CANADA

DEPARTMENT OF MINES

HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

W. H. COLLINS, DIRECTOR

MEMOIR 152

No. 133, GEOLOGICAL SERIES

St. Urbain Area, Charlevoix District, Quebec

BY

J. B. Mawdsley

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

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St. Urbain Area, Charlevoix District, Quebec

CHAPTER I

INTRODUCTION

This report deals with an area of about 250 square miles on the north shore of St. Lawrence river, about 60 miles east of Quebec city. The villages, Baie St. Paul and St. Urbain, are the principal settlements within the map-area, nearly the whole of which is drained by Gouffre river and its tributaries. The St. Urbain ilmenite deposits have been known since the latter part of the seventeenth century and the Palæozoic limestone in the vicinity of Baie St. Paul has been studied by various workers since 1849, but no detailed geological mapping had been done previous to 1923, when field work was commenced by the writer. It was known that the ilmenite was associated with anorthosite and related rocks, but further information was required on the nature and origin of these ilmenite deposits whose importance was enhanced by the increased market for titanium and the improved methods of treating ilmenite by electrical processes made possible by large supplies of cheap power.

In 1923, the principal available geographic information concerning the map-area was the cadastral plans of the settled area. Further information about the part of the area adjacent to St. Lawrence river was contained on the chart of St. Lawrence river, issued by the Department of Marine and Fisheries.[1] From the above sources the topography of the southern section of the area was compiled. In the northern section, telemeter surveys were made of all roads and the chief watercourses. The relief was indicated by sketch contours, using barometric elevations as a basis. The map produced is much less accurate than the standard topographic maps issued by the Geological Survey, but it gives a fair idea of the topography of the area.

The writer was ably assisted in the field by B. T. Denis. The laboratory work in connexion with the geological investigations was done in the laboratories of the Department of Geology, Princeton University, during the winter of 1923-24. The writer wishes to acknowledge the help and guidance given during the course of the work by Professors C. H. Smyth, jun., A. F. Buddington, and A. H. Phillips. Help was received in various phases of the work from Messrs. J. F. Walker, J. E. Gill, W. A. Kelly, and E. L. Perry, graduate students in geology.

[1] Malbaie to Goose Island chart.

POSITION AND MEANS OF ACCESS

St. Urbain map-area is in Charlevoix district, province of Quebec. It lies on the north shore of St. Lawrence river about 60 miles below Quebec and just north of Coudres island. The area extends northward from the river for some 30 miles and is of irregular width, varying from 8 to 15 miles.

Baie St. Paul, the principal settlement, is at the southern margin of the map-area, at the mouth of Gouffre river. St. Urbain, a smaller village of a few hundred people, lies 8 miles north of Baie St. Paul, within the valley of Gouffre river. Baie St. Paul is reached from Quebec by way of the Quebec Heat, Light, and Power railway. Good roads connect various parts of the settled areas, one of the principal roads being the Provincial highway, which extends from Baie St. Paul northward through St. Urbain to Chicoutimi on Saguenay river, about 90 miles to the north. A few winter roads and trails traverse the less settled parts.

HISTORY

Settlements were made in this part of Quebec early in the French occupation of Canada, and the history of the district is typical of the settlements on the north shore of the St. Lawrence. The fertile river valleys were cleared and cultivated. Settlement of the more barren uplands bordering the valleys has ebbed and flowed. During the last half century lumbering has been extensively carried on in the forests adjacent to the settlements. The population is entirely French Canadian and all, except a small percentage, derive the main part of their livelihood from the products of their farms.

Early in the history of the valley, some of the ilmenite deposits were discovered near St. Urbain; one was discovered in 1666, but apparently no development work was done on these deposits until 1872. The first geologist to do any work in the area was Sir William Logan in 1849. In the " Geology of Canada, 1863," there are various references to Baie St. Paul and St. Urbain; the limestones and their included fauna at the mouth of Gouffre river are described; and reference is made to the ilmenite at St. Urbain and the associated anorthosite. Further work was done in this area by Abbé J. C. K. Laflamme in 1890 and the results are set forth in the Summary Report of the Survey for that year. A reconnaissance of the southern half of the area was made in the eighties by Russel and Low and their unpublished manuscript map is now in the possession of the Survey.

The ilmenite deposits were scarcely mentioned in the reports of these investigators, but some detailed work was done on these deposits. T. Sterry Hunt made an analysis of the rutile-rich ilmenite and the results are contained in the Report of Progress for 1852-53. He, also, in the "Geology of Canada, 1863," discusses the saline springs in the vicinity of Baie St. Paul, analyses of which are listed. A report on the ilmenite deposits was made for the Quebec Government by P. E. Dulieux in 1911. A detailed study of the petrography of the deposits was made by Professor C. H. Warren.

The following is a list of most of the published geological accounts dealing with the area.

Logan, W. E.: "Geology of the Vicinity of St. Paul and Murray Bay"; Geol. Surv., Canada, Rept. of Prog. 1849-50.

Logan, W. E., et al: "Geology of Canada, 1863."

Laflamme, Abbé J. C. K.: "Geological Investigations in Charlevoix County, P.Q."; Geol. Surv., Canada, Sum. Rept. 1890.

Dulieux, P. E.: "Report on Mining Operations in the Province of Quebec, 1911"; Quebec Bureau of Mines, pp. 86-91 (1912).

Robinson, A. H. A.: "Titanium"; Mines Branch, Dept. of Mines, Canada, No. 579, pp. 46-53 (1922).

Warren, C. H.: "The Ilmenite Rocks Near St. Urbain, Quebec; A New Occurrence of Rutile and Saphrine"; Am. Jour. Sci., vol. XXXIII, Art. 25, pp. 263-277 (1912).

TOPOGRAPHY

Regional

The north shore of St. Lawrence river and gulf, from the strait of Belle Isle to not far below Quebec city, has a rugged, mountainous aspect. The "mountains" rise to a maximum height of about 3,000 feet above the sea and, a few miles back from the coast, have nearly the same elevation as the rolling plateau that extends far north into Quebec. The "mountains," therefore, are merely the dissected edge of this elevated plateau that falls off abruptly at St. Lawrence river. The plateau is part of the Canadian Shield or Laurentian plateau and through deep valleys in the southern margin the great rivers draining the interior of Quebec reach the St. Lawrence. Gouffre river, the geology of whose basin forms the subject of this report, is a comparatively small stream.

From the picturesque mouth of the Saguenay westward beyond Baie St. Paul, to a point 30 or 40 miles east of Quebec city, the north shore of the St. Lawrence is mostly bold and rugged, broken only by the gaps of the river valleys. Within 2 to 5 miles of the coast, rounded hills rise to a height of 1,000 to 2,000 feet. Between these hills run broad, level valleys up which glimpses can be caught of higher and more rugged hills rising to 3,000 feet 5 to 20 miles from the St. Lawrence.

Local

St. Urbain area includes the whole of the drainage basin of Gouffre river and some contiguous country. The river, following a sinuous course, flows south and empties into St. Lawrence river in the delta-filled bay of Baie St. Paul. Across the entrance of this bay, a couple of miles off shore, lies Coudres island. At Baie St. Paul the valley floor has a width of 3 miles. Four miles north it narrows to less than a mile. North of this point it widens again and at St. Urbain village has a width of 1½ miles. Throughout this distance of about 9 miles, except where the constriction occurs, the valley floor is comparatively flat and rises steadily from an elevation of 30 feet above sea-level at Baie St. Paul to about 400 feet at St. Urbain. Between the two villages the river flows in strongly entrenched meanders, the entrenched depth being 30 to 50 feet (Plate I A). At the constricted part of the valley, 4 miles north of Baie St. Paul, the valley floor is rolling and composed of sand and gravel ridges 10 to 20 feet high. Among these hills is a small, irregular pond with no visible outlet. Along the whole stretch north to St. Urbain, the valley walls rise in gentle slopes on which, in places, well-developed terraces (Plate I A) occur to a height of about 500 feet or perhaps higher.

North of St. Urbain, Gouffre river flows along the eastern side of a comparatively level plain 10 miles long in a direction of north 30 degrees east, and 4 to 5 miles wide. The northern and northwestern edge of this level stretch is formed by steep slopes which rise to merge into the mountainous stretch of the northern part of the map-area. The southeastern edge, along which flows the Gouffre, and the southern edge, are the foot of the lower, hilly country of the southern part of the map-area. The southwest end of this plain, near St. Urbain, has an elevation of about 600 feet; to the north and northeast the surface rises gradually to an elevation of about 1,000 feet at the foot of the mountainous area. Gouffre river and its tributaries which cross the plain from the northwest, occupy relatively deep depressions in the otherwise comparatively level, drift-covered area whose surface is broken here and there by rocky hillocks. The valleys of the Gouffre, and its tributaries, in many places are of loose rock or are strewn with large boulders. The valley walls are of sand and gravel with some boulders. The Gouffre and the lower parts of its tributaries have meandering courses between low-cut banks, but the upper stretches in the higher parts of the plain are entrenched and swift-flowing.

Rounded hills or uplands of comparatively low relief border both sides of Gouffre river from its mouth to St. Urbain and continue along its southeast bank for 10 miles above St. Urbain (Plate I A) where they form the southeastern boundary of the extensive plain north of St. Urbain. This upland extends east of Gouffre river towards Murray river. It stretches northward from St. Lawrence river for 12 miles and has a general elevation of 400 to 800 feet above sea-level. It is a somewhat flat, arable, clayey or sandy plain, broken here and there by irregular, rocky hills rising to elevations of 900 to 1,400 feet. The quick change from the level, drift-covered country along Gouffre river, to the rocky, steep slopes of these hills, is a noteworthy feature.

The west side of Gouffre valley below St. Urbain is flanked by higher and more rugged country than lies east of that part of the river. Immediately west of the river mouth and rising directly from the St. Lawrence shore, are hills reaching to 2,000 feet above sea-level. Where these border the wider part of the level Gouffre valley between Baie St. Paul and St. Urbain, they rise with gentle slopes from the valley, but their slopes are steeper and they closely approach the river along the constricted part of the valley 4 miles north of Baie St. Paul. This hilly country forms the southwest border of the plain north of St. Urbain and extends 4 miles northwest of the village to where it is terminated by the higher, rocky hills of the mountainous area.

The highest, mountainous part of the map-area is in the north. It rises directly with cliffs and steep talus slopes from the northeastern, northern, and northwestern border of the plain-like area north of St. Urbain and, within the map-area, extends a few miles south along the west edge of the plain to the edge of the lower, hilly country that stretches south to the St. Lawrence. This mountainous stretch is merely the southern fringe of a vast tract of similar country which extends many miles to the northward into the watershed of Saguenay river. The mountainous area, within the map-area, is composed of rugged, rocky hills and ridges whose summits in general have an elevation of 3,000 feet above sea-level. The sky-line formed by the hill tops is singularly level and regular. The relief is considerable and in most places is 1,500 feet. The hill tops are windswept, rocky, and treeless.

Many of the hills or mountains are block-like, with comparatively flat tops with a minor relief in the form of shadow valleys and lake basins. These blocks are, in many cases, 2 to 4 miles long and from 1 to 2 miles wide. Many are bounded by long, straight or curving scarps that are the upper walls of valleys 1,000 to 1,500 feet deep. These scarp-lines do not seem to follow any general direction. In several instances the hills are narrow ridges 2 to 4 miles long and flanked by deep valleys.

Most of the valleys are from $\frac{1}{2}$ to $\frac{3}{4}$ mile wide and U-shaped in cross-section. The streams flowing through them are turbulent and for stretches have beds of rock. Back from the edges of the streams are long talus slopes of large, angular boulders rising to the foot of the cliffs 200 to 500 feet high that mark the highest points of the valley wall. Tributaries to the main streams flow by precipitous courses from the mountains. Their sources in many cases are small, rock-bound lakes at elevations of 2,000 to 2,600 feet above sea-level. Many of these lakes are 1,000 feet above the main valleys, and the small streams that drain them descend in a series of falls and steep rapids. The main streams flow southerly or southeasterly and debouch upon the level plain south of the mountainous area, and flowing across this plain join Gouffre river.

NATURAL RESOURCES

Waterpower. The streams within the map-area have steep gradients along parts of their courses, but have little volume. Hence the available power derivable from any section of a stream is comparatively small. Although small power schemes to supply local needs are feasible, no large hydroelectric development within the area is possible.

Agriculture and Forests. In the valleys, which are the only fertile sections of the country, a mixed series of crops can be raised. The chief crops are the hardy grains such as oats, barley, and rye, various root crops, hay, and tobacco. Dairy products also form part of the produce of the farms.

An industry that has gained quite a foothold during the last few years is the raising of silver and black foxes. There are some hundreds of these animals on various farms in Gouffre valley.

Almost all the country within easy reach of the settlements has been lumbered, but there is still excellent timber in the less accessible parts. The rugged nature of the district and the small size and turbulence of the brooks make lumbering difficult and expensive. The northwest part of the area lies within the Laurentian reserve—a provincial timber reservation. Fires in the past and during the summer of 1923 have done great damage and have destroyed many square miles of excellent timber. Black and white spruce are the prevailing trees. Balsam is also very common. A certain amount of white pine and a smaller amount of red pine are present. On sandy areas are groves of jack-pine of fair size. Birch and poplar are locally common, but form only a small part of the timber of the whole area.

Game and Fish. The animals found at a distance from the settled districts are those common to the eastern part of the Canadian Shield. Moose are common and seem to hold their own even in spite of the great amount of hunting that is done. Black bears are to be found and also wolves. The latter may be responsible for the disappearance within the last fifteen years of the caribou. No deer are known in this part of Quebec. Beavers have been almost exterminated. The smaller fur-bearing animals, such as the muskrat, martin, mink, and weasel, are suffering the same fate.

The brooks and lakes teem with brook trout. The fishing, and shipping of these to Quebec city and other markets, employs a small number of the inhabitants during the early summer months.

CHAPTER II

GENERAL GEOLOGY

INTRODUCTION

St. Urbain map-area lies on the southeast margin of the great area of Precambrian rocks known as the Canadian Shield. A few areas and small patches of Ordovician strata occur in the valley of the Gouffre, but the map-area is almost wholly underlain by Precambrian rocks. In the southern part of the field, bordering the St. Lawrence, is a complex of schists and gneisses, presumably of sedimentary origin, invaded by, and intimately associated with, granitic masses. The metamorphosed sedimentary rocks are such as are known to occur with similar characters and relations in many parts throughout southern Quebec from Ottawa valley to the Labrador coast. They are the oldest known rocks within the map-area. The closely associated, invading granitic rocks may also be of a comparatively early Precambrian age, but possibly are only phases of a group of batholithic rocks which invade the sedimentary gneisses and schists and, bordering them on the west and north, occupy the greater part of the map-area and extend for great distances beyond its borders.

The batholithic rocks form two dissimilar groups. One group consists of granites, syenites, and diorites which here and there include relatively small bodies of gneissic and schistose rocks like those of the complex found in the south part of the map-area. The second group consists of anorthosites which exclusively occupy an oval area 18 miles long and completely encircled by the granites, syenites, and diorites. The relative ages of these two groups of plutonic rocks are not precisely known. Nowhere was a member of one group seen to invade the other group. Possibly all or some members of the granite-diorite series are essentially of the same age as the anorthosite, although the boss-like form of the great anorthosite mass suggests that it is intrusive into the surrounding granite-diorite series.

In the following table the various formations are listed in the order in which they are described; this order may or may not conform to their order of relative ages.

Table of Formations

Quaternary	Recent and Pleistocene	—
Palæozoic	Ordovician	Trenton and Black River limestone
Precambrian		Anorthosite
		Dykes (pegmatite, aplite, etc.)
		Granite-diorite series
		Diorite dykes and larger bodies
		Complex of sedimentary gneisses and schists, and foliated intrusives

COMPLEX OF SEDIMENTARY GNEISSES AND SCHISTS, AND FOLIATED INTRUSIVES

General Statement

The relatively old gneisses and schists and the intimately associated foliated intrusives occupy an area along the St. Lawrence coast which has a width, north and south, of 3 to 10 miles. The area extends east beyond the limits of the map, but on the west side is bounded in large part by batholithic rocks of the granite-diorite series, and perhaps is wholly replaced by these rocks in a short distance west. The northern edge is formed by the batholithic area, in which similar gneissic rocks occur in a few isolated areas ranging from one-quarter to several miles in length. The batholithic granite-diorite series unquestionably is younger than, and invades, the sedimentary gneisses and schists. It probably is also younger than the foliated intrusives so intimately associated with the gneisses and schists, although, as already stated, some or all of the foliated intrusives may be only a phase of the batholithic rocks. The foliated intrusives appear to be of two periods, because one type is found cutting another, but, on the other hand, the relations existing between the several types are so involved that it is difficult to determine their relative ages and in fact in places all appear to be of about the same age.

Banded Schists and Banded Gneisses

The banded schists and gneisses are more abundant than the associated foliated intrusives. The greatest single area of these rocks lies west of Baie St. Paul and occupies about 20 square miles. They also occur east of Baie St. Paul and in some but not all of the smaller areas of the older rocks that lie to the north in the granite-diorite batholith.

The banded schists and gneisses are largely light-coloured, but some dark, altered rocks, typical greenstones, are associated with them, although with unknown relations. In the few places where the greenstones were encountered they conform in strike and dip with the rest of the banded rocks. The banded schists and gneisses are notable for the variety of colour and composition shown by the alternating bands and the many intricate plications which they exhibit. The width of the bands varies from a fraction of an inch to a few inches, or, as at some places, a foot or more. The rocks are strongly foliated and the foliation conforms to the banding. The strike of the bands near St. Lawrence river varies from due north to 30 degrees east of north, but in the detached areas of these rocks lying to the north within the batholithic area, the strike of the banding, in some of the areas at least, conforms to the nearby course of the boundary of the anorthosite mass and in all cases the dip of the bands is outward from the anorthosite.

The variation in the colour of the bands is due to the varying ferromagnesian mineral content. Some bands have practically no ferromagnesian minerals and may be mainly quartz or quartz and feldspar in varying proportions, whereas others have a large proportion of the dark silicates. Garnet is usually present and in some cases is very abundant.

Zircon is common and idiomorphic. The crystals are usually strung out in the direction of the foliation. Garnets are common and in some bands attain a diameter of 2 centimetres. They are rounded and usually have crenulate outlines and hold inclusions of quartz, feldspar, and magnetite. Biotite is common and the mica plates have a diameter of 1 centimetre in some rock varieties. In places the biotite is so abundant that the rock is a typical schist breaking easily along cleavage planes. Hornblende is not present in all cases. Some hornblende-rich bands resemble very closely the diorite dykes that are described later. It may be that such hornblende-rich bands represent dykes. The feldspar is mainly microcline, although orthoclase also occurs. Minor developments of spindles of plagioclase in both microcline and orthoclase are observable. Acid plagioclase feldspar is present in some rocks, but in minor quantities. The feldspar in some cases has a grain of 1 centimetre, but is very generally much finer grained. Quartz is usually abundant. The grains in some cases have a diameter of 1 centimetre, but usually are much smaller. Some bands in the rocks are almost wholly glassy quartz with a few garnets.

These, on the whole garnet-rich, banded rocks give the impression of being altered sediments and, possibly, associated volcanics. The variation in the compositions of adjacent bands is so great and the rock as a whole is so decidedly banded, that it seems necessary to ascribe a sedimentary origin to the rocks. Possibly they eventually will be proved to be a phase of the assemblage of strata which passes under the name of Grenville.

Foliated Intrusives

The foliated intrusives in the area of the complex in the southern part of the map-area are most widely developed east of Gouffre river. They also occur west of the river and form several detached areas within the batholithic rocks east of the anorthosite body. All are foliated, but in marked contrast with the associated banded schists and gneisses they exhibit a regular structure and uniform composition over comparatively large areas. Several distinct petrographical types are present.

One type is a granite-gneiss almost devoid of ferromagnesian minerals. This variety occurs in the northeast part of the map-area and apparently forms three detached ovoid areas 1 to 3 miles long, enclosed in the batholithic rocks. Their relations with the surrounding rocks and their exact areal extent could not be determined because of the abundant drift. The granite-gneisses are strongly foliated with a vertical dip and a strike of north 20 degrees east, parallel to the course of the nearby anorthosite boundary. The grain of the rock is from 1 to 3 millimetres. Red garnets are sparingly present; other ferromagnesian minerals are practically absent. The feldspar is an intimate intergrowth of orthoclase and plagioclase spindles such as is sometimes termed eutectoperthite. A worm-like intergrowth of quartz and albite (myrmekite) invades the eutectoperthite in some places. Quartz varies in quantity, but is usually plentiful.

A second type of the foliated intrusives is a dark green, garnetiferous, foliated granitic rock which is mainly confined to a band 3 miles long and half a mile wide, bordering St. Lawrence river west of the village of Baie St. Paul. East of the village some outcrops of this rock occur in the vicinity of the Government quay and possibly some of the greatly weathered rock outcropping back from the shore east of Baie St. Paul is of the same variety. In the main area the foliation strikes north 30 to 40 degrees east, and dips 30 to 80 degrees southeast. The strike of the foliation is parallel with the boundary between these rocks and an area on the north of a third type of intrusives. The rock is composed essentially of dark, grass-green feldspar and thickly sprinkled red garnets usually arranged in streaks and patches which follow the foliated structure. The rock has a crushed structure and its grain varies from 6 millimetres to much less. A little apatite and iron ore are present. The garnets occur in varying amounts; in places they form more than 25 per cent of the rock. The garnets are deep wine red, granular and much crenulated. Many contain specks of iron ore and leucoxene. The feldspar grains are irregularly distributed and seem to have resulted from the crushing of larger individuals of orthoclase and plagioclase. Feldspar grains of the same composition tend to be grouped. Both feldspars are almost free from perthitic intergrowths. In the outcrops near the Government quay east of Baie St. Paul, the feldspar is an intimate intergrowth of orthoclase and plagioclase spindles (eutectoperthite). Some imperfect myrmekite intergrowths are present. In the area west of Baie St. Paul fresh surfaces of the garnetiferous rock at many places exhibit specks of a dark mineral, rarely exceeding the size of a pin head. Radiating from each dark speck is a halo of minute cracks. Mr. H. V. Ellsworth pronounces this mineral to be radioactive and states that the cracks are due to expansion during radioactive change.[1] The mineral has a refractive index of $1{\cdot}703\pm5$. It is isotropic, dark green, has a conchoidal fracture and contains minute, dark inclusions. The mineral is believed to be polycrase.

A third type of the foliated intrusives are light-coloured rocks holding ferromagnesian minerals. They are confined to two areas in the vicinity of St. Lawrence river. One irregular, band-like area lies west of Baie St. Paul and north of the area of dark, garnetiferous rocks just described, between it and the paragneisses to the north. The second area is east of Baie St. Paul where the much weathered rock of a large area seems to be mainly of this third type, though paragneisses and other phases of the foliated intrusives are also present. West of Baie St. Paul the strike of the foliation in these rocks is north 30 to 40 degrees east. East of the village the few observed strikes are in the neighbourhood of north 60 degrees east and the dip is 25 degrees to 60 degrees southeast.

The rocks of this third type of the foliated intrusives are varied. Some have a partly crushed or augen structure and others have been completely crushed. In some the ferromagnesian minerals are nearly absent and in all garnets are absent or only sparingly present. The chief

[1] Ellsworth, H. V.: Am. Jour. Sci., vol. IX, p. 139 (1925).

ferromagnesian mineral is biotite. In some rocks it amounts to 15 per cent or more and where present in quantity gives a distinctly dark colour to the rock. The feldspar seems to be predominantly orthoclase, much of it with a fair amount of intergrown perthitic plagioclase. Myrmekitic intergrowths are common and have been involved in the crushing like other constituents. Quartz varies in amount, so that in mineral composition the rocks grade from syenite to acid granite. The quartz in many cases appears in long, uncrushed lenses that evidently must have formed after the period of crushing.

Owing to drift cover observations were greatly hindered, but enough was seen to make it clear that these foliated rocks are definitely younger than the closely associated banded schists and gneisses described above. The relations with one another, of the various types of intrusive foliated rocks, has not been established. In a cliff face bordering the railway at a point a mile west of the crossing of the southernmost branch of Moulin river, the dark green, garnetiferous, foliated, granite type and a generally pink, coarse, augen granite are in contact, but the relations exhibited are complex. They give the impression that the rocks intrude one another, though it is possible that one type is earlier than the other.

The age relations of the foliated intrusives and the batholithic granite-diorite mass to the north are in doubt. The foliated intrusives generally present evidences of crushing, whereas much of the granite-diorite mass does not. If, as has been assumed, the period of crushing antedated the batholithic period, then the foliated intrusives are older than the granite-diorite series, but it is thought that possibly the foliated intrusives are merely phases of the batholithic rocks modified in various ways by reason of their close association with the banded schists and gneisses, and it may be that the distinction between the foliated intrusives and the granite-diorite batholith is purely petrographic and not one of age.

Diorite Dykes and Masses

Diorite dykes cut the foliated intrusives exposed east and west of Baie St. Paul. Diorite masses which may be related genetically to the diorite dykes occur in other areas considered to be occupied by the foliated intrusives and the paragneisses.

Along the railway half a mile south of the southernmost branch of Moulin river, there are three dykes, respectively 6, 8, and 200 feet wide. They strike north 60 degrees east and dip vertically. A mile farther west along the railway are two smaller dykes with strikes of, respectively, north 30 degrees east and north 70 degrees east; both dip 30 degrees south. East of Baie St. Paul, along the railway, two dykes outcrop a mile north of the Government quay. They have widths of 3 and 20 feet, respectively, and strike north 30 degrees east and dip steeply south. A diorite dyke is poorly exposed at the fall on Mare brook 3 miles from its juncture with Gouffre river. Large, irregular, dioritic masses whose relations are much obscured by drift are present in at least three parts of the map-area. One mass is 4 miles east of Baie St. Paul. A second occurs north of lake Pied des Monts in the northeast part of the map-area, and a third of an unknown size, but which is about 400 or 500 feet in width, lies a mile northwest of lake Prime en Haut.

The dykes have been foliated by dynamic action subsequent to their intrusion. Few of the larger masses of diorite show this foliated structure. The rocks are typical diorites. They are dark-coloured, and ferromagnesian minerals make up practically 50 per cent of their volume. With the exception of apatite, which occurs in small amounts only, the mineral constituents have an allotriomorphic relation to one another. Hypersthene is present, is slightly decomposed, and seems to have crystallized immediately after the apatite. A brown or dark olive-green hornblende, which appears to be primary, was the next mineral to crystallize. Considerable biotite is present in many examples and in places appears to replace parts of the hornblende. The feldspar is mainly basic andesine and only rarely shows perthitic intergrowths of orthoclase. In one thin section about 5 per cent of interstitial orthoclase was seen. No quartz was noticed.

All the discovered dykes cut the foliated intrusives. None was seen within the area of the granite-diorite batholith. The dykes, thus, are definitely younger than the banded schists and gneisses and most, at least, of the foliated intrusives; they probably are older than the granite-diorite batholith. The relations of the irregular, larger diorite masses is in doubt, but petrographically they are equivalent to the diorite dykes and probably are of the same age.

GRANITE-DIORITE SERIES

Introduction

Intrusive into the paragneisses and possibly the closely associated foliated intrusives, is a batholith which surrounds the St. Urbain anorthosite mass and apparently extends west, north, and east far beyond the borders of the map-area. Within the map-area, outliers of the batholith occur within the area of paragneisses and associated rocks bordering the St. Lawrence, and comparatively small, isolated bodies of the older rocks lie inside the batholith whose southern boundary crosses Gouffre river about 4 miles above its mouth. Owing to the presence of the anorthosite mass, the area of batholithic rocks studied and represented on the accompanying map (No. 2106) is chiefly confined to a band surrounding the anorthosite body and varying in width from less than 1 mile to about 5 miles.

The rocks forming the part of the batholith lying within the map-area vary in composition between granite and diorite. On the whole the dioritic facies occur in the southern and eastern parts of the mapped, annular area of the batholith, whereas the granitic varieties prevail in the northern and western parts. The rocks are mainly massive and jointing is not prominent, but in the vicinity of the anorthosite boundary the batholithic rocks are foliated within a zone for the most part several thousand feet broad. Elsewhere the rocks appear massive, or have only a faintly marked augen structure.

The rocks composing the batholith vary considerably in general appearance and composition, but only by the study of thin sections is it possible to classify them properly. No evidence was secured of one rock type cutting another. Instead, the evidence indicates that all are contemporaneous and merge into one another.

The various types on the whole have rather low contents of ferromagnesian minerals, but carry much magnetite or ilmenite, or both minerals. In places it seemed that the iron ore content increased in the vicinity of the anorthosite body, and along the northwest border of the anorthosite the iron ore constituent of the batholithic rocks is in many instances largely ilmenite instead of the usual magnetite. All phases of the batholithic rocks hold fragments of acid or intermediate andesine crystals. Many of these are 2 to 4 inches long. They form only a fraction of 1 per cent of the rock. They closely resemble the individuals of andesine found in some phases of the anorthosite. Two small blocks of anorthosite were found within the batholithic rocks on the Ste. Anne River road, a mile west of the anorthosite boundary. One block is 8 inches and the other 12 inches in diameter. They are rounded in outline. The rock is light grey and even grained, the grain varying between ½ and 2 millimetres. The rock holds a few grains of apatite and a little black iron ore in grains, with—radially disposed about them—a very small amount of green biotite. The remainder of the rock, or all but an insignificant fraction, is formed of plagioclase feldspar of the composition Ab_{65} An_{35}. In the vicinity of the anorthosite blocks was found a plagioclase crystal 8 inches long and many smaller fragments, all of which have a composition of Ab_{62} An_{38}.

The origin and meaning of these blocks of anorthosite, of the andesine crystal fragments, and of the possible variation with respect to the anorthosite boundary of the amount and character of the iron ore content of the batholithic rocks, are matters that may be variously interpreted. They have an added significance in that although the boundary between the large St. Urbain anorthosite body and the surrounding batholithic rocks is definitely known to be sharply defined, yet no off-shoots of the batholithic rocks penetrate the anorthosite body, nor despite the occurrence within the batholithic area of two small, apparently detached masses of anorthosite (not the blocks above referred to), is it certain that the main anorthosite body invades the batholithic rocks. In addition, theoretical considerations imply, perhaps demand, a close genetic relation between the anorthosite mass and some or all of the neighbouring batholithic rocks. The absence from the anorthosite and the presence in the batholithic rocks, in places at the very anorthosite contact, of masses of older paragneisses and associated rocks, conforms with a general hypothesis advanced by Bowen,[1] the application of which to St. Urbain area involves the supposition that the main anorthosite body developed practically in situ and formed as a substratum in a magmatic body with an overlying more acid rock phase. The general hypothesis further involves supposing that by reason of movement taking place at or about the time of differentiation of the various plutonic rocks, and as a result of much later erosion,

[1] Bowen, N. L.: "The Problem of the Anorthosite"; Jour. Geol., vol. XXV, pp. 209-243 (1917).

the original structural relation has been disturbed, the once overlying acidic rocks have been removed, and the anorthosite body so exposed that in plan it has the appearance of invading the surrounding batholithic rocks.

Until further lines of evidence are available, the meaning of the two small blocks of anorthosite discovered within the batholithic granite-diorite series, and the universal presence, though in small quantities, of the andesine crystals and fragments cannot be affirmed to be positively established. It may be that these features indicate that the batholithic rocks have invaded and caught up fragments from an anorthosite body which perhaps was the St. Urbain anorthosite or perhaps was a much older anorthosite body. Or it may be that these features merely arose during a process of differentiation which took place in situ and gave rise simultaneously to the batholithic rocks and to the St. Urbain anorthosite body.

The batholithic granite-diorite rock series intrudes the banded schists and gneisses. Its age relative to that of the diorite dykes and to that of the foliated intrusives associated with the banded schists and gneisses is not definitely known, but the batholith rocks are considered to be younger. It is thought that the St. Urbain anorthosite intrudes the batholith.

The batholithic rocks of the limited area investigated, which lies on the borders of the St. Urbain anorthosite mass, are mainly granites with which are associated syenites amounting in volume to about one-third of that of the granites. Diorites are abundant also and about three-fourths of them are quartz diorites. Rock types intermediate in composition between the granites and syenites, and the diorites, form perhaps 15 per cent of the whole.

Granites

The granites are commonly coarse-grained rocks composed of large grains of orthoclase or eutectoperthite and, in smaller quantities, ferromagnesian minerals with, interstitial to the above minerals, small grains of plagioclase and quartz, and myrmekitic intergrowths. Zircon, apatite, and iron ore are accessory constituents. The texture and mineral composition are variable. The grain is usually one centimetre, but finer phases were observed. An augen structure is typical. Near the anorthosite contact a foliated structure has developed, whereas at many points some distance from this contact no such structure is evident.

A few grains of apatite and zircon are usually present. These have crystallographic outlines and were the first to crystallize. The ferromagnesian minerals form usually not more than 30 per cent of the volume of the rocks. The species present are mostly hypersthene or green hornblende or both. Augite or diopside is present in some parts of the mass, and biotite in still other parts. The hornblende is believed to be primary. The biotite, in some cases, may be secondary after hornblende. Grains of black iron ore are usually closely associated with the biotite. The ferromagnesian minerals in most cases were contemporaneous with the small amount of black iron present, but which in some cases appears to have crystallized earlier than, and in other cases later than, the rest of the dark minerals. The iron ore appears to be mostly magnetite, but ilmenite was also recognized. A little leucoxene is present in some instances.

The earliest feldspar is a perthitic orthoclase or an eutectoperthite. The perthitic orthoclase contains from 10 to 40 per cent of plagioclase spindles. Eutectoperthite (an intimate intergrowth of about equal quantities of orthoclase and plagioclase spindles) was the chief feldspar in nearly half of the thin sections studied. The perthitic orthoclase or eutectoperthite commonly forms about 50 per cent of the volume of the rock and usually is in large grains having diameters of 5 mm. to 1 cm. Smaller grains of oligoclase interstitial to the perthitic orthoclase or eutectoperthite crystals are always present and form about 10 per cent of the rock. Many of the individuals show no twinning. The oligoclase is usually free from perthitic rods of orthoclase, but in one case a few interstitial grains of orthoclase without perthitic spindles of plagioclase were noticed. Myrmekitic intergrowths (vermicular intergrowths of quartz and plagioclase) are very common and in some examples form 15 or 20 per cent of the rock. They developed at the expense of the perthitic orthoclase and eutectoperthite grains and occupy embayments along their edges. Quartz was the last mineral to crystallize and is interstitial to all the other constituents. In several instances there is a suggestion that the quartz crystallized after crushing, which in such examples had developed an augen-like structure in the case of the large orthoclase individuals.

Syenites

The syenites resemble the granites, except that quartz is absent or present only in slight amount. In the few sections studied neither biotite nor myrmekitic intergrowths were seen. Intricate and involved boundaries between the perthitic orthoclase, plagioclase, and quartz grains were evident. Such a condition is uncommon in the granites.

Diorites

The diorites in many places have a foliated or augen structure and a porphyritic texture, the phenocrysts being plagioclase. Hypersthene and biotite are always present and in many instances in considerable quantities. The plagioclase is usually andesine. A little orthoclase occurs. Black iron ore, apatite, and zircon are accessory minerals.

The apatite is sparingly present in smaller amounts than in the granites and syenites. Zircon is not very common. These accessory minerals were the first to crystallize and have crystal forms. Varying quantities of black iron ore are always present; in some examples it forms as much as 10 per cent of the rock. Some of it is ilmenite and shows perthitic rods of hematite similar to those in the ilmenite of the deposits near St. Urbain. Most of the black iron ore, however, is magnetite. Where the black iron ore minerals occur in quantity the individual grains attain a diameter of 3 or 4 mm. and hold many inclusions of feldspar and of the ferromagnesian minerals of the rock. A little leucoxene is present in some specimens. The iron ore in all cases is closely associated with the hypersthene or hornblende.

Hypersthene is always present and forms from 5 to 25 per cent of the mass of the rock. It is the earliest of the ferromagnesian minerals. The iron ore usually is later than the hypersthene, but locally is earlier. Hornblende is closely associated with these two minerals, but is slightly later in time of crystallization. The hornblende is usually a green variety. It seems to be definitely primary. In about half the slides of the diorites studied, biotite was present in very small quantities; in one case only was it at all abundant. The biotite is apparently primary and later than the hypersthene and hornblende.

The plagioclase crystallized during the whole period of crystallization of the ferromagnesian minerals—starting earlier and ending later. It varies in composition from basic oligoclase to acid labradorite, but in most cases is basic andesine. The large phenocrysts of plagioclase found in the augen phases of the rock are from 1 to 2 cm. long. Perthitic rods of orthoclase are present in most of the plagioclase grains including those which form the augens. Interstitial orthoclase was the last mineral to crystallize and forms from 0 to 10 per cent of the rock mass. Quartz rarely occurs and myrmekitic intergrowths were not observed.

Quartz Diorites

The texture of the quartz diorites is very similar to that of the diorites and except for the presence of quartz the mineral constituents are the same.

The accessory minerals, apatite and zircon, are sparingly present and show idiomorphic forms. Black iron ore is usually present, but in smaller quantities than in the diorites. It is, as in the diorites, closely associated with the ferromagnesian minerals. Titanite and pyrite were noted in a couple of instances. Hypersthene is the most common ferromagnesian mineral. In several instances enstatite, and in one case augite, occur instead of hypersthene. Green hornblende is associated with hypersthene in a few sections. Biotite, usually in minor quantities, was found in about half of the sections studied; some patches of biotite have the appearance of being secondary after one of the other ferromagnesian minerals. A little secondary chlorite was seen. Plagioclase forms fully 50 per cent of the rock; it began crystallizing earlier and ceased later than the primary ferromagnesian minerals. Its composition varies from oligoclase to andesine, two species being present in about equal amounts. Most, but not all, the plagioclase individuals hold perthitic rods of orthoclase whose amount varies from grain to grain, from almost nothing to as much as 20 per cent by volume. A little interstitial orthoclase is always present and in some cases forms as much as 15 per cent of the rock. In some instances perthitic rods of plagioclase are present in the orthoclase. Microcline was recognized in several instances. Quartz was the last mineral to crystallize. It occurs in amounts ranging from 1 or 2 per cent to 30 per cent of the rock mass. Myrmekitic intergrowths were found in a few thin sections.

Intermediate Types

A very small proportion of the rocks studied are intermediate in composition between the granite-syenite group and the diorite-quartz diorite group. The minerals composing these rocks are the same as in the types already described. The chief difference is that the soda and the potash feldspars are present in approximately equal amounts. The relative order of crystallization of the two feldspars varies, but in general they are contemporaneous. By many, these rocks would be termed monzonites and by others granodiorites.

PEGMATITE, APLITE, AND OTHER DYKES

A few small dykes were seen at one locality along the Ste. Anne River trail just west of the anorthosite mass. None was seen elsewhere.

At the above locality was found a single pegmatite vein 2 inches wide, striking south 10 degrees east and dipping vertical. The pegmatite is coarse grained, having a maximum grain of 2 cm. Black iron ore in grains up to 1·5 cm. in diameter appears to have been the first mineral to crystallize. It apparently is all ilmenite. Biotite appears to be primary and to have had a long period of crystallization, the end phase probably having been contemporaneous with that of the quartz. Orthoclase with abundant spindles of perthitic plagioclase is common. Weathered plagioclase grains are present. Quartz was the last mineral to crystallize. A little myrmekite is present.

Several dykes are formed of magnetite-rich rocks which are quite fine grained—the grain being 2 mm. or less. These dyke rocks vary somewhat in composition. That of a 15-inch dyke is composed of the following minerals, mentioned in the probable order of crystallization: a little apatite; magnetite, mostly idiomorphic, 12 per cent; green hornblende, 18 per cent; oligoclase rich in perthite orthoclase, 35 per cent; microcline rich in perthite plagioclase, 35 per cent; and quartz, 10 per cent. This rock would be called by many a typical monzonite.

A few, fine-grained aplite dykes a foot or so wide were found. Orthoclase is the chief constituent and contains plagioclase spindles which form 10 to 30 per cent of the grains. A little twinned plagioclase, some light green hornblende, black iron ore, a little myrmekite, and considerable quartz are present.

One aplite dyke is bounded on one side by pegmatite. Crossing this compound dyke are two, narrow, magnetite-rich dykes curved in such a way as to suggest that the compound dyke was not completely solid when the later ones cut it. All the dykes cut the granite diorite batholith and occur not far west of the anorthosite mass, at a place where the contact of the anorthosite dips outward at a low angle. It seems possible that the dykes have some connexion with the anorthosite mass.

ANORTHOSITE

General Statement

Anorthosite is the most important rock type within the map-area, as regards area occupied and, possibly, as regards scientific interest. Large masses of anorthosite are not widely distributed over the earth's surface. The known areas are confined to Scandinavia, eastern Russia, the Sudan, and eastern North America. In eastern North America the southernmost mass is in the Precambrian of the Adirondack area of New York state. To the north, in Canada, from the vicinity of the lower Ottawa river, to the Labrador coast, is a great belt of masses of this rock. Some are many hundreds of miles in extent and few of them have been studied in even the most cursory way. Smaller bodies of anorthosite are found in other parts of the Precambrian of Canada, but areally they are, as a rule, very small phases of a typical gabbroidal mass.

The small anorthosite boss within the St. Urbain map-area is on the southeast margin of the belt of anorthosite masses extending through Quebec. This boss is oval in shape, with a major axis about 18 miles long and a minor axis of 9 miles. The major axis has a north and south direction and passes close to St. Urbain, which lies 3 miles within the anorthosite body. This ovoid area, except for a few deposits of ilmenite, is underlain, so far as known, only by anorthosite. The anorthosite varies in composition from place to place and ranges from a rock essentially composed of andesine ($Ab_{70-65}An_{30-35}$) to one essentially composed of labradorite ($Ab_{44-35}An_{56-65}$), but though a suite of specimens might be selected which would exhibit a gradual transition from the most acid to the most basic phases, yet the field evidence indicates that on the whole the more basic phases occupy distinct areas and are cut by more acid phases. In the field it was not possible to differentiate the various phases of the anorthosite, but by laboratory examinations of many specimens collected from many localities within the St. Urbain mass it has been possible to delimit the areas occupied by the more basic, labradorite-bearing, phases. As shown on the accompanying map (No. 2106) and on Figure 1, the labradorite anorthosite is mainly confined to an irregularly ovoid area which is about 7 miles long and lies towards the centre of the anorthosite body. In addition, there are eight smaller areas of labradorite anorthosite. These vary from about ¼ to 3 miles in length. Six of them occur at the immediate border of the anorthosite mass. As indicated on Figure 1, in the case of three of the smaller areas of basic anorthosite, the surrounding more acid anorthosite was observed in the field to cut the basic phase and in four places the same relationship was found to hold in the case of the large, central area of basic anorthosite. At one locality this general relationship is finely displayed (*See* Plate I B), large blocks of the labradorite anorthosite being clearly visible, which lie in and are penetrated by more acid anorthosite.

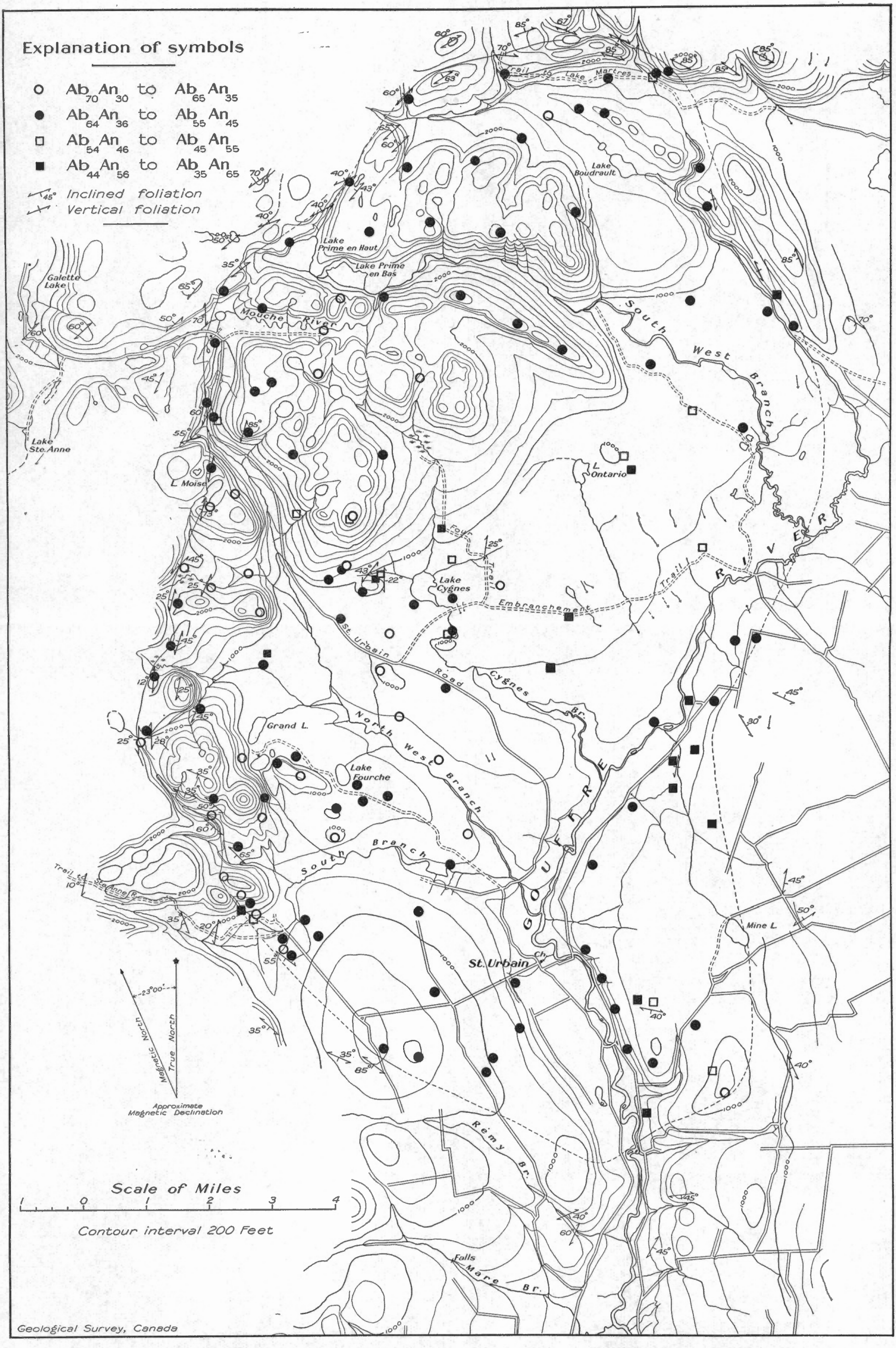

Figure 1. St. Urbain anorthosite showing structure and variations in composition, Charlevoix district, Quebec.

Description of the Anorthosite

In this section the petrographical and chemical characteristics of the various phases of the anorthosite will be dealt with. The indices of refraction of a number of specimens of feldspar from the anorthosite body were determined by means of oils, using the method and data given by E. S. Larsen.[1] Oils whose refractive indices varied by about 0·002 were employed, and as the highest and lowest indices were determined and the necessary temperature corrections made, it is believed that the amount of the anorthite molecule in the plagioclase feldspars tested has been determined within an error of ± 4 per cent. The feldspars examined were collected from localities distributed over the whole anorthosite area and the results obtained are graphically indicated on Figure 1. Where on this figure two symbols cut one another, they indicate localities at which one anorthosite phase was observed to cut another phase. Seven such instances were found, and at each andesine anorthosite cuts labradorite anorthosite. The areal distribution of the two main types of anorthosite was not determinable in the field and, therefore, only by laboratory examination of many specimens was it possible to delimit the areas occupied respectively by andesine anorthosite and labradorite anorthosite, as shown on the accompanying geological map (No. 2106). The andesine anorthosite for descriptive purposes is considered as forming three sub-phases, but these are not separately indicated on the map.

Large plagioclase crystals characterize the andesine anorthosite and in many places the labradorite anorthosite appears formed of crushed, large feldspars. In the andesine anorthosite the large plagioclase crystals in most places from less than one per cent of the rock mass, but in places they form 5 to 20 per cent of the rock and in such places occur in nests and masses scattered irregularly through the anorthosite. The individual crystals are fractured and have been invaded by the fine-grained, surrounding rock. These feldspars, except that they are usually larger, resemble in every way the feldspar inclusions of the batholithic granite-diorite series. The feldspars in many cases have a length of 8 to 10 inches and where present in considerable quantities are associated with hypersthene crystals as much as 4 inches across, and form a coarse norite, as at a few outcrops one mile north of the junction of the St. Urbain and Embranchement roads. At this place the norite fragments are a few yards in diameter and are invaded by the surrounding, finer-grained andesine anorthosite. In the norite fragments the feldspar individuals are euhedral and are partly enclosed by individuals of hypersthene which form as much as 20 per cent of the rock and attain diameters as great as 4 inches. Index of refraction determinations show the hypersthene to be composed of 72 to 77 per cent $MgO\ SiO_2$ and 28 to 23 per cent $FeO\ SiO_2$ and to be identical in composition and optical properties with smaller particles found in the various phases of the anorthosite body as a whole. A little ilmenite

[1] Larsen, E. S.: "Microscopic Determination of the Non-Opaque Minerals"; U.S. Geol. Surv., Bull. 679.

is closely associated with the hypersthene and appears to have commenced crystallizing somewhat later than the hypersthene. A polished section holding the ilmenite shows a hematite intergrowth similar to that in the ilmenite of the large bodies near St. Urbain village. The coarse-grained norite occurs as scattered shreds and fragments of rock, amongst which the largest seen had a maximum diameter of 4 feet. Such shreds and masses with many crystals and fragments of crystals of andesine and hypersthene in this locality, form about 20 per cent of the rock. The rock and crystal fragments are scattered through anorthosite whose grain is about one centimetre. The included rock masses and crystals have been fractured and along the fractures have been invaded by the finer-grained anorthosite.

None of the plagioclase crystals of the norite fragments, and none of the numerous feldspar crystals scattered throughout the areas of andesine anorthosite, show zoning, nor do the indices of refraction indicate any difference in composition between the centre and margin of the crystals or between them and the feldspar of the surrounding anorthosite. Their usual dark grey colour is due to fine schiller rods, 1 mm. in length and less, oriented along crystallographic planes and accompanied by a varying proportion of grains of what may be hematite or some other iron mineral and colourless rods of what appears to be rutile. In some cases the rods, as regards size, seem to form two definite classes—one a series of large rods and, mixed with these, a second series of much smaller, finer rods. In some of the plagioclase crystals what appears to be green pyroxene forms small grains of the same size as the larger schiller rods. Some of the feldspars lack the schiller rods, or these are present in small quantity only.

Where the dark grey, andesine crystals or fragments of crystals occur in smaller quantities, they are more broken and scattered, and hypersthene is either absent or occurs in a finely comminuted state.

By far the greater part of the anorthosite has a grain of ½ to 1 centimetre. The colour varies from white to mauve, depending on the presence or absence of schiller inclusions in the feldspars. The colour is mauve if they are present and the rock is colourless if they are absent. The anorthosite, on the basis of its component feldspars, has been grouped in four divisions, each of which is individually described below.

Labradorite ($Ab_{44}An_{56}$ to $Ab_{35}An_{65}$) Anorthosite. The labradorite-anorthosite phase occupies not more than 15 per cent of the anorthosite area. It forms six small areas at or near the margin of the anorthosite mass and one larger central area equalling the combined extent of the smaller areas. The specimens from the central mass are lower in ferromagnesian minerals than the border areas. All the specimens studied appear to have suffered crushing, but without giving rise to a foliated structure. The feldspar and, therefore, the rock, in most cases is either greyish or greyish-mauve. At two places within the foliated margin of the anorthosite boss the feldspar is mottled whitish and flesh-brown. The study of the thin sections shows that the colour is due to the presence of schiller inclusions.

Study of the thin sections of the labradorite anorthosite reveals a protoclastic structure indicated: (1) by the granulated state of the hypersthene; (2) by the polygonal outlines of many of the plagioclase grains; and (3) by the presence of plagioclase grains with schiller inclusions mixed with grains which do not contain the inclusions and possibly, therefore, crystallized later. The protoclastic structure is not well developed. The mineral grains range in size from 1 mm. to 8 mm. in diameter.

Plagioclase is the chief mineral constituent and in the various examples studied the proportion of the anorthite molecule in the feldspar varied between 58 and 61 per cent. Besides plagioclase the minerals found are the following, listed in their order of relative abundance: hypersthene, ilmenite, hornblende, and biotite. A Rosiwal analysis of a nearly typical thin section of a specimen from one of the marginal areas gave: plagioclase, 90 per cent; hypersthene, 7·2 per cent; ilmenite, 1·6 per cent; hornblende, 0·6 per cent; and biotite, 0·6 per cent. In the central area the ferromagnesian minerals in most places do not form more than 4 per cent of the rock. Apatite was present in several specimens from marginal areas. Biotite is commoner in these marginal areas than in the central body. Orthoclase does not occur. The indices of the hypersthene grains were determined and, making use of the curves prepared by Winchell[1], their composition was found to average 75 per cent Mg SiO and to be the same as that of the hypersthene in the other phases of the anorthosite where the mineral holds between 72 and 77 per cent Mg SiO.

The order of crystallization of the various constitutents appears to be: plagioclase starting first and continuing over a long interval; then both hypersthene and iron ore, the iron ore ceasing before hypersthene and the latter before plagioclase; hornblende and biotite commencing after the hypersthene and finishing with the plagioclase.

Andesine ($Ab_{54}An_{46}$ to $Ab_{45}An_{55}$) Anorthosite. Areally this variety of andesine anorthosite is closely associated with the labradorite anorthosite, and where one occurs the other is usually present in the immediate vicinity. At five places this variety was seen to be cut by a more acid phase.

In all ways this variety of anorthosite closely resembles the labradorite-bearing phase. Indications of a protoclastic structure are present in many examples. The feldspar in the sections examined is andesine with 49 to 55 per cent of the anorthite molecule. Except for the presence of a little pyroxene, difficult to distinguish from the associated hypersthene, the ferromagnesian minerals are the same and their proportions practically the same as in the labradorite anorthosite. Orthoclase is present and on the average forms about 5 per cent of the feldspar. Practically all of it is interstitial, although a few perthitic rods occur. In one instance a flake of biotite was noted intergrown with orthoclase. An intergrowth of orthoclase and plagioclase was also seen and resembled myrmekite in appearance, but the rods instead of being quartz were orthoclase. The hypersthene shows some alteration; brown and black patches occur in some grains and biotite replaces others. The order of crystallization is the same as in

[1] Winchell, A. N.: "Studies in the Pyroxene Group"; Am. Jour. Sci., vol. VI', pp. 503-520 (1923).

the labradorite-bearing phase. A Rosiwal analysis of a fairly typical section gave: plagioclase, 87 per cent; orthoclase, 5 per cent; hypersthene, 7·4 per cent; ilmenite, 0·5 per cent; biotite, 0·1 per cent.

Andesine ($Ab_{64}An_{36}$ to $Ab_{55}An_{45}$) Anorthosite. This variety of andesine occurs throughout the more acid part of the anorthosite boss and as Figure 1 indicates, it makes up half of the rock mass.

In general this phase contains much less ferromagnesian minerals than the two, previously described, more basic varieties; the average content is 3 to 4 per cent. The amount of orthoclase varies from 3 to 15 per cent, the average being close to 8 per cent. One-fifth to one-half of the orthoclase occurs interstitially, the rest in perthitic intergrowths. The widths of the orthoclase spindles forming these intergrowths vary. Some have a width of about 0·015 mm. and others of only 0·003 mm. The distribution of these orthoclase rods follows no definite rule. They usually occur in groups which only rarely are evenly distributed throughout a plagioclase host. They in some cases are confined to zones or twinning lamellæ. An intergrowth of biotite and plagioclase was seen and examples of orthoclase rods partly replacing plagioclase grains. The ferromagnesian minerals are the same as those of the first described variety of andesine anorthosite. Augite was seen in two sections. Biotite seems to be secondary. Zircon and apatite were noted. Many of the iron ore grains are banded and resemble the ilmenite and hematite intergrowths of the ilmenite deposits. The order of crystallization is as in the earlier described anorthosite varieties.

Although in this variety of anorthosite the content of ferromagnesian minerals is low in most instances, in several examples it was fairly large. A Rosiwal analysis of one such specimen gave the following: plagioclase and intergrown orthoclase, 76·2 per cent; hypersthene, 14·8 per cent; ilmenite, 0·9 per cent; interstitial orthoclase absent. The composition of a more typical specimen is: plagioclase, 89 per cent; hypersthene, 3·5 per cent; ilmenite, 0·5 per cent; orthoclase, 7 per cent.

The colours of the rock differ from that of the previously described rock varieties only by being a little lighter. The colour depends on the schiller inclusions in the feldspars. Where these are absent the rock is almost white, with just a cast of grey. The only two specimens showing faulting and shearing are colourless. The mottled appearance of some specimens is due to the absence of schiller rods from some of the feldspar grains and their presence in others. In some sections, coarse schiller rods characterize the larger grains of plagioclase and finer rods the smaller grains. The coarse schillerization is made up of blackish rods and grains. In one specimen found near the southwestern border of the map-area the schillerization is entirely due to long, slender, transparent rods that resemble the rutile crystals seen in quartz.

Andesine ($Ab_{70}An_{30}$ to $Ab_{65}An_{35}$) Anorthosite. Five specimens of the anorthosite examined held andesine in which the anorthite molecule formed 30 to 35 per cent of the mineral. Except for the feldspar, the thin sections of these rocks corresponded closely with those of the previously described varieties of anorthosite. Orthoclase in perthitic intergrowths forms on an average about 15 per cent of the rock; little or none is interstitial to the plagioclase grains.

The Feldspars of the Anorthosite

The anorthosites being composed so very largely of feldspars a thorough study of these mineral constituents is essential. With this in mind much time in the field and laboratory was devoted to the study of the feldspars.

The determination of the composition of the feldspars was chiefly performed by obtaining their indices of refraction by the oil immersion method, and about two hundred such determinations were made. Forty representative thin sections were studied. Four complete chemical analyses of feldspars were made by Professor A. H. Phillips, Princeton University. Owing to the importance of the alkalis in this investigation their oxides were in each case determined twice.

It is believed, as already stated, that the determinations of the index of refraction of the feldspars permits estimating the amount of the anorthite molecule to within 4 per cent of its true value. Alling[1] considers that the orthoclase molecule in solid solution in plagioclase feldspar will act much as though it were albite and, therefore, will not affect the ratio of the anorthite molecule as estimated by the index of refraction. The chemical analyses of the rocks of St. Urbain area seem to support this hypothesis. Owing to the obvious importance of the perthitic rods of orthoclase in the plagioclase of the anorthosite, a systematic study of their quantities was made. Owing to the mechanical difficulty of measuring these small spindles their amount had to be estimated, but it is believed that the estimates are reasonably accurate. The following diagram (Figure 2) shows the percentage content of orthoclase in perthitic rods, and in interstitial grains, and of the anorthite molecule (as indicated by indices of refraction) of the plagioclase feldspars in each of forty thin sections of the anorthosite.

The following table presents the results derived from chemical analyses. The materials chosen for analyses are considered to be typical samples of each of the four types of anorthosite and to contain typical amounts of perthitic and interstitial orthoclase. The samples were perfectly fresh and the small amount of ferromagnesian minerals present was removed, so that the results give the composition of the feldspars. The separation of the ferromagnesian constituents is believed to have been thorough, for the total amount of TiO_2, MgO, and Fe_2O_3 remaining, amounts to only from 0·62 to 0·72 per cent of the total. Much of these oxides represents the schiller rods of the feldspar.

[1] Alling, H. L.: Jour. Geol., vol. XXIX, p. 292 (1921).

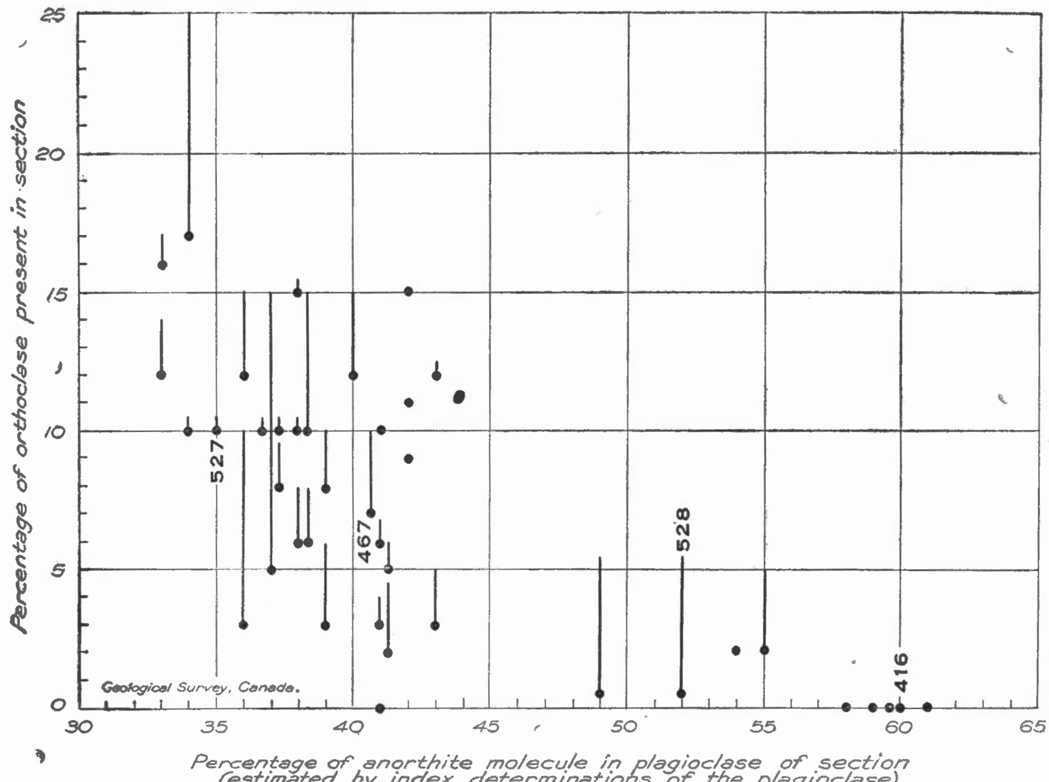

Figure 2. Diagram showing the percentage of the anorthite molecule in the plagioclase, and of the orthoclase in each of forty thin sections of anorthosite. In the case of each thin section the percentage of the anorthite molecule in the plagioclase and of orthoclase perthitic rods is indicated by the position of a black dot, and the percentage of interstitial orthoclase, if any present, by the length of a line drawn vertically upwards from the dot. Specimens chemically analysed are indicated by their specimen numbers.

Table of Chemical Analyses and Calculations

Spec. No.	Constituents	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	Total	Molecule props.	Percentage of total analysis	Percentage of total feld. molecules
527	Percentages	58·52	25·67	0·43	0·14	7·97	6·55	0·81	0·05	100·14			
	Molecule props.	0·9753	0·2517	0·0027	0·0035	0·1423	0·1056	0·0086	0·0006				
	Orthoclase	0·0516	0·0086					0·0086			0·0688		4·7
	Albite	0·6336	0·1056				0·1056				0·8448	98·2	57·7
	Anorthite	0·2750	0·1375			0·1375					0·5500		37·6
	Unapportioned	0·0151		0·0027	0·0035	0·0048			0·0006		0·0267	1·8	
467	Percentages	56·50	27·27	0·45	0·13	9·12	6·60	0·23	0·04	100·34			
	Molecule props.	0·9417	0·2674	0·0028	0·0032	0·1629	0·1065	0·0024	0·0005				
	Orthoclase	0·0144	0·0024					0·0024			0·0192		1·3
	Albite	0·6390	0·1065				0·1065				0·8520	97·3	58·9
	Anorthite	0·2883	0·1441			0·1441					0·5765		39·8
	Unapportioned		0·0144	0·0028	0·0032	0·0188			0·0005		0·0397	2·7	
528	Percentages	53·56	29·86	0·42	0·16	11·30	4·60	0·34	0·03	100·27			
	Molecule props.	0·8927	0·2927	0·0026	0·0040	0·2018	0·0742	0·0036	0·0004				
	Orthoclase	0·0216	0·0036					0·0036			0·0288		2·0
	Albite	0·4452	0·0742				0·0742				0·5936	97·1	41·5
	Anorthite	0·4036	0·2018			0·2018					0·8072		56·5
	Unapportioned	0·0223	0·0131	0·0026	0·0040				0·0004		0·0424	2·9	
416	Percentages	52·31	30·01	0·61	0·07	12·58	4·23	0·32	0·04	100·32			
	Molecule props.	0·8718	0·2942	0·0038	0·0017	0·2246	0·0682	0·0034	0·0005				
	Orthoclase	0·0204	0·0034					0·0034			0·0272		1·9
	Albite	0·4092	0·0682				0·0682				0·5456	99·3	37·4
	Anorthite	0·4422	0·2211			0·2211					0·8844		60·7
	Unapportioned		0·0015	0·0038	0·0017	0·0035			0·0005		0·0110	0·7	

The proportions existing between the different feldspar molecules as calculated from the results of the chemical analyses, and the proportion of the anorthite molecule as derived from determinations of the indices of refraction, are given below.

Specimen number	Proportions of feldspar molecules			
	Determined by chemical analyses			Determined by index of refraction
	Or	Ab	An	An
527	4·7	57·7	37·6	35
467	1·3	58·9	39·8	41
528	2·0	41·5	56·5	52
416	1·9	37·4	60·7	60

The feldspars have been considered as being, within certain limits, solid solutions of the various feldspar molecules. The plagioclase feldspars are considered to be solid solutions of the albite and anorthite molecule and, in most cases also, the orthoclase molecule to an appreciable extent.[1] The low content of the orthoclase molecule as found by the chemical analyses, considered in conjunction with the results obtained from optical analyses of the same materials, indicates the absence or virtual absence of orthoclase in solid solution in the plagioclase of three of the samples analysed. The chemical analysis of the fourth sample, a specimen of labradorite anorthosite, reveals the presence of nearly 2 per cent of orthoclase which apparently must occur in solid solution in the plagioclase feldspar, since no orthoclase in perthitic intergrowths or in other forms is visible. In the remaining three samples, respectively representative of the three phases of the andesine anorthosite, the quantity of the orthoclase molecule, indicated by chemical analysis to be present, is far less than is required for the formation of the observed perthitic rods and interstitial grains of what appears as orthoclase. In the two more basic andesine anorthosites the interstitial grains alone more than account for the indicated amount of the orthoclase molecule. The quantity of the orthoclase as determined optically may have been somewhat overestimated, but not unduly so, and the whole excess of observed orthoclase can not be accounted for in this way. The only possible explanation is that the plagioclase present has practically no orthoclase in solid solution and that what appears to be orthoclase contains the albite molecule in solid solution and is, therefore, anorthoclase. That orthoclase does contain albite in solid solution when both albite and orthoclase are present in perthitic intergrowth has been shown by C. H. Warren.[2] As determined by optical analyses, all save one of the more acid (andesine) anorthosites carry perthitic rods, or perthitic rods and interstitial grains of orthoclase or, as indicated above, of anorthoclase. In the one exceptional specimen, the

[1] Alling, H. L.: Jour. Geol., vol. XXIX, pp. 290 and 292 (1921).
[2] Warren, C. H.: Proc. Am. Acad. Arts and Sci., vol. LI, No. 3, p. 142 (Oct., 1915).

plagioclase feldspar contains 41 per cent of the anorthite molecule and orthoclase is not visibly present, but presumably does occur in solid solution in the plagioclase.

The results obtained from optical analysis, as represented in Figure 2, indicate a fairly regular increase in the amount of orthoclase or anorthoclase, with an increasing content of the albite molecule in the rocks. The interstitial grains of orthoclase (or anorthoclase) are believed to have crystallized immediately after the completion of the crystallization of the plagioclase. The perthitic rods on the other hand are considered[1] to be due to exsolution, that is, they formed from and within crystalline (solid) solutions of the two plagioclase and the orthoclase molecules. Alling has stated,[2] and Warren's work indicated, that . . . . "all plagioclase specimens contain some potash component," . . . . but as already shown the plagioclase feldspars of the St. Urbain anorthosites in some, perhaps in most, cases, contain practically none of the orthoclase molecule in solid solution. The plagioclase feldspars thus appear to have reached a stage of exsolution far beyond that believed to be usual unless, indeed, the anorthoclase (the so-called, orthoclase) forming the perthitic rods and the interstitial individuals have an excessively low content of the potassium molecule. On the whole, it seems more probable that the process of exsolution was so facilitated (perhaps by the plagioclase crystals being kept for a long time at a temperature close to the inversion point of the solid orthoclase from the solid plagioclase), that almost complete exsolution of orthoclase from the plagioclase in the anorthosite rocks took place.

The large andesine crystals, which attain a length of 8 to 10 inches and which in places make up 20 per cent of the anorthosite and in such places are in ophitic relationship to 4- and 5-inch crystals of hypersthene, have been previously mentioned. Where these andesine crystals form a low percentage of the rock, they occur in most cases as fragments, and the hypersthene is absent or in a much comminuted state. The light-coloured, albite anorthosite groundmass definitely invades these crystals, and index of refraction determinations show that these crystals and the invading material have the same composition. No zoning was detected in any of the crystals. Since the crystals occur only in the more acid phases of the anorthosite and since the range over which the crystals and their hosts were tested covered a difference of only 10 per cent in the anorthite molecule content, it is possible that the albite crystals do not everywhere have the same composition as their hosts. But though this possibility exists, it seems more probable that in all cases the albite fragments have the same or nearly the same composition as their anorthosite host and that the phenomenon is a striking example of a reaction which has been dealt with by Bowen.[3] According to Bowen, it has been experimentally shown that in a given quantity of melt of suitable composition, when the temperature drops sufficiently, plagioclase feldspar will form of a composition

[1] Alling, H. J.: "The Mineralography of the Feldspar"; Jour. Geol., vol. XXIX, p. 291 (1921).
Warren, C. H.: "A Quantitative Study of Certain Perthitic Feldspars"; Proc. Am. Acad. Arts and Sci., vol. LI, pp. 143 (1915-16).

[2] Op. cit., p. 292.

[3] Bowen, N. L.: "The Reaction Principal in Petrogenesis". Jour. Geol., vol. XXX, p, 178 (1923).

which is in equilibrium with the liquid phase with which it is in contact. The crystal phase is more basic than the liquid phase. As the temperature drops and crystallization proceeds, the liquid is impoverished with regard to its basic elements and becomes more acid. The already formed crystals alter to keep in equilibrium with the liquid, a slow interchange of molecules being effected between the two phases. The change is continuous and the plagioclase is said to belong to a continuous reaction series. This state of affairs, continued under conditions of slow cooling, will finally result in the disappearance of the liquid phase and the formation of plagioclase with no zoning and no interstitial acid minerals.

As previously mentioned, large andesine crystals, usually in a broken state, occur in very small quantities as inclusions in all the phases of the already described, granite-diorite batholithic intrusive. They resemble in every way the above described, large, schiller-rich crystals found in the andesine anorthosite phases of the anorthosite body. Since, as will later be shown, it is believed that the batholithic rocks and the anorthosites were finally consolidated at or about the same date, it seems reasonable to consider that large andesine crystals and fragments found both in the granite-diorite batholith and in the andesine anorthosite have a common origin. It is considered that the fragments of coarse, hypersthene-andesine rock in the andesine anorthosite and also the broken andesine crystals in the granite-diorite series and in the anorthosite are remnants of a coarse-grained rock whose formation probably marked a first stage in the consolidation of an igneous body which gave rise to the granite-diorite batholith and the various phases of anorthosite. But it is thought that in the beginning the plagioclase of the norite was much more basic than andesine. The change to andesine is considered to have resulted from the invasion of the norite by anorthosite of a more acid composition, with which the feldspar crystals were brought into chemical equilibrium. If, as is believed, this process has taken place, the local presence of hypersthene gives additional grounds for the supposition that the original coarse-grained rock was a norite with feldspar of basic composition, since hypersthene is usually associated with basic plagioclase.

Relations of the Anorthosite with the Granite-Diorite Batholith

The contact between the anorthosite and the granite-diorite batholith is almost everywhere concealed by glacial or fluvial debris, and only in two places were outcrops found as close to the contact as 5 or 10 feet; in most places the nearest outcrops were 200 or 300 feet away. However, the position of at least a quarter of the total length of the contact was located within several hundred feet of its true position.

The regular outline of the oval mass of anorthosite is a notable feature. No dyke-like off-shoots from the anorthosite mass into the granite-diorite batholith were seen. Neither were dykes of the granite-diorite rocks noted invading the anorthosite. Two exceptions to the regular relations were noticed. On the western margin of the anorthosite mass, northwest of Grand lake, a body of anorthosite appears to lie in the batholithic rocks.

At this place the exposures consist of a magnetite-rich diorite having an augen structure, and a foliated anorthosite. The contact strikes north 40 degrees east and, as indicated by the foliation, dips 35 degrees northwest. Diorite forms a southeastward facing cliff 20 to 30 feet high and a few hundred feet long. At the foot of this cliff is a ledge 20 to 50 feet wide bounded by a second cliff-like drop of 10 to 20 feet. The ledge floor and its cliff-face are formed of foliated anorthosite. The strike of the foliation parallels the course of the boundary between the anorthosite and the apparently overlying diorite. Stretching southeast from the foot of the anorthosite cliff is a depression 300 feet wide and 30 feet deep. The depression is at least partly floored with easily weathering diorite. On the southeast edge of the depression is an outcrop of foliated anorthosite in which the foliation has the direction of the strike and the dip is as before, but the angle of dip is 10 degrees steeper. Three hundred feet farther southeast is another outcrop of anorthosite and 1,800 feet farther southeastward are outcrops of anorthosite undoubtedly belonging to the main body. The exposures in general seem to indicate the existence of a sill-like body of anorthosite lying in the granite-diorite batholith, close to the edge of the main anorthosite body.

Another mass of anorthosite which may have the same general relation, but which is largely hidden by drift, was seen north of lake Prime en Haut.

A marked feature of the contact between the anorthosite and the granite-diorite batholith is the foliated zone which follows the contact. The anorthosite is foliated over a width of 1,000 to 3,000 feet and the adjacent granite-diorite rock is foliated over a somewhat smaller width (*See* Figure 1). Outside of this zone, the anorthosite shows foliation only in a few places in the central part of the stock-like body.

The strike of the foliation very closely parallels the course of the contact between the two rocks. The dip of the foliated structure along the west boundary ranges from 12 to 45 degrees and, in places, to 80 degrees away from the centre of the anorthosite mass. Along the north contact the angle of dip steepens, and in places is almost vertical. The few dips observed on the east side are for the most part vertical or nearly so. In the south, both within the anorthosite and the adjacent granite-diorite rock, the dips are at various angles away from the centre of the anorthosite mass.

West of Grand lake the exposures clearly display the foliated structure. Starting from within the anorthosite mass near Grand lake and travelling westward towards the contact, the anorthosite at first displays no foliated structure, but at a distance of 1,000 to 2,000 feet from the contact there is observable a distinct foliation which continues across the contact and into the granite-diorite rocks for a distance of 1,000 or 2,000 feet where the foliated structure gives place to an augen structure or grades in to a massive, structureless phase of granite-diorite rocks.

The foliated structure in the anorthosite near Grand lake is clearly shown by lenses of intermixed grains of hypersthene and of plagioclase feldspar. The lenses are 10 to 12 inches long and $\frac{1}{2}$ to $\frac{1}{4}$ inch wide. The lenses as a result of weathering give rise to lenticular depressions. Across the valley, beneath which in this vicinity lies the contact between the anorthosite and the batholithic rocks, are cliffs of granodiorite rich in magnetite. The foliated structure is made apparent by the arrangement of the ferromagnesian minerals and conforms with that in the nearby anorthosite, but is not as pronounced. The structure rapidly fades away westward and a well-defined augen structure takes its place.

A study of thin sections of both types of foliated rock seems to indicate that the foliation is largely due to protoclastic crushing, that is, took place while both rocks, although largely crystallized, contained a percentage of uncrystallized liquid. In the granodiorites and in the syenites in which some quartz is present, the quartz is in long, lenticular individuals interstitial to the other constituents of the rock and whereas the other minerals in many cases show crushing the quartz is quite uncrushed, although it is one of the first of the constituents of a rock to show the effects of strain. From this relation it must, therefore, be inferred either that at the time of crushing of the feldspars, etc., the quartz still was in a liquid state, or, as is difficult to imagine, that the already crystallized quartz was by some process of recrystallization transformed into long, lenticular individuals which show uniform extinction.

The development of a protoclastic structure in both the granite-diorite series and in the anorthosite, and the virtual limitation of this structure to a zone paralleling and including the contact between the granite-diorite series and the anorthosite series, seems to indicate: (1) that the two groups of rocks were in contact with one another when both were still only partly crystallized; (2) and that the plane of contact between the two rock groups was a plane of differential movement.

Theoretical considerations referred to in a succeeding section of this report indicate a possibility that the granite-diorite series and the anorthosite were developed in situ in stratiform fashion with the granite-diorite rocks overlying the anorthosite, and that the stratiform arrangement was in part obliterated by movements of the two rock groups while still at least only partly crystallized.

In view of the absence of direct evidence of the relations existing between the granite-diorite series and the anorthosite body, it does not seem possible to determine these relations by indirect arguments. Any explanations of the relations existing must take the following considerations into account.

(1) After the granite-diorite series and the anorthosite body came into contact with one another, both series of rocks were still only partly crystalline.

(2) The two rocks are foliated (a protoclastic type) in a comparatively narrow zone following the contact. The plane of foliation apparently parallels the contact plane. The foliation everywhere is vertical or dips outwardly from the centre of the anorthosite body. In places, over considerable stretches the foliation dips at angles of 12 to 25 degrees. The anorthosite body apparently, therefore, is boss-like, with a cross-section increasing in size with increasing depth.

(3) In plan, the outline of the anorthosite mass is smoothly ovoid. The anorthosite body is not embayed by the granite-diorite series nor, so far as known, cut by apophyses from that assemblage.

(4) Two small, detached masses of anorthosite lie in the granite-diorite rocks close to the anorthosite boundary.

(5) The banding exhibited by the detached bodies of paragneiss that lie in the granite-diorite series close to the anorthosite boundary, that is within the zone of foliation, parallels the foliation of the zone of foliation.

(6) Within the anorthosite body, less basic phases cut and hold blocks of more basic phases and these blocks in places exhibit a faint foliation not reflected in the surrounding more acid phase.

(7) The granite-diorite series, at one locality at least, holds blocks of anorthosite.

(8) The granite-diorite rocks nearly everywhere hold fragments of andesine crystals closely similar to if not identical with andesine fragments held by the andesine anorthosites.

(9) Theoretical considerations render it not improbable that the granite-diorite series and the anorthosite rocks are genetically closely related, that the anorthosite formed practically in situ, and once was overlain by syenitic rocks or rocks such as form the granite-diorite series.

(10) Theoretical views indicate that the anorthosite never existed as such in a purely fluid state, that it came into being only when it was already largely crystalline. If the anorthosite did so originate, the body could scarcely move far from its seat of formation unless: (*a*) by the development of pronounced pyroclastic or cataclastic structures, such structures are not markedly developed in the St. Urbain mass; (*b*) or by being largely converted into a fluid condition after having reached a nearly completely crystalline stage.

Genesis of the St. Urbain Anorthosite

The genesis of large bodies of monomineralic rocks has been a subject of considerable speculation by students of petrographic theory. As regards the large anorthosite masses the only attempt to solve the problem in the light of modern petrographic knowledge has been made by N. L. Bowen.[1]
His conceptions of the method of formation are in his own words[2] as follows:

"Anorthosites are made up almost exclusively of the single mineral plagioclase, and in virtue of this fact they present a very special problem in petrogenesis. The conception of the mutual solution of minerals in the magma and the lowering of melting temperature consequent thereon is no longer applicable. Yet anorthosites give no evidence of being abnormal in the matter of the temperature to which they have been raised, in other words they give no evidence of having been raised to the temperature requisite to melt plagioclase. A possible alternative is that they may never have been molten as such, and are formed simply by the collection of crystals

[1] "The Problem of the Anorthosites"; Jour. Geol., No. 3, vol. XXV, pp. 209-243 (1917).
[2] Op. cit., p. 242.

from a complex melt, probably gabbroic magma. This possibility is in harmony with the expectations that grow out of experimental studies and for this reason a consideration of the likelihood that anorthosites have originated in the stated manner becomes imperative.

"A consideration of the method whereby accumulation of plagioclase crystals might take place leads to the conclusion that the most promising is the separation by gravity of the femic constituents from gabbroid magma, while the plagioclase crystals, which are basic bytownite, remain practically suspended. Then, at a later stage, when the liquid has become distinctly lighter, having attained diorite-syenite composition, the plagioclase crystals, which are now labradorite, accumulate by sinking and give masses of anorthosite, at the same time leaving the liquid out of which they settle of a syenitic or granitic composition.

"Some of the consequences of this manner of origin of anorthosite are as follows. Typical anorthosite, very poor in bisilicates, should not occur as small dykes, for a mass of accumulated crystals should have little invading power. A proportion of about 15 or 20 per cent bisilicates or other foreign material such as orthoclase and quartz should be necessary for the formation of small dykes."

As stated by Bowen,[1] . . . .

. . . "It is believed, then, that anorthosites were never liquid as such, but that their material when liquid was part of a solution probably of gabbroid nature. Only in virtue of the sorting of solid, crystalline units from this solution does anorthosite come into being."

The hypothesis developed by Bowen and as stated by him involves supposing that the larger anorthosite bodies found in nature must have formed essentially in situ; that when formed they consisted primarily of crystals and not more than in the neighbourhood of 20 per cent of interstitial liquid; that any movements of an anorthosite body as a whole would necessarily give rise to protoclastic structure and granulation, since the anorthosite mass does not come into being until it is mainly composed of feldspar crystals; that the anorthosite body develops by gravitational settlement or other processes from what was a magma of gabbro-like composition; that as a result of the differentiation of the anorthosite portion, the remaining portion would have an average syenitic composition, would overlie the anorthosite, and cutting relations might or might not be established by the two contrasting rock types; that regional movements at or subsequent to the period of differentiation of the anorthosite would in part destroy or mask the stratiform relations of the syenitic and anorthositic masses; that on the whole the presence of anorthosite at the present earth's surface implies great erosion in which not only the roof of the magma chamber but the overlying syenitic complex was removed by erosion.

The general hypothesis advanced by Bowen seems to accord with the general relations exhibited by the St. Urbain anorthosite body, although the meaning to be attached to various phenomena are not, in the writer's opinion, obvious.

The penetration along fractures, of the blocks of earlier formed, more basic anorthosite by the younger, andesine anorthosite, the analogous relations exhibited by the larger crystals and fragments of andesine feldspar now embedded in the andesine anorthosite, and in general the cutting of

[1] Op. cit., p. 211.

one phase of the anorthosite by another, seem to imply that the andesine anorthosite as a whole did exist in a liquid state and with the composition of andesine anorthosite. The various phenomena also seem to imply that the andesine anorthosite as a liquid may have advanced to its present position relative to the surrounding rocks. If this did happen, there is no reason for supposing that the earlier-formed, labradorite anorthosite did not also come into place in a liquid condition.

If it be admitted that large bodies of anorthosite may exist in what is essentially a liquid state, many of the observed phenomena seem to indicate that anorthosites differ in no essential respects from other plutonic rocks. Such a conception, of course, is irreconcilable with the general hypothesis put forward by Bowen, but adopting it for the moment, it is possible to imagine an otherwise consistent chain of events. The norite fragments and the andesine crystals found in the andesine anorthosite according to the alternative hypothesis are merely products of an earlier stage of crystallization of the anorthosite magma or of a parent magma. The blocks of labradorite anorthosite are of analogous origin. The anorthosite mass is an intrusive body.

Any attempt, by deductive or inductive methods, to establish the nature and sequence of the main events in the history of the St. Urbain anorthosite body, seems futile because natural conditions in the field prevent obtaining direct evidence in regard to important matters. Lacking the control that would have been afforded, if such evidence had been available, any explanation of the phenomena exhibited by the anorthosite body involves adopting assumption after assumption.

BLACK RIVER AND TRENTON

Limestones of Black River and Trenton age outcrop in a comparatively few places in the valley of Gouffre river from the St. Lawrence shore to a point 14 miles inland. The beds in places are nearly horizontal, in other places they are tilted at high angles as the result of faulting. The largest single area presumably underlain by these limestones is near Baie St. Paul and measures 3 by 4 miles, but the strata of this area are very largely concealed by drift. The other areas are small, a few hundred feet or several thousand feet long.

The beds outcropping along the west slope of Gouffre River valley near Baie St. Paul are flat-lying in many places, but in various localities along the edges of the Ordovician area they have been faulted and now abut against the Precambrian (*See* Plate II A). On the east valley slope the same relation holds, but there the limestones dip more sharply westward in a broken monoclinal structure. Along the railway east from Baie St. Paul, remnants of the limestone strata occur dipping nearly vertically toward St. Lawrence river. These patches of steeply dipping limestone lie along what undoubtedly is a fault zone which forms this part of the north shore of the river.

The heavy drift in Gouffre valley hides any limestone that may remain immediately north of Baie St. Paul. Farther north, in the vicinity of St. Urbain, patches of limestone outcrop on the west side of the river; they lie on the western and downthrow side of a fault. Five miles northeast, on the southeast bank of the Gouffre, are other small areas of limestone lying along a fault zone.

Because the strata are much faulted and poorly exposed, it is difficult to estimate the thickness of the Ordovician. In a canyon on Bras Nord Ouest, 1½ miles west of Baie St. Paul, a thickness of over 100 feet is exposed and careful measurement of the exposures above and below this point indicate that the total thickness is probably much greater. Near the Government quay, east of Baie St. Paul, a thickness of about 200 feet may be seen, and there again the indications are that the total thickness developed in that vicinity is much greater than the amount exposed.

The contact between these sediments and the underlying Precambrian rocks was not seen. On Mare river, a very small thickness of impure sandstone appears to belong to the basal part of the formation. The grain of this sandstone is from 5 mm. down. The rock is largely made up of glassy quartz, possibly derived from the igneous rock of the neighbourhood. A little feldspar is present, and some fine, argillaceous and calcareous material. The sandstone grades upward in a few feet into limestone.

Limestone composes most of the formation. It varies a little in colour, but where free from argillaceous material it is, for the most part, a very dark, bituminous rock weathering blue-grey. Some of it weathers slightly brown and this phase on fresh surfaces is lighter in colour than the previously mentioned variety. Some parts of the limestone have dark, argillaceous partings, which, when weathered, look like shale. These partings vary in thickness and distribution, but for the most part are about ¼ to ½ inch thick and from 2 to 10 inches apart. In the pure limestones most of the beds are 6 to 10 inches thick. In some places, thin beds weather with a nodular surface.

The limestones in places are rich in fragmentary fossils. Previous collections from Baie St. Paul, mentioned in "Geology of Canada, 1863," page 160, prove the strata to be Black River and Trenton in age.

Faulting no doubt occurred within St. Urbain area in Precambrian time, but no evidence of such movements was obtained. The earliest faulting of which clear evidence is obtainable is that which affected the Ordovician beds which have been down-faulted against the adjacent Precambrian rocks. Undoubtedly the preservation of this comparatively easily eroded formation is due to this accident of down-faulting. Presumably the down-faulting took place before the commencement of the great cycles of erosion that followed the withdrawal of the Palæozoic sea.

PRE-PLEISTOCENE EVENTS

In the northern, mountainous section of St. Urbain map-area, the mountains, and numerous others visible to the northward, rise to a common elevation of about 3,000 feet and form a level sky-line. Many of the mountain blocks are 2 to 4 miles long and 1 to 2 miles wide and have tops that are essentially flat with only minor features of relief, such as lake basins and shallow valleys. The level sky-line produced by these mountains, composed of rocks of varying resistance to erosion, and the forms of the upper surfaces of the mountain blocks, point very strongly to the presence of a dissected peneplain. This peneplain formed at about sea-level and has since been uplifted, dissected, and, it is believed, faulted.

The large U-shaped valleys in the mountainous area and the outwash plain north of St. Urbain indicate definitely that the present mountainous country in the northern part of the map-area existed prior to the Pleistocene ice-sheets. Therefore, the uplifting of the peneplain occurred before late Pleistocene time and long enough prior to that date for erosion to carve the deep valleys in the mountainous section and for the St. Urbain plain to have formed. The dates of formations and uplift of this peneplain, which probably extended over a considerable area of the Canadian Shield, cannot be determined from evidence available in St. Urbain area.

As already stated, the Trenton limestone exhibits evidence of considerable down-faulting. Fault-planes were seen between the Precambrian of the region and the Trenton (*See* Plate II A) and it is reasonable to assume that faulting was not confined to where Trenton limestone still remains, but that it also occurred in other places.

Ordinary erosion could not form three contiguous and dissimilar sections such as the mountainous northern section, the inclined plain north of St. Urbain, and the uplands bordering Gouffre river, nor may the differences be ascribed to the action of the Pleistocene ice-sheet or sheets. Differential erosion can not account for the marked differences in elevation between adjacent parts of the map-area, because the underlying rocks are in large part the same. The St. Urbain plain is drift-covered, but enough evidence is available to indicate that, like the smaller plain at a somewhat higher elevation south of lake Boudrault, it has an essentially level rock floor with minor irregularities that make the relief of the bedrock surface identical with that of the tops of the mountain blocks, 1,400 to 2,000 feet above these two plains. Both plains and the mountains immediately north are underlain by anorthosite.

The two plains at their junction with the mountainous, northern part of the map-area are bounded by steep scarps, whose lower slopes are covered with talus and whose upper parts are cliffs. Scarps like that west of lake Boudrault, the one passing east of the lake and extending southeasterly along Gouffre river, and another extending westward for 8 miles from lake Pied des Monts, are comparatively straight. The long scarp which bounds the St. Urbain plain on the north and the shorter one, 4 miles long, which, west of Grand lake, forms the west boundary, are broken. Their irregularities are probably due to cross-faulting and to the results of river and ice erosion.

These and other scarps within the map-area, which are boundaries between areas of different elevation, have all the signs of youth. The plucking action of the Pleistocene ice-sheets may be partly responsible for the youthful aspect, but only in a slight degree. It is thought that these apparently youthful topographic features must be due to faulting. Fault breccia was found on the line of these scarps in one place only, namely where the extension of the scarp-line west of Boudrault lake crosses the southwest branch of Gouffre river. In other parts of the area, where fault breccia might be expected, talus and drift conceal the bedrock. Nevertheless it is considered that the evidence is definite that these youthful-looking scarps are due to faults. The similarity of the bedrock surface of the St. Urbain plain, and of the higher, smaller plain near Boudrault lake to that of the peneplain surface in the mountainous area, suggests that these two surfaces were once part of the peneplain which lies at an elevation of about 3,000 feet. But within the limits of the St. Urbain plain are small patches of Ordovician limestone lying along the east edge of a downthrown fault block. As already stated, the comparatively easily eroded, Ordovician limestones presumably owe their preservation to the fact that they lie within a down-faulted area. Similarly, the larger area of some 10 or 12 square miles of Ordovician near Baie St. Paul, at the mouth of Gouffre river, is a downfaulted block. If these areas in which Ordovician limestone occur were downfaulted after the uplift of the peneplain it seems necessary to conclude that the surface of the peneplain very closely corresponded to the surface of an older peneplain on which had been laid down the Ordovician strata, or else that the later peneplain surface truncated a faulted area in which Ordovician and perhaps later Palæozoic beds had been preserved as the result of downfaulting. It seems improbable, though not impossible, that the present peneplain surface approximately coincides with the early Palæozoic or Precambrian surface of erosion. It seems more probable that the area has been repeatedly subjected to one general type of faulting whereby at an early period blocks of Palæozoic strata were downfaulted amongst the resistant Precambrian rocks and thereby partly preserved when the region was peneplained; that after peneplanation further faulting occurred; and that the youthful-looking scarps are due to the later faulting. A third possibility is that the faulting was mainly or solely accomplished when the Palæozoic strata were downfaulted and thus preserved from erosion; and that the youthful-looking scarps owe that quality to a comparatively recent exhumation resulting from a recent destruction of the infaulted Palæozoic beds.

The height of the scarps under any view of their mode of origin as fault scarps is a measure of the minimum vertical displacement due to faulting. This displacement is from a few hundred feet to 2,000 feet. The lateral displacement seems small, for the boundaries between formations where crossed by the faults show no evident displacement. The faulting, apparently, was essentially vertical.

None of the fault scarps is very long and no tendency to strike in one or more definite directions is noticeable. In fact the pattern formed by the faults is extremely irregular like that of a giant breccia. Such a condition suggests that this part of the Canadian Shield was and is in tension.

PLEISTOCENE AND RECENT

Erosion within St. Urbain area has been greatly influenced by the nature of the bedrock, and certain peculiarities distinguish the topographic forms produced in the anorthosite areas from those developed in areas underlain by rocks ranging in composition from granite to diorite. The anorthosite is practically altogether composed of feldspar, a mineral that does not weather rapidly. The granite-diorite types, on the other hand, are made up of two or more minerals, some of which weather rapidly. The heterogeneous content and the susceptibility of many of the minerals to weathering have resulted in a more rapid breaking down of the rocks of the granite-diorite series. The forces of erosion, therefore, have developed hills with more subdued outlines in the granite-diorite areas than in the anorthosite areas.

A marked result of the differential weathering of the two rock terrains is to be seen in the drainage about the margins of the anorthosite mass. The streams have cut deeper in the less resistant granite-diorite rock series and the drainage consequently has been deflected towards the areas of these rocks. This effect is seen in a marked degree in places along the boundary of the anorthosite mass, as on the western margin where numerous drainage courses closely follow the contact of the two rock types. Valleys, short streams, and lake basins mark the contact. Two of the lake basins, owing to the cutting down of their outlet and silting of the basin, are now occupied by muskegs, through which sluggish streams meander. Just north of these two muskegs is lake Moise in a cirque basin hollowed out in the contact zone. The upper part of the U-shaped valley of the Northwest branch also lies close to this contact. Farther north, the short stream flowing into the north side of lake Prime en Haut follows the contact.

The Pliocene topography has been modified by the geologic events of Pleistocene and Recent time. The Pleistocene ice-sheets passed over this part of the Canadian Shield, left their typical deposits, and produced characteristic erosional features. On their retreat the Champlain Sea invaded the lower parts of the area and following its fluctuating retreat left its beaches and typical deposits. The forces of erosion since the disappearance of the Champlain Sea have only slightly modified the topographic features of the region.

Traces of the action of the Pleistocene ice-sheets and their typical deposits are well developed in the higher parts of the area. Glacial striæ were found at only two localities in the level country in the central part of the area a mile northeast of Mine lake where the direction is north 102 degrees east; and at the Coulomb ilmenite deposit 2 miles south of St. ? Urbain where the direction is north 135 degrees east. These determinations indicate that the ice-sheets flowed southeasterly. The rough topography of the northern part of the area greatly influenced the direction of flow of the lower part of the sheets and the striæ in this part of the area conform to the direction of the valleys. No striæ were noticed on the hilltops.

The most outstanding examples of the erosive power of the ice are in the northern section of the map-area, where subsequent processes have done little to modify the topography. The Northwest branch of Gouffre river furnishes the best example of a U-shaped valley within the high plateau area north-northwest of St. Urbain. The floor of this valley, in its length of about 4 miles drops 1,000 feet on a comparatively uniform grade. The valley has one rather sharp curve, but on the whole follows sweeping regular curves. The valley is ½ mile to ¾ mile wide, is 800 feet deep at its head and approximately 2,000 feet at the southern end of the mountain stretch. It has, in cross-section, essentially, a boulder-strewn, level rock floor. Many of the rocks and boulders are of great size and show little rounding. Glacial striæ are numerous on the rock floor. Some hundreds of feet from the banks of the river talus slides slope upward to heights of 400 to 1,000 feet above the valley floor. Many of the rock blocks in the talus slides are of considerable size, blocks of anorthosite 10 to 20 feet in diameter being abundant. Above these talus slopes are cliffs, in most places from 200 to 800 feet high and reaching to the highest points of the scarps bounding the valley. The top edges of the scarps have an approximate elevation of 3,000 feet above sea-level and are the edges of the high, dissected plateau.

The cross-section of the valley thus has a U-shape. Most of the other valleys in the mountainous section of the map-area also have U-shaped cross-sections, which in many cases are not quite symmetrical. There is no doubt that the U-shape of the valleys is largely due to the lateral erosive action of glaciers flowing through them. The plucked cliffs, the striated valley floors, the partly rounded boulders, many of great size, strewn on the valley floor, and the deposits of typical glacial material lying at the mouths of many of these valleys, leave no doubt that these valleys were once filled with masses of flowing glacier ice.

Numerous small lakes occur in the northern mountainous area. Most of them are not more than 500 to 2,000 feet long. A few of these lie at the heads of the U-shaped valleys, but most of them occur within the hills and at a considerable elevation amounting to, in many cases, 1,800 to 2,500 feet above sea-level. The shores of these lakes are, for the most part, steep. Rock cliffs of moderate height border many of the lake basins. The outlet streams have steep gradients, are mostly short, and flow into the main, U-shaped valleys after, in most cases, dropping 500 to 1,300 feet in distances not exceeding 1½ miles. The high valleys in which many of these lakes lie open abruptly into, and at considerable elevations above, the larger main valleys of the region. They are typical hanging valleys. The lake basins are cirque-like, and they and the hanging valleys owe their characteristic features to the action of mountain glaciers which once flowed from them to join the main valley glaciers.

Ground moraine occurs on all the higher parts of the area above the level of the deposits of the Champlain Sea. In the northern mountainous area the ground moraine is quite scanty in most places, and on the hill tops is represented only by a few large erratics. In the depressions on the hill tops, boulders are more numerous, but nowhere form more than a thin cover to the underlying rocks.

On the lower hills bordering Gouffre valley the till is much thicker and covers the gentle slopes of these hills. The morainal material is typical boulder clay. Few of the boulders exceed 2 feet in diameter and most are much smaller. They are intermixed with considerable clay and finer debris. Most of the boulders are of crystalline rocks derived from the adjacent Precambrian terrains and are fairly well rounded. In the lower part of Gouffre valley where it is underlain by Trenton limestone and not obscured by Champlain Sea deposits, there is a thin veneer of till whose larger fragments are in great part angular fragments of the underlying limestone. In the valley of the Northwest branch, 5 miles northwest of St. Urbain, typical glacial till forms a bed 8 feet thick, interstratified with outwash sands and gravels.

Some parts of the map-area above the 600-foot contour are covered with stratified sands and gravels with a small admixture of boulders. The large plain north of St. Urbain is so covered, and the streams traversing it have cut through it in places to bedrock. In some places crossbedding is clearly visible, whereas at others this structure is not at all obvious. The high, comparatively level areas in the uplands bordering Gouffre river are, in many cases, covered by sand and gravel drift that resembles the material found north of St. Urbain. The nature of these partly stratified deposits, their position at an elevation above the possible level of the Champlain Sea, and their location close to high regions in which valley glaciers existed, lead to the conclusion that these deposits are outwash material laid down by the waters flowing from the foot of the melting glaciers. The largest depressions in the plain north of St. Urbain are occupied by the two lakes, Ontario and Cygnes. A lake of a similar nature and possibly similar origin is Mine lake, 3 miles east of St. Urbain. Their shores are low, marshy, and formed of drift. These lakes apparently owe their origin to the irregular deposition of the outwash material, or possibly to the melting of buried ice blocks that once formed parts of the glaciers extending over these plains.

Two well-defined terminal moraines are known within the area. One dams the outlet of Four valley, out of which flows the brook which feeds lake Cygnes, and the other dams the outlet of the valley through which the upper part of Mouche river flows. The ridge-like dam of glacial till across the mouth of Four valley has been cut through by Four brook and the lake that once existed north of the dam has been drained. The position of the lake is now marked by a muskeg, through which Four brook meanders.

In the valley along which Mouche river flows in an easterly direction, at a place just east of the sharp bend in Mouche river where it turns northward to join the Southwest branch, the floor rises over 300 feet. This is due to a deposit of morainal material of a very ill-sorted nature, which fills the valley for nearly a mile eastward. Along the south flank of this morainal hill, at the foot of the scarp forming the south valley wall, are two small, shallow lakes whose shores and bottoms are strewn with large boulders. The morainal hill was undoubtedly the terminal moraine of a glacier that occupies Mouche valley. The melting ice must for a time have fed a stream which flowed eastward through the two lakes on the south flank of the morainal hill. As the level of the ice and water west of the morainal dam dropped towards the close of the glacial epoch, the Mouche valley must have been the basin of a lake which discharged through a short stream at its eastern end into the Southwest branch lying to the north of it. This stream, having a considerable flow of water, was able to cut a canyon-like gorge and to drain the lake. Where the lake once existed, a muskeg is now found and through it Mouche river flows in its sluggish, meandering course.

The upper course of Gouffre river seems definitely to indicate derangement by morainal material. It is very probable that originally the river flowed through the present basin of lake Boudrault instead of, as at present, to the north and east of the lake. The forcing of Gouffre river out of this old course was probably due to the damming effect of morainal deposits and ice from the glacier that once filled the long valley northwest of lake Boudrault.

It is believed by Goldthwait[1] that the Champlain Sea at its maximum stage reached in the vicinity of Baie St. Paul points that are now at an approximate elevation of 500 feet above sea-level. Within St. Urbain map-area, the country lying below the 500-foot contour is a narrow fringe along St. Lawrence river, and an area extending up Gouffre valley a short distance beyond St. Urbain. In the valley of Gouffre river the high valley walls confined the arm of the Champlain Sea to an area which at its broadest was not more than 6 miles wide.

Beaches. On the upper slopes of the valley wall at an elevation of about 500 feet above sea-level are terraces that in many instances can be traced for some distance. They are best developed near Baie St. Paul, and in the narrow part of the valley 4 miles north of this village. A few distinct terraces occur on both sides of Gouffre river a mile or so north of St. Urbain and near the village. Near St. Urbain the highest terrace is just below a low cliff of anorthosite at whose foot a talus slope lies. The old beach shelves rapidly eastward to a lower level and is comparatively narrow. The terrace is made up of boulders, sand, and gravel. Two or three narrow terraces occur at still lower levels, and are composed of sand and gravel. A pronounced terrace a mile or more long is visible on the east bank of Gouffre river just east of Baie St. Paul village.

These terraces follow the smooth, curving outline of the valley wall and have no cusps or breaks in their outline. They resemble terraces and beaches described by various writers in neighbouring regions and ascribed to wave-action of the Champlain Sea.[2] These sea beaches in many places are very poorly marked and apparently indicate that the sea remained stationary at their levels for comparatively short periods.

Two miles southwest of Baie St. Paul there is a limestone plain at an elevation probably close to 500 feet above sea-level. It slopes gently eastward and is covered by a scanty coating of residual soil and a few large boulders. As the road traversing the area is followed northeastward and downward from the plain, gravel and sand beds are encountered. It seems very likely that both wave and current scour swept this limestone plain clear, and that the material thus swept off was deposited in the adjacent deeper water as beds of gravel and sand.

At an elevation of 60 to 70 feet above Gouffre river, terraces at a lower elevation than the ones so far described are found along parts of the valley. These terraces have a cusped outline and other features that show them to be river benches rather than sea beaches.

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1 Geol. Surv., Canada, Mem. 140, p. 150.

2 Goldthwait, J. W.: "The Twenty-foot Terrace and Sea-cliff of the Lower St. Lawrence"; Am. Jour. Sci., vol. XXXII, pp. 291-317 (Oct., 1911).

On both sides of the bay of Baie St. Paul are level areas approximately 20 feet above sea-level and having widths of 20 or 30 to a few hundred feet. These areas are backed by cliffs that rise abruptly from the level shelf. On the east side of the bay the surface of the shelf is extremely rough, being formed of the truncated, steeply-dipping Trenton limestone beds found in this part of the area. Goldthwait[1] considers these to be part of the pronounced beach which has been traced from Quebec city to a point 225 miles down St. Lawrence river and which is known as the Micmac terrace. Goldthwait considers this to be a terrace cut by wave-action, towards the close of Champlain time. This terrace, which in places outside St. Urbain area has a width of a couple of miles, must mark a long period of stability of this part of the Canadian Shield.

Besides the beach terraces there are deposits of gravels, sands, silts, and clays which were laid down in the arm of the Champlain Sea that invaded the valley of Gouffre river. The Champlain Sea in this restricted area must have been relatively calm and wave erosion along the shores of this estuary must have been comparatively slight. Such a condition possibly accounts in a great measure for the somewhat imperfect beaches that are found. Sands and gravels occur in many places adjacent to the old beaches. In the lower part of Gouffre valley adjacent to the village of Baie St. Paul, are a half-dozen square miles of farming land which constitutes the most fertile section of the valley. This section is underlain by silts and clay. This material was brought down by the streams flowing into this Champlain bay, and owing to the fineness of the material was deposited in the deeper parts of the bay.

Since the retreat of the Pleistocene ice-sheets and the Champlain Sea, the forces of erosion have slightly modified the pre-existing topography. Such superficial features as the beaches of the Champlain Sea have, however, suffered very little erosion.

On the tops of the hills of the mountainous area in the north, a type of erosion is found which is also met with in regions of high altitude or latitude. The flat surfaces of the rocky hills are covered with small, angular fragments of the underlying rock. These fragments in many places are held together by a slight amount of soil and moss. The thin veneer of fragmental material is largely due to the action of frost. Water filtering along cracks freezes and then expands, and thus fractures the rock and forms angular fragments. The transporting force of rain water, or water from the melting of the winter snows, is insufficient to carry off this debris and it remains as a mantle on the underlying rock.

The talus slopes at the foot of the cliffs found in the northern area are composed of large blocks of rock which have been in great measure spalled off the cliff faces by frost action.

The brooks in the rocky northern areas, except at certain places, have only slightly eroded their channels since the retreat of the Pleistocene ice. Instances of the exceptions are as follows: Mouche river has cut a gorge

[1] Goldthwait, J. W.: "The Twenty-foot Terrace and Sea-cliff of the Lower St. Lawrence"; Am. Jour. Sci., vol. XXXII, p. 297 (1911).

which carries its water northward into the Southwest branch. The two muskegs on the anorthosite contact north of Grand lake have been formed by the draining of lakes whose outlets were once dammed by a rock lip or morainal ridge and the same is true of the muskeg north of lake Cygnes. In the lower parts of the map-area the brooks have cut channels in the drift of the region. On the outwash plain north of St. Urbain some of these youthful, V-shaped valleys are cut in drift to a depth of 100 feet.

From a point some distance north of St. Urbain to Baie St. Paul, Gouffre river follows a meandering course cut in gravels, sands, and clays to a depth of 30 to 50 feet. The river is swift and in this distance flows over many gravel bars, but nowhere is there a fall or rapid due to the effect of bedrock or boulders. The meanders are entrenched in a plain which laterally is bounded at varying distances from the river by low cliffs of gravels, silts, and clay, which in many places rise 20 or 30 feet above the plain to the level of a second plain. The outlines of these cliffs are not regular and they have pronounced cusps, many of which have a depth of 100 feet or more. The crest of these cliffs also differs from the crest of the beach terraces previously described. It is a sharp break from the high, level plain to the steep slope of the cliff. The previously described beach terraces have a crest which slopes off more gradually. There is no doubt that these cliffs are due to the lateral erosion of the Gouffre at a time when it meandered across the plain at the foot of these cliffs. Gouffre river at present is adding another bench to its valley walls. Every year its meanders alter, and arable land is undercut and swept away by the swift river. The considerable depth of the present entrenched meanders of Gouffre river is evidence of rapid uplift in very recent time.

Three miles south of St. Urbain is an area of sand. Sand dunes are present and in one place have dammed a couple of ponds fed by water flowing down the west valley wall. These ponds discharge by seepages through the sand to Gouffre river. This area of sand at this constricted point in Gouffre valley was very probably deposited by current action during the Champlain invasion which here developed sand-bars. These sand-bars on the retreat of the sea were reworked by wind action to produce the present dune surface.

North of St. Urbain, on the large outwash plain, are minor areas of peat. The marshy shores of lake Ontario and lake Cygnes are in the process of forming similar deposits.

A delta of silt and mud is now forming at the mouth of Gouffre river and at low tide muddy flats are exposed for a width of a mile. Along the shores of St. Lawrence river, near the mouth of Gouffre river the flats exposed have a width of from 500 feet to 2,000 feet.

CHAPTER III

ECONOMIC GEOLOGY

INTRODUCTION

Materials in the area of present economic value are practically all non-metallics and their consumption is limited and local. The area is mainly underlain by deeply eroded, igneous rocks, and only the deep-seated types of metalliferous deposits may be expected to occur. In this category are the titaniferous iron deposits of St. Urbain. From time to time other types of deposits were thought to have been found. For instance, some years ago galena was discovered a mile southwest of Baie St. Paul, but the driving of a 10-foot tunnel into the limestone showed the deposit to be a very small stringer which quickly petered out. The deposit was not due to igneous action, but very likely was produced by meteoric waters which derived the lead sulphide from the Ordovician limestone.

A sulphur spring rises near this point and others are found elsewhere in the vicinity. They are connected in origin with the Trenton limestone and probably, as pointed out by Lindgren[1], owe their sulphur content to the reduction of gypsum by waters carrying carbonaceous material. The subsequent oxidation of the hydrogen sulphide thus formed gives rise to the film of sulphur deposited by them.

About sixty years ago at the foot of the St. Croix road on the east bank of Gouffre river, 6 miles north of Baie St. Paul, a tunnel was driven a short distance into the faulted and barren anorthosite in the hope of obtaining silver. No trace of metallic minerals could be found on the present dump. The venture was ill-starred and was based, so it is said, on imperfect information. Silver was found in the vicinity, but it consisted of a few hundred coins in a kettle, buried by one of the early settlers and later dug up by a Frenchman who was in possession of exact information as to its whereabouts.

A pegmatite vein carrying graphite, noted by Low on his unpublished manuscript map, occurs 5 miles northwest of Baie St. Paul. The inhabitants describe it as small in size. It could not be found by the writer.

A fair-sized pegmatite deposit of muscovite and biotite mica occurs just north of lake Pied des Monts in the northeast part of the area. This deposit was not studied by the writer. Mention of it was made by Ells and Zirkel.[2]

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[1] Lindgren, W.: "Mineral Deposits," p. 313 (1919).
[2] Ells, R. W.: Geol. Surv., Canada, Min. Res. Bull. on "Mica," p. 7 (1904).
Zirkel, F.. Mines Branch, Dept. of Mines, Canada, Bull. on "Mica," p, 18 (1905).

ILMENITE

History

Early in the French occupation of the valley some of the ilmenite deposits in the vicinity of St. Urbain were discovered. It is stated that Seigneur de la Tesseric discovered one deposit in 1666.[1] Although exploration was carried on next year by order of Colbert, Prime Minister of Louis XIV, nothing apparently came of it. In 1872 an attempt was made to smelt the ore with wood charcoal, but it proved economically impossible and the following year the company ceased operations.[2] Since that time various deposits in the vicinity of St. Urbain have been worked on a small scale and the ore shipped to Niagara Falls and other places for the manufacture of titanium oxide paint and ferro-titanium alloy. There are indications that owing to cheap hydroelectric power and an increasing demand for titanium oxide, these deposits may eventually prove of considerable economic importance.

Various workers have investigated these deposits and the following is a bibliography of the main articles.

Obalski, J.: Rept. on Mines of the Province of Quebec: Dept. of Colonization and Mines, Quebec; p. 17 (1900).

Dulieux, P. E.: "Report on Mining Operations in the Province of Quebec"; Que. Bureau of Mines, pp. 94-96 (1912).

"Les Minerals de Fer de la Province of Quebec"; Que. Bureau of Mines, pp. 125-127 (1915).

Warren, C. H.: "The Ilmenite Rocks Near St. Urbain, Quebec; A New Occurrence of Rutile and Saphrine"; Am. Jour. Sci., Art. 25, vol. XXXIII, pp. 263-277 (1912).

Robinson, A. H. A.: "Titanium"; Mines Branch, Dept. of Mines, Canada, No. 579, pp. 46-53 (1922).

Location

The main ilmenite deposits lie within an area 1½ miles in diameter. The centre of this area is 2 miles southwest of St. Urbain. Most of these known deposits lie close to the boundary between range St. Urbain and range St. Jerôme. The most westerly are near the top of the gentle eastern slope of Gouffre River valley. All are 450 to 700 feet above the bed of the river.

Two other small deposits, a quarter of a mile distant from one another, are 8 miles north of St. Urbain and ¾ mile east of lake Ontario. Another small deposit is 2 miles east of these on the trail following Bras Sud Ouest river.

General Geology

All these deposits lie within the anorthosite area, the three last-mentioned are close to the centre of the mass, but the larger deposits, southwest of St. Urbain, are within ¼ to 1½ miles of its border. The anorthosite mass has a major diameter of 18 miles and is surrounded by a

[1] Wurtele, F. C.: "Historical Record of the St. Maurice Forges"; Trans. Roy. Soc., Canada, p. 77 (1886).

[2] Robinson, A. H. A.: "Titanium"; Mines Branch, Dept. of Mines, Canada, Rept. No. 579, p. 46 (1922).

batholith composed of rocks varying in character from granite to diorite. The rocks of this granite-diorite series in most cases carry an appreciable amount of iron oxide minerals, usually magnetite, but as the border of the anorthosite is approached the black iron ore becomes a mixture of magnetite and ilmenite. In the anorthosites the iron oxide is ilmenite alone. Much of the feldspar of the anorthosite shows schillerization due, in some cases at least, to minute rods of rutile and in some other instances, possibly to dark rods of titaniferous iron.

Polished sections of the larger grains of black iron oxide in the anorthosite and of pieces of ore from the ilmenite deposits show that all the ilmenite contains hematite lamellæ and that these form about 20 per cent of each grain (*See* Plate II B). The hematite lamellæ are usually 0·2 mm. wide and many times longer. The intergrowth of hematite and ilmenite resembles the perthitic intergrowth seen in some feldspars and seems to have had a similar origin. Warren[1] calculating from chemical analyses decided that the mineral in the lamellæ was hematite. This deduction has been confirmed by the writer who found that hydrofluoric acid slowly etches ilmenite, readily attacks magnetite, but has no effect on hematite. The larger specks of hematite of the intergrowths exhibit a still finer intergrowth of ilmenite in spindles or flakes. As pointed out by Warren, the ilmenite between the larger hematite lamellæ holds smaller hematite lamellæ which increase in numbers away from the larger forms.

The ore of the Fourneau deposit near St. Urbain, as do all the deposits, exhibits the characteristic intergrowth of ilmenite and hematite. In addition, microscopic examinations reveal the presence of pleonaste spinel, pyrite, pyrrhotite, and chalcopyrite, as well as a weathered gangue mineral which is probably feldspar. The sulphides in certain instances form 2 per cent of the ore. All these minerals appear to have crystallized at one period. The spinel and ilmenite have in one case a straight boundary between them and indications are present that the spinel was in part earlier than the ilmenite. The three sulphides in various cases occur together with allotriomorphic relations to the ilmenite. The pyrite was the first of the three sulphides to crystallize and in one case pyrrhotite nearly surrounds it and chalcopyrite definitely cuts the pyrrhotite (*See* Plate II B). Little areas of ilmenite extend into the pyrite and chalcopyrite and appear to have attacked the sulphides. The ilmenite immediately bounding the spinel grains is free of hematite lamellæ and the same condition, though not so well marked, holds where it encloses the sulphides. The feldspar, although it and the ilmenite were almost contemporaneous, has been corroded by the ilmenite. No rutile was seen.

The ilmenite of the General Electric deposit shows the usual intergrowth with hematite. Rutile is present and it and the ilmenite appear to be contemporaneous in some cases, whereas in others the rutile appears to be a little younger. No sulphides were seen in the material of this deposit.

A sapphirine-bearing rock is associated with this deposit. Sapphirine has been found at only two other places in the world, namely at Fiskernas in Greenland, and Vizapatam district, Madras presidency, India. In both

[1] Ec. Geol., vol. XIII, p. 434 (1918).

of these cases the mineral is believed to be of metamorphic origin: "The mingling and subsequent metamorphism of ultra-basic igneous borders and very aluminous para-schists rich in sillimanite."[1]

The writer was able to find only small quantities of the mineral, and where noted it formed a fraction of 1 per cent of a rock high in rutile and having approximately the following mineral composition: plagioclase, 40 per cent; ilmenite-hematite, 35 per cent; rutile, 15 per cent; pleonaste spinel, 4 per cent; mica, 3 per cent. What work was possible with the specimens at hand seems to confirm Warren's conclusions that the mineral is primary.

The ilmenite of the Bouchard deposit has a little lower than the average content of hematite lamellæ. They form about 15 per cent of the grains. They are finer and are about half the width of those found in other deposits of the area. Interstitial to the ilmenite are grains of pyrite, chalcopyrite, and gangue, probably feldspar, all in small quantities. The gangue includes a piece of pyrite in one case and in another ilmenite appears to have corroded the gangue. No rutile was found in this deposit.

Polished specimens of the ore from the Coulomb and East Coulomb deposits show that the material has been strongly brecciated, both the ilmenite and the rutile being shattered. Some of the smaller rutile grains replace ilmenite, but not the intergrown hematite, which in certain instances passes from the ilmenite into the rutile. One polished section seems to indicate that pyrite crystallized after the ilmenite and during the application of a force which strung out the pyrite in blebs.

One polished specimen of ore from the Joseph Bouchard deposit contains an intergrowth of ilmenite and hematite three times as fine as the average, and the hematite makes up no more than 12 per cent of the grains. A little pyrite, chalcopyrite, and gangue which had crystallized later than the ilmenite, were observed. These minerals are in long, bleb-like masses, the chalcopyrite closely associated with the pyrite. Parts of the gangue are probably mica. This deposit has suffered dislocation since the consolidation of the ore, as can be seen by the brecciated character of the ilmenite and pyrite grains. The sulphides only form 1 per cent or less of the ore and are not due to later solutions, but are the last minerals to crystallize from the ilmenite mass.

Origin

It is quite clear from the field evidence that the ilmenite deposits are later than the anorthosite, but genetically related to it. It is the writer's opinion that they are magmatic in origin and were intruded as a liquid magma of essentially their present composition. The absence of any great alteration in the adjacent anorthosite and the comparative scarcity of biotite and other minerals indicating the presence of mineralizers, shows that these deposits cannot be considered as pneumotectic in origin. The small quantity of sulphides found is believed to be insufficient to have

[1] Walker, T. L., and Collins, W. H.: "Petrological Study of some Rocks from the Hill Tracts, Vizapatam District, Madras Presidency"; Records of the Geol. Surv., India, vol. 34, pt. 1, p. 18 (1907).
Warren, C. H.: "Ilmenite Rocks Near St. Urban;" Am. Jour. Sci., vol XXXIII, p. 273 (1921).

greatly aided the deposition of the ilmenite mass. These sulphides were apparently in solution in the titaniferous iron and were the last to crystallize out. They are minor features and could in no sense be considered as a vehicle of transfer for the ilmenite. Quartz, which is usually associated with mineralizing solutions, is not found in these ores nor in the adjacent wall-rock. Some biotite occurs, but only in minor amounts. The associated anorthosite, apparently, is unaltered, even in the horses found in the ore itself. If mineralizers had been active, they should probably have affected these blocks considerably.

There is no outstanding structural relation or mineralogical association that seems to give a clue as to the discovery of other deposits of ilmenite in St. Urbain area. It seems safe to say that any found in the future will lie within or near the anorthosite mass. Rough prospecting has been done over most of the area and the most fruitful method by which to discover further ilmenite masses will very probably be that of making magnetic or electric surveys about the present known deposits.

Deposits Near Lake Ontario

The deposit on the Southwest Branch trail, 2 miles east of lake Ontario, is exposed over an area of only 6 by 6 feet. The outcrop is of weathered, granular ilmenite. Although the drift did not allow a precise estimation of the extent of the deposit, it is probably only a small mass, because the greatest deviation of the dip-needle anywhere in the surrounding drift-covered area did not exceed 2 degrees and was obtained within a few feet of the edges of the outcrop. The relation of the ilmenite body to the anorthosite could not be determined.

The northernmost of the two deposits just east of lake Ontario shows, in an outcrop of 20 feet long and a few feet wide, two masses of ore respectively 6 and 5 feet across, each bounded on two sides by anorthosite and separated from one another by 3 feet of the rock. The masses dip steeply. A gneissoid banding and shearing of the ferromagnesian minerals is faintly exhibited in the adjacent anorthosite.

The ilmenite grains composing the ore are from 3 to 7 mm. in diameter and show the characteristic ilmenite and hematite intergrowth. A little pyrite is interstitial to the ilmenite. Both these minerals have suffered granulation and an unknown mineral, probably a silicate, occurs along the fractures and replaces the ilmenite, but not the hematite spindles.

The deposit a quarter mile south of the last-mentioned, occurs in an outcrop 35 feet by 12 feet, all of which, except a small, wedge-like mass of anorthosite on its northern side, is ilmenite. The relations of the ilmenite to the anorthosite are hidden by drift. Pyrite is absent and except for one small fracture brecciation was not noticed. What looks like a little interstitial plagioclase was seen.

Dip-needle readings at distances of 50 feet from these last two deposits gave deviations no greater than 4 degrees and at a greater distance a smaller amount. These deposits are, therefore, probably small.

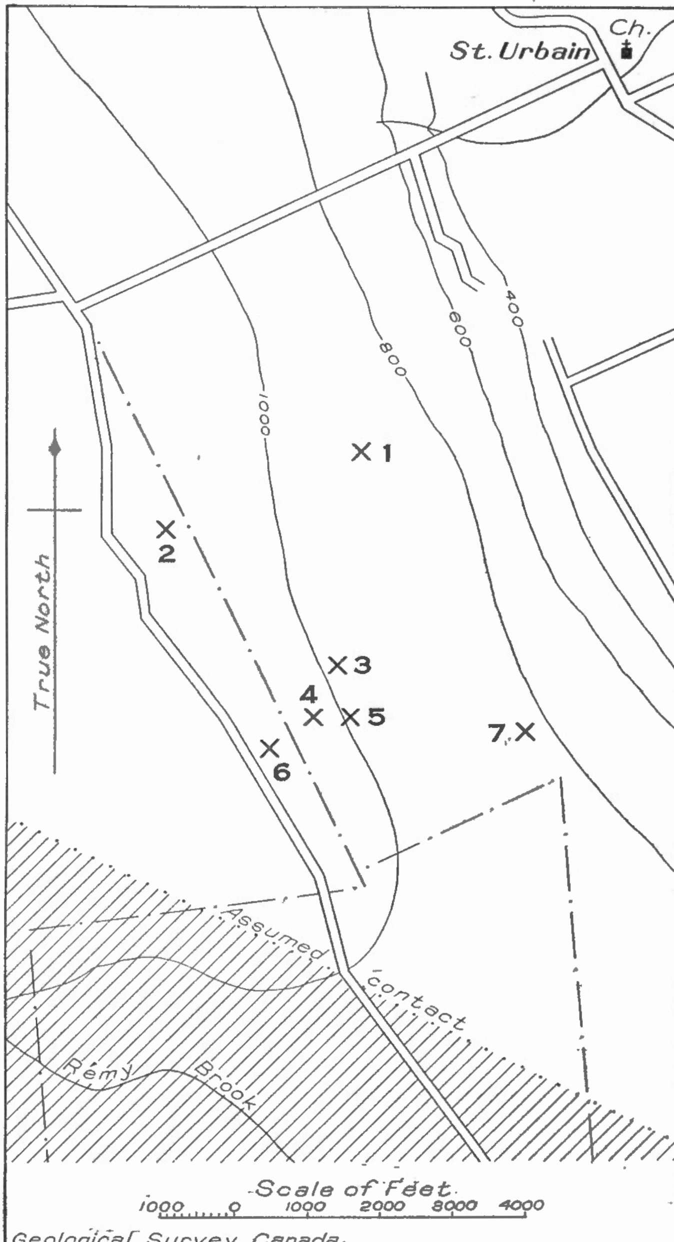


Figure 3. Index showing positions of ilmenite deposits, St. Urbain area, Charlevoix district, Quebec. 1, Fourneau; 2, Bignell; 3, General Electric; 4, Coulomb; 5, East Coulomb; 6, Bouchard; 7, Joseph Bouchard. Granite-diorite series shown by diagonal ruling; anorthosite left blank.

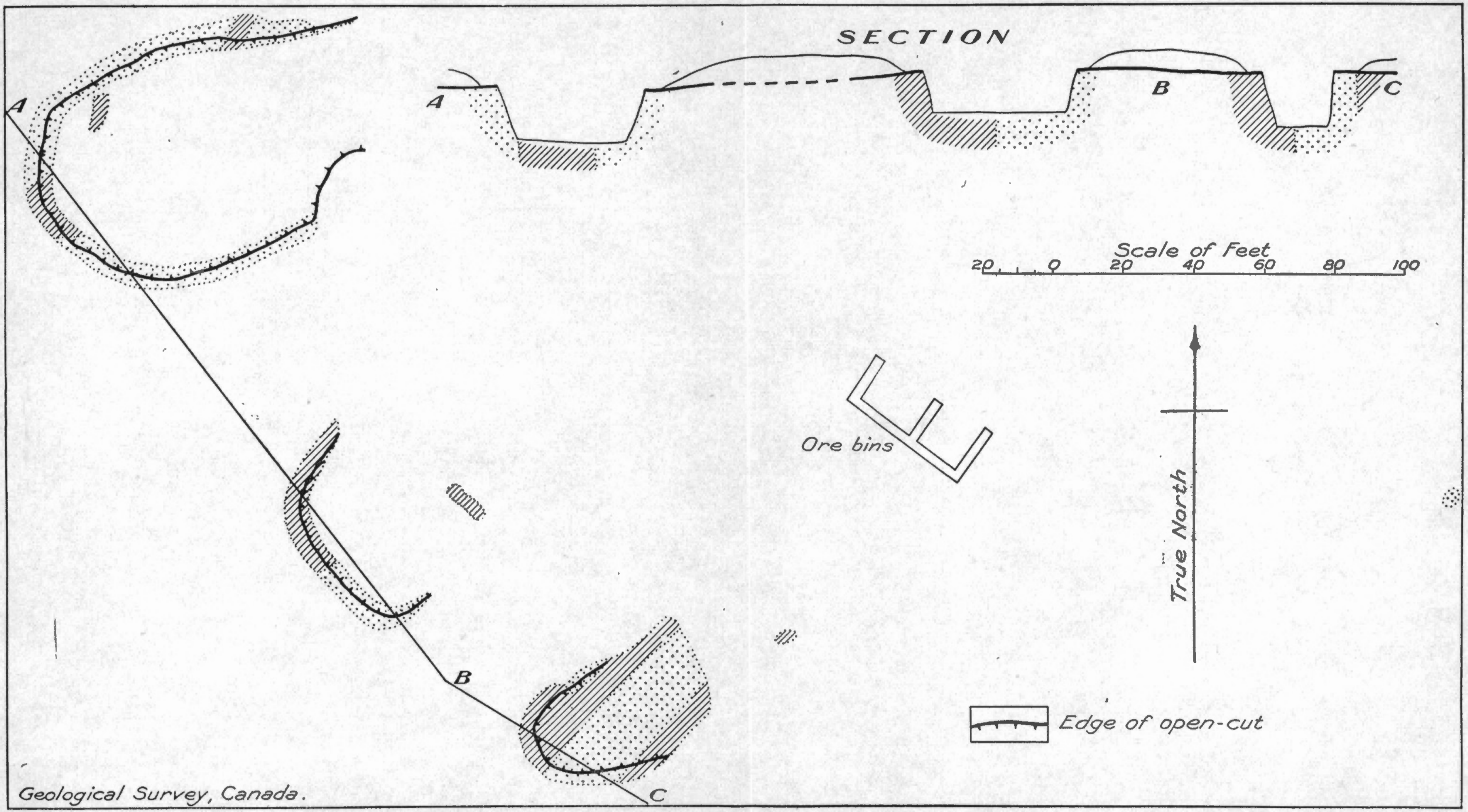


Figure 4. Plan and vertical section of Fourneau ilmenite deposit, St. Urbain area (locality 1 on Index map). Ilmenite shown by pattern of dots; anorthosite by diagonal ruling; drift left blank.

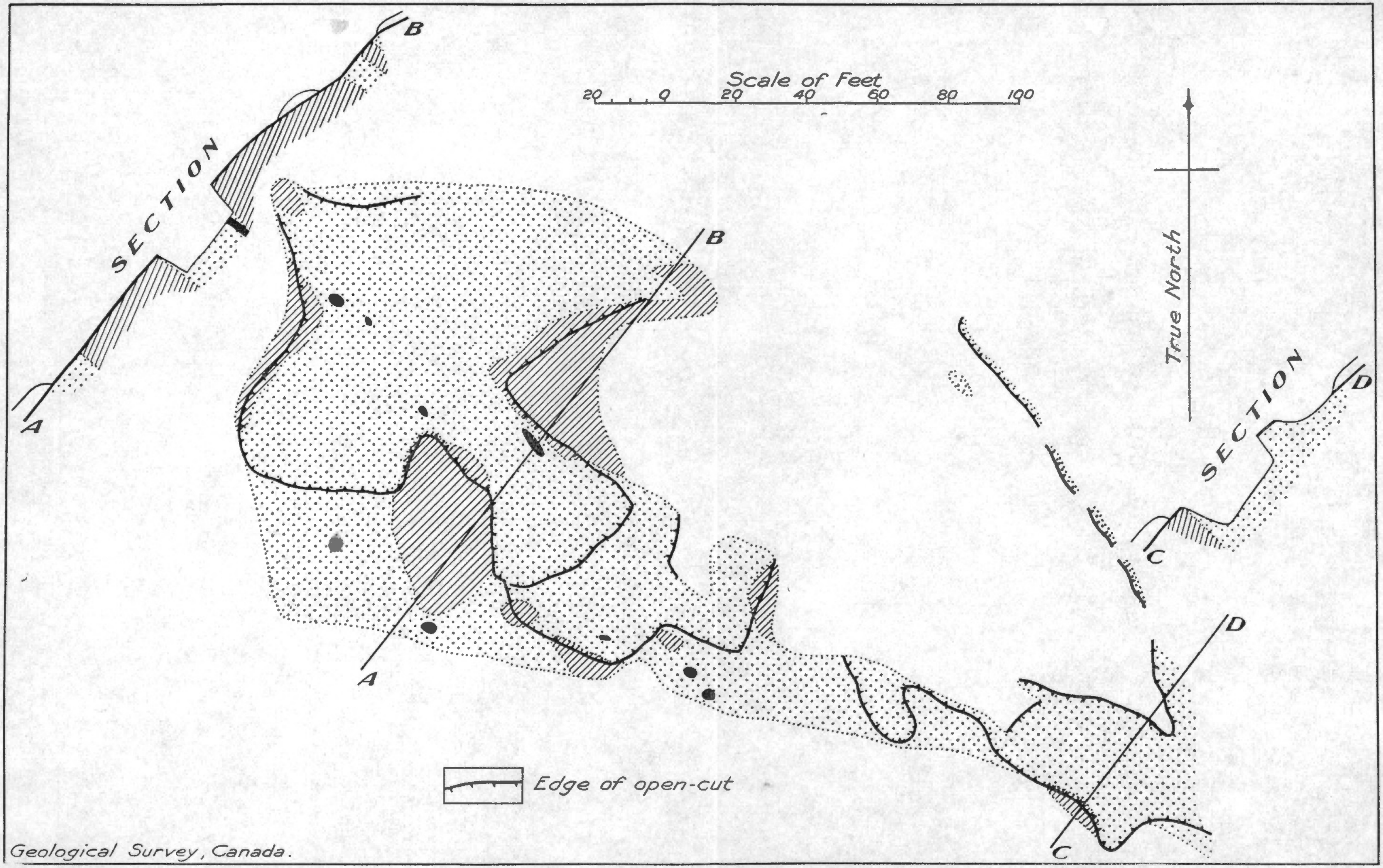


Figure 5. Plan and vertical sections of General Electric ilmenite deposit, St. Urbain area (locality 3 on Index map). Ilmenite shown by pattern of dots; anorthosite by diagonal ruling and solid black; drift left blank.

Deposits Near St. Urbain

The deposits near St. Urbain lie in an area not more than 1½ miles across (Figure 3). They do not seem to be along any definite zone nor to be structurally closely related to one another. Dip-needle readings taken at distances of from 50 to 300 feet from the deposit, in many places show considerable deviation amounting to from 10 to 60 degrees. This seems to indicate the existence of bodies of ore beneath the drift in the vicinity of the exposed deposits.

The deposits have intrusive relations with the anorthosite and hold fragments of the rock. The ilmenite is similar to that of the deposits about lake Ontario and contains up to 20 per cent of hematite in a perthitic intergrowth. A foliated structure is clearly developed in most of the deposits and is especially well shown on the north margin of the Coulomb and Electric bodies, where the foliated structure parallels the contact of the anorthosite with the granite-diorite rocks.

Considerable faulting is exhibited by the deposits. This condition, and the fact that the only outcrops visible in the vicinity of the deposits are limited to the various workings, makes impossible any prediction of the size of the deposits. The faulting is probably of the same age as the fracturing that affects the northern of the two deposits near lake Ontario.

Bignell Prospect. The Bignell prospect is the most westerly of the occurrences in the vicinity of St. Urbain. It is on the east end of lot 608, range St. Jérôme. The test-pits which were sunk here some years ago have caved in and nothing now can be seen of the ilmenite deposit referred to by A. H. A. Robinson.[1]

Fourneau Deposit

This deposit lies at a lower elevation and about ¾ mile east of the Bignell prospect. It is situated midway along the boundary between lots 352 and 361, range St. Urbain (*See* Figure 4). Open workings have been carried into the sloping hill-side. The working faces and the three pits are roughly in a north and south alignment. The ilmenite outcrop has an area of 250 by 100 feet, but is much cut by slippage planes and involved with anorthosite which in part, apparently, is in the form of displacement blocks surrounded by the ilmenite.

General Electric Deposit

This deposit (*See* Figure 5) is on lot 324, range St. Urbain. The stripping and pits are extensive and the ilmenite body has been attacked at various points over a length of 300 and a width of 150 feet. The longest axis of this area is roughly in an east-west direction and a foliated structure present in places strikes with the same direction. A number of the different pits and strippings are separated from one another by blocks or masses of anorthosite. The deposit has suffered faulting. In

[1] Robinson, A. H.: "Titanium"; Mines Branch, Dept. of Mines, Canada, Rept. 579, p. 47 (1922).

certain parts, usually where the foliated structure is well developed, is found a considerable quantity of rutile. The boundary between the rutile-rich and the rutile-poor parts of the mass is quite sharp in most places.

Bouchard Deposit

This deposit (*See* Figure 6) is at the east end of lot 622, range St. Jerôme. A dyke of ilmenite here cuts anorthosite. Quarrying operations have removed practically all the visible ore. The main body seems to strike about northeast and the dip is almost vertical.

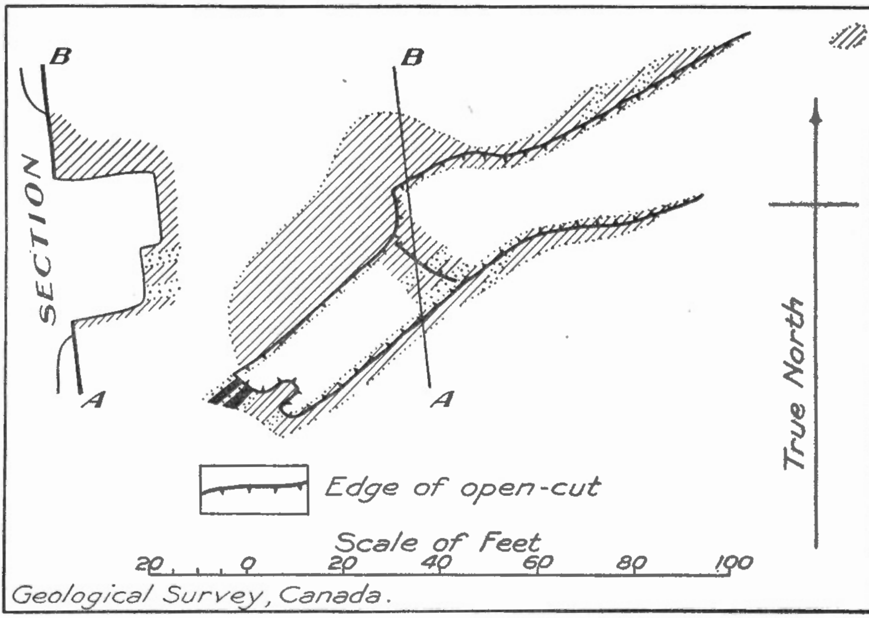


Figure 6. Plan and vertical section of Bouchard ilmenite deposit, St. Urbain area (locality 6 on Index map). Ilmenite shown by pattern of dots; anorthosite by diagonal ruling and solid black; drift left blank.

Coulomb and East Coulomb Deposits

The Coulomb deposit (*See* Figure 7) is east of the Bouchard, at the west end of lot 319, range St. Urbain. Ore has been mined at the west end of a flat, stripped area which shows a mass of ilmenite 100 by 150 feet. This mass has a rough gneissoid structure which trends east and west and is parallel to the longest direction of the stripping. Three hundred and fifty feet east is the East Coulomb deposit (*See* Figure 8) whose exposed ore-body is about 150 feet long, and from 20 to 40 feet wide. The relative positions and the gneissoid structure seen in both deposits point to a connexion between the two bodies. On the north side of the Coulomb body, where the gneissoid structure is best developed, a little rutile is found.

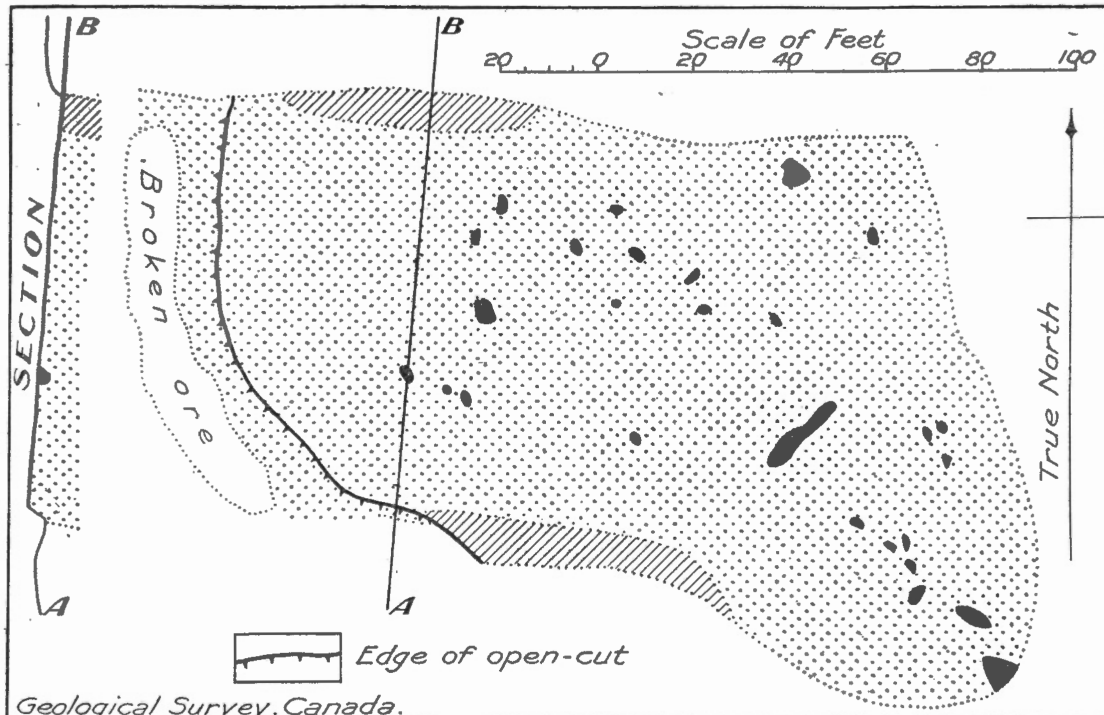


Figure 7. Plan and vertical section of Coulomb ilmenite deposit, St. Urbain area (locality 4 on Index map). Ilmenite shown by pattern of dots; anorthosite by diagonal ruling and solid black; drift left blank.

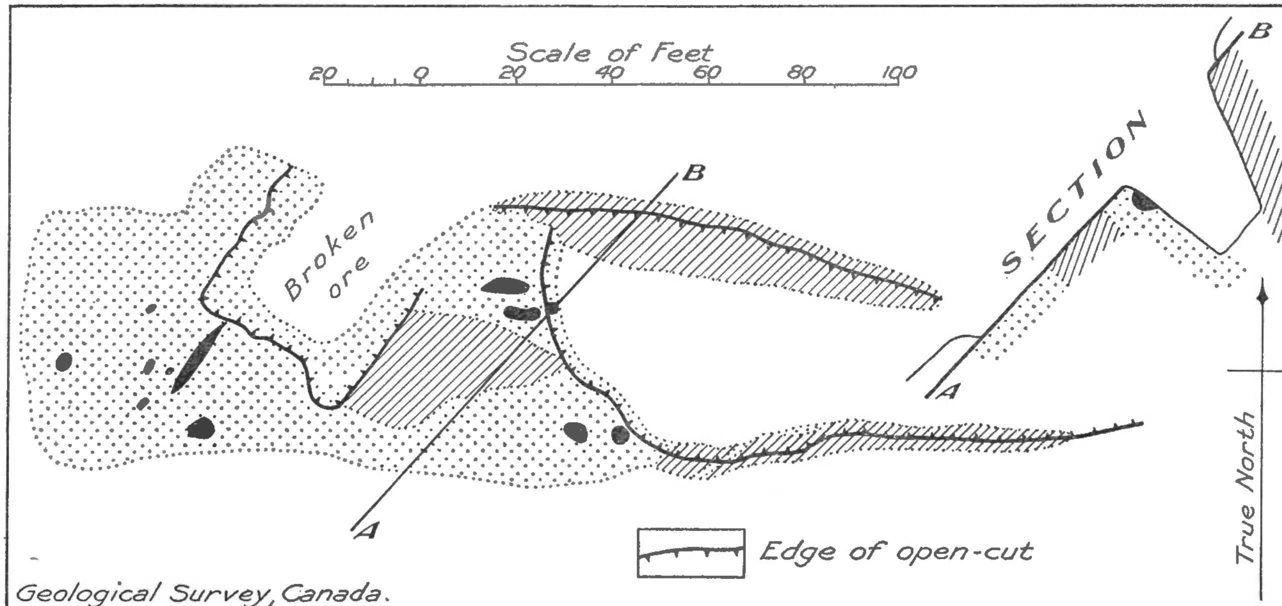


Figure 8. Plan and vertical section of East Coulomb ilmenite deposit, St. Urbain area (locality 5 on Index map). Ilmenite shown by pattern of dots; anorthosite by diagonal ruling and solid black; drift left blank.

Joseph Bouchard Deposit (also known as the Glen Prospect)

This deposit (*See* Figure 9) is three-quarters of a mile from the west end of lot 312, range St. Urbain. In some ways it resembles the Bouchard, being dyke-like in shape and bounded by anorthosite. Faults cut the ilmenite mass and may in part be responsible for the dyke-like appearance.

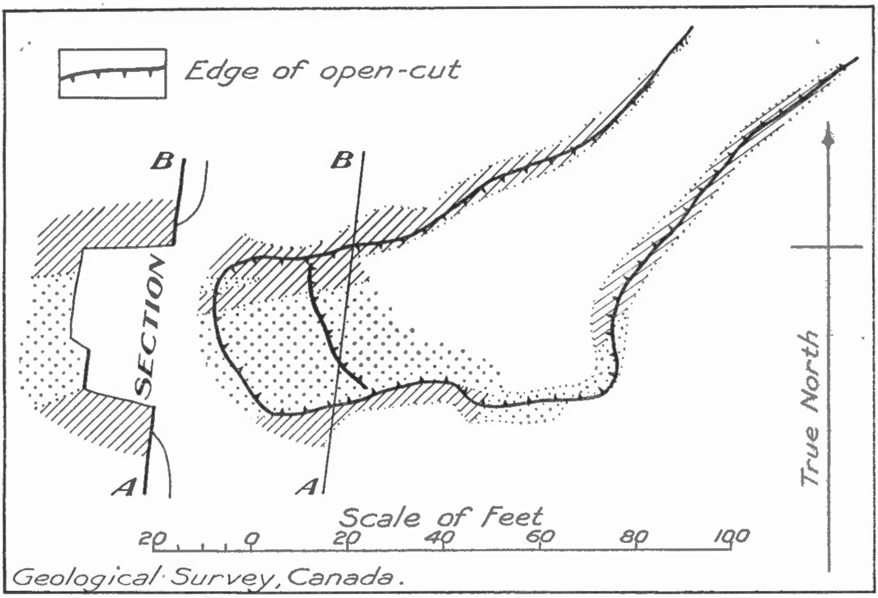


Figure 9. Plan and vertical section of Joseph Bouchard ilmenite deposit, St. Urbain area (locality 7 on Index map). Ilmenite shown by pattern of dots; anorthosite by diagonal ruling, drift left blank.

PEAT

Various small areas of peat occur on the north side of Gouffre river a few miles northeast of St. Urbain, and on the marshy margins of such lakes as lake Ontario and lake Cygnes. A little of this peat is at present used to enrich the sandy soil of a few adjacent farms.

CLAY, SAND, GRAVEL, AND LIME

The Pleistocene deposits of clay in the valley of the lower Gouffre are extensive and may prove suitable for the manufacture of brick. The suitability can be proved only by actual tests. At present all brick used in the valley is imported.

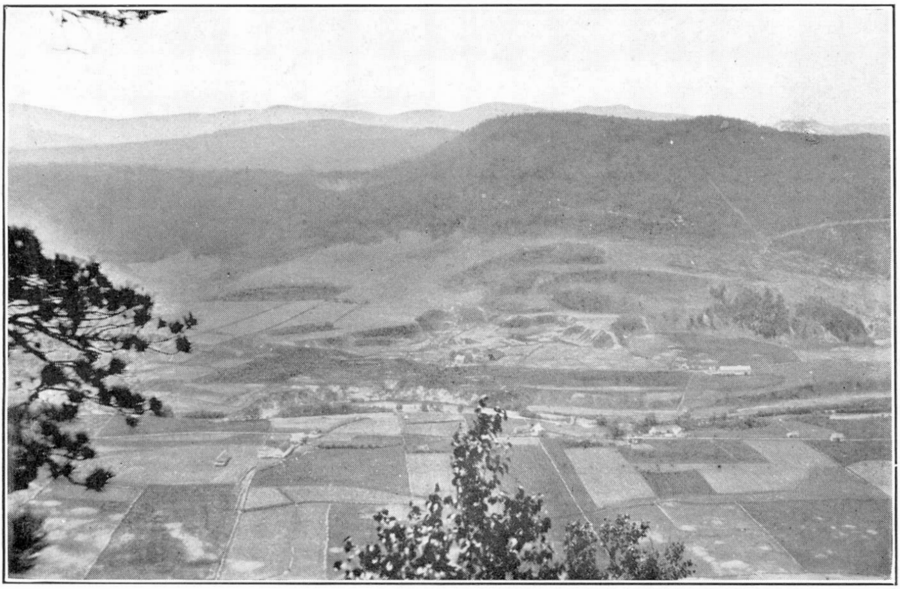
Deposits of sands and gravels of both Pleistocene and Recent age are present in many parts of the area and are suitable for building purposes, ballast, and road metal.

Since the first days of the settlement the Trenton limestone has supplied the raw material for burnt lime used for building and other purposes.

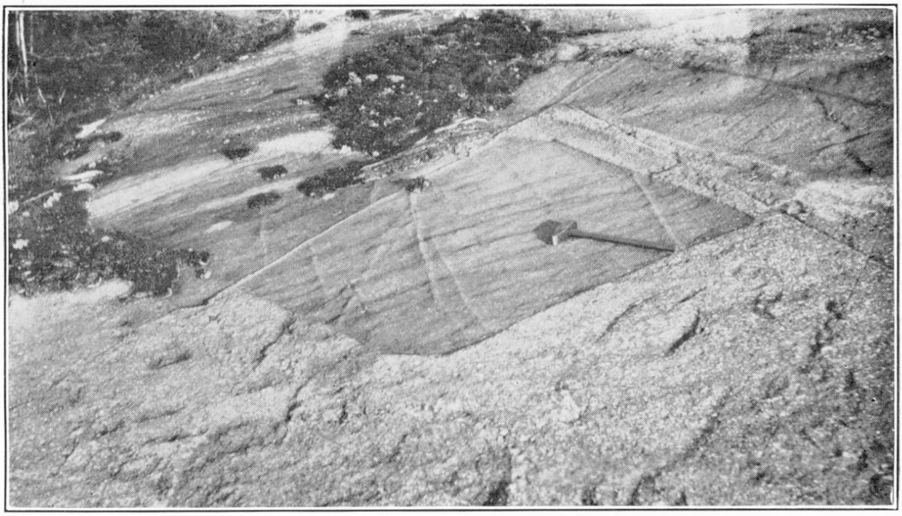
BUILDING STONE

Building stone is at present little used in the Gouffre valley, wood being handier and cheaper. Few real quarries exist. The most extensively worked one is on the right of way of the railway a couple of miles east of Baie St. Paul. The Precambrian rock there is a green syenite with a fairly regular jointing. Most of the igneous rocks of the area that are at all suitable for building purposes have an irregular jointing that would make them difficult to quarry on a commercial scale.

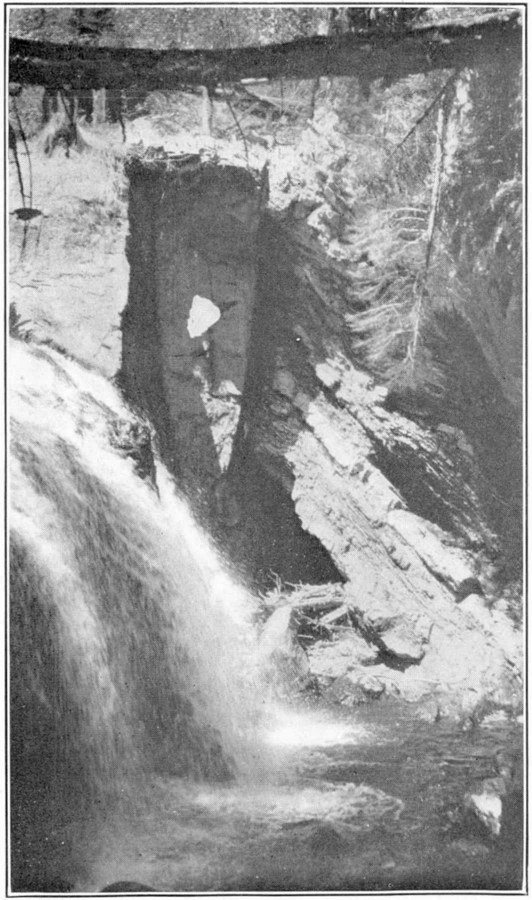
The Trenton limestone near Baie St. Paul is used to a small extent for building purposes. It is not unduly contorted and with joints, a foot or two apart, it occurs in quantities sufficient for local building requirements.



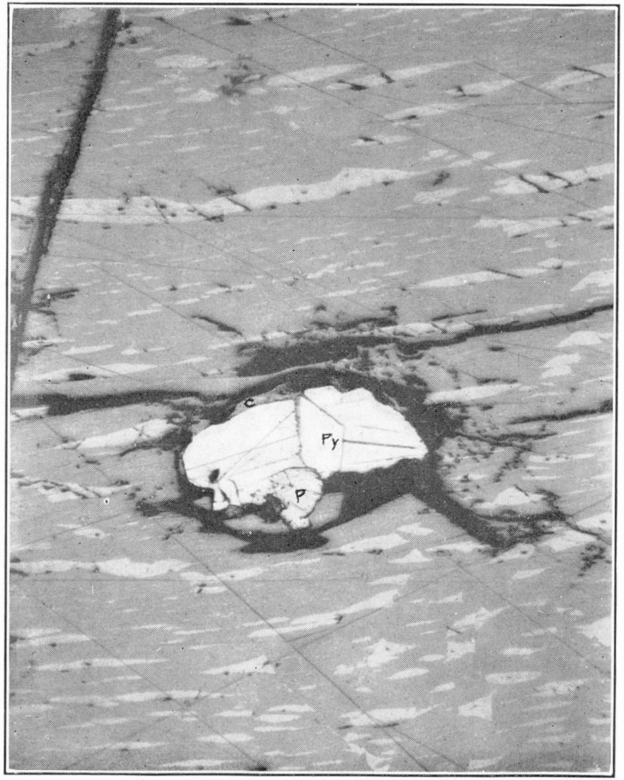
A. Gouffre River valley, 4½ miles above Baie St. Paul. (Page 4.)



B. Blocks of labradorite anorthosite cut by andesine anorthosite. (Page 18.)



A. Trenton limestone faulted down and against Precambrian gneisses. (Pages 33, 35.)



B. Polished section showing ilmenite with hematite intergrowth surrounding a grain of pyrite, P, which is partly surrounded by pyrrhotite. The pyrrhotite, Py, is cut by chalcopyrite, C. Magnification, about 15 diameters. (Page 45.)

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