being, however, most marked towards the sides of the area, and especially toward the eastern side.

2. Where it occurs there is neither saussurite nor uralite. However granular the plagioclase may be, no trace of saussurite can be seen. In like manner, no uralite is detected, even though the granulation of the pyroxene is so far advanced that only the smallest remnants of the original individuals remain. Now and then some small grains of compact hornblende occur with the pyroxene in the neighbourhood of the contact with the gneiss, exactly as in many normal gabbros. But even these are by no means invariably present; the finely foliated rock, consisting of alternate layers of unaltered pyroxene and plagioclase, while remnants of the large individuals of both constituents, from which the granulated portion has originated, are still seen. The only place in which saussurite occurs is, as before mentioned, near New Glasgow. It forms here, like epidote, strings and veins which have no relation with the foliation of the rocks, but represent small crushed zones, which have originated at another much later period. These very occurrences show most distinctly how different the products of the normal dynamic agencies are from the structure now under consideration.

3. In the main portion of the area, the granul. . is not accompanied by foliation, and in the large weathered surface. plagioclase individuals can be observed which are in the act of breaking in every possible direction. In the arm-like extension from the south-east part of the area, where the rock, as already mentioned, is often distinctly foliated, this foliated structure originated, as shown by a careful study, from the movement in one direction, of a mass whose iron-magnesia constituents were irregularly distributed, being especially concentrated in some places. (Plate VI.) The more or less rounded spots where the iron-magnesia constituents are abundant, became pulled out into irregular, ill-defined streaks, and parallel to these run portions of the rock, which still contain in large numbers fragments of plagioclase individuals.

These phenomena have been caused by movements in the rock. These movements probably took place under the following conditions:— Conditions under which movements took place.

1. When the rock was still so far beneath the surface of the earth and so weighted down by the overlying rocks that breaking and shearing with the movement of the resulting masses was impossible. The alterations in the character of the mass were probably induced very slowly, the constituents became granulated and the small broken parts moved one over another. The granulation progressed with the duration and intensity of this movement up to a certain point. Such a motion would present certain resemblances to that of a very tough pasty mass. While deeply buried.

2. While the rock was still very hot and perhaps even near its melting point. This would explain why the pyroxene, which, according to the experiments of Fouqué and Michel-Lévy, represents the stable form of the molecule at a high temperature, is not changed into amphibole, which represents the more stable form at a low temperature, as is usually the case in crushed and pulverized rocks. It is perhaps owing to the same cause that no saussurite is formed; still, the conditions necessary to the formation of these minerals are so little understood that opinions on this point cannot be ventured upon as yet. While very hot.

A clastic structure in many respects similar to that above described, in which plagioclase grains are twisted and broken or even suffer peripheral granulation, occurs in certain specimens of the theralite of the Montreal Mountain, which also present a streaked appearance marked by variations in size of grain. Here it must also be regarded as evidence of motion, but of motion which in all probability took place before the complete solidification of the rock, being an instance of what Brögger has termed "protoclastic structure," for the field relations of this old volcanic plug show that it has not been submitted to any great pressure since the mass solidified. This structure, however, is only developed very locally in the rock, and in many sections no trace of it can be found; nevertheless its occurrence here is of interest showing as it does that the mere detection of such a structure here and there in an igneous rock is not indubitable proof that the rock has been submitted to great pressure and has been crushed. Protoclastic structure.

It would thus seem that the clastic structure described as occurring in these anorthosites occupies, in a way, a position intermediate between the protoclastic structure of Brögger and the cataclastic structure commonly observed in sheared rocks.

In the Morin area, then, we have a great intrusive mass of anorthosite, or gabbro very rich in plagioclase, breaking through the Laur- Résumé.

ention, cutting off successive horizons, including portions of the gneiss, sending an apophysis into it, and in some places bounded by a zone of rock which exhibits many characteristics of a contact product. This mass in most places shows irregularities in size of grain and in some places a streaked or irregularly banded structure, while in one part of the above-mentioned apophysis it is well foliated, which foliated structure there is reason to believe is a secondary one. It certainly does not represent a partially obliterated bedding as the earlier observers seem to have believed, while the other supposed evidences of the existence of a great overlying sedimentary series, of which it was supposed to form part, are also wanting; the gneiss and limestone with which it was thought to be interstratified, really belonging to the Grenville series, while the apparent interstratification of the anorthosite is due to intrusion.

Anorthosite possessed its present characters in Cambrian times.

The whole is furthermore unconformably overlain by flat unaltered strata of Potsdam and Calciferous age, and thus possessed in Cambrian times the characters which it now presents, while the nature of the anorthosite and its relation to the Laurentian, lead us to suppose that it is much nearer in age to the latter than to the overlying Cambro-Silurian probably not much more recent than the Grenville series itself.

Other Anorthosite Masses.

Stratigraphical Relations and Petrography.

Other anorthosite masses.

In addition to the Morin anorthosite, there are in the district embraced by the present report twelve other occurrences of anorthosite lying to the south and east of the Morin area and much smaller in size.

These are—commencing the enumeration from the west:—

(1.) The Lakefield area—an area lying to the east of the village of Lakefield, situated partly in the Gore of the township of Chatham and partly in the parish of St. Columban.

(2.) The St. Jérôme area, on which is situated the town of that name.

(3.) Three elongated and approximately parallel areas in the township of Kildare and its Augmentation.

(4.) Two rather larger areas on the east side of the township of Cathcart.

(5.) Two occurrences, much smaller than the rest—one by the side of the River L'Assomption near the Pont des Dalles and to the east of the village of Ste. Beatrix, the other a short distance to the west of the village of St. Jean de Matha.

(6.) Three bands of anorthosite intercalated in the nearly horizontal gneisses of the township of Brandon.

These anorthosite masses are from one hundred to several hundred yards in width, the greatest length of any one area being about seven miles. They run parallel to the strike of the gneiss, in which they are intercalated, and are usually well defined against it, the most notable exception being the St. Jérôme occurrence. The gneiss, however, sometimes appears to be more basic near the contact.

The anorthosite varies somewhat in character in the different areas. It is usually coarsely crystalline, frequently showing a great variation in size of grain and resembling that of the Morin area, but it is perhaps on the whole richer in iron-magnesia constituents, and often contains minerals such as hornblende, biotite and in one case scapolite, which occur very sparingly, or are entirely wanting, in the Morin anorthosite. The anorthosite of these several areas also frequently contains garnet near its contact with the gneiss. It frequently exhibits in an eminent degree the granulated structure described in the Morin anorthosite, and has a more or less well marked arrangement of the constituent minerals parallel to the longer axis of the areas.

As the several areas present certain differences, they will be considered separately.

The Lakefield Area.

This is four and a half miles long and about a mile wide. The anorthosite of the peripheral portions is fine grained, foliated, very poor in bisilicates and weathers white. In the inner part of the area it is more massive and appears on the whole to be rather richer in iron-magnesia minerals, which vary in amount from place to place, often giving to the rock an irregularly banded structure. It is crossed, as shown on the map, by two roads, while a third passes immediately to the north of it. The Lakefield anorthosite.

In this area a rapid change in strike is observable, the anorthosite and its accompanying gneiss in the southern part striking, on an average, N. 45° W., while all about the northern extremity both rocks strike N. 20°–50° E.

A thin section from a specimen collected near the eastern side of the area, on the most southerly of the roads above mentioned, shows the rock at this point to be a typical anorthosite, the plagioclase preponderating very largely, while the iron-magnesia constituents are represented chiefly by augite, in addition to which there are very small quantities of green hornblende and brown biotite. Less than a mile south of the southern edge of this area, at the very edge of the Laurentian escarpment, a diabase dyke cuts through the gneiss which is here the country rock. The diabase, however, contains a great number of angular fragments of white anorthosite, which in many places are so abundant that they make up the greater part of the dyke. Under the microscope this anorthosite is seen to be a rather fine-grained variety composed almost exclusively of plagioclase, with a few grains of iron ore. The plagioclase, is however, largely altered into mica, the little mica scales being arranged principally in two directions parallel to the cleavage of the felspar (Section 415). These fragments, which were brought up by the molten diabase, probably mark an interground extension of the Lakefield area to the south.

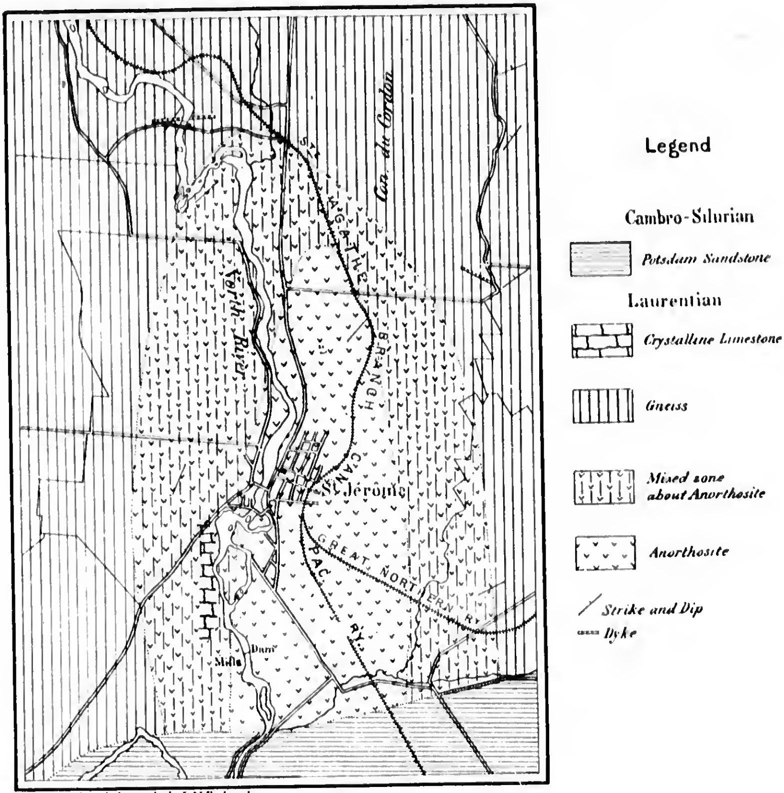
The St. Jérôme Area.

The St. Jérôme anorthosite.

Only a portion of this area, situated, as it is, immediately at the edge of the Laurentian region, is exposed to view. The southern part of it is covered up by the flat-lying Palaeozoic strata, which come in a short distance to the south of the town. What proportion of the whole mass is represented by that portion exposed to view, it is impossible to say. It differs considerably from the other areas, not only in the fact that the anorthosite composing it is not so typical in character, but also in that there intervenes between it and the gneiss a zone of rocks of intermediate character.

The anorthosite, or gabbro, as it should more properly be called, is best seen in the large exposures on either side of the Canadian Pacific railway track a few hundred yards south of the railway station at St. Jérôme. These are situated about the middle of the area as exposed, and towards its southern limit, and probably present the anorthosite in its most typical development, freest from contact effects, and nearest to the actual centre of the mass.

Here the rock is fine-grained, usually foliated in structure, and weathers brownish-gray. In some places it possesses a more or less distinctly banded structure, due to the alternation of portions rather rich in bisilicates with others consisting almost entirely of plagioclase. Individuals of dark-coloured plagioclase, usually small in size, but



PLAN

Vicinity of St Jérôme

Terrebonne County, Que.

Scale

Chains 80 — 0 — 1 Mile

FIGURE 11.

sometimes as much as six inches in length, are abundant in places. They are frequently seen to be curved or twisted, and are usually without good crystalline outlines.

Microscopical character.

Under the microscope, the rock is seen to be composed essentially of plagioclase and pyroxene, the former preponderating largely, with hornblende, biotite, garnet, iron ore and pyrite as accessary constituents, and with a few grains of quartz, calcite, chlorite and apatite. The pyroxene is light-green in colour, and is for the most part augite, which is often decomposed to calcite and chlorite. Some of it, however, is trichroic, in red, yellow and green tints, and is probably hypersthene. The hornblende, which is green in colour, and the biotite are present in but very small amounts. The garnet is pink and perfectly isotropic; it is often well crystallized, and usually has some approximation to good crystalline form. It is generally associated with the iron ore, but often occurs in little strings through the rocks. The iron ore is black and opaque, and is often present in considerable amount. As in certain parts of the Morin anorthosite, there are probably two kinds of iron ore associated with one another, one rich in titanium and one poor in, or free from, that element. A portion of it is titanic iron ore, for leucoxene often appears as a decomposition product. The calcite is always present as a decomposition product, and the quartz, which is found in very small amount, is associated with the bisilicates, and may also be secondary.

Little strings an inch or less in thickness, consisting of quartz and orthoclase felspar, and which run through the rock sometimes parallel to the stratification and sometimes across it, are rather abundant in places, and are evidently distinct from the anorthosite and of later origin.

The rock in its present form probably represents an advanced stage of granulation, for although but little is seen in the way of twisted grains and strain-shadows, these, as has been shown in describing the Morin anorthosite, are not distinct when the granulation is complete. The large remnants of plagioclase, on the other hand, which occur abundantly in many places, in view of the light thrown on their origin by the study of the Morin anorthosite, point very strongly to an advanced stage of crushing.

Cataclastic structure.

At the bridge over the North River at St. Jérôme, at the western edge of the area, as well as at a point about a mile and a quarter north of the above-mentioned exposures and near the northern end of the area, the same anorthosite is well exposed. At the latter place, however, an exceedingly well marked cataclastic structure is seen when the rock is examined under the microscope, the large individuals of plagioclase being twisted in a marked manner, broken apart, and embedded in a mass of granulated material derived from them.

This anorthosite mass is surrounded by a zone of rocks of varied character, many of which strongly resemble the anorthosite in appearance but which are quite different in composition. They are well exposed back from the North River to the west of St. Jérôme, and by the side of the river to the north of the town.

This zone includes a large amount of ordinary orthoclase gneiss, and in it occurs the band of crystalline limestone to the south-west of the village, but it consists chiefly of rocks which in addition to augite and plagioclase contain variable amounts of hornblende, orthoclase and quartz, and which are thus intermediate in character between the gneiss and the anorthosite, some of the many varieties represented approaching more nearly to gneiss and others more nearly to the anorthosite in character and composition. It is thus a matter of great difficulty to trace upon a map the exact limits of this zone. In the map (Fig. 11), however, this has been done as accurately as possible, with the aid of a microscopal examination of the rocks from a number of points, which served to determine the actual character of such specimens.

This zone surrounding the anorthosite probably represents a peculiar border facies of the latter, which, in many places, has been intruded into the gneiss parallel to its foliation, giving an appearance of interstratification, while movements induced by pressure subsequent to the intrusion, have served to render this appearance more pronounced. Like the anorthosite, the rocks of this zone frequently present evidence of a more or less complete granulation, while the appearance of a certain amount of quartz in the anorthosite near its contact with the gneiss, is a phenomenon observed in several of the other anorthosite bands described below. Border facies of anorthosite.

About eight miles to the north-east of St. Jérôme, cutting the Morin anorthosite close to its western contact at New Glasgow, and running north for about six miles in a direction very nearly parallel to that of the limestone band in the gneiss just west of the contact, is a band of peculiar gabbro, nearly black in colour, which protrudes through the drift in a series of great roche moutonnée bosses, contrasting in a marked manner with the white anorthosite through which it cuts. The band is narrow, and immediately to the north of New Glasgow New Glasgow gabbro.

sends out an arm about a quarter of a mile long from its eastern side, which cuts across the foliation of the anorthosite. To the north this gabbro disappears on reaching the Beauport River, being exposed between the gneiss and anorthosite, and apparently cut off by a fault. It is seen again about a mile in a north-easterly direction from the point where it disappears, by the side of the road running from St. Calixte to St. Lin, and is then lost. Under the microscope the rock presents an extremely well marked cataclastic structure, the constituent minerals having been completely granulated under the great pressure to which they have been subjected.

Areas in the Township of Kildare and its Augmentation.

Kildare anorthosites.

These areas, three in number, are long and narrow, running with the strike of the gneiss, and might be referred to as bands. They are parallel to one another in position, and two westerly bands averaging a little over a quarter of a mile in width, while the most easterly is somewhat wider, being on an average rather over half a mile wide. They have lengths of six, five and seven miles respectively. Although in places covered with drift, they are generally well exposed, and being crossed by a number of roads are easily accessible. The three bands resemble one another closely in petrographical character. The rock is on the whole richer in bisilicates than the Morin anorthosite, approaching more nearly a normal gabbro or norite in composition. A specimen from the most westerly band, collected on lot 4 of range I. of the Augmentation of Kildare, proved when examined microscopically to be a typical norite, being made up of plagioclase and pyroxene in about equal amount. The latter is chiefly hypersthene, though a certain amount of augite is also present as well as a very small amount of biotite. Under the microscope the rock shows a very distinct granulation. Toward the middle of each band it is coarsely crystalline and sometimes shows but little foliation; usually, however, in this position, a more or less distinct foliation, parallel to the length of the band and conforming to the strike of the surrounding gneiss, is to be observed. This is sometimes accompanied by an indistinct banding of fine and coarser grained portions of the rock coinciding in direction with the foliation, and identical in character with the banding described in the Morin area.

At their borders the bands become finer in grain, distinctly foliated and richer in bisilicates. The finer grained character of the marginal portions may, however, be due, not to more rapid cooling, but to more intense granulation. Garnet is very frequently seen. Quartz also makes its appearance near the contact, and the rock having thus altered its character considerably, it is often difficult to determine its exact limits against the gneiss where the latter has been shattered and penetrated by the gabbro in a direction parallel to the strike.

Basic developments.

It is especially difficult to determine the exact position of the extremities of the several bands, these not only consisting of basic developments of the rock, but running into the gneiss for long distances parallel to its foliation. Such basic rocks composed essentially of hypersthene, hornblende, plagioclase, and probably some orthoclase, and which may be a contact facies of the gabbro, occurring intimately associated with the ordinary orthoclase gneiss, are found as much as two miles to the south of the limit of the most westerly of the three gabbro areas as represented on the map. In the most easterly of the three bands also, no exposures are seen on the line between ranges VI. and VIII. of Kildare, the country being drift-covered, but to the south of the road there are large exposures of certain basic rocks in line with the strike of this area, which are supposed to belong to the gabbro, and the area has accordingly been represented on the map as extending southward as far as range VI.

Areas in the Township of Cathcart.

Cathcart anorthosites.

On the eastern side of this township are two areas of the anorthosite separated by a narrow band of gneiss. They extend southward a short distance into the Seigniory of D'Aillebout, but how far they extend to the north-west beyond the ninth range of Cathcart has not been determined, the country in that direction being covered with heavy forest and very difficult of access. Judging from the dimensions of the areas, as measured on the two roads which cross them transversely, as well as from the position of their southern limits and the shape of the other areas on the same strike further to the south, the northern limits assigned to them on the map are believed to be substantially correct.

The rocks constituting these areas are well exposed on the two roads above mentioned, which roads run approximately on the lines between ranges VI. and VII., and VIII. and IX., respectively, as well as on a road connecting these two and running through the western anorthosite area in the direction of its longer axis. The gneiss band separating the two areas, as exposed on the more northerly of the two roads, consists of a finely foliated quartzose orthoclase-gneiss, with some bands of quartzite, while on the southerly road it takes the form of a coarse-grained basic gneiss, often resembling augen-gneiss in structure and frequently holding pyroxene and some plagioclase as well as intercalated masses of the anorthosite.

Variation in size of grain.

The anorthosite varies considerably in character from place to place, and is most typically developed in the western area. Here it is often very coarsely grained, almost massive, and shows the great variation in size of grain even in different parts of the same exposure, described in the Morin area. In other parts of the area, it shows the indistinct banding, so common in anorthosites, and often a more or less pronounced foliation. The proportion of bisilicates varies considerably; hypersthene and titanic iron ore are readily recognized on the weathered surface and in certain places many large broken individuals of plagioclase are also seen.

The anorthosite thus strongly resembles that of the Morin area, though probably on the average richer in bisilicates and thus approaching more nearly in composition to an ordinary gabbro. It is, however, in the case of the easterly band more intermixed with the surrounding gneiss, the two rocks being in some places apparently interbanded, owing to the intrusion of the anorthosite into the shattered gneiss about the contact, and the development of a more or less distinctly foliated or banded structure in the whole by subsequent squeezing.

Specimens of this rock which were examined microscopically, resembled very closely that of the anorthosite bands in the township of Brandon, described later on. Hypersthene is the chief iron-magnesia constituent, a few grains of augite and biotite being also present. Plagioclase is the most abundant constituent.

The rock in a great majority of cases is in an advanced state of granulation, the whole process being exhibited in a striking manner by the thin sections.

Area near Pont des Dalles on the River L'Assomption.

Pont des Dalles anorthosite.

This comparatively small occurrence is situated on the River L'Assomption at a point rather over one mile in a straight line east of the village of Ste. Beatrix. It is well exposed about a quarter of a mile west of the Pont des Dalles on a road which runs close to the river, but is still better seen where the river cuts through the mass in a high cliff on the south bank. The rock is coarsely crystalline and shows the usual variation in size of grain with here and there large masses of augite and hypersthene, and an indistinct parallel arrangement of the constituents in the direction of the prevailing strike of the surrounding gneiss.

When examined on the face of the cliff above referred to, the rock often presents an approximately horizontal foliation, by apparently following lines of motion. A specimen of this horizontal foliated variety which was collected and examined microscopically, was found to present a feature of interest in the presence of a large amount of scapolite, a mineral which has not been found in any of the other Canadian anorthosites. The iron-magnesia constituents were found to be represented by augite and hypersthene in large amount, with a good deal of biotite and a little hornblende. The non-ferruginous constituents consist of plagioclase and scapolite, which are both present in abundance. Iron ore and pyrite, present in very small amount, complete the list of constituents. The scapolite is uniaxial and negative, polarizes in brilliant colours and presents the usual prismatic cleavages with parallel extinction. The augite and plagioclase present the appearance of having been subjected to a process of granulation, but the grains do not show strain-shadows or twisted lamellæ. This, as has been shown, is usually the case in the plagioclase of thoroughly granulated anorthosite. The biotite does not show such distinct evidence of granulation, while the scapolite occurs in large, clear, unbroken grains with uniform extinction, which like the other constituents run in strings, sometimes in the plagioclase but usually between the plagioclase and the bisilicates. It is possible that the biotite may be a secondary mineral, and it is highly probable that the scapolite is an alteration product of the plagioclase, as in the case of the "spotted gabbro" of Norway and certain allied rocks in Canada and elsewhere.* Scapolite.

Anorthosite near St. Jean de Matha—Seigniory of De Ramsay.

About half a mile south-west of the village of St. Jean de Matha, on the road running toward the River L'Assomption, large exposures of garnetiferous quartzose gneiss are succeeded by others of anorthosite. The latter rock is exposed for a width of about one hundred yards along the road and is succeeded by drift. It shows considerable variation in size of grain, weathers white, and is without foliation. St. Jean de Matha anorthosite.

When examined under the microscope, it is found to be a typical anorthosite composed almost entirely of plagioclase. The iron-magnesia constituent is augite. Biotite and apatite, both in very small quanti-

* Michel Lévy—Sur une roche à sphène, amphibole et wernérite granulitique de Bamle-Norvège. Bull. Soc. Min. France, No. 3, 1878.

Michel Lévy—Sur le gisement de l'amphibolite à wernérite granulitique d'Oedegaard près Bamle-Norvège. Bull. Soc. Min. France, No. 5, 1878.

F. D. Adams,—On some Canadian Rocks containing Scapolite. Can. Rec. of Science, Oct., 1888.

ties, with a little titaniferous iron ore and pyrite complete the list of constituents. The rock has undergone a certain amount of granulation.

Anorthosite Bands in the Township of Brandon.

Anorthosite in Brandon.

In the western half of this township there are three important areas of anorthosite, which occur interbanded with the nearly horizontal gneisses of this district. The most easterly of these, which is also the smallest, forms a hill on lot 14, range IX., by the side of the road which crosses near the front of the lot. It disappears beneath the drift to the south of the road, and is not met with on the concession roads further south, nor is it again seen to the north, the township along its strike in that direction being so heavily mantled with drift that very few exposures are met with. The associated gneisses strike N. 25° W. and dip at low angles to the east, the gneiss immediately to the east of the anorthosite being a basic variety poor in quartz, while that to the west is rather fine in grain and highly quartzose. The anorthosite has the appearance of an interbanded or interstratified mass, an appearance probably due to the rolling out of the whole complex under the great pressure to which it has been subjected. The rock is in some places massive, but elsewhere shows great irregularities in size of grain, or is distinctly foliated, with strings of bisilicates arranged in a direction rudely parallel to the longer axis of the band and to the strike of the adjacent gneiss. On weathered surfaces large crystals of plagioclase, much cracked and broken, can occasionally be seen, but the rock usually presents the appearance of having been subjected to such prolonged movements that the large plagioclase individuals have been entirely destroyed.

Three bands.

Like most of the small anorthosite bands described in this Report, these from the township of Brandon are usually richer in bisilicates than a true anorthosite should be, and resemble in this respect certain varieties of anorthosite rich in bisilicates which occur in the eastern portion of the Morin area.

The central of these three anorthosite bands in Brandon, seldom attaining and never exceeding a width of half a mile, runs through the township in a north-westerly direction, conforming to the strike of the gneiss, from lot 19 of range V. to lot 17 on the front of range XII., a distance of six and a half miles. It pinches out on range V., being bounded by almost continuous exposures of gneiss to the south, while on range XII., where but small exposures are seen, it disappears under the drift about Lake Mattabon. It closely resembles, both in stratigraphical relations and petrographical charac-

PLATE IX.—ANORTHOSITE, SHOWING PARALLEL ARRANGEMENT OF HYPERSTHENE MASSES, BETWEEN LAC NOIR AND LAC CORBEAU, TOWNSHIP OF BRANDON.

ter, the more easterly band above described, like it being apparently interbanded with the gneiss, the whole series as before dipping to the east at a low angle. At the contact near Lake Mattabon, elongated fragments of the anorthosite or gabbro were observed in the gneiss, having been apparently detached from the main mass by the movements which induced the foliation. The rock is coarse-grained, and as before the proportion of bisilicates, chiefly hypersthene, is rather large, and the rock should be termed a norite rather than an anorthosite. Toward the middle of the band the tendency of the constituents to arrange themselves in strings or bands is very obscure, and the rock is almost massive. It is frequently very irregular in grain, displaying coarser or finer grained patches, the former often containing masses of hypersthene, sometimes measuring from five to six inches across. The usual irregular-shaped remnants of large plagioclase individuals indicate that the rock has suffered an intense granulation. Toward the side of the band, a parallel arrangement of the hypersthene masses usually makes its appearance, coinciding in direction with that of the adjacent gneiss. (Plate IX.)

Westerly band.

The most westerly of the three bands, is first seen about the middle of lot 22 of range III., in the line of hills which forms the northern boundary of the drift plain occupying the southern corner of the township. It then runs in a north-westerly direction to the side-line of the township, which it meets on lot 22 of range V., where it attains a width of about a third of a mile, appearing in large exposures, and is flanked on either side by gneiss. It was not observed, however, beyond the limits of the township, the country in the line of its strike in that direction being again drift-covered. In character and composition it is identical with the other two bands just referred to, under the microscope thin sections of the anorthosite composing the several bands resembling one another so closely that they cannot be distinguished apart. The iron-magnesia constituent is pyroxene, occurring in the foliated specimens as long strings of grains marking the foliation of the rock. It is for the most part a rhombic pyroxene (hypersthene), with strong trichroism in reddish, greenish and yellowish tints, but in most cases a certain amount of monoclinic pyroxene, intimately associated with the hypersthene and resembling it in appearance, but having an inclined extinction and no pleochroism, is also present. In every slide, a small amount of biotite and a few grains of iron ore are found. The felspathic constituent of the rock is essentially plagioclase, well twinned, and presenting the usual characteristics. An untwinned felspar is also present, usually in comparatively small amount, with rather strong dispersion of the

Microscopical character.

bisectrices, giving rise to pale bluish and brownish tints respectively on either side of the line of maximum extinction. This may be orthoclase. A few grains of pyrite and a few more or less rounded individuals of apatite are the only other constituents found in these rocks.

The thin sections also afford indubitable evidence that these rocks have suffered great internal movements. The large grains of felspar can be seen to have been twisted and fractured, and are often clearly seen to be in the very act of breaking up into smaller grains. The same is true, though less noticeably so, in the case of the pyroxene, giving rise to a mosaic of grains of various sizes and shapes, which grains are seen to have moved over and around one another, but in one plane, that, namely, of the foliation of the rock, which foliation in fact results from this movement. All the evidence goes to show that this granulation of the rock is a purely mechanical process. The pyroxenes are quite unaltered, and there is no evidence of any re-crystallization or alteration in the case of the felspar. The resulting foliated rock differs from the original massive one only in being fine in grain and in the possession of a foliated structure, due to the granulation as above described.

Another fact before referred to in connection with the Morin anorthosite, and exemplified by all these granulated rocks—ordinary gneiss as well as anorthosites—is that in those portions of the sections where the granulation is complete, but little in the way of conclusive evidence of any granulation could be obtained were these to be studied alone. In such cases mosaics of little angular grains are seen, each individual of which has an even or almost even extinction. That this must b is realized when a large grain in process of breaking up is studied microscope; for the strain to which such a grain is subject to cause it to become resolved into a number of optical anded by strain-shadows, but within such areas little or no st is developed, so that when the next step is reached and the large grain actually breaks along the lines of maximum strain the result-ing grains, representing the areas in question, never show more than very faint strain-shadows while most of them, the strain being relieved, have a uniform extinction. A mosaic thus results, which while pro-duced by intense granulation bears, when studied apart from its sur-roundings, little or no evidence of its origin, and might be considered to have originated in other ways. It thus becomes evident that if the whole rock had reached the final stage of granulation, which stage would be reached much sooner in the case of rocks fine in grain than

No evidence of cataclastic structure when granulation is complete.

in those composed of large individuals, but little conclusive evidence as to its true origin might be obtained from a study of thin sections. The very thoroughness of the granulation would mask its existence, and it might be concluded that the rock had crystallized in its present form. This fact is an important one to bear in mind when studying rocks such as those at present under consideration. In this process of granulation, the pyroxenes while presenting all the phenomena above referred to, usually retain their form much better than the felspars.

The examination of the sections shows, furthermore, that the movements in question must have taken place when the rock, if not completely crystalline, was almost so. All the minerals are granulated and must, therefore, have been crystallized out before the movement took place, and if any residual magma whatever was present when the movement took place, no sign of it can now be detected. Rock crystalline when movements occurred.

Occasionally in a section a little line of faulting or shearing can be observed traversing the foliation obliquely and apparently developed at a later date. Along such lines the granulation is exceedingly fine, differing in a marked manner from that of the rest of the rock and being in many cases accompanied by the development of calcite in large amount, thus showing that the conditions under which the original granulation took place were quite different from those under which the faulting originated.

A table of analyses of anorthosites and of certain of their constituent minerals is subjoined :—

Analyses of anorthosites.

TABLE OF ANALYSES OF ANORTHOSITES, ETC.

	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	XXIII.	XXIV.	XXV.
SiO_2	59·55	59·80	58·50	51·85	51·35	—	57·20	57·55	54·45	54·20	54·47	54·62
TiO_2	—	—	—	—	—	39·86	—	—	—	—	—	—
Al_2O_3	25·62	25·39	25·80	3·96	3·70	—	26·40	} 27·10	28·05	29·10	26·45	26·50
Fe_2O_3	0·75	0·60	1·00	—	—	—	0·40		0·45	1·10	1·30	0·76
FeO	—	—	—	20·20	20·56	56·64	—	—	—	—	0·67	0·56
MnO	—	—	—	trace	—	—	—	—	—	—	—	—
CaO	7·73	7·78	8·06	1·60	1·68	—	8·34	8·73	9·[illegible]8	11·25	10·80	9·88
MgO	trace	0·11	0·20	21·91	22·59	1·41	—	—	—	0·15	0·69	0·74
Na_2O	[illegible]·09	5·14	5·45	—		—	5·83	5·38	6·25	[3·80]	4·37	4·50
K_2O	0·96	1·00	1·16	—	—	—	0·84	0·79	1·06		0·92	1·23
H_2O	0·45	—	0·40	0·20	0·10	—	0·65	0·20	0·55	0·40	0·53	0·91
	100·15	99·82	100·57	99·66	99·88	102·84	99·66	99·75	100·49	100·09	100·20	99·70
Sp. Gr.	2·66 to 2·67	2·66 to 2·67	2·67	3·409 to 3·417	3·409 to 3·417		2·68 to 2·69		2·69	2·68 to 2·69	2·72	2·70

	XXVI.	XXVII.	XXVIII.	XXIX.	XXX.	XXXI.	XXXII.	XXXIII.	XXXIV.	XXXV.	XXXVI.	XXXVII.
SiO_2	50·33	46·28	56·0	55·59	58·1	53·56	53·43	54·00	52·23	54·34	54·26	54·36
TiO_2	0·07	0·59	—	—	—	—	—	—	—	—	—	—
Al_2O_3	3·36	7·38	27·5	25·41	} 27·9	27·78	28·01	27·82	26·96	29·36	} 29·29	29·36
Fe_2O_3	1·03	2·21	0·7	2·73		1·1[illegible]	0·75	—	—	—		
FeO	19·40	14·80	—	—	—	—	—	1·50	1·98	0·22	—	—
MnO	0·71	—	—	—	—	—	—	trace	trace	trace	trace	trace
CaO	2·77	18·78	10·1	11·40	9·4	12·01	11·24	11·20	13·25	10·79	11·26	11·16
MgO	21·40	8·91	0·1	—	trace	trace	0·63	0·05	0·12	—	trace	trace
Na_2O	—	—	5·0	4·83	5·1	4·10	4·85	4·76	5·23	5·19	4·87	4·81
K_2O	—	—	0·4	0·32	—	1·68	0·96	0·43	0·23	0·46	0·48	0·63
H_2O	1·14	1·11	—	—	—	—	trace	—	—	—	0·22	0·22
	100·21	100·06	99·8	100·28	100·5	100·28	99·87	100·04	100·00	100·66	100·38	100·54
Sp. Gr.	3·459	3·386	2·697				2·673					

XIV. & XV. Large fragments of reddish plagioclase from the anorthosite of Château Richer. (T. S. Hunt, Geology of Canada, 1863). Notes to table.

XVI. Fine-grained plagioclase groundmass, in which the former are imbedded. (*Ibidem.*)

XVII. & XVIII. Hypersthene from the same rock. (*Ibidem.*)

XIX. Ilmenite from the same rock, with 4·9 p.c. of insoluble matter, quartz, etc. (*Ibidem.*)

XX. Bluish plagioclase in large fragments from another hand specimen of the Château Richer anorthosite occurring imbedded in a fine granular groundmass of plagioclase. (*Ibidem.*)

XXI. Similar plagioclase from an anorthosite boulder from the neighbouring parish of St. Joachim. (*Ibidem.*)

XXII. Very fine-grained, almost white anorthosite, from Rawdon (Morin area). (*Ibidem.*)

XXIII. Blue opalescent plagioclase from the Morin anorthosite. (*Ibidem.*)

XXIV. Bluish opalescent plagioclase from the summit of Mount Marcy in the State of New York, U.S.A. (A. R. Leeds, 13th Ann. Rep. New York State Museum of Natural History, 1876.)

XXV. Very fine-grained yellowish anorthosite from the State of New York, U.S.A. (*Ibidem.*)

XXVI. Hypersthene from the anorthosite of Mount Marcy in the State of New York, U.S.A. (*Ibidem.*)

XXVII. Diallage from anorthosite, New York State, U.S.A. (*Ibidem.*)

XXVIII. Labrador felspar, Paul's Island, Labrador. (G. Tschermak, in Rammelsberg's Mineralchemie).

XXIX. Labrador felspar, Paul's Island, Labrador. (*Ibidem.*)

XXX. Plagioclase from a fine-grained, whitish anorthosite from Labrador (granular groundmass). (H. Vogelsang, Archives Néerlandaises, T. III., 1868).

XXXI. Bluish-gray untwinned labradorite, Paul's Island, Labrador. (G. Hawes, Proc. Nat. Mus., Washington, 1881).

XXXII. Labrador-rock. The chief rock of the vicinity of Nain, Labrador. (A. Wichmann, Z. d. D. G. G., 1884).

XXXIII. Labradorite, Paul's Island. With traces of Li_2O and SrO; v. 19 lost on ignition. (Jannasch, Neues Jahrb. für Min., 1884, II., 43).

XXXIV. Labradorite, Paul's Island. The part soluble in HCl. With traces of Li_2O and SrO. (*Ibidem*, p. 43.)

XXXV. Labradorite, Paul's Island. The part insoluble in HCl. (*Ibidem*, p. 43.)

XXXVI. Labradorite, Paul's Island. With traces of Li_2O. (Ber. Deutsch. Chem. Ges., 1891, XXIV., 277.)

XXXVII. Labradorite, Paul's Island. With traces of Li_2O. (*Ibidem.*)

Notes on the Anorthosites occurring in other parts of Canada and in Foreign Countries.

In addition to the anorthosites described in the present Report, a number of other similar occurrences, some of them of much greater extent, occur in other parts of Canada. A noteworthy fact in connection with these anorthosites is that they are distributed along the

Anorthosites elsewhere in Canada.

Relation to Archæan Protaxis.

southerly and easterly limits of the main Archæan protaxis bordering the great ocean basin in which the Cambrian rocks were deposited later on, showing that in these ancient times the eruptive rocks apparently followed the same law that now obtains in the distribution of volcanoes; namely, that they occur along the borders of the continents as belts around great oceanic depressions. By far the largest of these is the great anorthosite area about the upper waters of the River Saguenay, which is known to occupy not less than 5800 square miles, and which may stretch across the headwaters of the River Betsiamites and connect with the area lying about the headwaters of the Moisie, in which case the area of the mass will be probably double that just given. Over this great area, the rock consists almost entirely of plagioclase.

The other areas which lie chiefly along the north shore of the River and Gulf of St. Lawrence are described in my paper entitled "Ueber das Norian oder Ober Laurentian von Canada," and in other papers to which references are given in Appendix I.

Anorthosites in Norway

The largest developments of anorthosite with which we are acquainted outside of Canada, excepting those of Minnesota and the State of New York, described by Emmons, Kemp, Lawson and others, are probably found in Norway.

The rock called by the Norwegian geologists Labrador rock, as well as some of Esmark's norites and many of the so-called gabbros of that country, are anorthosites.

These rocks have been described by Kjerulf,* Reusch,† and others. They form enormous mountain-masses, and are, as in Canada, sometimes violet or brown in colour, and sometimes as white as marble. They are sometimes massive and sometimes banded or foliated. Many of them in hand specimens can not be distinguished from the corresponding varieties of Canadian anorthosite.

They are intrusive rocks, and generally break through the gneiss. But in Laerdal and Vos-Kirchspeil, according to Kjerulf, they cut through beds of Primordial age, and are therefore probably somewhat more recent than the Canadian anorthosites. An accurate comparison of the rocks cannot yet be made since the Norwegian occurrences have not as yet been investigated in detail. But so far as we know at present, the rocks of the two countries are identical.

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*Kjerulf, Die Geologie des südl. und mittleren Norwegen, p. 261.
†Reusch, Die fossilien führenden krystall. Schiefer von Bergen, p. 84.

Anorthosites in Russia.

In southern Russia, near Kamenoi-Brod, in the Government of Kiew, and in many other places in the governments of Volhynia Podolien and Cherson, large areas of anorthosite also occur. In these the labradorite predominates almost to the entire exclusion of other constituents. The rock occurs in some places in a coarsely granular form, which is dark violet or almost black in colour, and elsewhere as a porphyritic variety with large dark-coloured individuals of plagioclase in a light-gray groundmass. These varieties are said to pass into one another. Where the coarsely granular variety contains pyroxene, it shows ophitical structure like that observed in some parts of the Saguenay area. According to the description of these rocks by several authors,* they must resemble in a remarkable manner the anorthosites described in this paper, and also exhibit the same varieties. They are found in the great district of granitic rocks which occupy this portion of the Russian Empire, which rocks, where they occur in the Government of Volhynia are classified by Ossowski as Laurentian. The magnificent pillars of labradorite in the Church of Our Saviour in Moscow, are from quarries in these rocks.

Anorthosites in Egypt.

Another occurrence of anorthosite of particular interest is found in Egypt. Sir William Dawson, while on a visit to that country in the year 1883, observed a rock that resembles exactly the banded variety of the Morin anorthosite, and which had been used for a magnificent statue of Kephren, the builder of the second pyramid. This statue now stands in the Gizeh Museum, with a few other fragments of statues of the same material. Through the kindness of the curator of the Museum, Sir William obtained a few small pieces of the rock for examination. In the hand-specimen the rock cannot be distinguished from the granular anorthosite which is found in the neighbourhood of New Glasgow in the Morin area. It is fresh,† bright gray in colour and almost entirely composed of plagioclase, with a little hornblende, which mineral is occasionally intergrown with pyroxene. It is the foliated variety of the anorthosite, and the dark lines which are caused by the presence of hornblende can plainly be distinguished in the statue, especially on the right side. Sir William did not find the rock in place, but Newbold appears to have found it among the very

*Schrauf, Studien an der Mineralspecies Labradorit. Sitzungsber Wiener Akad. 1869, p. 996.—W. Tarrasenko, Uber den Labradorfels von Kamenoi-Brod. Abhandl. d. Naturw. Ges. in Kiew. 1886, p. 1-28.—M. K. De Chroustchoff, Notes pour servir a l'étude lithologique de la Volhynia. Bull. Soc. Min. France, IX., p. 251 (containing further references).

† Dawson, Notes on Useful and Ornamental Stones of Ancient Egypt.—Trans. Victoria Institute, London, 1891.

ancient rocks which form the mountainous country to the east of the Nile, where it appears to have the same geognostical relations as in Canada. It was probably prized by the Egyptian sculptors for the reason that it possesses a pleasing colour, similar to marble, while at the same time taking a better polish and being considerably harder.

These anorthosites, therefore, are found in five of the countries where the Archæan has an extensive development: in Canada, in the United States, in Norway, in Russia and in Egypt. They are found in enormous masses in the first four co tries, and their extent is not yet known in the last mentioned. To these occurrences others will probably be added as the Archæan of other parts of the world is carefully studied.

Post-Archæan Dykes.

Post-Archæan dykes.

Here and there throughout the area, but especially in its southern portion, dykes of fine-grained black rock, allied to diabase in composition, occur cutting across both the gneisses and anorthosites. As these have not been observed traversing the Palæozic strata of the plains they are probably pre-Potsdam in age.

In mode of occurrence they present the characters commonly seen in trap dykes. The walls are well defined and approximately parallel to one another, their attitude being nearly vertical. They frequently hold fragments of the country-rock, caught up by the dyke-rock while yet in a molten condition, and can occasionally be observed to send off lateral apophyses into the surrounding rock. The dykes can frequently be seen to be much finer in grain toward the margins of the dykes, indicating that the country-rock was comparatively cold at the time of their intrusion. There is no evidence whatever to show that these dykes have been subjected to the folding and deforming forces which have so profoundly affected the Archæan rocks of the region. They have been practically undisturbed since the time of their solidification.

The prevailing course of the dykes is approximately east-and-west, but many of them run in directions almost at right angles to this.

They differ greatly in width, ranging from five or six feet to over 300 feet—several over 100 feet wide having been observed—and are usually traversed by several sets of well marked joint plains.

The rock is black on fresh fracture and usually weathers brownish.

In the south-west corner of the district, Sir William Logan noted the occurrence of black dykes in a number of localities, and considered them to be portions of three large dykes running across the country in an approximately east-and-west direction, all of which were interrupted by the syenite intrusion mentioned on page 29 J.

The most northerly of these dykes was traced by Sir William Logan as far east as lot 6 of range VI. of Chatham Gore, and what is in all probability its continuation was found on the line separating St. Columban from the Augmentation of Mille Isles, near the north-west corner of the former. It crosses the road at this point, and has a width of 300 feet. On the same course further east, what is probably the same dyke is exposed at the foot of the falls on the North River, at the pulp mill, about three miles above St. Jérôme. It is exposed for a width of 105 feet, but only one wall is seen. The course of this wall is east-and-west. Further east still, a short distance north of Ste. Sophie, a whole series of parallel dykes, thirteen in number, and aggregating 69 feet in thickness, is seen within a distance of 200 yards. These also strike east-and-west. They possess a flow structure in some cases, and hold fragments of gneiss and quartzite as well as some of white anorthosite, indicating an extension of the arm of the Morin anorthosite under this locality, as might be expected.

Dykes noted by Logan

St. Jérôme.

Although it is quite possible that these several occurrences do not represent one continuous crack or fissure, they evidently mark the same line of weakness, which may be represented by a series of shorter parallel fissures approximately in the same line, as is often seen in the case in such dykes. The line of weakness has been now traced in a direction almost parallel to the edge of the protaxis, from the eastern side of the seigniory of Petite Nation, a distance of fifty-five miles, and in all probability continues still further to the west. The other dykes represented on the map in the district between St. Jérôme and Ste. Sophie are much smaller in size.

One of the two more southerly dykes traced out by Sir William Logan, may find its eastward continuation in a dyke exposed at the immediate edge of the protaxis to the south of the Lakefield anorthosite and running N. 50° E. This dyke is filled with angular fragments of white anorthosite (although that rock does not occur in the immediate vicinity) which fragments must have been derived from an underground extension of the Lakefield anorthosite in this direction.

Two other important dykes occur further north, cutting the Morin anorthosite. The first of these is exposed on lot 16 of range VII. of the township of Rawdon. It is seventy-five feet wide, and runs N. 47° W., having been followed for a distance of a mile and a half.

Dykes cutting anorthosite.

The other occurs on the third, fourth and fifth ranges of the township of Chilton, and runs parallel to the River Ouareau, near its eastern bank, for a distance of about two and a half miles, having a width of 120 feet.

Another smaller dyke, ten feet wide and running N. 87° W., is exposed on the first range of the Augmentation of Kildare, near the line between lots 4 and 5 on the road.

St. Lin dyke.

A number of other smaller dykes which were observed do not here merit especial mention, with the exception of one which is quite different from those already referred to both in composition and mode of occurrence. This is found on the plains about one mile from St. Lin, being exposed in the bed of the Little River. The exposures, however, are not very good, so that the precise relations of the rock cannot be determined. It cuts the Chazy limestone apparently in the form of an intercalated sheet, converting it into a highly crystalline red marble, which has here been quarried. The river is paved with this trap for a distance of about fifty yards, a thickness of about ten feet of the trap appearing in a cascade which occurs at this point. The marble is referred to on page 153 J, in the section treating of economic geology.

Diabase.

The great dykes traced out by Sir William Logan in the south-east corner of the area are referred to by him as dolerites,* and would be classed as diabases in the modern petrographical system. The St. Columban dyke when examined microscopically (Section 361) is seen to possess a typical diabase or ophitic structure consisting essentially of plagioclase and augite, the former running in lath-shaped individuals through the latter. A small amount of green hornblende, which may be either primary or secondary, and a small quantity of iron ore are present as accessary constituents. The rock also contains another mineral which is not commonly found in fresh diabases, namely, quartz, which occurs in considerable amount in micropegmatitic intergrowths with felspar, in the little corners between the other constituents. The supposed continuation of the dyke crossing the North River above St. Jérôme (Sections 273, 342) is almost identical in character and composition, the hornblende, however, being replaced by a small amount of biotite. The augite, which is of the common variety usually found in rocks of this class, often occurs in long narrow forms of irregular shape, and is twinned according to both the base and the orthopinacoid, and with it a lighter coloured malacolite is frequently associated in parallel intergrowths, as in the Konga diabase of Sweden

* Geology of Canada, 1863, p. 38.

Quartz in small amount, in clear grains or micropegmatite intergrowths, is present as before.

The dyke (Section 338) occurring at the edge of the Laurentian protaxis to the south of the Lakefield anorthosite, and which may represent an easterly continuation of another of Sir William Logan's dykes, is also a diabase of the same type, consisting of plagioclase, augite and iron ore, with a very little biotite, and the same micropegmatite intergrowth of quartz and felspar in the corners between the other constituents. It is, however, much decomposed.

Quartz-diabase.

This quartz diabase with typical ophitic structure, occasionally holding malacolite, is apparently the normal rock of the great east and west dykes of the district. The quartz occurs in micropegmatitic intergrowths with the plagioclase and is in all probability primary, as it is found in the rock even where it is perfectly fresh. It belongs to the Konga type of this rock described by Törnebohm in Sweden.

Augite-porphyrite.

Some of the smaller dykes in the district about Ste. Sophie and New Glasgow, which closely resemble these diabases in appearance, and probably have essentially the same chemical composition, possess a minutely porphyritic character, phenocrysts of plagioclase and augite being imbedded in a fine groundmass composed of the same minerals with iron ore and a little biotite. This groundmass probably cooled as glass, and has since taken on a crystalline character through a process of devitrification. They belong to the spilite type of the augite porphyrites, and in one or two instances show an amygdaloidal structure. One of these dykes, twenty-five feet wide, was observed on the road about one mile north-west of Ste. Sophie, and another forty feet wide in the bed of the River Achigan on lot 16 of range IV. of Kilkenny. The two dykes above mentioned as cutting the Morin anorthosite, one on lot 16 of range VII. of the township of Rawdon (Sections 626, 427), and the other on the third, fourth and fifth ranges of Chilton (Section 364), are identical with one another in all respects, and as they have almost the same course were probably intruded at the same time. Although having the same general composition, they are distinctly different in structure from both the quartz diabase and augite porphyrite above described. The rock is of medium grain, becoming fine-grained at the margins, and is black in colour but weathers brown. Under the microscope, the Rawdon rock is seen to consist of large phenocrysts of well twinned plagioclase, having perfect crystalline forms and filled with minute dark dust-like inclusions, giving it a dark colour, with large phenocrysts of pyroxene, also having a good crystalline form, embedded in a species of ground-

Dyke in Rawdon holding micropegmatite.

mass composed of a most beautiful micropegmatitic or granophyric intergrowth of quartz and plagioclase. This latter plagioclase is free from dust inclusions, the granophyric intergrowth being thus colourless. A small amount of hornblende and biotite as well as a considerable amount of iron ore and apatite, the latter in large and well formed elongated hexagonal prisms, are also present in the rock.

The plagioclase often occurs in beautiful Baveno twins, and a careful examination of the sections, combined with the evidence obtained from a crystallographic examination of the pulverized rock after separation by heavy solutions, shows that two pyroxenes occur intimately intergrown with one another, one a monoclinic augite of the ordinary type found in diabases, and the other a rhombic pyroxene having the parallel extinction, pleochroism and other optical properties characteristic of hypersthene.

Granophyre structure.

The granophyre constitutes a very considerable proportion of the whole rock, and makes the sections beautiful objects when examined between crossed nicols in polarized light. The intergrowth of the quartz and plagioclase is in some places very fine but elsewhere rather coarse, and the polysynthetic twinning of the plagioclase in it can be plainly seen. The granophyre can often be seen to have started its growth outward from phenocrysts of dark plagioclase or of augite, as shown in Plate X. reproduced from a micro-photograph of a thin section of the dyke, showing the granophyre growing about a crystal of plagioclase. The hexagonal crystal included in the plagioclase phenocryst is apatite, while the augite with good crystal form is seen on the right. It is doubtful whether any rock of this character hitherto described contains so large a proportion of granophyre. The rock is neither a diabase nor a gabbro, having neither the ophitic structure of the former nor the hypidiomorphic granular structure of the latter. The structure is rather a porphyritic one and exactly like that sometimes seen in the Konga occurrence before referred to. The constituents of the rock have separated out in the following order:—Apatite and iron ore, augite, plagioclase—the series concluding with the simultaneous crystallization of the quartz and plagioclase of the granophyre, which has all the characters of a primary structure. The rock contains 49·66 per cent of silica.

This micro-pegmatitic or granophyric intergrowth of quartz and felspar will probably be found to be very widespread in its occurrence in the dykes cutting the Archæan in Canada, as it is known also in diabases of the township of Templeton, in the county of Ottawa, in

PLATE X.—GRANOPHYRIC INTERGROWTH OF QUARTZ AND PLAGIOCLASE ABOUT A PHENOCRYST OF PLAGIOCLASE—DYKE ON RANGE VII., LOT 16, TOWNSHIP OF RAWDON. × 38.

the province of Quebec, while Dr. Lawson describes it as occurring abundantly in the dykes of the Rainy Lake district to the west of Lake Superior.*

The dyke near St. Lin which, unlike the others, is found cutting rocks of Cambro-Silurian age, is also entirely different in composition. Its original character cannot be determined, as the rock is exceedingly decomposed, but it probably belongs to the class of nepheline or melilite dyke-rocks like those found associated with the nepheline syenites about Montreal and elsewhere. Hydrochloric acid dissolves about twenty-five per cent of the pulverized rock, which effervesces freely. Under the microscope (Section 389), nearly colourless augite, with rhombic pyroxene for the most part altered to a mixture of bastite and iron oxide, and biotite in large crystals bleached nearly white, can be recognized. Also in the groundmass is a colourless mineral, uniaxial and negative and readily attached by acids, which is probably nepheline. A mineral which is probably perowskite is also present, as well as a large quantity of light yellow garnet, often having good crystalline form, together with much calcite or other rhombohedral carbonates, the products of decomposition.

Dyke near St. Lin.

While therefore the dykes occurring in the area are not very numerous, their study brings out a number of points of considerable interest.

Economic Geology.

Minerals and rocks of considerable economic value occur at a number of points in the area embraced by this report.

The following occurrences are referred to, either on account of their actual economic importance, or because they have been supposed to be of value and have attracted, or are likely to attract, more or less attention. Those deposits situated in the county of Argenteuil, to the south-west of the Morin anorthosite area, are not here referred to, as they have been examined by Dr. R. W. Ells, and will be described by him in a forthcoming report.

Iron Ore near St. Jérôme, County of Terrebonne.

Two and a half miles south-west of St. Jérôme, on the road which follows the northern bank of the North River, there is a deposit of magnetic iron ore. This occurs as several thin bands interstratified

Iron Ore—St. Jérôme.

*Report on the Geology of the Rainy Lake Region. Annual Report, Geol. Surv. Can., Vol. III. (N S.), p. 156 F.

with a dark hornblende rock and with the red orthoclase-gneiss of this part of the area, the whole dipping toward the river at a very high angle. At the time of my visit, in 1886, the ore had been exposed by the removal of the drift at a number of points along its strike, and a small opening had been made at one place. Subsequently, from October, 1891, until March, 1892, it was worked by the Canada Iron Furnace Co., during which time about 365 tons of ore was taken out and shipped to the company's furnace at Radnor, and there smelted. The following information has been kindly supplied to me by Mr. Arthur Cole, B.A. Sc [illegible]ho was engaged in carrying out the work :—

"Most of the ore was taken out of a pit which, when abandoned, was about 35 feet deep, 10 feet broad and 12 feet long. The ore-bed varied from two and a half to three feet in width, and was for the most part free from gangue. At a depth of 35 feet the bed narrowed down to a few inches, and was then entirely lost. A drift was driven from the west end of the pit along the bed for about 40 feet, the floor of the drift being about 15 feet from the surface.

"Work was then discontinued, but was resumed in August, 1892, but this time at a point about 100 yards further west along the outcrop of the bed. The ore here was in beds varying from a foot to a foot and a half in width. These beds often widened, but then they would separate into two beds with an intervening bed of rock.

"In some places the walls of the beds were very clearly defined, while in others the ore gradually faded away into the surrounding rock. About 50 tons was taken out of this opening, about ten feet deep and thirty feet long.

"Work was finally discontinued early in September, as it was found that too much rock was being handled."

Analysis.

A sample of the ore was analysed by me and was found to have the following composition :—

	Per cent.
Ferric oxide	59·059
Ferrous oxide	26·807
Titanic acid	none.
Phosphoric acid	·015
Sulphur	·001
Insoluble matter	9·897
Metallic iron	62·191
Phosphorus	·007
Sulphur	·001

This analysis brings out in a striking manner the distinction between the iron ores of the orthoclase-gneiss and those of the anorthosite, the former being usually free from titanium, while the latter is rich in this deleterious constituent. This ore, although so near the anorthosite, is quite free from titanium, while the similar ores in the neighbouring anorthosite areas contain a large percentage of this element.

Most of the other iron ores of this area, with the exception of the bog ores, which belong to the superficial deposits, unfortunately occur in or associated with the Morin anorthosite mass, and are, therefore, highly titaniferous. To these belong the following deposits :—

Township of Rawdon—Range II., Lot 2.

This deposit is near the village of Ste. Julienne, and although it has never been worked has attracted a good deal of attention. It occurs in the Morin anorthosite, near the eastern edge of the arm-like extension before referred to. The ore is found in a foliated white-weathering variety of the anorthosite rather rich in bisilicates. with a strike varying from N. 8° W. to N. 25° W. and a nearly vertical dip. Several black dykes, apparently of diabase, occur in the vicinity. The ore varies a great deal in character, being much purer in some places than others, and often occurs in the form of bands, from a few inches to several feet in width, generally conformable, or nearly so, to the foliation of the anorthosite, but in a few cases cutting across it. Both the anorthosite and iron ore are much twisted and faulted, and it is difficult to determine whether the ore has been erupted through the anorthosite or whether the cases where it cuts across the anorthosite are to be attributed to faulting. It, however, has a general trend in the direction of the strike of the anorthosite, the principal mass being exposed for about 200 feet at right angles to this direction. The "ore" appears to be in reality a variety of the anorthosite, and in most places too poor in iron to constitute an ore in the proper sense of the term. Rawdon

It is also highly titaniferous and contains iron-pyrites as a frequent constituent. A specimen collected by me and assayed by Dr. Hoffmann was found to contain :—

Metallic iron	42·29 per cent.
Titanic acid	Large amount.

Two samples examined by Dr. B. J. Harrington*, formerly Chemist to the Geological Survey, gave the following results :—

	I.	II.
Metallic iron	38·27 per cent.	40·71 per cent.
Titanic acid	33·67 "	33·64 "

while a third specimen, in which the iron was not determined, was found to contain :

Titanic acid.........	35·09 per cent.

Township of Wexford—Range I., Lot 7.

Wexford.

On this lot a small opening has been made in a dark-coloured, heavy massive rock containing a certain amount of iron ore. The field relations indicate that this is merely a local variety of the Morin anorthosite, exceptionally rich in the darker coloured constituents of the rock, and a microscopic examination proves this to be the case.

When thin sections are examined, the rock is seen to be composed essentially of a dark-coloured pyroxene, with plagioclase and iron ore. A not inconsiderable amount of apatite, with a few grains of pyrite, garnet and biotite, are also present. The proportion of iron ore is comparatively small, this mineral being entirely absent from some thin sections.

A specimen collected to represent the richest portion of the mass was examined by Dr. Hoffmann, with the following result :—

Metallic iron...	20·27 per cent.
Insoluble residue.	58·58 "
Titanic acid	Decided reaction.

Not very far from this locality, a remarkable case of local magnetic variation was observed in surveying the road between Ste. Adèle and St. Sauveur, where it runs on the side-line between the township of Abercrombie and the Augmentation of Mille Isles, on range X. of the former township, and thus near the margin of the Morin anorthosite. At one point on the road the needle suffers a deflection of 44° in a distance of 200 yards, returning again, further on, to its normal position. The road runs up a drifted valley and there are no rock exposures on it, the nearest exposures to the position of maximum deflection being 430 yards to the south-west and 70 yards to the north-east respectively, the rocks in both cases being the ordinary

* Report of Progress, Geol. Surv. Can., 1876-77, p. 475.

anorthosite of the district. Whether the variation is caused by a body of iron ore, and if so the position of the latter, can only be determined by a magnetic survey of the locality.

Township of Chertsey—Range VIII., Lots 5 and 6.

This deposit is also situated in the Morin anorthosite area, near its edge. It is, as in the case of the occurrence above mentioned, a variety of the anorthosite rich in iron. The anorthosite at this locality is rudely banded, some of the bands being poor in iron ore while others consist of a nearly pure ore. Large exposures which are very rich in ore occur all over the southern part of lot 6. The ore, although it has not been examined chemically, is in all probability, like the other iron ores occurring in the anorthosite, rich in titanic acid. Chertsey.

Township of Chertsey—Range I., Lot 9.

This deposit occurs in anorthosite which is associated with quartzose gneiss at the edge of the Morin area. Although containing a good deal of disseminated iron ore and locally considered to be of value, in no part of the deposit was the ore found to be sufficiently concentrated to be of economic importance.

Township of Kilkenny—Range VII., Lot 7.

This deposit is an impure ochre or limonite, occurring near the edge of the Morin anorthosite and apparently derived from the alteration of iron-pyrites, which occur as an impregnation in a band of anorthosite intercolated in the gneiss near the limits of the main area. The band of rock through which this limonite is distributed has a considerable width, but could not be examined everywhere at the time of my visit, owing to the fact that the forest covering the hill was on fire. No mass of the iron ore over one foot in thickness could be found, and the deposit, I should judge, is valueless as a source of iron. Kilkenny.

A specimen of the limonite collected by me was examined by Dr. Hoffmann, and was found to contain :—

Metallic iron..	25·75 per cent.
Insoluble matter............	Large amount.

It also contained a considerable amount of manganese, but no titanium.

Township of Kildare—Range X., Lot 11.

Kildare.

On this lot a deposit of bog iron ore was exposed in digging a drain.

A trench three feet deep was cut through the iron ore without reaching the bottom of the deposit, and it was exposed in the drain for a distance of about thirty feet. The deposit is probably of considerable size and the ore is similar in character to that so extensively worked and smelted further east in the district of Three Rivers.

Bog ore in Joliette.

A large deposit of bog ore also occurs on the line of the Canadian Pacific Railway between Joliette and St. Gabriel de Brandon, in the County of Joliette. This has been examined by Mr. Giroux.* The Canadian Iron Furnace Co. has worked this deposit and expected to take out about 200 car loads in 1891.

This company has also worked a deposit on ranges III. and IV. of the township of Joliette. That on range III. is considered to be one of the best hitherto opened up by the company. It varies from twelve to eighteen inches in thickness and is about three chains wide by five long.

All through the Joliette district, at intervals from the Laurentians to the St. Lawrence, deposits of bog ore have been discovered, and more or less has been taken out at a great many different points. The quality and richness of the ore is found to vary greatly from place to place. The Canada Iron Furnace Co. received from this district during the years 1893, 1894 and 1895 about 6000 tons of this ore.

The occurrence of bog iron ore at other points in the drift of the south-eastern portion of the area is referred to in the Geology of Canada (1863), p. 685, as follows:—

"Within four or five miles of the village of Industry (Joliette), there are several places in which bog iron ore is met with. One of these is partly in the township of Kildare, and partly in the Augmentation of the seigniories of Lanoraie and Dautraye, comprising a superficies of about nine square miles; and it exhibits patches of ore in so many of the parts which have been cleared of forest, as to lead to the hope that it may become profitable. Among other localities in this region, the ore is found on the line between the first and second ranges of Kildare,

*Summary Report of the Operations of the Geological Survey for the year 1891, p. 43 A.
Summary Report of the Operations of the Geological Survey for the year 1892, p. 44 A.

on the seventh and eighth lots; and on the seventh lot, on the road between the fourth and fifth ranges. Other localities where the ore was observed were in Côte Ste. Emelie and Côte Ste. Rose; but these portions being still in part covered with wood, it is difficult to determine the extent of the ore, although it appears to be considerable. Further to the east, this ore was also met with between the rivers Ste. Marie and Achigan and at the Seigniory of Lachenaye."

Ochre.—

A deposit of iron ochre, of a dark-yellow colour, was observed on the road between ranges II. and III. of the township of Kildare, about 600 yards north-east of the point where the road from the village of St. Ambroise de Kildare crosses this range-line. It occurs in the sandy drift which covers this district, and was exposed in an excavation about three feet deep. For a foot from the surface the ochre is impure, being mixed with a good deal of sand, but below this, as far as exposed, it was of a purer character. Ochre.

Gold.—

At intervals during the past thirty years or more, locations have been taken up at various points in this district and worked for gold. These, which are situated principally in the townships of Chertsey and Kildare, were visited and examined. None of them were promising in appearance, but with a view of determining conclusively the presence or absence of gold, a number of carefully selected specimens from several of them were collected and handed to Dr. Hoffmann to assay. They were found to be uniformly barren. As these deposits, however, have attracted much attention in the locality, and are still referred to as "gold mines," a few short notes concerning them may be of value. Gold.

The first group of these locations is in the township of Kildare, at or near the contact of the Morin anorthosite with the Laurentian gneiss, which latter here runs up as a tongue into the anorthosite, and is surrounded on three sides by the latter. The following four occurrences belong to it:—

Township of Chertsey—Range IV., Lot 11.

The county-rock is anorthosite, which here protrudes through the drift as a knoll. This anorthosite is traversed by small quartz veins, and both the anorthosite and the quartz veins in places contain a considerable amount of pyrite, giving to the weathered surface of the rock a very rusty appearance. A good deal of work was done here about forty years ago by a local company, and the location was then abandoned. Two sets of specimens selected, one to represent the Chertsey.

more pyritiferous and the other the more quartzose portions of the deposit, were, when assayed, found to contain neither gold nor silver.

Township of Chertsey—Range V., Lot 15.

The country-rock is fine-grained anorthosite, in which there are a great number of bands and strings of a coarse-grained anorthosite, varying from an inch to two feet in width, and containing in many places disseminated iron pyrites. This latter constitutes the "ore." The location was worked for three years, about thirty years ago, and some eleven thousand dollars are stated to have been expended. The principal working consists of a shaft 35 feet deep. A certain amount of surface work was also done on the face of a cliff of the anorthosite.

The rock, having been raised, was carted a distance of about a mile to the bank of the River Ouareau, where it was treated in a mill erected at that point. This, at the time of my visit, was fast going to decay. It contained a battery of five stamps as well as ten amalgamating pans. Some gold is stated to have been obtained, although the quantity was insufficient to pay expenses. A series of specimens were collected from the various parts of the exposure worked, with a view to representing an average of the "ore" which could with care be obtained. These were assayed by Dr. Hoffmann, and were found to contain neither gold nor silver.

Township of Chertsey—Range V., Lot 7.

On the south-western portion of this lot there is a cliff of bluish gray quartzite with interstratified bands of white quartzite, both rocks containing in places a little pyrite. This rock has not been assayed, but is very lean in appearance.

Township of Chertsey—Range VII., Lot 9.

Near the northern end of the lot the anorthosite is traversed by many veins of white and bluish quartz, the largest seen being three feet in width. One of these veins has been opened up but there are no indications of the presence of gold to warrant further expenditure.

Township of Kildare—Range IX., Lot 9.

Kildare.

On this lot a pit 25 feet deep was sunk about thirty years ago.

The rock worked for gold consists of white and grayish quartz, occurring as veins in the red and gray gneiss of the district, and conforming in a general way to the direction of their foliation. These sometimes attain a width of two feet but present no indication of the presence of any precious metal.

Augmentation of Kildare—Range IV., Lot 5.

The rock here consists of a more or less impure crystalline limestone associated with a gray quartzose gneiss. Both contain in places little specks of pyrite or pyrrhotite. A good deal of work has been carried on at different times. This was commenced by Mr. Dupuis, of Joliette, who many years ago formed a company and put up a battery of five stamps, with amalgamators and other appliances. He worked the pyritiferous gneiss and states that he obtained gold from it but not in paying quantities. Augmentation of Kildare.

At the time of my visit in 1888, operations had been resumed and were being carried on by a small local company. The workings consisted of a shaft about 25 feet deep and two short tunnels, the second of these, in a band of crystalline limestone flanked on either side by gneiss. Three sets of specimens were collected for assay; the first being some of the gneiss originally worked by Mr. Dupuis; the second from the roof near the entrance to the second tunnel above mentioned, from a spot from which samples assayed in Chicago were stated to have yielded $160 of gold to the ton; the third from the east wall of the same tunnel at its end.

These three sets of specimens were separately assayed by Dr. Hoffmann, and were found to contain neither gold nor silver.

The rocks worked at this locality are not such as either from their character or mode of occurrence might be supposed to contain gold in paying quantities, and the result of the assays as given above shows the correctness of these negative indications.

Township of Rawdon—Range VII., Lot 27.

A small excavation has here been made in rusty-weathering garnetiferous gneiss, which in some cases is micaceous and holds small strings of pyrite. The rock was stated to have been assayed and to have yielded gold in varying proportions. Rawdon.

Specimens collected, however, were assayed by Dr. Hoffmann, and found to contain neither gold nor silver.

Township of Rawdon—Range VI., Lot 24.

A similar rusty-weathering garnetiferous gneiss often holding a little graphite and some pyrite. The latter mineral is sometimes present in considerable amount. A series of specimens representing the average of a band of this rock about six feet in width were collected, but were found by Dr. Hoffmann, as before, to contain neither gold nor silver.

Township of Cathcart—Range V., Lot. 8.

Cathcart.

A gneiss, white on the fresh fracture, but for the most part so decomposed that excavations for foundations and other purposes several feet in depth have been chopped in it by means of an axe. The decomposed rock looks like a hard ochre and contains in places disseminated graphite. It was found by Dr. Hoffmann to contain neither gold nor silver.

"La Barrière"—Township of Courcelles.

La Barrière.

Near the south corner of the township of Courcelles, on the Mattawin road, a few hundred yards north of the line between Tracy and Courcelles, there is another "gold mine" at a place called "La Barrière." A good deal of work has been done here by the "Compagnie des mines d'or de Mattawin." A small quartz vein from six to eight inches wide and holding a little pyrrhotite was first worked, but subsequently a trench was excavated down the face of the gneiss cliff, in which the above-mentioned vein occurred, but without following any well defined vein. The gneiss is gray or sometimes white, often garnetiferous, and sometimes holds a little pyrrhotite and pyrite. It is stated that some specimens from this locality, assayed in the United States, have been returned as containing gold to the value of $434 to the ton. Others holding less gold are stated to have contained several ounces of silver to the ton. Samples collected by Mr. Giroux at the mine, and others of the quartz assayed in the United States and returned as containing considerable quantities of both gold and silver, were assayed by Dr. Hoffmann in the laboratory of the Survey and were found to contain only a trace of gold and no silver.*

Graphite.—

Graphite.

This mineral often occurs in considerable amount, in the rusty-weathering gneiss of certain parts of the area, especially in the eastern

*Summary Report of the Operations of the Geological Survey for 1891, p. 43 A.

portion of the township of Rawdon, N.N.E. of the village of Rawdon, and on the continuation of the strike of these rocks to the north in the township of Cathcart, as well as still further north on the River Assomption. At none of the localities in this part of the area, however, was the graphite found in sufficient abundance to make the deposit of economic importance, though the geological conditions are such as to render the discovery of valuable deposits of graphite in this district highly probable.

On the western side of the area, graphitic gneiss was observed on the Devil's River, in the western corner of the township of Archambault, while extensive deposits of graphite are known in the extreme south-west portion of the area embraced by the accompanying map, in Grenville and the adjacent townships. These latter are referred to in previous reports of the Geological Survey (See Geology of Canada, 1863, p. 794), but were not visited by me since, as has been mentioned, the survey of this corner of the area was carried out by Dr. Ells. Further reference to them will be found in his report.

Apatite.—

Deposits of this mineral are also known to exist in the south-western corner of the area, and will be referred to in Dr. Ells's report. The only occurrence of apatite known in the remaining portion of the area is that on range I., lot 33, of the township of Cartier. Here two openings, each about eight feet deep, have been made, on a coarse-grained granite vein six feet wide, cutting grayish garnetiferous gneiss. This vein consists essentially of quartz, white to dark-brown in colour, with white orthoclase, biotite and muscovite, the largest crystals of the latter being four inches in diameter. Apatite, tourmaline and garnet occur in smaller amount. One small crystal of pale-green beryl was also observed. The apatite is found in small crystals, but not in sufficient abundance to enable the vein to be profitably worked, and the hopes entertained that the quantity of the mineral would increase on going down on the vein were not realized. The black tourmaline has all through the district been mistaken for coal, and the deposit is commonly referred to as a "coal mine." Apatite.

Mica.—

Lac Ouareau.

Mica in large sheets is found at a number of places in the parish of St. Donat about Lake Ouareau. At the time of my visit, in 1887, it had Mica.

not been found in place, but was turned up in considerable quantities by the farmers when ploughing in certain fields. Specimens obtained from one of these localities, where the road running down the west shore of Lac Ouareau crosses the 11th range of the township of Chilton, when examined proved to be phlogopi e.

Kildare, Range VII., Lot 12.

Phlogopite occurs on this lot, scattered through a pyroxene rock containing quartz, felspar, and a little tourmaline. Sheets six by eight inches in size have been obtained. An opening has been made in the deposit and a small amount of mica shipped.

Infusorial Earth.—

Infusorial earth.

A small deposit is mentioned by Mr. Giroux as occurring near a small lake a few miles north of Chertsey, where the farmers use it for whitewashing their buildings.

Garnet Rock.—

Bands of highly garnetiferous gneiss are found at many localities within this area, associated with rusty-weathering gneiss, quartzite, and crystalline limestone. At two localities these are associated with bands of granular garnet rock, sufficiently thick to be of economic value.

Garnet rock.

The first of these localities is on the rear of lot 20 of range VII. of the township of Rawdon, where several beds of a rock composed very largely of a red garnet, occur interstratified with a fine-grained garnetiferous gneiss and white quartzite, the largest of the garnet beds being about two feet thick. Some portions of these beds consist of almost pure garnet, while in others this mineral is mixed with a little quartz, felspar and dark mica. A few blasts have been put in at this locality, but the deposit has not been worked as yet, although an abundance of garnet is to be obtained. The microscopic characters of the rock are described on page 84 J. A still purer variety of the garnet rock in beds of considerable thickness occurs on the adjacent lot, No. 21 of range VII. of Rawdon, but these have not been opened up as yet. The other locality is one mentioned many years ago by Sir William Logan (Report of Progress, 1853-56, p. 43), and referred to by him as follows :—

"On the west side of the crystalline limestone at St. Jérôme, beds of garnet-rock are interstratified among the quartzite of the locality.

They vary in their composition, and sometimes consist of a number of hyacinth-red garnets weathering pink, with yellowish-white prisms of diopside, among which are present small grains of greenish felspar weathering opaque white, a few minute scales of graphite and still fewer and more brilliant black grains supposed to be schorl. In some layers the garnets almost exclude the other minerals, but many variations occur in the proportions in which they are disseminated, in parallel undulating bands, in the thickness of the four or five feet composing the escarpment in which they are exposed, the bands being separated by thin divisions of quartzite and felspar. On the whole the garnets greatly prevail, and would appear to be in sufficient quantity for economic application."

Crystalline Limestone.—

The heavy bands of crystalline limestone which occur in many parts of the area and whose distribution has already been referred to, have a very considerable economic value as well as a high scientific interest. Although too coarse in grain to afford a good quality of marble, and the local demand for building stone being very limited, the limestone is in many places burned for lime, the local requirements being largely supplied in this way, especially in the remote districts in the rear of the area, which lie far from the Palaeozoic limestones bordering the St. Lawrence. Crystalline limestone.

Near St. Sauveur, in the Augmentation of Mille Isles, the coarsely crystalline bluish-white limestone, which here appears in very large exposures, has been burnt at intervals for many years, the suitability of the rock for the production of lime having been pointed out to the farmers in that settlement by Sir William Logan in the early years of the Canadian Survey. St. Sauveur.

At Lake Ouareau, about the rear-line of the township of Chilton, as has been mentioned (p. 23 J), a heavy band of similar limestone was discovered forming the greater part of two islands situated about half way up the lake and near its west shore, and also exposed elsewhere in the vicinity. The settlement here was, before this discovery, very remote from all known sources of lime, the necessary supplies of this material being drawn from St. Jérôme, a distance of forty miles, over roads not always of the best. The inhabitants of the district will now build kilns and burn their own lime. To the west at St. Jovite, in the township of De Salaberry, crystalline limestone is also burned, and in course of time the band which has been mentioned as passing down Trembling Lake will probably be similarly utilized. Lake Ouareau. St. Jérôme.

Rawdon.

The limestones to the east of the Morin anorthosite area are also burned at a number of places. There are kilns on lot 28 of range X. of Rawdon, and also on lot 28 of range XI. of the same township, for which the very extensive limestone deposits of that locality are utilized. The lime produced is said to be rather dark in colour, but clean and very strong, hardening into a sort of cement. On the northern continuation of the same band in the township of Cathcart, the limestone is burned at several points in the vicinity of St. Come. One of the principal kilns is situated on lot 23 of range IX., and has a capacity of 100 bushels. To burn this charge, about six cords of wood is required, which is to be obtained for fifty cents a cord; firing being continued for three days and nights. The lime, which is pure, clean and strong, sells for $1.00 per barac (six bushels). Another kiln is situated on lot 27 of range XI. of the same township.

Burned for lime.

The limestones at many other points above referred to in describing their distribution, would also afford abundant supplies of excellent lime. It may be mentioned, however, that the lime yielded by these Laurentian limestones is not as a general rule so suitable for the finer plasters used in interior work as it is for mortar for brick and masonry, being usually darker in colour than that obtained from the Palæozoic limestones of the plains, and often somewhat "sandy," on account of impurities contained in the rock.

Marble.—

Marble.

In addition to the limestones above mentioned, which have been burnt for lime, two occurrences of limestone have been worked as marble.

The first of these is situated in the township of Cathcart, near the line between lots 8 and 9 of range VI., and was opened for marble in 1881 by Messrs. Guibault and Dupuis of Joliette and Mr. William Burns of Rawdon. An excavation about 30 feet by 40 feet was made, and work was then suspended. Some specimens of marble of a good quality and taking a good polish are said to have been obtained. An examination of the location, however, shows that the marble, which is medium to rather coarse in grain, is mixed up with bands and strings of a green serpentine and of a gray pyroxene rock, the latter seriously impairing its value as a marble. The quantity also appears to be limited. The pyroxene, which occurs in the form of a granular aggregate somewhat resembling marble in appearance, is a malacolite having a specific gravity of 3·228 and containing 52·48 per cent of silica, with a little alumina and traces of iron and manganese. The serpentine is derived from the alteration of this pyroxene, and can be seen to gradually pass into it in many places. It is sometimes light-green and sometimes deep-green in colour, and frequently runs through the pyroxene, dividing it up into rectangular areas separated by narrow serpentine seams, giving the rock a somewhat striking appearance. A little brown mica, tourmaline and iron-pyrites are seen in some specimens.

Another marble, quite different in character and age, occurs about a mile from St. Lin, on the road to New Glasgow. The rock belongs to the Chazy formation and is exposed where a small stream tributary to L'Achigan River cuts through the drift and lays bare the underlying rock. The marble is produced by the alteration of the Chazy limestone by an intercolated sheet of trap which occupies the bed of the stream. It is red in colour and forms a thin layer over the traps. The marble has been quarried to a limited extent, but work had been suspended at the time of my visit. The trap, which has a somewhat unusual composition, has already been referred to in describing the dykes of the area (p. 139 J).

Anorthosite.—

This rock, although it has been but little used for building purposes, might in many cases be employed with advantage for decorative construction. It may be obtained in unlimited amount in the Morin area, of any colour from deep violet to white. The opalescent varieties occur but sparingly in this district. To judge of its appearance when cut and polished, two large blocks, one of the violet and one of the white variety were collected, and six-inch cubes were prepared from them. These were exhibited in the Colonial and Indian Exhibition held in London in 1886. The violet variety was collected on the eastern side of range II. of the township of Morin, and when polished presented a handsome appearance, but was rather dark in colour. The white variety, which was taken from the large exposures at New Glasgow, took a high polish, and in this state was found to bear a striking resemblance to marble. It is more difficult to work than marble, but would be more durable and would retain its polish better, especially in exposed situations, and might well be employed for many purposes in construction. Anorthosite.

On account of its toughness and durability, this white anorthosite from New Glasgow has been extensively used for paving stones in the Paving stone city of Montreal, especially on streets where there is a heavy traffic. A number of small quarries have been opened in the vicinity of New Glasgow, while a larger one is operated about two miles to the north of the village. The stone is blasted out in large blocks and is then dressed to the required size by means of large hammers. The industry which has thus sprung up is somewhat extensive; up to the time of my last visit in August, 1881, 541,000 anorthosite paving blocks having been shipped to Montreal by rail.

SUMMARY OF ARCHÆAN GEOLOGY.

1. The Archæan rocks in this area are of Laurentian age, and are in part referable to the Grenville Series and in part to the Fundamental Gneiss.

2. The Grenville Series contains gneisses, as well as limestones and quartzites, which are of aqueous origin, having the chemical composition and the stratigraphical attitude of sedimentary rocks. With these are intimately associated, however, other gneisses which are of igneous origin.

3. The Fundamental Gneiss consists largely, if not exclusively, of igneous rocks in which a banding or foliation has been induced by movements caused by pressure.

4. Both series are penetrated by various igneous masses, of which the most important are great intrusions of anorthosite, a rock of the gabbro family, characte ized by a great preponderance of plagioclase. This rock is in places perfectly massive, but generally exhibits the irregular structure which is so often observed in gabbros and which is brought about by a variation in the size of the grain or the relative proportion of the constituents from place to place. In addition to this original structure, the rock almost always shows a peculiar protoclastic, cataclastic or granulated structure which is especially well seen in the foliated varieties. This differs from the structure characteristic of dynamic metamorphism in the great mountainous districts of the world, having been produced by movements in the rock-mass while this was still deeply buried in the crust of the earth and probably very hot—perhaps near the melting point.

5. The same granulated structure is also seen in all those gneisses which have been formed from massive igneous rocks by dynamic movements.

6. The fine-grained aqueous rocks of the Laurentian, on the other hand, have been alte ed chiefly by a process of recrystallization.

7. The "Upper Laurentian" or "Anorthosite Group" of Sir William Logan does not exist as an independent geological series—the anorthosite, which was considered to be its principal constituent,

being an intrusive rock, and its remaining members belonging to the Grenville Series.

8. In all cases of supposed unconformable superposition of the anorthosite upon the Laurentian gneisses, which have been carefully investigated, the unconformability is found to be due to intrusion.

9. The anorthosites are probably of pre-Cambrian age, and seem to have been intruded about the close of the Laurentian.

10. The Canadian anorthosites are identical in character with the anorthosite associated with the Archaean rocks of the United States, Norway, Russia and Egypt. The Norwegian occurrences, however, are probably more recent in age than those of Canada.

APPENDIX I.

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APPENDIX II.

The Smelting of Titaniferous Iron Ores.

As the anorthosites in different parts of the Laurentian frequently contain great bodies of iron ore which are invariably rich in titanium, the question of the possibility of smelting such ores is one of great practical importance in the Dominion.

Several attempts to smelt these ores having proved unsuccessful the deposits in question have been looked upon as of but little value. Some recent investigations into the conditions under which titaniferous iron ores may be profitably smelted, by Mr. A. J. Rossi, have however an important bearing on the subject, and Mr. Rossi's paper presenting the results of his investigation, which appeared in "The Iron Age" for February 6th and 20th, 1896, is accordingly here presented in a slightly abridged form. It is possible that some of the less highly titaniferous of these Canadian anorthosite iron ores might be worked if the practice recommended by Mr. Rossi were followed.

THE SMELTING OF TITANIFEROUS IRON ORES.

BY A. J. ROSSI, NEW YORK.

General Considerations

In a paper read at the Montreal meeting of the American Institute of Mining Engineers in February, 1893,* we have had occasion to treat a subject which has been the cause of much controversy—viz., the smelting of titaniferous ores. In this paper, to which we will refer in what follows, we have placed ourselves as the champion of these much abused ores, and it was our good fortune in the discussion, short as it was, to see our efforts to rehabilitate these ores sustained by persons who occupy a prominent place in the metallurgical and scientific world. At that time we called attention to the fact that these ores had been smelted successfully in England in 1868, for a few years, at Norton-on-Tyne, by Dr. Forbes, quoting the able paper of Wm. M. Bowron,† then the chemist in charge of the works. In it he explains in detail the metallurgical treatment, giving the composition of all the materials charged in the furnace (16 feet diameter at boshes and 50 feet high),

*Vol. XXI., p. 832.

†A.I.M.E., Vol. XI., p. 159.

and that of the resulting slag. He says: "The uncertainty of the importation of the ores"—which came from Norway—"their leanness" (35 to 36 per cent of iron), "and the enormous quantity of titanic acid they contained" (38 to 40 per cent), "having militated seriously against the commercial economy of the process after a few years' working;" but, as he adds, "the process, regarded as a process, was a perfect success."

It was brought out in the discussion of our paper that: "Titaniferous ores from Taberg (Sweden) had been readily smelted for years;" "that these ores are of special value, being usually entirely free from phosphorus;" "that ores containing 5 to 6 per cent of titanium (8·33 to 10 per cent TiO_2) have been regularly used for a long time in a large establishment in Pennsylvania with very great advantage;" "that there were furnaces using titaniferous ores, without being aware of it, with beneficial results."* These ores occur in large deposits in this country, "some of these deposits having been placed providentially where they would prove the most inviting." Dr. Forbes has stated emphatically that whenever the amount of titanium did not exceed about 8 per cent (13 to 14 per cent TiO_2) "no difficulty was found in working the ores cleanly and profitably."

In the same discussion Dr. W. B. Phillips of Birmingham, Ala., summarized very clearly and tersely our own views on the subject when he said: "How long will American metallurgists cling to their opinion that these ores cannot be profitably treated?" "That the verdict recorded against them was unjust, based entirely on insufficient grounds and far from creditable to the progressive spirit of American metallurgy;" "that he, for one, believes that in the smelting of titaniferous ores there is abundant promise of success."

As to the special qualities of the metal obtained from them, to whatever cause it might be attributed, the absence of phosphorus or some specific action, there seems to be a sort of *consensus omnium*, and the results of our own experiments on a large scale on the resistance, properties of chill, &c., of mixtures in which entered the pig metal, afford another contribution to the truth of this assertion. "These ores yielded in England a forge iron which has brought double the market price of common iron. For use as a mixture to impart the properties of cold toughness to other irons, for making an iron to be mixed with other irons that are not quite up to the mark for boiler plates, sheets of cold stamping and the like, and for extra good iron generally these ores are most valuable."†

* A.I.M.E.—H. B. Netze, paper, Baltimore Meeting, Feb. 9.

† W. M. Bowron, paper.

We have had occasion to mention the continuous smelting for years in this country, some 40 or 50 years ago, of similar ores that occur in large deposits in the Adirondacks.* We have given even the plans of a furnace of some 15 tons capacity which is standing there yet, and was erected after the successful running of two smaller stacks. Lack of railroad communications, the death of the principal interested parties and the civil war caused alone the abandonment of the enterprise at the time, but in this case also the extra qualities of the product were attested by many official government tests. The fact that specimens of iron and steel made from the pig metal obtained from these ores received the "reward of a prize medal"† at the World's Fair in London, in 1851, affords another evidence of this superiority. References could be multiplied.

Briefly, we find:—

1. That these ores have been certainly smelted in Sweden for years without any difficulty.

2. That their metallurgical treatment for a certain number of years in England by Dr. Forbes, in a large furnace, has proved a perfect success.

3. That furnaces were run for years in the Adirondacks with these ores with excellent results.

4. That the metal they yield, either as pig metal, iron or steel, possesses special valuable qualities.

5. That these ores, which occur in large masses in many States of the Union, are almost invariably "Bessemer ores," and as such it is asserted have been used in Pennsylvania furnaces with great advantage.

6. That when containing very large percentages of titanic acid (as much as 38 to 40 per cent and even 48·60 per cent, like the ilmenite of Canada), and consequently a very small amount of iron (32 to 35 per cent, or less), their treatment though perfectly successful, metallurgically speaking, has not proved economical as to fuel.

Obvious as this last observation may appear and applicable as it may be to any kind of non-titaniferous ores, it has been put forward for a long time as a serious objection against the smelting of these ores on the score of economy! But, as was ably brought out in the discussion of our paper by Prof. B. J. Harrington of Montreal, "there are titan-

* A.I.M.E.—Montreal Meeting, '93.

† *Ibidem.*

iferous ores and titaniferous ores, and when speaking of smelting them we should keep the distinction in mind. There is a great deal of difference between an ore containing 40 per cent of titanic acid and one containing 10 or even 20 per cent." It would be more proper indeed to call an ore like the St. Urbain ore (Canada), which was smelted in Canada and which contains 48·60 per cent of titanic acid, corresponding to 29·10 per cent titanium and only 28·49 per cent iron, a titanium ore than to call it an iron ore.

Such was the state of the question when we took it up in 1893. Confident, from the work of others, that titaniferous iron ores had been and could be worked successfully, what we have done in the matter is to propose a new process of smelting them, suggested to us by a protracted study of the compounds of titanium, which we believe to be more economical than those followed previously. We experimented with it in 1892 in a very small blast furnace, an apparatus hardly worth the name, but at least reproducing the conditions of working and of reduction of a blast furnace as to the charging of materials, ore, stone and fuel, in lumps and in layers and blowing hot air under pressure through the mass, with the ordinary and distinct outlets for slags and pig metal. Successful as this experiment was, as we obtained several hundred pounds of very good metal, there could not be any attempt to secure or demonstrate economy under these circumstances. Since then we have operated on a much larger scale, in a furnace of a practical capacity, with results which will be described in this article. But before proceeding further, and in order to enable one to judge of the possible economy, it may be necessary to recall briefly certain properties of the titanium compounds and to explain what the different methods of treatment to be compared consist of.

Different Methods of Treatment of Titaniferous Ores.

Dr. Forbes's treatment, to all appearances, anticipated by those who smelted these ores before him, in Sweden or in this country, consists in adding to the titaniferous ores, as fluxes, limestone and quartz or silica bearing materials in such quantities as to form, with the titanic acid. compounds reproducing approximately a natural mineral of titanium, known to be fusible at a moderate temperature (3 of the scale of Dana), the sphene or titanite, a silicotitanate of lime containing about 35 per cent of TiO_2, 25 to 33 per cent of lime and 28 to 35 per cent of silica. The silica being generally deficient in titaniferous ores, often not exceeding 1 to 2 per cent and rarely going above 5 or 6 per cent, a large amount of quartz or silica bearing material has to be added besides the limestone in order to supply the desired and supposedly indispensable percentage of silica in the slag. This taxed the furnace as to productive capacity, actual amount and cost of fluxes required and consequently greater consumption of fuel for melting the excess of slag.

Our experiments have shown us that entirely satisfactory results can be secured without this addition of silica, and that titano-silicates, so to speak—that is, compounds in which in a general manner the titanic acid is predominant or constitutes an essential acid element for the slag, sometimes to the extent of making the substance practically a titanite—are fusible and quite fluid, at the temperature obtainable in a blast furnace in which even the blast is but very moderately heated, when the basic elements of the compound are alumina, lime and magnesia. Those slags are the more fusible in which the ratio of the oxygen of the acid to the oxygen of the bases does not reach over 4 : 3 approximately (1 : 0·75). The fusibility increases *cæteris paribus*, as the acid element predominates until certain limits are attained. It diminishes (if not the fluidity) as the basic element increases above this ratio, although the compound may prove perfectly admissible still as a slag in a blast furnace. In this respect titano-silicates, or even titanites, behave like silicates, but the difference lies in the fact that titanites decidedly more basic than those corresponding to the oxygen ratio 4 : 3 are apparently less fusible than the corresponding silicates; or, more strictly speaking, the diminution in the fusibility seems to increase more rapidly for the titanates than for the silicates with the same increase in the basic element. This is directly in favour of titanic acid as far as blast furnace practice is concerned, since its presence in a certain quantity in an ore will require the addition of less fluxes than the same quantity of silica would demand in order to obtain an equally fusible compound, if not one of the same oxygen ratio. On these experiments we have based our proposed method of treatment of titaniferous ores, which consists in introducing magnesia to a good amount into the slag by using a magnesian limestone, a dolomite. The alumina from the stone and ash of fuel and that very generally present as principal basic constituent of these ores furnished all the amount which is required to form the tribasic compound with the magnesia and lime of the stone and the titanic acid of the ore. In the same manner as magnesia introduced in certain proportions into an alumina lime silicate renders the latter more fluid and fusible, the addition of magnesia to a titano-silicate of lime and alumina considerably increases its fusibility and especially its fluidity. This observation is of importance inasmuch as it has been claimed sometimes that when minerals contain both magnesia and titanic acid they are rendered more refractory. True as this may be in a general manner as regards the compounds of titanic acid and magnesia, the presence of magnesia in a titaniferous ore would prove an advantage when properly fluxed with alumina and lime. Silica, which is a factor not necessary or depended upon to insure the fusibility in a titano-silicate, is to be found in the latter in such variable quantities as the silica of the ores, stone and ash of fuel will make it in each case, without extra addition of quartz or the like to bring it to a definite percentage considered indispensable.

In the very small furnace referred to above, with a blast at a temperature not over 250 or 300 degrees F. at the most, we ran without any difficulty slags of the following composition: SiO_2, 14·63; TiO_2, 34·66; CaO, 26·03; Al_2O_3, 7·36; MgO, 10·27; FeO, 7·12. Oxygen ratio, 4 : 3 practically; actually, 4 : 3·1.

The ore smelted in this small furnace contained only 1·50 to 2 per cent silica and 20 per cent titanic acid, and still the amount of silica derived only from fuel, fluxes and ores reached about 15 per cent of the total.

Let us apply now the two methods just described to ores, fuel and fluxes of the same composition as those used by Dr. Forbes in England in his large furnace, the only difference being that in our case the stone will be a dolomite, in his a calcite with an extra flux of quartz or silica-bearing materials. Mr. Bowron in his paper gives the following analysis of all the materials actually used in the furnace:—

Ore.		Coke, 5 per cent ash.		Calcite.		Old bricks.	
SiO_2	5·70	SiO_2	2·50	SiO_2	0·90	SiO_2	59·60
TiO_2	39·20	Al_2O_3	2·25	CaO	54·60	Al_2O_3	24·30
Al_2O_3	2·89			Al_2O_3	0·40	CaO	2·33
MgO	0·80			MgO	0·43		
MnO	0·60						

As will be observed, the amount of silica present could not in this case, in any manner, form with the bases, omitting the titanic acid, a slag of a composition admissible in a blast furnace. It would correspond to a percentage of SiO_2, 21·14; CaO, 42·74; Al_2O_3, 16·00, and MgO, 20·00, with an oxygen ratio of 4 : 9·80. The most extreme slags we have seen recorded exceptionally reached an oxygen ratio of 4 : 6 (or 2 : 3) of oxygen of acid to oxygen of bases. The use of a dolomite containing 7 or 8 per cent silica would alone raise the SiO_2 in the slag to about 13 per cent, diminishing the titanic acid proportionally. We give the above merely as an illustration of the possibilities, as we would not certainly smelt such poor ores when an abundance of titaniferous ores can be found containing at least 55 per cent of iron and up to 64 per cent and more, with only 14 to 10 per cent or less of titanic acid.

Such as it is, we have found the preceding compound perfectly fusible. It melted in a crucible, pla ed in charcoal, through which we blew cold air at a pressure of 3 or 4 ounces. It was distinctly crystallized in bluish black needles. We may remark here in passing that such a small amount of silica could hardly be expected in a blast furnace. With ores containing 20 per cent of titanic acid and 50 to 53 per cent of iron, such as were smelted in our larger furnaces last summer, the slag still contained about 15 per cent of silica and only 35 per cent of titanic acid. With richer ores, of an average of 60 per cent of iron and 10 per cent of titanic acid, not less than 18 per cent silica could be expected in the slag, with about 32 to 34 per cent of titanic acid. If the presence of silica were to be considered as an important element for the fusibility, these two latter slags ought to be still more fusible.

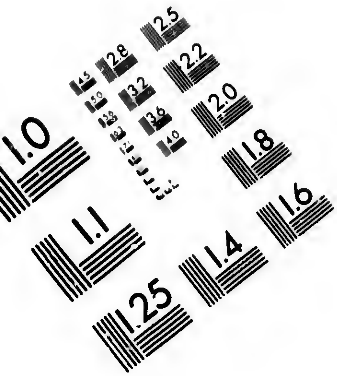
Properties of Titanic Compounds.

The results of the experiments which we have published in 1893, made either in crucibles or in our very small furnace, have been confirmed by the subsequent ones and by the protracted test we have made this summer in a blast furnace of a practical capacity.

Titano-silicates of lime, magnesia and alumina of an oxygen ratio of acid to basic element of 4 : 3, or still more acid, or slightly more basic, melt readily and prove more fluid at the temperature reached in a blast furnace working under unfavourable conditions as to heat. We will quote the following examples :—

SiO_2	11·94	14·82	16·00	15·60	18·00
TiO_2	38·20	32·99	28·8	40·50	34·50
CaO	23·40	21·02	26·00	24·00	27·60
MgO	6·50	9·50	10·00	8·00	10·00
Al_2O_3	15·00	10·45	10·00	10·00	12·70
FeO	5·00	4·50	6·50	2·00	....
Oxygen ratio	4 : 3·10	4 : 3	4 : 2·3	4 : 2·5	4 : 3

That the fusibility of a titanic compound does not necessarily depend upon the smaller amount of silica and the high percentage of titanic acid, but bears a more direct relation to the oxygen ratio, was proved by the following experiments :—



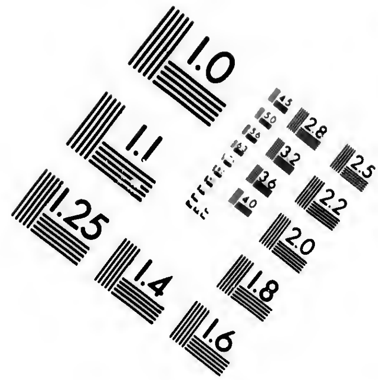
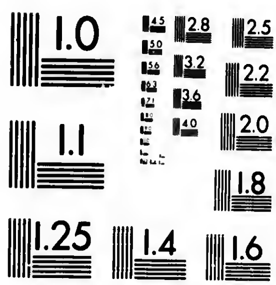
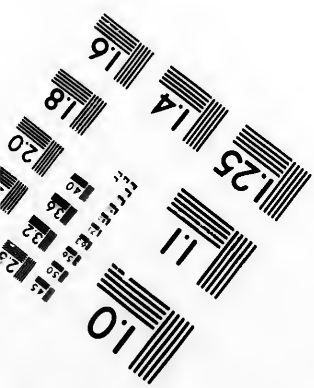
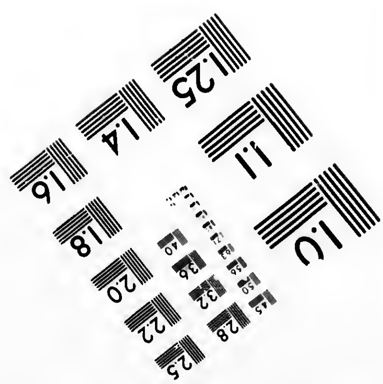


IMAGE EVALUATION TEST TARGET (MT-3)







1. By proper mixture of titanic acid (rutile) and bases we formed the following compound: SiO_2, 0·61; TiO_2, 44·05; CaO, 25·24; Al_2O_3, 14·40; MgO, 10·50, and FeO, 5·30, with an oxygen ratio of 4 : 4·78. It melted in the crucible. The fusibility, however, was decidedly affected; the appearance was stony and lumpy. We repeated the experiment with practically the same results, the only difference being that there was increased fluidity and the fusibility was better when the temperature in the crucible could reach a good white heat.

2. We mixed together in a graphite crucible impure titanic acid, commen rutile containing about 10 per cent of ferric oxide and 0·90 of silica, with lime, alumina and magnesia in such proportions as to form a decidedly acid titanate. Heated in charcoal, under a blast of 3 or 4 ounces of cold air, the mass (500 grams) melted completely. The compound was beautifully crystallized throughout in fine bluish black needles. We repeated this experiment several times, and have obtained several pounds of this curious substance, of which we have given specimens to the School of Mines of Paris and New York (Columbia College). Its composition, on an average, was: SiO_2, 0·72; TiO_2, 65·53; Al_2O_3, 10·92; CaO, 14·60; MgO, 7·30, and FeO, 0·90. What is characteristic and of great importance is that practically all the iron of the oxide of iron of the rutile separated cleanly at the bottom in the shape of a metallic button, a very small percentage of the iron only finding its way into the slag. The button was decidedly gray iron, No. 3, if not higher yet, in grade. There were no signs of the formation of cyano-nitride of titanium where the button touched at the bottom the graphite of the crucible. The oxygen ratio in this case was practically 4 : 2 (exactly 4 : 1·86).

In another experiment we tried to reproduce the mineral orthoclase, on a titanic base, by mixing together proper proportions of rutile, freed from iron as much as possible, and alumina and potash. Orthoclase has a composition of SiO_2, 64·6; Al_2O_3, 18·5; K_2O, 16·9. It melts at 6 (Dana) and has been found occasionally in crystals in some furnace scoriæ in Germany. Its oxygen ratio is 4 : 1·33 (3 : 1). By replacing the 64·6 of silica by such an amount of titanic acid as would contain as much oxygen (86·4 TiO_2) we have obtained a compound of the following composition: TiO_2, 67 to 70; Al_2O_3, 14·30, and K_2O, 17·00. It melted and crystallized, but not as perfectly as the preceding compound. Its fusibility was certainly less. Magnesia, alumina and lime appear to form with titanic acid compounds more fusible than others containing, with alumina, even such a percentage of potash as 17 per cent.

Briefly, the presence of titanic acid, even in large excess and without silica, in a substance, is far from being a cause of infusibility *a priori* if it is judiciously combined with the proper bases in suitable proportions.

Within the limit which we have briefly indicated there are, of course, many intermediary mixtures which, according to circumstances and the materials available, could form the basis of very fusible and fluid slags.

In our blast furnace experiments of last summer the temperature of the blast was not over 400 degrees F., and its pressure not more than 1 to 1¼ pounds, and still we had no trouble whatever to run from ordinary ores non-titaniferous slags of a ratio of oxygen of silica to oxygen of bases of 4 : 6 (2 : 3)—that is, of such a type as corresponds to the hottest working with blast at 1400 degrees F. under a pressure of 8 to 10 pounds, and to the darkest grades of iron most charged with silicon and graphitic carbon. The iron was white, and contained but a few tenths of 1 per cent of silicon. Though high enough to melt the more refractory silicates admissible in a blast furnace, the temperature was not sufficient to reduce the silica. This has a direct bearing on the smelting of titaniferous ores as corroborating the observations of Dr. Forbes in his practice and showing that such conditions can be made to prevail in a furnace as will melt the most refractory slags admissible and reduce the oxides of iron, and still they will not be such as to reduce the silica, and still less the titanic acid. Under these circumstances the furnace cannot be troubled with "titanium deposits," as it has been claimed.

These deposits consist of cyano-nitride of titanium, which supposes for its formation not only the reduction in the furnace of titanic acid to titanium, but the highest temperatures and other conditions. We have experimented considerably on this particular point, and inasmuch as under certain conditions, of which we may have to speak at some future time, and which were intended to secure the formation of this cyano-nitride which we wanted to produce, we failed to obtain it, we have reasons which justify us in taking exception to the too sweeping assertion in regard to the formation of these deposits. Some of the slags run in our furnace last summer contained as much as 32 to 35 per cent of TiO_2 and 16 to 14 per cent of silica, with alumina, lime and magnesia as bases; their oxygen ratio was 4 : 3. We made a number of analyses of such slags and in all cases we found them to dissolve completely, without any residue, in hydrochloric acid in the cold if very finely pulverized or under a gentle heat. The silica and titanic acid separated in a gelatinous state as the substance was heated. Had the titanic acid been merely carried mechanically, even partially, by the slag as so much infusible sand, it would have separated as an insoluble residue. This was never observed, and certainly furnishes the best proof that we had to deal with a definite compound, a titano-silicate. It explains why compounds containing a large amount of a substance infusible *per se*, the titanic acid, may prove quite fusible when this titanic acid can be carried into a definite combination with the proper bases, and also explains the tendency of these compounds to crystallize.

It may be argued that circumstances may so occur in the running of a blast furnace smelting any kind of non-titaniferous ores that they would lead to an obstruction whose removal would require forcing the heat and the pressure of the blast, and that these circumstances in the special case of titaniferous ores would be favourable to the formation of titanium deposits by the reduction of the titanic acid. The tendency of our days is to have in charge of the furnace competent persons capable of judiciously proportioning their charges from analyses made from day to day of the materials used, and such accidents have become certainly much more rare.

At all events this objection has been anticipated by Dr. Forbes, and, in the paper of Mr. Bowron referred to, a ready mode of relief is indicated. He says: "Throw off the titanic ore, and using non-titaniferous ore for a while, raise the heat and pressure of the blast and run the furnace on easily fusible slags until obstruction is removed; then resume the use of titaniferous ores."

The charges of the furnace were as follows: Coke, 2240 lbs.; ore, 2240 lbs.; calcite, 1200 lbs.; old bricks, 500. Making the proper calculations, he finds that from ores, coke and fluxes there could be expected a total amount of cinder-making materials of 2347·66 lbs. for every ton of ore used in the charges, 2·75 tons of ore being required per ton of pig metal with an ore carrying 36 per cent of iron. Assuming for convenience sake, and which is practically sufficient, that all the iron goes into the pig metal, this gives per ton of pig 6456 lbs. of slag, and a consumption of 4675 lbs. of fluxes. The resulting slag, as run from the furnace, had a composition from analysis by Mr. Bowron of: SiO_2, 27·83; TiO_2, 36·18; CaO, 24·36; Al_2O_3, 9·18; MgO, 0·60. As will be seen, the amount of silica present, 27·83, is still high enough to form with the 9·18 alumina and 24·36 of lime (independently of any titanic acid as an acid element) a perfectly fusible slag. It would correspond, reduced to a percentage and omitting the titanic acid, to a composition of: SiO_2, 44·80; CaO, 39·29; Al_2O_3, 14·80; MgO, 1·00, with an oxygen ratio of 4 : 3·10, nearly. This is a very fusible blast furnace slag, not very basic, not even corresponding to the darkest grades of iron.

Let us apply exactly the same mode of calculation in our case, assuming the same ore and fuel and the same quantities of each in the charges, but using a magnesian limestone not any more siliceous than Forbes's calcite, for fairness of comparison. The dolomite chosen has a composition similar to that of the ore we have used this summer in our larger furnace (except for amount of silica). It contained SiO_2, 0·90; CaO, 39·00; MgO, 12·00, and Al_2O_3, 2 to 3. It is easy to calculate that for every ton of ore and fuel in the charges 1000 lbs. of such dolomite stone would be sufficient to obtain a slag of the composition SiO_2, 10·78; TiO_2, 49·08; Al_2O_3, 8·10; CaO, 21·80, and MgO, 10·21. The total amount of slag from the materials of the charges per ton of ore would be found to be 1788·78 lbs. Per ton of pig metal we would have 4919·34 lbs. slag, as against 6456 lbs. as before, a saving of 23·80 per cent on the amount of cinder to melt, and consequent saving of fuel, and 2750 lbs. of magnesian stone, as against 4675 lbs. of fluxes, calcite and bricks, a saving of 41·30 per cent on the amount of fluxes added, although we have assumed the same quantity of coke to be required in both cases.

Of course it is not in our province, within the limits of this article, to discuss all that could be done in such cases. It would certainly depend on the circumstances which would have been likely to cause the obstruction, and others which could be only judged on the spot, and which might occur with any kind of ores. The cause may be the use of an excess of limestone. It is a recorded fact that furnaces smelting non-titaniferous ores have been thus choked up by such an excess of lime in the slag, so that it was too pasty to tap, and infusible blocks weighing thirty tons were formed, the removal of which required blasting. But the throwing off of the titaniferous ores for a while and the use of ordinary ores in their stead would at once create the ordinary conditions of practice. Furthermore, in the special case considered we could suggest several means which could prove efficacious.

Blast Furnace Tests.

When we had to make a practical test of these titaniferous ores last summer, conditions of economy imposed upon us the necessity of adopting a smaller scale than we would have desired. We decided on building a furnace of about three tons daily capacity, a size sufficiently large already to judge practically of the advantages of a certain treatment and to furnish valuable information, convinced that, if we were successful in these conditions as to running of slags, reduction of the ores, &c., we would be certain to obtain much more satisfactory and especially more economical results in a larger furnace provided with modern improvements.

For the same reasons we did not judge it necessary to complicate the construction by using a cup and cone, and for simplicity and economy sake we built our furnace open top. We could not in such circumstances expect to obtain a very high temperature of blast; in short, we placed ourselves in conditions of running rather unfavourable. But as it was important also to determine as much as possible the relative economy, if any, of the melting of titaniferous and non-titaniferous ores, we decided to run the furnace for a certain time first on ordinary ores, such as Lake Superior hæmatites, in order to study its working and ascertain what we could expect from it as to production, quality of pig-metal and amount of fuel required per ton of pig-metal before we should begin to use the titaniferous ores. By so doing we secured, we believe, a reasonable basis for a useful comparison of the economy of smelting the two classes of ores, or of the different treatment of the same ores, whatever might be the size of the furnace, since in both cases we were placing ourselves in exactly the same conditions as to apparatus used, temperature, pressure and volume of blast.

We give below the composition of the materials which entered the furnace from actual analyses made by the chemist in charge, supplementing them by such others as we have had made by different analysts in New York, or which have been furnished to us by outside parties.

Non-titaniferous Ores.—Lake Superior Hæmatites.

	Chemist in charge.		From parties furnishing the ore.	
SiO_2	4·58	5·24	5·60	4·66
Al_2O_3	9·16	7·19	.....	.....
CaO	0·29	.....	.....	.....
MgO	0·42	1·82	.....	.....
S	0·03	0·04	0·02	0·04
P	0·08	0·10	0·07	0·116
Fe	64·20	64·76	57·50	62·00

Calcite (fossiliferous).

	Chemist in charge.
SiO_2	2·89
CaO	52·00
Al_2O_3	0·59
MgO	Little.

Connellsville Coke.

(7·38 per cent ash.)

	Chemist in charge.
S	0·78
SiO_2	3·99
Al_2O_3	1·82
Fe_2O_3	1·50
CaO	0·07
MgO	....

Hackettstown, N. J., Dolomite.

—	I. E. S. Moffat.	II. Philadelphia Iron Works.	III. Lafayette College.	IV. Average analysis by the writer at Boonton, N. J.
SiO_2	8·06	9·44	9·27	8·75
CaO	29·09	28·18	29·29	28·60
Al_2O_3	} 1·12	4·97	3·37 }	3·00
Fe_2O_3				0·76
MgO	18·57	15·35	17·30	16·90
				0·18 S.
				0·15 P_2O_5.

Titaniferous Ores of the Adirondacks (Essex County).

	"Mill Pond."			"Sanford."				"Cheney."	
	Habershaw.	Chemist in charge.		Habershaw.	Middling good ore.			Wilbur.	Chemist in charge.
—	Rich ore.	Average rich.	Middling good.	Rich.	Rickett's Bank.	Chemist in charge.	Ledoux & Co.	Rich.	Poor ore.
SiO_2	1·09	3·67	1·53	0·87	2·46	1·39	1·34	....	9·79
TiO_2	10·73	13·38	19·74	10·91	20·03	19·52	18·70	8·25	15·77
Al_2O_3	0·44	1·50	3·50	0·53	3·50	4·00	....	....	7·12
CaO	traces.	little.	little.	.....	....	....	....	....	8·89
MgO	traces.	0·50	1·60	....	....	....	....	....	3·00
Mn_3O_4	0·13	....	....	....	....	....	....	....	....
Fe_3O_4	87·20	82·37	73·62	87·60	70·73	70·80	71·03	86·53	55·64
P	none.	0·017	0·037	none.	....	0·022	....	0·74	1·00
S	none.	0·068	0·08	none.	...	0·028	....	0·30	....
Fe	63·45	59·56	53·62	62·65	51 22	51·30	51·44	62·15	40·33

The Cheney ore was also used, but sparingly, one-fifth to one-sixth only being added to the charge, and none but the poorer ore, this last ore, which occurs in the gneissoid gabbro in decidedly stratified rocks, differing in this respect from the preceding. It has almost identically the same composition as certain ores from Split Rock and Lake Champlain, distant some 50 miles from each other and analysed by Professor Maynard some years ago. They occur in the same formation, if we quote rightly Professor Kemp, Professor of Geology at Columbia College, who, we understand, intends to publish at an early date the results of his investigations on the genesis of the titaniferous ores of this district.

The furnace as built stands 20 feet from the bottom of the hearth to the charging platform, the diameter of crucible is 2 feet 6 inches, its height 2 feet 3 inches, boshes 3 feet high, diameter 4 feet 6 inches at top. The stack is 14 feet 9 inches high, with a diameter of 4 feet 6 inches at its junction with the boshes, and 2 feet 10 inches to 3 feet at top, the inside capacity of the furnace being then very nearly 200 cubic feet. The lining proper was made of B. furnace fire-bricks 9 inches long, with a back lining of bricks $4\frac{1}{2}$ inches, making the total thickness nearly 14 inches. The stack rests on six cast iron pillars bearing at the bottom on a cast iron ring resting on the masonry of the foundations, and which bears the upper ring supporting the stack. The circle pipe is 6 inches in diameter, taking the blast from a system of two parallel rows of 6-inch diameter iron siphon-pipes arranged in an oven heated by a coke fire on a grate at one end. With this arrangement we have not been able to obtain practically more than 400° F. as temperature of blast measured at the tuyere's nozzle. The tuyeres, three in number, take the blast from the circle pipe through 3-inch diameter drop pipes having a diameter of 2 inches at the nozzle, which could be reduced by means of proper bushings, if found advisable, to all dimensions from 2 inches to 1 inch.

The tuyeres are provided with iron coils fitting them loosely, and where this coil passes through the back lining the latter was replaced by a special cast iron hollow box taking the circular shape of the furnace, and allowing the coil bearing the tuyeres to pass freely through a circular opening in the box, this opening and the space between the coil and tuyere being rammed in with fire-clay during the run. An independent circulation of water through the coils and boxes insured the cooling. In order to protect the boshes we resorted to a simple special device which proved very satisfactory. I used thick sheet iron plates made to fit snugly the curve and slant of the boshes between the pillars. These plates were upset at the bottom so as to form a shallow collector for water, closed at both ends. The water, supplied by a circular pipe around the furnace, sprayed through pin-hole openings provided for the purpose on the inside of this feed pipe and trickled down in fine streams on the inclined surface of the plates to the collector at the bottom, to be there wasted

The blast was supplied by a positive rotary blower capable of delivering at a normal speed at least 1000 feet per minute; more or less could be obtained according to the speed of the small steam engine driving it. The delivery pipe was 6 inches in diameter. Where it entered the hot blast oven it was provided with a release gate valve control the volume and pressure of air admitted in the furnace. In no case was the volume above 500 cubic feet per minute; generally from 350 to 400 cubic feet under a pressure of 16 to 20 ounces (1 to 1¼ pounds). In order to meet possible contingencies a by-pass with special arrangement of valves connected the admission pipe and delivery pipe of cold and hot air, so that in case of accidents happening to the oven we would have been able to blow in with cold air during the repairs; but we did not have occasion to use it.

It was soon found that by driving the furnace fast the best results were obtained. The slags, to our surprise, considering the small height of the furnace, did not contain much iron, no matter whether the ores used were Lake Superior hæmatites or titaniferous ores. By driving slowly the percentage of iron in the slag could be kept below 2 per cent (2·66 per cent FeO at most), a very small amount indeed. The slags of the large Dowlais furnaces, as stated by Percy, carried, in his time, 2·50 FeO, and not unfrequently 4·50, 5·50 per cent FeO, and even 7 and 8 per cent in running as white iron. At the Ebbw Vale and Blaena Iron Works, says the same writer, the regular amount of iron carried by the slag reaches 5 per cent or more, or 6·50 to 7 per cent FeO; it was exceptionally that we had more than this, and we may say that practically, in our condition of running, the reduction of the oxides of iron was quite satisfactory.

As could be expected, the furnace was extremely sensitive to any sudden changes in the burden, as well as to disturbances or irregularities in the amount or pressure of blast. On the other hand, it answered quickly to any such changes, and some 15 hours after the charges had been modified, sometimes less, the expected slag was tapped. Numerous analyses proved this to be the case. This feature of the apparatus was very advantageous for our purpose, as it allowed us to experiment on almost any composition of slag desired and ascertain rapidly the effect on the running of the furnace.

It could be easily observed also that, though the heat in the furnace were sufficient for a satisfactory reduction of the oxides of iron and the melting of almost any slag, it was not high enough to reduce the silica and cause the metal to charge itself with silica and graphite carbon. The iron obtained from both kinds of ores, titaniferous or not, was invariably white, and still during our run with Lake Superior haematites, not containing any titanic acid, we so proportioned our charges purposely to obtain slags so basic and so aluminous that some of them would have appeared, *a priori*, to be only admissible in furnaces in which the greatest heat prevails. Their composition corresponded to that of slags accompanying the darkest grades of iron, most charged with silicon and graphite, obtained in furnaces in which the temperature of the blast reaches as high as 1400 degrees F. and its pressure 8 to 10 pounds. Under these conditions of working, no titanic acid could be reduced. We made a great many analyses of slags during this run, No. 1, with non-titaniferous haematites, their average oxygen ratio being over 4 : 4 (1 : 1), and we ran slags extra basic of a ratio of 4 : 6 (1 : 1½), and still the iron was white. We quote as types the following:

SiO_2	30·10	33·40	36 to 37
Al_2O_3	22·98	22·70	22·50
CaO	36·87	30·80	28 to 27
MgO	4·38	4·70	4·5 to 5·0
FeO	3·80	6·60	2·80 to 5
Oxygen ratio	4 : 6	4 : 5	4 : 4·40 to 4·44

In this run we used as limestone the calcite of which the analysis has been given above, adding generally a little dolomite, of which we had a large stock.

The greatest run made in 24 hours with these ores, which contained an average of 62 per cent of iron, was 4600 pounds. These haematites were not reduced as fast in the furnace as we expected they would be; driving fast increased the production but not to the extent looked for. The blast was kept at a pressure of an average of 16 to 18 ounces, its volume fluctuated between 350 and 450 cubic feet.

When we had ascertained what we could expect from our furnace with ordinary ores, we began to add the titaniferous ores mentioned above in the proportion of four-fifths to five-sixths of Mill Pond or Sanford, and one-fifth to one-sixth of Cheney. It had not been the intention to use this Cheney ore at all at first, but owing to some mistake at the mines we had to dispose of some 40 or 45 tons of it. We proceeded by gradual increases of one-eighth titaniferous ores in the charges, keeping the furnace a certain time on each new mixture, until the burden of ore was all in titaniferous ores.

During this run, No 2, the mixture averaged 55 to 56 per cent of iron. Our best run in 24 hours was 5035 pounds. As will be noticed, as soon as we began to charge the titaniferous ores the yield of the furnace increased to a decided extent. It appeared as if these ores were more readily reduced than the hæmatites, made iron faster, at least under the conditions under which we were working. Large lumps not being admissible with a tunnel head 2 feet 10 inches to 3 feet in diameter, we broke all our stock, ores and flukes, from beginning to the end of the tests, to pieces of the size of the fist or a very large egg. The pressure of this blast during this run—No. 2—was about the same, 17 ounces on an average, and its volume varied, as before, between 350 and 400 cubic feet.

During this run we changed our stone from a calcite to a dolomite, or rather a dolomite to which we added enough calcite to bring the percentage of magnesia in the mixture of stones to about 12 to 14 per cent. We give below the principal analyses of the slags run as types :

	At beginning.	Middle of run.	Toward end of run.
SiO_2	34·10	29·50	27·29
TiO_2	4·90	9·96	17·48
Al_2O_3	22·00	18·26	14·43
CaO	23·63	24·12	22·71
MgO	10·00	9·72	11·55
FeO	3·82	6·40	4·30
Oxygen ratio	1:4·40	1:4·10	1:3·50

When the furnace was fully on titaniferous ores, the ore mixture averaged about 52 per cent of iron. It was soon noticed that the furnace could be driven fast with great advantage. A charge would reach the bottom in less than 15 hours; 12 to 15 hours was the rule. The yield increased considerably. We had runs of 4800, 4900 and 5600 pounds in 24 hours, and our best run in any single day reached as high as 6735 pounds, fully 3 gross tons. The blast was kept at very nearly 18 ounces throughout ; it did not vary to any extent, and the only changes observed were independent of our control. They were due to the irregularities in the blowing apparatus, which, owing to the exigencies of the works where these experiments were made, had to be located at a considerable distance from the hot blast oven. The economy of running the furnace fast was clearly apparent and confirmed our views in this respect, views corroborated by A. Pourcel, late technical director of the steel works at Bilbao, Terre Noire, France, and Port Clarence, England, in a letter, from which we extract the following:

"Mr. Rossi's ideas concerning the treatment of titaniferous ores in the blast furnaces have struck me from the start, as you are aware, as eminently logical. Furthermore, they seem to me to be sufficiently justified by the trial, on a small scale (in 1893), which Mr. Rossi has described in detail. * * * The easy reduction of the titaniferous ores justifies the expectation that with a blast furnace of 300 ccm. (10,500 cubic feet) capacity, for instance, it will be possible to reach easily a production of 100 tons of pig iron in 24 hours with ores containing 52 to 56 per cent metallic iron. * * * In conclusion I will say that the formula of slag and of moderate temperature of blast (300 to 400 degrees C.) recommended—with proof to sustain his opinion—by Mr. Rossi, ought to ensure the success of the treatment of titaniferous ores from the start, but there is nothing to exclude, *a priori*, the hypothesis that, with a rapid driving, by forcing somewhat the production, it may be possible to produce the same forge iron or pig iron for open hearth steel (Siemens-Martin furnace) with a temperature of blast higher—that is, in the conditions of running economical as to fuel. * * *"

In order to judge of the relative economy of these three runs, under as nearly as possible similar conditions, we will compare the amounts of fuel and stone required per unit of pig metal when the furnace gave the greatest production in each case. This supposes indeed, for the kind of ores or mixtures of ores considered, the most favourable conditions of running for each. By making precisely the same ample allowance of time in each case for stone and coke before each maximum cast of 24 hours as chargeable to that cast, we found the figures given below.

We feel justified in doing so by the fact that with titaniferous ores we had two successive casts of 12 hours each of 3325 and 3410 pounds (in all 6735 pounds in 24 hours) followed by a cast of 3200 pounds, and in other runs a cast of 2400 pounds in 12 hours followed by one of 2635 pounds (in all 5035 pounds in 24 hours), for the mixture of titaniferous ores and hæmatites, and a cast of 2200 pounds followed by one of 2400 pounds (in 12 hours), in all 4600 pounds in 24 hours, for the non-titaniferous hæmatites smelted alone.

Run No. 1.—Non-titaniferous hæmatites from Lake Superior:

Pig iron..........	1·00	
Stone.............	1·15	
Coke	2·15	Ores 62 per cent iron.

Run No. 2.—Mixture of hematites and titaniferous ores :

Pig iron	1·00	
Stone	1·19	
Coke	2·20	Ores 56 per cent iron.

Run No. 3.—Titaniferous ores from the Adirondacks :

Pig iron	1·00	
Stone	0·95	
Coke	1·99	Ores 52 per cent iron, 20 per cent titanic acid.

Hence, to say the least, the titaniferous ores, under the same conditions of furnace running, did not require any more fuel per unit of pig metal than excellent non-titaniferous ores; really, they require decidedly less, and the production of the furnace was increased considerably. We should remark here that run No. 1 was made with ores containing 62 per cent of iron, while in run No. 3 the amount of iron was not over 52 per cent.

We purposely chose the titaniferous ores not too rich and high in titanic acid. Had we used ores such as are found in very large quantities in that same district, averaging 60 to 62 per cent of iron and reaching even 64 per cent, with only 13 to 10 per cent of titanic acid, the saving on both fuel and stone, especially the latter, would have been much more in favour of titaniferous ores. If we make the calculation for such richer titaniferous ores containing 60 to 64 per cent of iron, of which we have given the analysis above, it is easy to see that, even in assuming 100 coke to 100 ore, in this case some 0·50 to 0·60 ton only of dolomitic stone would have been required per ton of pig metal to obtain a slag containing some 22 per cent of silica and 30 per cent of titanic acid with lime 24 per cent, alumina 14 per cent and magnesia 10 per cent as bases. With such a reduction in the amount of resulting slag to melt and of fluxes to add the economy as to fuel by rapid driving would have appeared of considerable importance.

We should remark also that if 2 tons of coke for 1 ton of pig metal would certainly be considered excessive in a modern furnace, we must not lose sight of the fact that the furnace was small and had an open top; that the temperature of the blast was not over 400 degrees F., and that we were wasting the gases which if utilized could have raised the temperature of the air easily to 800 or 900 degrees F. We would have desired to obtain the latter figure, and even 1400 degrees F. We have seen open top furnaces 65 to 70 feet high, of a capacity of 35 to 40 tons per day, not making a better showing as to amount of fuel per ton of iron, with ores richer yet than our titaniferous ores were. At any rate, we required even more than 2 tons of coke for 1 ton of pig metal with non-titaniferous ores, under the same conditions of furnace work.

We kept the furnace running until we exhausted our supply of ore, and we were able to empty it to within 1 foot of the tuyeres. When we opened it we found, as usual, in the crucible a small salamander, but no traces of cyano-nitride of titanium were visible either in the crucible, the boshes or any part of the furnace. This could be expected. The conditions of running of our furnace were not such as to reduce the silica, and still less the titanic acid. Though much inferior as to heat to those which could be adopted (a temperature of 800 degrees F. being perfectly admissible with these ores), they were reproducing in a general manner those which, with these ores, have given very satisfactory results. The iron contained but 0·1 to 0·2 per cent of silicon and only traces, practically, of titanium. Far from building, the ores had cut the lining several inches, and the latter was covered with a good protecting glazing material. We made a great number of analyses of the slags during this last run; others have been made since in New York. We give below the most characteristic ones as types:

SiO_2	20·59	15·32	14·82	15·90
TiO_2	26·81	31·26	31·97	31·38
Al_2O_3	10·17	14·50	12·43	11·23
CaO	23·60	20·56	21·00	22·40
MgO	10·24	9·09	9·97	9·70
FeO	6·90	6·02	4·50	6·40

An examination of these figures shows that the only varying elements of the analyses are the proportions of SiO_2 to TiO_2. In the last slags run the general composition was, in round numbers, 15 per cent SiO_2, 35 per cent of TiO_2, 10 to 12 per cent of alumina, 20 to 25 per cent of lime, and some 10 per cent of magnesia. In all the titanic acid is predominant.

These furnace tests, on a practical scale, have demonstrated, we believe, that under the conditions in which they were conducted:—

1. In a furnace only 20 feet high, with blast at only 400 degrees F., under average pressure of 16 to 18 ounces, titaniferous ores containing 20 per cent of titanic acid and 52 to 53 per cent iron can be perfectly reduced, making iron faster and with a consumption of fuel (coke) not any greater, or even less, per ton of pig metal than other ores free from titanium, with an economy as to quantity of fluxes used.

2. The titaniferous ores did not build. The lines of the furnace were found cut just as much as is the case with any other ores, non-titaniferous, after a limited run. No titaniferous deposits were observed.

3. Slags very high in titanic acid, containing 30 to 35 per cent of TiO_2 and but 15 per cent of silica, with alumina, lime and magnesia as bases, were found perfectly fusible under these conditions of low heat. They were fluid, running liquid 40 feet from the furnace on a snake-like course. Chemically, they were soluble without residue in hydrochloric acid; physically, they crystallized in a distinct manner.

4. With richer ores containing less titanic acid, with a greater temperature of the blast, at least 800 degrees F., as it has been done, much more economical results might be legitimately expected.

5. It is possible to form fluid and fusible compounds with titanic acid by the addition of the proper quantities and nature of fluxes, such as a dolomitic stone introducing magnesia. The latter, combined with alumina and lime, will contribute to render the titano-silicate or titanate much more fluid and fusible: contrarily to what has been asserted as to the difficulty or impossibility of tapping slags containing a few per cent of titanic acid (1 to 2 per cent).

6. There is nothing in the premises which could lead to suppose that a furnace could not be kept running under these conditions for an indefinite period.

Properties of the Iron Obtained from Titaniferous Ores.

Whatever may have been the opinion of many metallurgists as to the advantages, or even the possibility, of smelting these ores, the refractory character of slags containing titanic acid, there is one point on which they seem all to agree, the excellent qualities of the iron and steel obtained from titanic pig metal and the special value of the latter. We refer the reader for more details on this subject to the authority quoted in our Montreal paper and a preceding one read before the American Chemical Society in 1890.*

Speaking of the iron made at Norton-on-Tyne, J. Deby, late foreign secretary of the J. I. and S. Inst., says:† "It went to the armour plates of Sheffield on account of the toughness which this iron not only possesses but imparts to others in admixture." Mr. Bowron, alluding to the same iron, states that "it commanded double the price of ordinary iron." ‡ Such expressions as "wonderfully good" are found in the scientific press in England, relating to this titanic iron. It is

* Titanium in B. Furnace, Vol. xii. No. 4.

† Journal I. & S. Inst., 2, p. 19, 1877.

‡ Bowron paper.

not our intention in this article to examine the causes of this superiority. In a general manner we may say that if it is due to the presence of titanium in the pig metal, very small quantities of this substance are then sufficient to secure such results. In our blast-furnace tests we have not been able to obtain more than a few hundredths to one tenth of one per cent of titanium. It is met in quantities varying from 0·2 to 1 per cent in many pigs here and in England, to which it seems to impart a "greater tenacity."* The higher the grade of the iron the more titanium it is likely to contain. On the other hand, titanic pig made from ores from St. Urbain, Canada, containing as much as 41 to 48 per cent of titanic acid, smelted by the Forbes treatment under low temperature and pressure of blast, contained only traces—0·03 to 0·05, exceptionally 0·26 titanium—and still the qualities of the pig metal and iron were "exceptionally good" (analyses made at the Paris School of Mines).

But, if but omparatively very small amounts of titanium and silicon are found in the pig metal from a cold furnace, the percentage of carbon, mostly in the combined state, is often very high. Analysis of the metal from our small coke furnace of 1893 gave:—

Silicon	0·36	traces to 0·16
Titanium	None	0·07
Comb. carbon	2·835	2·99
Graphitic carbon	0·253	0·24

Even the salamander contained only Si, 1·05; Ti, 0·054. The metal, though "white," has not the ordinary characters of white iron. Its grain is generally very close and fine, its fracture more steel-like in colour and appearance and it is remarkably tough and hard. Under special conditions we have obtained pig metal containing:—

Silicon	0·29	0·62	and even 0·84
Titanium	0·85	0·78	1·94
Manganese	0·34	....	....
Carbon	4·56	4·12	...

It was so hard that it could hardly be broken on an anvil with a sledge hammer. It blunted the hardest drills and we had difficulty in obtaining samples for analysis.

Having been called upon by a large manufacturing firm to make tests on the chill, strength and resistance of mixtures of cast iron into which entered small percentages of different metallic elements, we had occasion to test, on the machine, our white cast iron obtained from titaniferous ores. Square bars of 1 inch section and 12 inches long between supports, broke under a load at the centre of 2700 to 2900

* Rivat Docimasie, p. 156.

pounds, which corresponds to a modulus of rupture, in cross breaking, of 48,600 to 52,200 pounds per square inch.

Cast in chilled molds, this iron offered a remarkable depth of chill on the test blocks. It had become so hard that drills or chisels of the hardest steel would not touch it. Its resistance to attrition was exceptional. For many obvious applications these properties would open a very extensive use for this iron as pig metal. Pieces of machinery requiring speci ' hardness were cast from this material and were subjected to particu.arly hard and trying conditions of wear. They have been found, after a year's service, in good order yet.

By mixing with irons showing a breaking load of 3350 pounds per square inch and a chill on the test pieces of 1·125 inches small percentages of this titanic pig metal, we increased the resistance to breaking to 3900 pounds and more, corresponding to a modulus of 70,000 pounds per square inch. The depth of the chill was increased to 1·375 inches. It compared favourably for resistance with other mixtures into which entered certain metallic elements, mixtures much more costly, and with which the chill dropped to 0·81 inch, and in some cases to 0·062 inch, making them unfit for the purposes for which they were intended, strong though they were. Hence the simple addition of this titanic pig metal, not more expensive, practically, than any other cast iron, to ordinary mixtures used for specific purposes, though increasing the hardness and the chill of the product in a remarkable manner, considerably increased also its resistance to cross breaking, bringing it to equal the strength obtained by much more expensive mixtures of which the cost would industrially exclude the use, and which, to all purposes, destroys the chill, an essential factor in the case considered. Industrial products were manufactured from these titanic metal mixtures to be submitted to the regular tests for strength, which they stood with very satisfactory results. The experiments were repeated many times and under different conditions. They dealt with a number of different mixtures. but they are of a more private character, and what we have quoted from them is sufficent, we believe, for the purpose of this present article.

Referring again to the two papers mentioned above for qualities of the iron and steel obtained from this pig metal, we see that either as such, or as a transformed product, the metal obtained from titaniferous ores could command numerous and important applications owing to its special qualities.

Conclusion.

In conclusion we may repeat what Wm. B. Phillips said in the discussion of our Montreal paper: "The verdict against titaniferous ores has been based on insufficient ground."

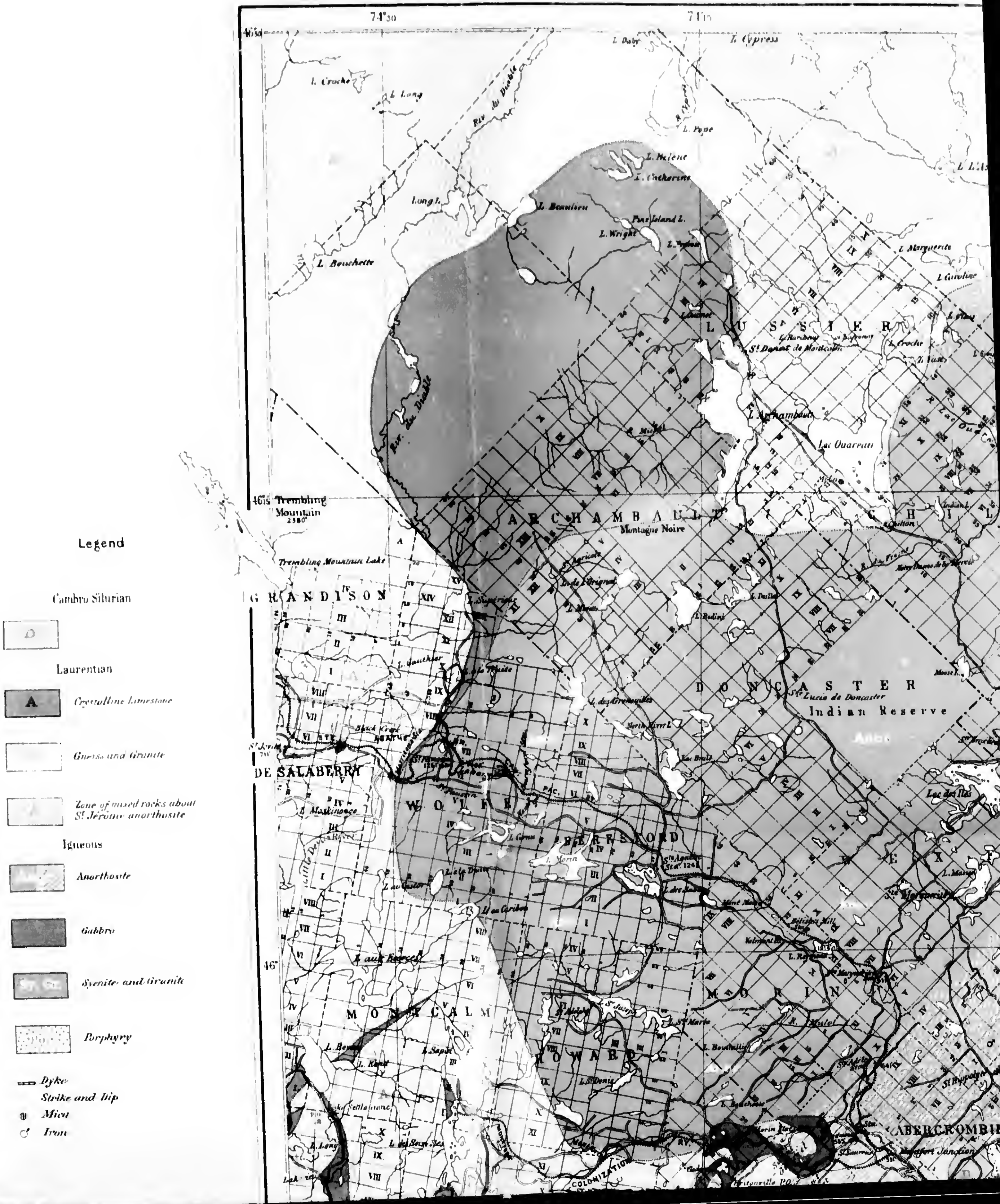
1. As anybody who may desire to make the experiment can verify, titanic acid can form definite compounds, perfectly fusible, if properly fluxed, containing as much as 35 to 40 to 50 per cent of titanic acid, with alumina, lime and magnesia as bases, and admissible as slags in blast furnace work. Larger percentages still, such as 65 per cent can enter into a compound, and it remains fusible. The objections to the smelting of titaniferous ores on account of the refractory character of the slags are not sustained by our practice, or that of others, or by direct experiments on the properties of these compounds.

2. In running a furnace under special conditions of temperature and pressure of blast, no trouble has been experienced from titanium deposits. We never observed any in our blast furnace tests, and none are mentioned by Dr. Forbes in his practice in England and Norway.

3. If these special conditions of the lower heat, considered more favourable in smelting these ores, are held to imply against them a waste of fuel, it is a question whether this is not offset by the smaller amount of cinder to melt, the lesser quantity of fluxes necessary and their indirect effect on the productive capacity of the furnace, as well as the greater value of the pig metal obtained for specific and numerous applications. This is without taking into account the possibility of not submitting to it by a rapid driving and forcing the production, conditions which, to judge from our tests, could be easily realized with these ores.

The most economical results are obtained by the introduction of magnesia to an important extent into the composition of the slag, with alumina and lime. Many objections raised against the use of these ores have proved, when practically examined, of as little value as those brought forward against the use of magnesia in a blast furnace.

We have tried in the above to present the facts as we have observed them, and to state, as near as possible, the conditions in which we have conducted our experiments. We hope that enough has been accomplished to induce others to help us in our efforts to rehabilitate a class of ore, Bessemer in character, which could furnish to the metallurgists materials of excellent quality, and available in many districts where others prove costly.


Legend
Cambro Silurian
Laurentian
Crystalline Limestone
Gneiss and Granite
Zone of mixed rocks about St. Jérôme anorthosite
Igneous
Anorthosite
Gabbro
Syenite and Granite
Porphyry
Dyke
Strike and Dip
Mica
Iron
Trembling Mountain
GRANDISON
DE SALABERRY
WOLFE
BERESFORD
MONTCALM
HOWARD
ARCHAMBAULT
DONCASTER
Indian Reserve
MORIN
ABERCROMBIE
Montagne Noire
L. Archambault
Lac Ouareau
L. Beaulieu
L. Bouchette
L. Croche
L. Cypress
Riv. du Diable
Trembling Mountain Lake
Lac des Iles

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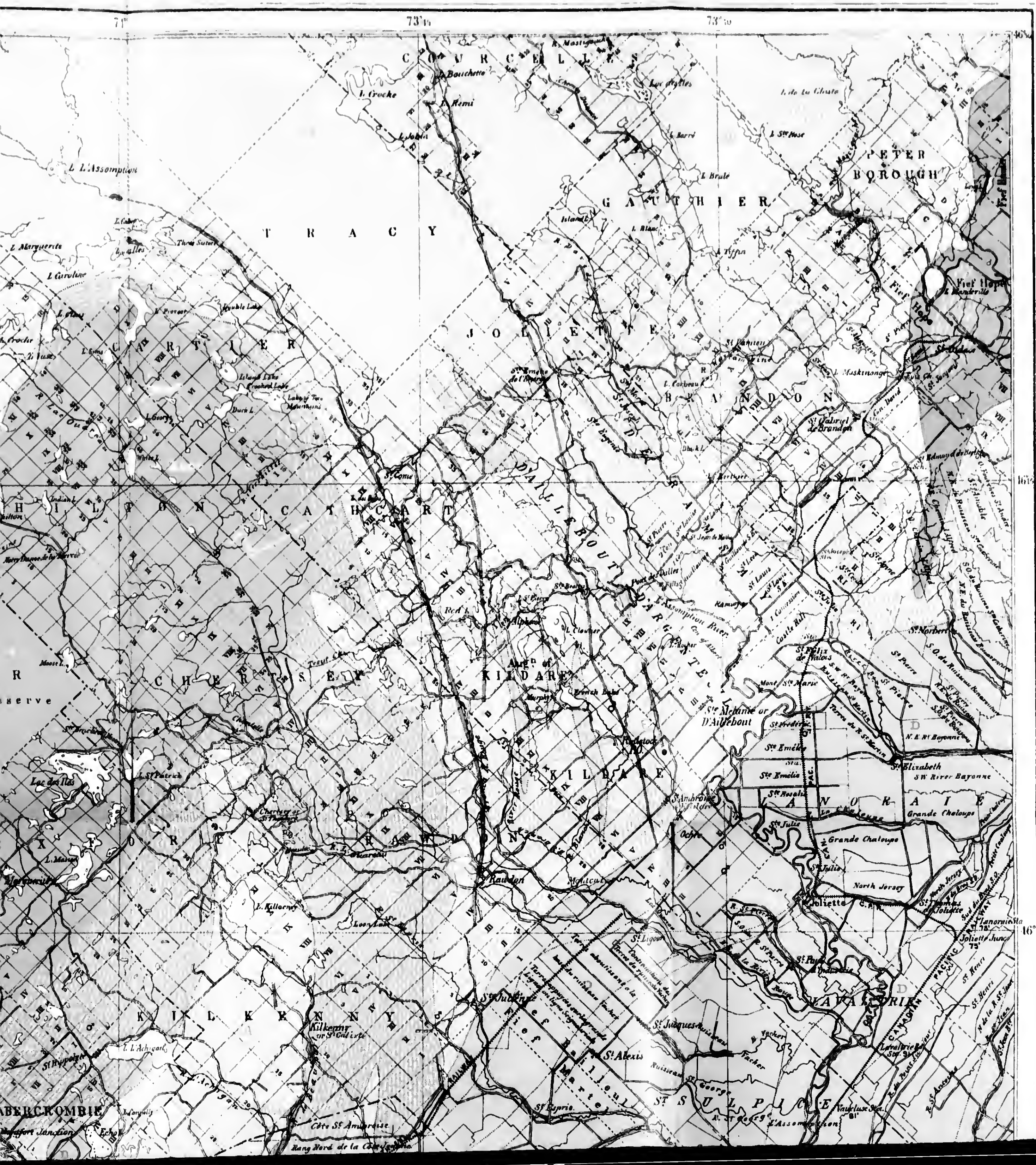
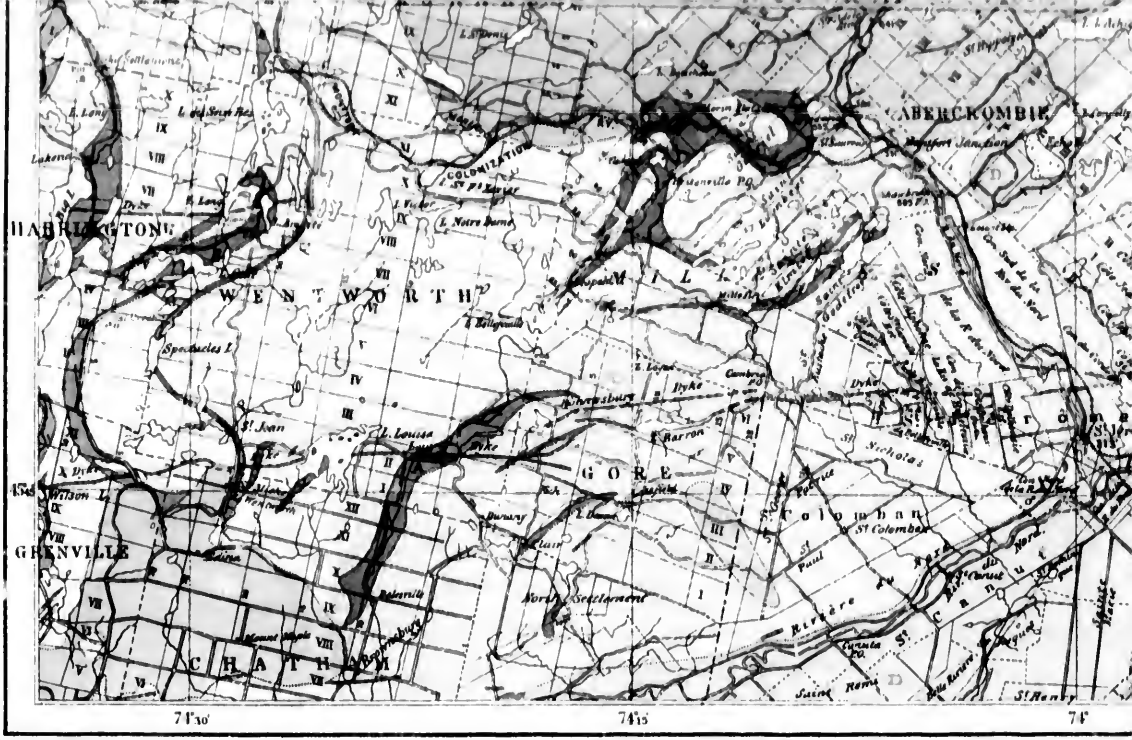


Dyke
Strike and Dip
Mine
Iron



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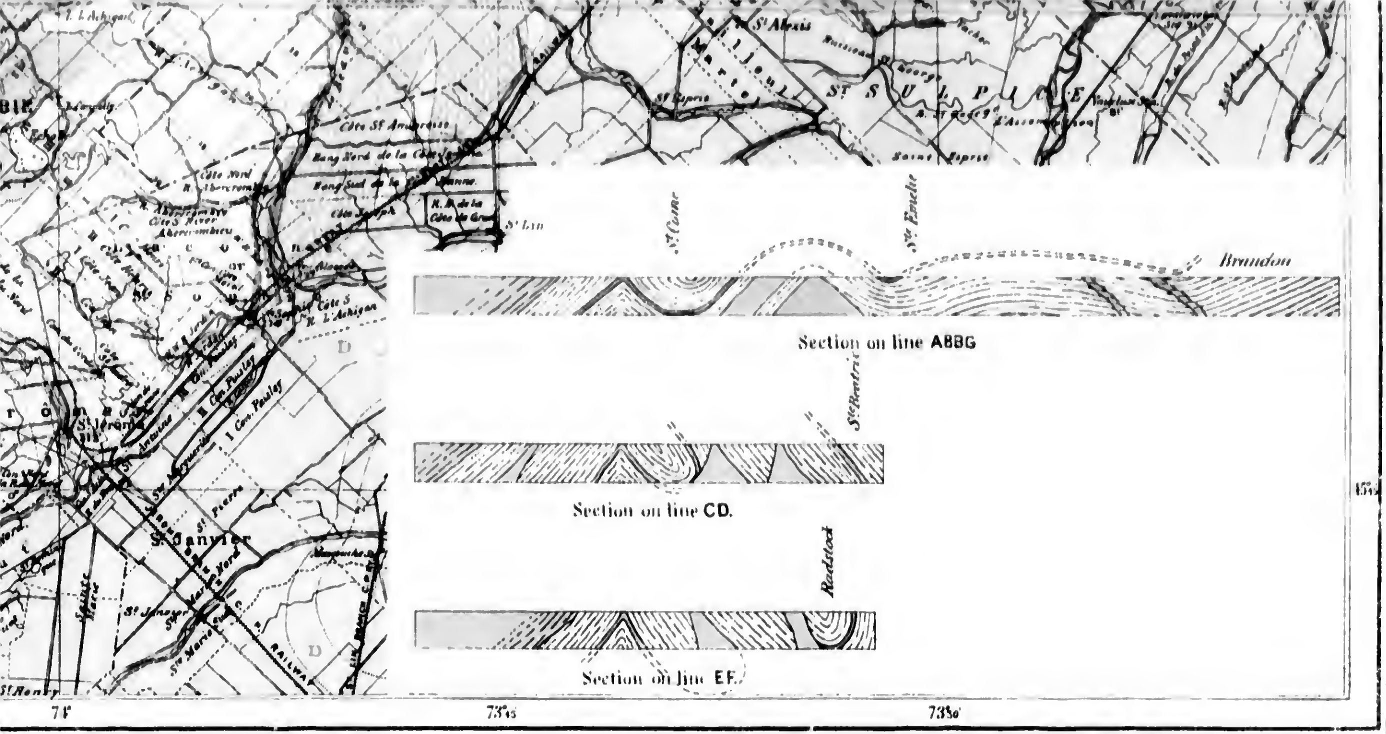

Accompanying Report by F D Adams
Part J Vol VIII (New Series)

PROVINCE OF QUEBEC
Geological Map
of parts
of
Joliette Argenteuil Terrebonne and Montcalm Counties.

Natural Scale

Scale 4 Miles to 1 inch

0 1 2 3 4 5 6 7 8 9 10 Miles