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GEOLOGICAL REPORT 127

BELLEAU-DESAULNIERS AREA

Saint-Maurice, Maskinongé and Laviolette Counties

BY

A.R. PHILPOTTS

QUEBEC
1967

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BELLEAU-DESAULNIERS AREA*

Saint-Maurice, Maskinongé and Laviolette Counties

by

A.R. Philpotts

INTRODUCTION

General Statement

The Belleau-Desaulniers area was mapped geologically during the summer of 1961 by pace and compass traverses at a scale of 1/2 inch to 1 mile. The map accompanying this report is based on Sheet 31 I/11 East of the National Topographic Series, with the addition of many roads and trails obtained by traversing or from aerial photographs.

Location and Access

The area is bounded by latitudes 46°30' and 46°45' and longitudes 73°00' and 73°15'. It is approximately 100 miles northeast of Montreal and 30 miles north of Louiseville. The nearest village, Saint-Alexis-des-Monts, is 3 miles south of the area on Highway 44.

The area covers 210 square miles and includes parts of Belleau, Caxton, Desaulniers and Allard townships in Saint-Maurice county, parts of Hunterstown, De Calonne and Chapleau townships in Maskinongé county, and a very small part of Cap-de-la-Madeleine seigniory in Laviolette county.

The first-class gravel road that joins Sorcier lake with Saint-Alexis-des-Monts follows Loup river across the southwestern part of the area and, with its many branching secondary roads, renders the central

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* Corresponds to National Topographic Series map 31 I/11, Lac au Sorcier, East.

and western parts of the area readily accessible. The eastern part is reached by gravel road via Saint-Mathieu, a small village east of Saint-Alexis-des-Monts. Two long lakes, Shawinigan and Wapizagonke, provide good canoe routes through much of the northern part. Only the north-central sector, around Caribou lake, is relatively isolated, being accessible only by portage from Shawinigan or Wapizagonke lakes.

Previous Work

The earliest work in the Belleau-Desaulniers area was by McOuat who, in 1870 (Ells, 1898), surveyed Loup river. In 1880, McConnell (Ells, 1898) outlined a large body of reddish granite lying to the east of Saint-Gabriel-de-Brandon and extending through the southern part of the present area. He also found several bodies of anorthosite. In 1891, Giroux (Ells, 1898) traversed through the lakes in the northern part of the area. In 1898, Ells traversed much of the "Three Rivers map-area", and incorporated in his report for that year the information gained by previous workers. From 1887 to 1889, Adams (1895) did extensive work to the west of the present area, paying particular attention to the anorthosite bodies.

Osborne (1936a) mapped the Shawinigan Falls district and Béland (1961) mapped the area adjoining the present area to the east. During the summer of 1960, R. Béland (MSS.) mapped the area adjoining to the south, as well as the extreme southern part of the present area.

Acknowledgements

J. Beauregard (graduate student, University of Arizona), R. Mahfoud (graduate student, Université Laval), J.A. Earthrowl (student, McGill University), W. Perron (student, Ecole Polytechnique), Y. Frappier (canoeman) and C. Marineau (cook) greatly assisted the writer in the mapping of the area. The writer is indebted to the many residents of Saint-Alexis-des-Monts who helped in various ways during the field season, and to G. Simmons for indicating some of the interesting geological features in Belleau township. The Commodore Fishing Club kindly permitted the party to use its cabin on Caribou lake for two weeks.

The potassium-argon age determinations were done in the Department of Geodesy and Geophysics at the University of Cambridge by J.A. Miller, to whom the writer is very grateful. The chemical analyses were done in the laboratory of the Department of Mineralogy and Petrology, Cambridge. C. Hall kindly prepared the glasses of some of the Morin Series rocks. The writer is indebted to I.D. Muir for reading and criticizing the manuscript.

DESCRIPTION OF AREA

Topography

Although the area has the typical hilly topography of the Laurentians, with a subaccordance of hill-tops at an elevation of approximately 1,300 feet above sealevel, many of the valleys are subsequent and much of the structure is readily visible on a topographic map or aerial photographs. Structures are particularly evident in the northern part where southerly dipping paragneisses form a series of west-trending cuestas that swing towards the south around the nose of a large syncline at the western boundary. Lakes Maréchal, Caribou. Brodeur, Shawinigan, Barnard, Pins Rouges, Couveuse (Coureuse), Larose and Sacacomie all occupy subsequent valleys, as do many of the rivers in the area, such as the Shawinigan and Caribou. Because of the gentle southerly dip of the paragneisses, these valleys, whether occupied by lake or river, tend to have steep slopes on their southern sides and very gentle ones on their northern sides. These asymetrically shaped valleys, which are so characteristic of the northern part of the area, were noted by the earliest workers in the region (Ells 1898, p. 40).

The southern part of the area, which is underlain predominantly by igneous rocks, is relatively high and undissected, with the exception of the deep Loup River valley. The Loup River valley is of interest because it extends southeasterly across the west-trending cuestas. Wapizagonke lake, in the northeastern corner, also trends southeasterly. However, it appears to occupy the crest of a very gentle anticlinal flexure and probably owes its origin to erosion along this crest. Loup river, however, cuts directly across rocks that dip 10-40° to the southeast and does not follow zones of structural weakness. The southeasterly direction of flow of the river corresponds to the regional slope of the summits of the hills in the area. It appears likely, therefore, that this river is a superposed one and is much older than the rest of the subsequent drainage in the area.

The southern and western parts are drained by Loup river, whereas in the northern and eastern parts the drainage is through Shawinigan and Wapizagonke lakes into Shawinigan river.

Vegetation

Almost all of the area, with the exception of the Loup River valley at the southern boundary, is thickly wooded with coniferous and deciduous trees, spruce, pine, birch and maple being the most abundant. In the northern part, the southerly facing slopes of the cuestas are covered in most cases with hardwood, whereas the steeper northerly facing

slopes support conifers. The large sand-covered area of the Loup River valley at the western boundary has dense stands of jack pine.

Resources and Settlement

The main industry of the area is lumbering, and much wood is floated down to various saw-mills. Three mills were being operated in the area in 1961. One is at the outlet of Pins Rouges lake, the second is on Loup river near the western boundary of the area, and the third is on the lake directly north of Jouet lake. Large parts of the area have been lumbered and are now covered with small second-growth timber. Only a small amount of cutting now goes on in the area, mostly in the northwest.

A few summer cottages have been built at the eastern end of Barnard lake and Carufel lake. All the large lakes have fishing and hunting clubs located on them and most of the area, with the exception of Loup river, has been leased to such clubs. Like much of the Laurentian region, this area is very scenic and could be developed to attract its share of tourists.

Some farming is done in the southern part of the Loup River valley. However, the soil is extremely sandy and the fields are used mainly for grazing.

GENERAL GEOLOGY

The area is underlain by Precambrian metamorphic and igneous rocks. It occupies a part of the Canadian Shield that has undergone only moderate deformation, with the result that folds are very open and the dip of the gneisses rarely exceeds 40°. This simple structure makes it possible to obtain a fairly accurate picture of the Grenville Series exposed in the area and provides excellent conditions for studying the Morin Series intrusions.

The Grenville, found mainly in the northern half, is approximately 16,000 feet thick. The lower 14,000 feet is composed of amphibolites, near the top of which occurs a thin layer of crystalline limestone. The amphibolites are composed of two very similar types; one has been formed from graywackes and the other, probably from andesitic lavas. Above the amphibolites are paragneisses, which include quartzite, garnet-sillimanite gneisses and graphite-quartz-feldspar gneisses. The paragneisses may be separated from the amphibolites by a disconformity.

The Grenville rocks were folded about 1,000 million years ago into a broad syncline now plunging to the southeast. This deformation

was accompanied by the intrusion of concordant masses of granite and dikes and sills of gabbro. The high amphibolite grade of regional metamorphism now exhibited by all these rocks was probably developed during this period, for some of the diagnostic minerals bear a definite structural relationship to the southeasterly plunging syncline.

A second period of deformation, which took place almost at right angles to the first, did not affect the entire area, but was restricted to northeasterly trending bands. During this deformation a granodioritic magma was intruded into the rocks of the southern part of the area and underwent very strong fractional crystallization, with the result that diverse rock types such as anorthosite, norite and mangerite were formed. These rocks, which were intruded approximately 936 million years ago, form a large concordant body in the older gneisses.

A large discordant body of coarse-grained quartz monzonite cuts all the rocks in the area. It forms an extension of the batholith lying to the southwest between Saint-Gabriel-de-Brandon and Hunterstown that probably was intruded around 910 million years ago.

A series of northeasterly trending faults occurs in the area; the most southerly fault contains glassy amygdaloidal dikes of pseudotachylite that have an age of 900 million years. Pyrrhotite-pentlandite mineralization is associated with this fault at the eastern boundary of the area.

Till mantles most of the area, but is of notable thickness only in the northwestern part and directly northeast of Eau-Claire lake.

GRENVILLE SERIES

Amphibolites

Amphibolites are the most abundant rocks of the Grenville Series in the Belleau-Desaulniers area. They underlie the other rocks of the series and occupy most of the northern half of the area, where their thickness is approximately 14,000 feet. They also underlie a small part of the southeastern corner of the area where they are overlain by crystalline limestone and quartzites. Amphibolites are shown by Béland (1961) to be extensive in the northern part of the Shawinigan area, and it is likely that their total thickness in that area is greatly in excess of the amount exposed in the present area. Osborne (1936a) mapped the amphibolites in the Shawinigan Falls district and considers them to form the lower part of the Grenville Series at that locality; the upper part consists of metasedimentaries, including quartzites, aluminous beds, and

Table 1. - Table of Formations

	Age m.yrs.	Oro-geny		Formations
Recent and Pleistocene				Sand and till
PRECAMBRIAN	900		Faulting (mineralization)	
	936	2	Morin series	Fine-grained pink granite Coarse-grained quartz monzonite ——————— Jotunite Mangerite Norite Anorthosite
	1,000?	1		Amphibolite (metagabbro)
				Granite gneiss
			Upper Grenville series Lower	Granite gneiss Quartzite Garnet-sillimanite gneiss Feldspar-quartz-graphite gneiss POSSIBLE DISCONFORMITY Crystalline limestone Amphibolites* Quartzite Granite gneiss

* Hornblende and /or pyroxene andesine gneisses of adjacent areas (Béland, 1961)

minor amounts of crystalline limestone. Such an interpretation is compatible with the evidence found in the present area, since the amphibolites lie beneath the obviously metasedimentary part of the series with dips so gentle as to make it unlikely that the section is overturned.

Amphibolites are extremely common in many areas where Grenville rocks are exposed, and, although they have been described by many authors, there are very few cases in which their origin has been explained satisfactorily. Osborne (1936a, p. 203) states that the original nature of the amphibolites in the Shawinigan area is not clear, but suggests that they may be Keewatin basic tuffs, flows, or graywackes. In other areas, such as the Haliburton-Bancroft area (Adams and Barlow,1910, p. 62-128), workers have invoked metasomatism of Grenville limestone to produce amphibolites. Faessler (1942, p. 12) describes amphibolites occurring with marbles in the Sept-Iles area and suggests that they have been formed from impure limestones.

Amphibolites can be formed in many different ways and from many different rocks, but unfortunately the final products give few clues as to the identity of the original rock (Engel and Engel, 1951). In the present area, three recognizably different types of amphibolite have been observed. The one that has its origin most easily explained, but that is the least abundant, occurs as sills and dikes throughout Grenville rocks and was originally an igneous rock of gabbroic composition intruded into Grenville sedimentary rocks during the regional folding. As this amphibolite is younger than the Grenville rocks, it is considered separately in a later section. The two types of amphibolite that remain form the larger part of the thick sequence of gneisses occurring in the northern half of the area. These two, although chemically different, are so much alike physically that it was impossible to map them separately. Both types are andesine, hornblende, quartz, and alkali-feldspar rocks, and the difference between them is that of quantity of the constituent minerals. The two types do not occur in equal amounts. The slightly more feldspathic variety, which is also the most abundant type, is believed to have been derived from graywackes, whereas the other variety is thought to represent metamorphosed andesitic lavas. The chemical evidence for this is given below.

The amphibolites usually form buff, massive weathering outcrops, many of which exhibit banding owing to the concentration of ferromagnesian minerals into layers. This banding is brought out slightly in some cases by differential weathering. On fresh surface, the rock is dark green, a color imparted to it by the feldspars rather than the ferromagnesian minerals. It is medium grained and composed essentially of plagioclase, quartz, alkali-feldspar, hornblende, pyroxene and magnetite ilmenite. The content of quartz and alkali-feldspar is fairly constant, being 15% and

13% respectively. However, the amount of plagioclase ranges from 50% to 20% and the iron-magnesium silicates range reciprocally from 15% to 35%. The content of magnetite-ilmenite (intergrown) is variable, but never exceeds 10%. The average mineralogical composition based on several modal analyses is plagioclase 50%, quartz 15%, alkali-feldspar 13%, iron-magnesian silicates 16% and magnetite-ilmenite 6%.

The plagioclase ranges in composition from An_{27} to An_{37}, but An_{32} is the most common. A large part of the alkali-feldspar occurs as antiperthitic blebs in the plagioclase and the rest, as interstitial patches between the plagioclase grains. It is possible that at one time almost all the potash feldspar was held in solution in the plagioclase and has since been liberated. The 50^{o}-60^{o} 2Vs of the alkali-feldspars indicates that they are orthoclases with a fairly high structural state.

Hornblende, pleochroic from dark brownish-green to pale greenish yellow, is the most abundant mafic constituent in these rocks. Clinopyroxene and orthopyroxene are also present in most samples, but are commonly partly replaced by hornblende. A small amount of biotite is developed in many places as a replacement of orthopyroxene. The resulting texture is an interlayering of quartz and biotite. The mica was probably formed by retrogressive metamorphism, or during a later period of metamorphism perhaps associated with the intrusion of the Morin Series. Apatite and zircon are the common accessories, although small amounts of pyrrhotite occur as scattered grains in some parts of the gneiss.

One total analysis and four partial analyses of the amphibolites from the area are given in columns 1, 4, 5, 6 and 7 of Table 2. From these it can be seen that there are two general types, one containing approximately 5.4% lime and the other, 7.1%. For comparison, an amphibolite from the Shawinigan Falls district (Osborne,1936a, p. 206) and another from Rouge river in Grenville township are given. The Rouge River amphibolite falls into the first class since it contains only 5.16% lime, but the Shawinigan Falls one contains 6.90% lime and, therefore, belongs to the second group. The rocks of the first group tend to have lower iron and magnesia and higher potash and silica than those of the second group.

A prominent feature of all these amphibolites is the high soda/potash ratio. The amphibolite given in column 7, which has the highest soda/potash ratio, comes from 3 feet above the layer of crystalline limestone on the east bank of Loup river. The hornblende in this rock has a bluish tinge. Such high soda/potash ratios in rocks containing 55% silica or less can be found amongst andesitic lavas. However, in lavas containing higher amounts of silica, similar high soda/potash ratios are not obtained normally until the silica content reaches 70%, as in the keratophyres, but such rocks contain much less lime than Grenville amphibolites. Therefore,

Table 2 - Analyses of Amphibolites

	1	2	3	4	5	6	7
SiO_2	59.20	58.97	55.70				
TiO_2	1.00	1.87	.90				
Al_2O_3	16.63	15.22	15.50				
Fe_2O_3	3.72	3.09	2.95	8.89*	5.49*	5.38*	4.88*
FeO	3.75	5.62	6.14				
MnO	.13	.10	.05				
MgO	1.43	2.89	5.21				
CaO	5.40	5.16	6.90	7.31	5.44	5.32	5.60
Na_2O	4.81	4.02	3.43	5.06	5.49	5.06	6.07
K_2O	2.35	1.96	1.78	1.23	2.03	2.32	1.64
P_2O_5	.25	.59	.35				
H_2O+	.82	.27	.60				
H_2O-	.02	.00	.30				
	99.51	99.76	99.81	22.49	18.45	18.08	18.19
Wt. Norm.							
Q	9.91	12.95	6.18				
or	13.86	11.58	10.52				
ab	40.70	34.04	29.00				
an	16.86	17.69	21.67				
wo	3.53	1.84	4.36				
en } di	2.02	1.04	2.62				
fs	1.36	.71	1.50				
en } hy	1.55	6.15	10.35				
fs	1.04	4.16	5.94				
mt	5.39	4.47	4.28				
il	1.90	3.55	1.71				
ap	.55	1.31	.79				
	98.67	99.49	98.92				

(* Total iron as Fe_2O_3)

1. Amphibolite from east end of Larose lake, Belleau-Desaulniers area. Analyst, A.R. Philpotts.
2. Amphibolite from Rouge river, range VI, Grenville township. Analyst, A.R. Philpotts.
3. Amphibolite from Shawinigan Falls area. (Osborne, 1936a, p. 206). Analyst, W.H. Herdsman.
4. 5, 6, 7. Amphibolites from northern half of the Belleau-Desaulniers area. Analyst, A.R. Philpotts.

it appears that, although the amphibolites given in columns 3 and 4 could have once been andesitic lavas, the others do not have common volcanic equivalents and the only rock type that is chemically similar is graywacke. This thick sequence of amphibolites is consequently interpreted as being composed largely of metamorphosed graywackes with intercalated layers of andesitic lava or tuff. It is possible, however, that the "andesitic" layers are also of sedimentary origin.

Within the amphibolites many thin sheets of quartzite and pink granite gneiss occur, only the thickest of which could be shown on the map. The layers of quartzite appear to grade into the amphibolite and probably represent variations in the composition of the original sediment. The bodies of granite gneiss could have a similar origin, or they could have been emplaced at some later date by igneous or metasomatic activity. This rock type is discussed in a later section.

Many small irregularly shaped bodies of granitic pegmatite occur in the amphibolites. They are composed of quartz, pink alkali-feldspar and hornblende. A few in the extreme northern part of the area contain black tourmaline, which would suggest a correlation with some of the pink granite gneiss that also contains tourmaline. Although pegmatites occur throughout the amphibolites, they appear to be much more abundant in the northern part of the area. If the Grenville gneisses are not overturned, this northern part of the area represents the zone of greatest burial and it is, therefore, not surprising to find that the number of pegmatites is greater here.

Crystalline Limestone

Approximately 600 feet below the top of the amphibolitic part of the Grenville Series there is a layer of crystalline limestone from 50 to several hundred feet thick. It forms very few outcrops, but sufficient were found to show that it strikes east and extends across the center of the area. It appears to continue into the Shawinigan area, but is not shown on the Shawinigan map (Béland,1961). According to Ells, ten miles west of the area the only outcrop of crystalline limestone observed on a traverse between Sans-Bout lake and Matawin river occurs on a small lake just north of Sans-Bout lake (Ells,1898, p. 53). This outcrop is on strike with the limestone mapped in the present area, and, therefore, although the layer is thin, it appears to be a fairly continuous member of the Grenville Series in this region.

The crystalline limestone is white (rarely pink) on its fresh surface and gray weathering. It is composed largely of grains of calcite with abundant twin planes. Pale green clinopyroxene and dark green serpentine are the other major components, with quartz, microcline, sphene, apatite, pale green amphibole and pyrrhotite being common accessories.

Rounded inclusions of paragneiss are nearly always present and give the rock the appearance of a conglomerate. These inclusions were undoubtedly once parts of continuous thin layers of gneiss in the limestone that were disrupted by the flow of the surrounding carbonates during orogenic movement. Signs of deformation are very evident in the marble. The glide planes in the calcite grains tend to be subparallel and at an angle of approximately 30° to the foliation in the surrounding gneisses. All the minerals in the marble, with the exception of amphibole, occur as rounded grains. This probably results from abrasion of the grains during the deformation of the rock. The perfectly euhedral form of the amphibole strongly suggests that it crystallized after deformation.

Another thin layer of crystalline limestone occurs in a small syncline in the extreme southeastern corner of the area, where it is overlain by quartzite and overlies amphibolites. This limestone has been converted largely to skarn, and contains clinopyroxene, scapolite, quartz, microcline, garnet, epidote, sphene, pyrrhotite and apatite. Many of these minerals are euhedral, which suggests that they were developed after the regional deformation and are probably connected with a later metamorphism brought about by the intrusion of the Morin Series.

Upper Paragneisses

The youngest member of the Grenville Series in the map-area consists of a variety of paragneisses, including quartzite, graphite- and garnet-bearing quartzo-feldspathic gneisses, garnet sillimanite gneiss, and pyroxene granulites. These rocks are so interlayered that it was not feasible to separate them at the present scale of mapping. They are commonly rusty weathering, especially the quartz-poor varieties, and the surface alteration extends to such a depth in many cases that it is impossible to obtain fresh samples of rock from the outcrop. The gneisses are fine to medium grained, usually thinly foliated, and well jointed. They are 1,400 feet thick. At the base they are composed largely of garnetiferous quartzite, and the contact with the underlying amphibolites is gradational through 5 to 10 feet. Intrusive rocks of the Morin Series limit the upward extent of the paragneisses.

Quartz, microcline, garnet and orthopyroxene are the most abundant minerals in this member of the series. Andesine, graphite, sillimanite and biotite are common minor constituents, and in places are sufficiently abundant to be readily visible in hand specimen. Clinopyroxene, magnetite, pyrrhotite, apatite and zircon are accessories. The occurrence of microcline in these rocks is of interest since the potash feldspar in the amphibolites of the lower part of the series is an orthoclase with a moderately small 2V. Whether this is due to a difference in the grade of metamorphism between the northern and southern parts of the area, or to the

fact that most of the potash feldspar in the amphibolites has at some time exsolved from the plagioclase, whereas that in the southern paragneisses has existed as a separate phase, is not certain (see section on plagioclase in Morin norites).

Thin sheets of pink granite gneiss and hornblende plagioclase gneiss occur in these rocks, as well as in the amphibolites, and are described in a separate section.

General Features of the Grenville Series

A generalized stratigraphic sequence of the Grenville Series in the Belleau-Desaulniers area is given in Figure 1. Such as has already been mentioned, the pink granite gneiss that occurs in these rocks, particularly in the lowermost amphibolites, is of uncertain origin. However, the quartzite that occurs with the amphibolites is definitely of sedimentary origin, and, therefore, the lower part of the series can be interpreted as a thick suite of rocks consisting of metamorphosed graywackes, andesitic lavas or tuffs and minor amounts of quartzite (perhaps originally layers of chert). Towards the end of the period during which the "amphibolitic" rocks were laid down, a thin, but continuous, bed of limestone was deposited. More graywacke was deposited on top of the limestone. From this time on, the variety of superposed sediments indicates that the conditions of sedimentation were much more variable than those during the deposition of the early part of the series. The upper rocks probably originally ranged from orthoquartzite to shales. The limestone in the southeastern corner of the area probably belongs to this part of the series.

Because of the striking difference between the rocks of the lower and upper parts of the series, it would not be unreasonable to expect an unconformity between the two. Osborne (1936a. p. 204) considered this possibility in the Shawinigan Falls area and concludes that, although the change from the lower to upper parts of the series appears transitional, an unconformity probably separates the two, because the red granite gneiss occurs only in the lower part of the series. However, in the Belleau-Desaulniers area both the pink granite gneiss and the amphibolite dikes (metagabbro) cut the lower and upper parts of the series. This, however, does not rule out the possibility of an unconformity.

A difference in the degree of metamorphism between the rocks of the upper and lower parts of the series is suggested by the difference in the structural states of their alkali-feldspar. The amphibolites contain orthoclase with a 2V that has a 50-60° range, whereas the upper Grenville paragneisses contain microcline. However, such as was stated in the section on the upper paragneisses, this difference might be a result of the alkali-feldspar in the amphibolites having exsolved from the plagioclase, whereas that in the plagioclase has existed as a separate phase.

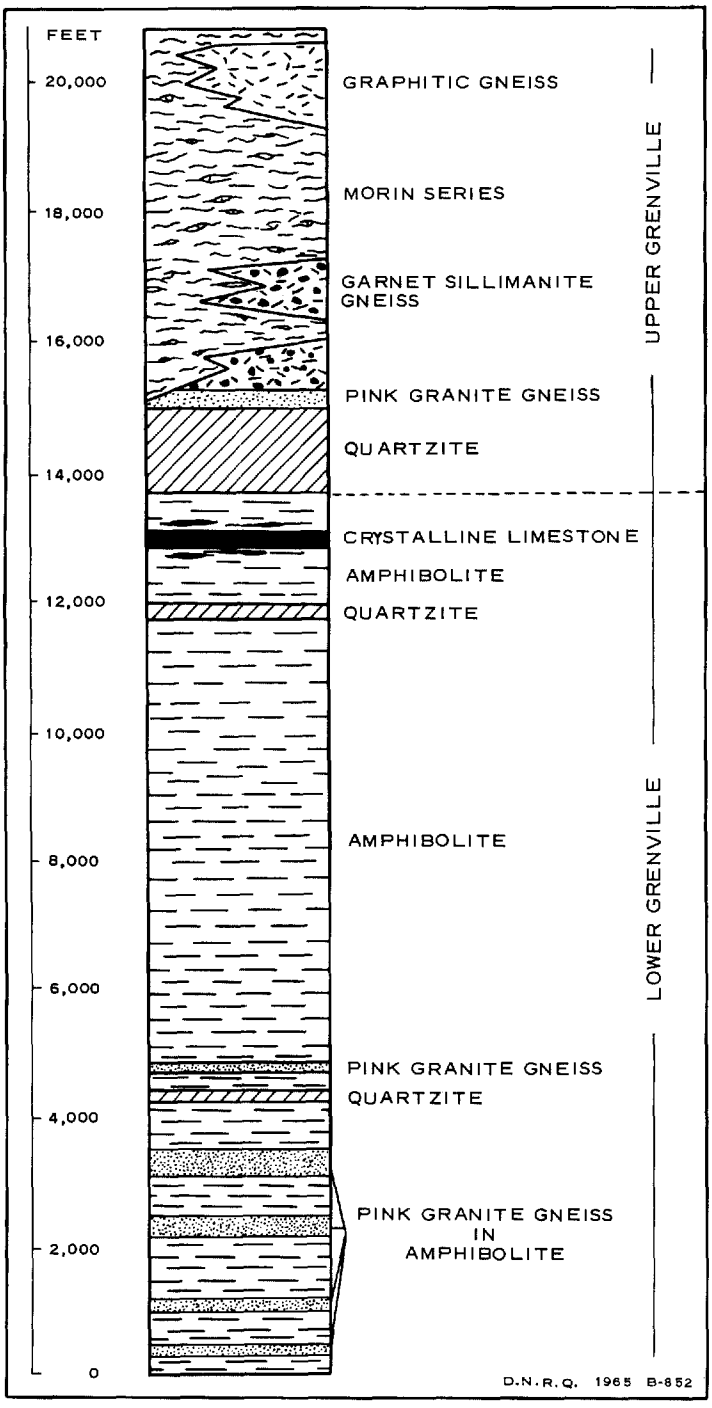


FIGURE 1

GENERALIZED STRATIGRAPHIC COLUMN OF THE ROCKS IN THE BELLEAU–DESAULNIERS AREA

The general sequence of Grenville rocks in the map-area resembles that found elsewhere. The similarity to the sequence in the Shawinigan Falls area has already been mentioned. Similar sequences are found at much greater distances from the present area. For example, in Methuen township, Peterborough county, Ontario (Hewitt, 1960, p. 110), the lower part of the Grenville Series consists essentially of amphibolites, pink arkose and quartzite, whereas the upper part consists of marble, slate, argillite and conglomerate. At this locality, a conglomerate separates the upper and lower parts of the series, and suggests an unconformity between the two. Adams and Barlow (1910, p. 49), after considering this conglomerate, make the following statement concerning the total sequence of Grenville rocks in that area:-

> "...the whole development of sedimentary rocks in the area has been mapped as one continuous series, although it is possible that two series, identical in petrographical character and closely enfolded, exist."

It is apparent that the nature of the contact between the upper and lower parts of the Grenville Series is not clear. There appears to be no structural break between the two and, therefore, other criteria must be relied upon to distinguish an unconformity. Unfortunately the metamorphism that these rocks experienced has obliterated almost all of the original sedimentary features. In the present area, as in the Shawinigan Falls area, the contact between the upper and lower parts of the series appears to be gradational. Osborne (1936a, p. 204) states that "this apparent transition zone between the two parts of the series might be explained by metamorphism of a weathered zone above massive lavas, suggesting an unconformity". Recent work by Chinner (1960) and others has shown that the oxidation ratio of the original sediments tends to survive regional metamorphism. Therefore, it might be possible to identify a zone of metamorphosed weathered rock between the upper and lower parts of the series by studying the variation in the oxidation ratio across the transition zone.

GRANITE GNEISS

Large quantities of fine-grained, pink granite gneiss occur as thin concordant sheets in both the upper and the lower parts of the Grenville Series in the area. Many of these layers are too thin to be shown on the map, and others, because of the scarcity of outcrops, could not be traced from one traverse line to another. Consequently only the thickest layers are shown on the map. One exceptionally thick lens extends northward from Sacacomie lake, along the western shore of Canitchez (Canitche) lake to Lambert lake.

The granite gneiss is invariably pink, fine grained, and well foliated. Under the microscope it has a pronounced cataclastic texture similar to that of many granulite rocks. It is composed almost entirely of pink microperthitic orthoclase, quartz, and a small amount of oligoclase. The orthoclase occurs as strained augen-shaped grains surrounded by much finer-grained, granular orthoclase and oligoclase. In this granular feldspar, quartz occurs in lenses commonly so elongated that they produce a very pronounced lineation in the rock. This lineation coincides with the fold axes in the Grenville gneisses. The quartz in these lenses, in contrast with the feldspar augen, shows no signs of deformation, and has undoubtedly undergone recrystallization.

The granite gneiss contains almost no dark minerals. A few grains of magnetite and biotite were found in some samples. Apatite, zircon and tourmaline are accessories, but are not present in every sample of the rock.

The origin of this gneiss is uncertain. It is possible that there are two genetically different types that are mineralogically similar. The thin layers of pink granite in the Grenville gneisses could be metamorphosed arkose, whereas the thick lens north of Sacacomie lake could be of igneous origin. However, no evidence was found to distinguish two such groups or to indicate the mode of origin of the rocks.

The granite gneiss can probably be correlated with the Mont Tremblant (Trembling Mountain) gneiss. Osborne (1936b, p. 17) considers this rock to be of igneous origin, but the evidence given to support this idea is not very strong. If the rock is of igneous origin it must have been intruded before or during the orogeny that developed the folds in the Grenville rocks.

Evidence in favor of a sedimentary origin for at least part of the granite gneiss can be found by comparing the sequence of Lower Grenville rocks with a similar sequence from a less metamorphosed region. In Methuen township, Ontario (Hewitt,1960, p. 110), the lower part of the Grenville Series is composed largely of amphibolites, pink arkose and quartzite. The pink arkose is very similar in composition to the granite gneiss in the present area. Adams and Barlow (1910, p. 180) describe the arkose as being composed "essentially of quartz, orthoclase, microcline and plagioclase, the first-mentioned constituent being the most abundant, and the orthoclase preponderating among the feldspars". They also point out that the rock is practically free from iron-magnesium constituents, scattered grains of magnetite being the only mafic mineral found. Adams and Barlow, as well as Hewitt, consider this rock to be of sedimentary origin. It is possible, therefore, that the thin layers of granite gneiss in question here are also of sedimentary origin. However, it is difficult to conceive of the thick body of granite gneiss north of Sacacomie lake as being an original localized

thickening of an arkosic bed. At no place in the area has structural deformation caused such a thickening of a layer. Consequently, this body is believed to be of igneous origin.

PLAGIOCLASE-HORNBLENDE GNEISS (AMPHIBOLITE)

The plagioclase-hornblende gneiss occurs as thin sheets and small discordant bodies in the Grenville gneisses and granite gneisses. It is a dark gray, medium-grained, equigranular rock composed largely of labradorite and hornblende, with smaller amounts of clinopyroxene and orthopyroxene and intergrown magnetite and ilmenite. The hornblende is pleochroic from reddish brown to yellowish green. Garnets are scattered irregularly throughout the rock, and are particularly common around pegmatitic patches. This rock differs from the Grenville amphibolites in that it contains no quartz and shows very little banding. Although most of the rock is granular, a relict ophitic texture is commonly evident, owing to the distribution of the various recrystallized minerals. This relict texture indicates that the original grain size was fairly coarse, the plagioclase laths having been as much as 1/4 inch long. The amphibolite along the shore of Maréchal lake on the northern border of the area provides excellent examples of this relict texture.

There appears to be little doubt that this rock was once a medium-grained gabbro that formed dikes and sills in the Grenville gneisses and pink granite gneiss. Since the mineralogy of the rock suggests that the upper amphibolite grade of metamorphism was reached, the intrusion must have occurred before the regional metamorphism came to an end.

MORIN SERIES

Rocks of the Morin Series are extensive in the southern part of the Belleau-Desaulniers area. The earlier rocks of this series (anorthosite, norites and mangerites) occur in a gently dipping concordant body intruded into the Upper Grenville paragneisses approximately 2,000 feet above the contact with Lower Grenville amphibolites. The body is approximately 7,000 feet thick and composed largely of mangerites. A large discordant intrusion composed of quartz monzonite and minor amounts of granite constitutes the later part of the Morin Series in the area. These later rocks are pink, in contrast with the dark green of most of the rocks of the earlier part of the series. The difference in the mode of occurrence of these two parts of the series suggests a difference in age, the earlier part of the series being syntectonic and the later part, post-tectonic. For this reason the two parts of the series are considered separately.

Anorthosite

The largest body of anorthosite is in the syncline east of Larose lake. This body, which lies on Grenville quartzite, is composed of pure anorthosite at the base, but grades upward through noritic anorthosite into norite. Because no completely exposed section through this body was found, it is difficult to state accurately the thickness of the various members. However, the zone of pure anorthosite at the base cannot be thicker than 100 feet, the overlying noritic anorthosite is many hundreds of feet thick, and true norite was found only in the very center of the syncline.

Another small body of anorthosite occurs near the road on the east side of Loup river 6,000 feet north of Paillé lake. It is exposed in only one outcrop and is surrounded by norite. The anorthosite here is fine grained and intensely crushed. Its relationship to the surrounding norite is not clear, but it is possible that post-consolidation movements have played a role in determining its present location.

Rocks of anorthositic composition (including noritic anorthosite) are not abundant; they constitute approximately 8% of the total Morin Series exposed.

The anorthosite and anorthositic rocks are dark purplish gray and weather light gray. They are coarse grained, with most of the plagioclase laths being about an inch long. Larger crystals occurring at the base of the mass tend to be granulated around their margins. The plagioclase is generally euhedral, and, where orthopyroxene is present, the rock has an ophitic texture. A subparallelism of the plagioclase laths, which is commonly evident on the weathered surface, produces a layering that conforms with the general structure of the syncline and is, therefore, probably formed by settling of the plagioclase on the floor of the magma chamber.

The plagioclase of the anorthosite is An_{60} and, although it occurs in large grains, there is no evidence of zoning. It commonly exhibits combined carlsbad-albite twins. With the gradation upward through anorthositic norite to norite, the composition changes gradually to An_{50} (Figure 2). It contains many small opaque rod-like and plate-like inclusions, which give the feldspar its dark purplish color. Adams (1895, p.93) describes similar inclusions in the plagioclase of the Morin anorthosite mass north of Montreal and concludes that they must be titaniferous iron ores. X-ray powder photographs (Philpotts,1961) of similar inclusions in the plagioclase of an anorthositic gabbro in Grenville township indicate that the inclusions are composed of both hematite and ilmenite. These probably represent exsolved phases rather than minerals that were enclosed during the growth of the plagioclase, for many of the directions of preferred

orientation of the inclusions do not lie in planes that are common growth surfaces for feldspar. Also, hematite was not found to be one of the opaque minerals that crystallized in these rocks.

Orthopyroxene* is the major mafic constituent, and ranges in composition from En_{80} in anorthosite to En_{75} in the norites (Figure 2). Most of the orthopyroxene contains exsolved plates of ilmenite, which, in turn, can be seen to contain exsolved hematite. Only extremely small amounts of clinopyroxene were noted. In some cases hornblende has formed as a reaction rim around the pyroxene. Small amounts of intergrown magnetite and ilmenite occur in some of the rocks, particularly the more noritic varieties. Apatite is the only common accessory, but it is not very abundant.

A chemical analysis of a typical noritic anorthosite is given in Column 1 of Table 3. It will be noted that 9.5% olivine occurs in the norm, whereas none occurs in the rock. Part of this is due to the alumina content of the orthopyroxene, but most of it is probably attributable to the hornblende that occurs as rims around the pyroxene. Whether the original rock contained olivine before the hornblende was formed is not certain. Anorthositic rocks of the Morin Series commonly contain olivine and in places grade into troctolites. It is of interest that this noritic anorthosite is the only rock of the Morin Series from the present area that contains normative olivine. This point is discussed in a later section.

Norites

The anorthositic rocks grade upward into true norites, which are the most abundant representatives of the basic end of the anorthosite-mangerite suite in the area, constituting 17.6% of the total amount of Morin rocks exposed. The norites occur in four main localities: the central part of the Larose Lake syncline, to the east of Cailly lake, north of Paillé lake, and between Douai (Caché) lake and Loup river. The last of these bodies is surrounded by the later pink quartz monzonite. The relationship of the norite in the Larose Lake syncline to the underlying anorthositic rocks has already been described. The norites in the other two bodies are surrounded by quartz mangerites. A group of transitional rocks occurs between the norites and mangerites and is discussed below.

The norites are coarse-grained, dark buff-weathering ophitic rocks. The plagioclase laths, most of which are approximately half an inch long, tend to be subparallel, giving the rock a layered appearance. This layering, which is particularly well developed in the body of norite between Douai lake and Loup river, is roughly horizontal. It appears likely, therefore, as in the case of the anorthositic rocks, that the layering is

* Compositions of plagioclase and pyroxene have been determined by optical methods only.

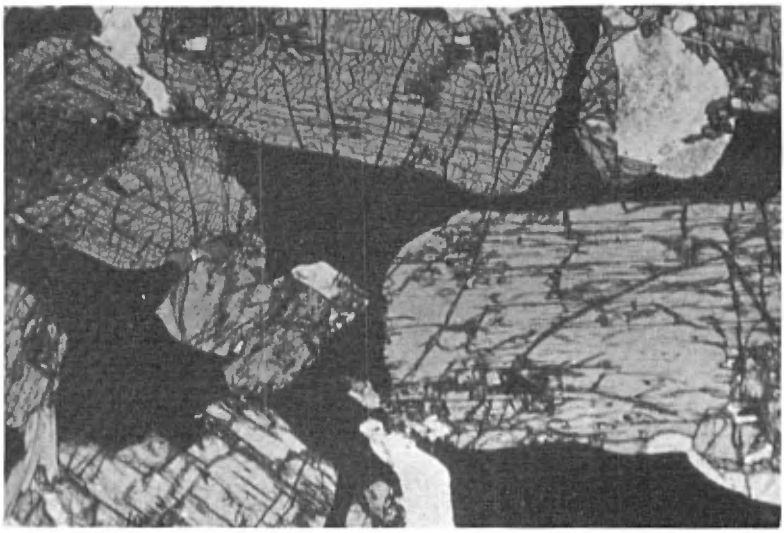
brought about by settling of the plagioclase from the magma. The plagioclase grains are euhedral and orthopyroxene fills the interstices between them. The orthopyroxene, consequently, tends to have the grain boundaries of the surrounding euhedral plagioclase. However, in the norites close to the mangerites, magnetite-ilmenite is commonly present and the pyroxene is euhedral (Plate 1A). This would suggest a sequence of crystallization beginning with plagioclase, followed by orthopyroxene, and ending with magnetite-ilmenite.

The plagioclase of the norites is similar in appearance to that of the anorthositic rocks. It is purplish and contains the same opaque inclusions. The most common twinning is the carlsbad-albite type. The plagioclase, which is An_{60} in the anorthosites, becomes more albitic as the rock becomes more noritic and reaches An_{45} where the norites grade into the transitional rocks. The plagioclase of the typical norite contains 45-50% An.

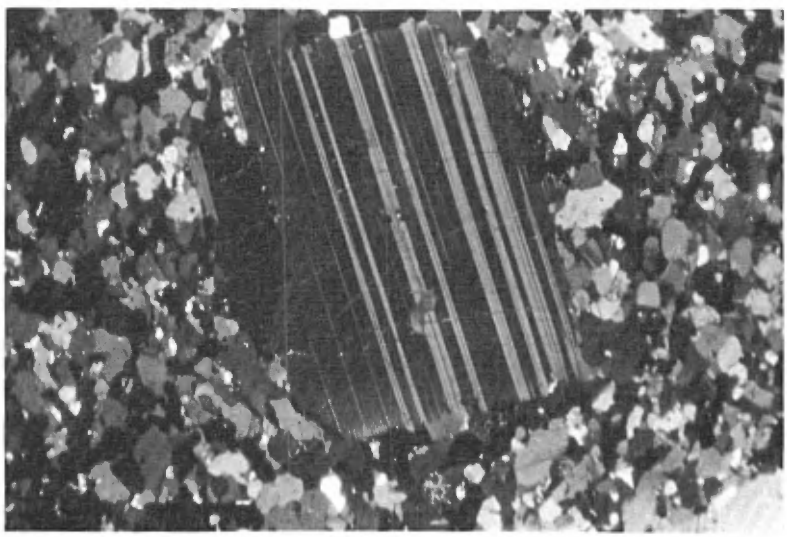
Potash-feldspar first appears in the anorthosite-mangerite suite as antiperthitic blebs in the borders of the plagioclase laths of the norites. A conoscopic measurement of the 2V of the feldspar in one of these blebs gave 51^{o}, which indicates that it is orthoclase. It was found from X-ray powder work that all of the plagioclase in the rocks of the early part of the Morin Series have intermediate structural states between the high- and low- temperature forms. However, the antiperthitic plagioclase from the rims of the large plagioclase laths in the norites has a higher structural state than the pure plagioclase from the center of the grains. It appears, therefore, that where potash-feldspar and plagioclase are intergrown, the potash-feldspar tends to prevent the plagioclase from becoming more ordered. It is possible that the plagioclase, in turn, has a similar effect on the exsolved potash-feldspar, which would explain the fairly small optic angle of the exsolved orthoclase in the norites.

The major mafic constituent of the norites is orthopyroxene. It varies in composition in a similar manner to the plagioclase in passing from the anorthosite, where it is En_{80}, to the norites, where compositions ranging from En_{75-70} are common (Figure 2). The orthopyroxene of the norites contains exsolved plates of ilmenite-hematite similar to those of the pyroxene of the anorthositic rocks. Clinopyroxene is only a minor constituent, but does increase in amount towards the mangerites. Magnetite-ilmenite constitutes approximately 5% of the norites, but also increases in amount towards the mangerites. Biotite commonly occurs around the grains of magnetite-ilmenite.

Chemical analyses of two typical norites are given in columns 2 and 3 of Table 3. It will be noted that a small amount of quartz appears in the norms calculated from these analyses, although none was observed in the rocks.



A - Orthopyroxene crystals surrounded by intergrown magnetite and ilmenite in a norite. The opaque minerals have crystallized later than the pyroxene. In some places a small zone of plagioclase separates the pyroxene from the magnetite-ilmenite. Plain light, x 30.



B - Single, subhedral phenocryst of plagioclase (An_{32}) in a fine-grained jotunitic groundmass. The groundmass is rich in ilmenite and magnetite (black) and there is no zone of pure granular feldspar surrounding the phenocryst. Crossed nicols, x 30.

Where the norite has been intruded by the later pink quartz monzonite (not the mangerite), it becomes granular and gneissic. A large amount of biotite has been developed, apparently at the expense of the magnetite-ilmenite. The effects of the intrusion are evident in the norite up to several hundred feet from the contact with the quartz monzonite. The plagioclase laths are bent and granulated around the rims. The granular plagioclase is much more sodic than the remaining bent plagioclase laths. Plagioclase with a composition of An_{50} is commonly surrounded by granular plagioclase with a composition of An_{35}. This change was probably brought about by an alkali metasomatism that, at the same time, was responsible for the development of most of the biotite. These contact metamorphic effects are well displayed in the rocks northwest of Douai lake.

It is extremely important, in considering the relationship of the mangerites to the norite, to note that changes in the norites brought about by the intrusion of the pink quartz monzonite in no way resemble the changes in the transitional rocks found between the norites and mangerites.

Transitional Rocks, Jotunites

Where the norites approach the mangerites they become more mafic, clinopyroxene becomes increasingly more abundant, the plagioclase becomes more albitic, potash-feldspar increases in amount and quartz begins to appear. The rock changes gradually from a norite to one composed essentially of andesine (An_{32}), orthoclase, clinopyroxene and orthopyroxene, magnetite-ilmenite and a small amount of quartz. These rocks, although gradational into the norites, are considered separately because they are of a markedly different composition from any of the other rocks of the series and because they are considered by the author to have played an important role in the later stages of crystallization of the anorthosite-mangerite suite of rocks and probably represent the last remaining liquid to have crystallized.

A typical transitional rock close to the mangerite is composed of 10% quartz, 15% orthoclase, 45% plagioclase, 12% clinopyroxene, 8% orthopyroxene and 10% magnetite-ilmenite. Such a rock from the anorthosite series in the Jotunheim district of southern Norway was named a "jotun-norite" by V.M. Goldschmidt (1916, p. 35), which he defined as consisting of plagioclase, potash-feldspar (with microperthite), a little quartz, hypersthene, diallage, some biotite and ore, as well as apatite, and commonly zircon in remarkably rounded grains.

Goldschmidt gives the composition of the plagioclase as 30-35% An (1916, p. 36). However, the term jotun-norite is an unfortunate one because the plagioclase of a norite, by definition, contains at least 50% anorthite. For this reason Hødal (1945, p. 140) suggested the adoption of the term "jotunite" instead of "jotun-norite". Jotunite, as used in the present

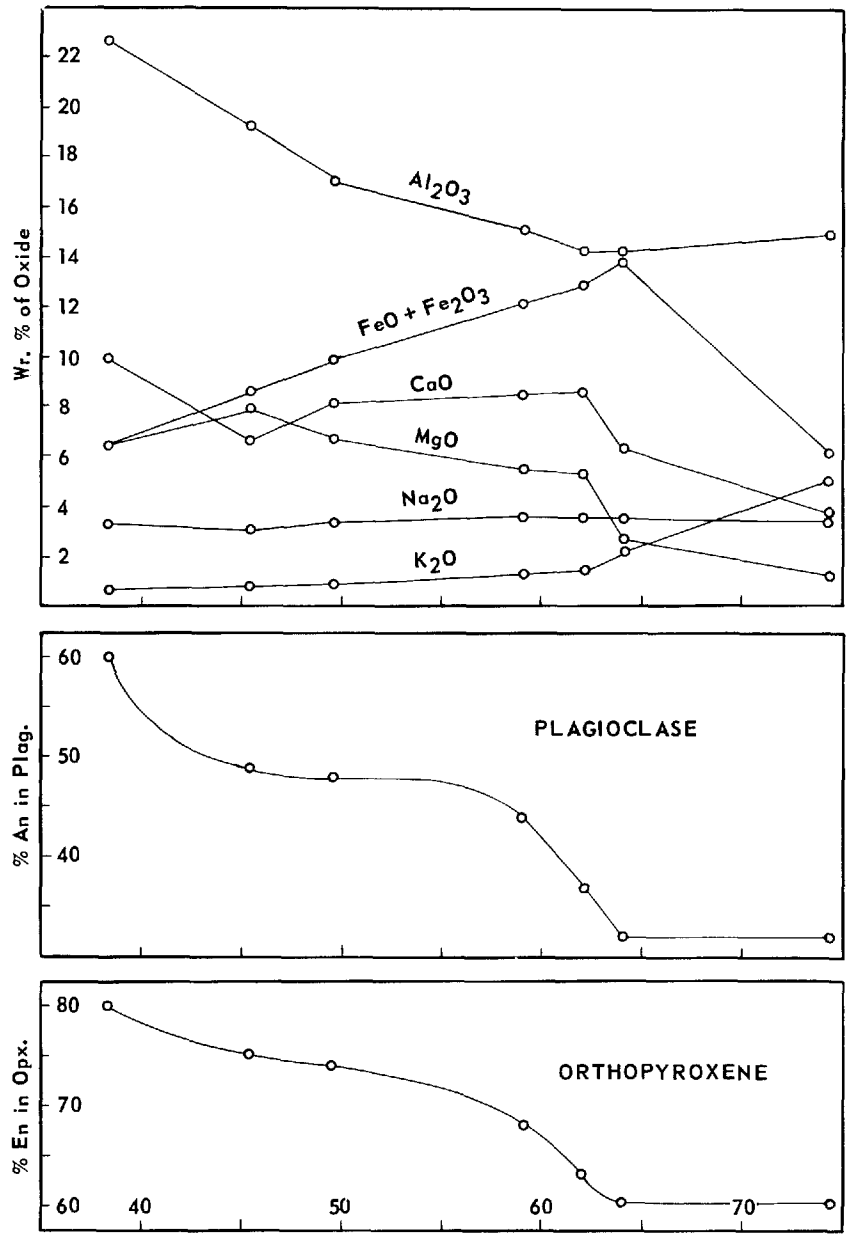


FIGURE 2

VARIATION DIAGRAM OF THE PRINCIPAL MEMBERS OF THE MORIN SERIES, SHOWING THE VARIATION IN THE MAJOR ELEMENTS (EXCEPT SILICA) AND OF THE COMPOSITION OF THE PLAGIOCLASE AND ORTHOPYROXENE

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report, refers to rocks of the above composition that characteristically occur in the transition zone between the norites and the mangerites.

The jotunites in this area are fine- to medium- grained granular rocks that are dark green on the fresh surface and weather yellowish buff. Where norites grade into jotunites, the grain size decreases and the ophitic texture disappears, probably because of the larger number of phases that crystallized in the jotunites. A slight foliation is commonly evident in these rocks, which fact is due to the concentration of dark minerals into layers.

Most of the plagioclase in the jotunites is An_{32}, but all compositions from An_{45} to An_{32} are found in passing from norites to the jotunites in contact with mangerite. Much of this plagioclase occurs as small polygonal-shaped grains that are twinned according to the albite and pericline laws. Both orthopyroxene and clinopyroxene are present. The orthopyroxene shows a similar compositional variation to the plagioclase, passing from En_{70} in the norites to En_{60} in the jotunite in contact with mangerite (Figure 2). In the true jotunites, pale green clinopyroxene is slightly more abundant than orthopyroxene, but decreases in amount towards the norites. The potash-feldspar is a microperthitic orthoclase with a 2V of 50-60%. Magnetite-ilmenite constitutes from 10-15% of the jotunite. In the jotunite in contact with mangerite, 10% of quartz is present, but the amount decreases in the rocks closer to the norites. Apatite, which is an accessory found in all of the Morin Series rocks, is particularly abundant in the jotunites, where it occurs as long, slender prisms. Zircon also occurs as an accessory in the quartz-rich jotunites.

Chemical analyses of three typical jotunites from the area, given in columns 4, 5 and 6 of Table 3, cover the range in composition from noritic varieties (4) to jotunite in contact with mangerite (6).

The first sign of a change from jotunite to mangerite is the occurrence of lenses of coarse, augen-shaped grains of feldspar in the jotunites. At first these lenses may contain only a few large feldspar grains. In a few outcrops single large grains of feldspar were observed surrounded by jotunite. In thin-sections of the jotunites from these contacts, phenocrysts of feldspar were found to be more common than was apparent in the field. Plate 1B is of a typical feldspar phenocryst surrounded by granular jotunite. These single phenocrysts are fairly euhedral compared with the augen-shaped grains in the lenses of feldspar or in the mangerites. The composition of the feldspar in the lenses is the same as that of the feldspar in the surrounding jotunites. It is composed of plagioclase (An_{32}) and microperthitic orthoclase. Closer to the mangerites the lenses of feldspar become thicker and thicker until the rock eventually becomes a massive mangerite. Thin lenses of jotunite, however, continue to occur sporadically throughout the mangerites, even at great distances from norite-jotunite-mangerite contacts.

Similar relationships have been described in other areas where anorthositic rocks are in contact with mangerites. Balk (1930, p. 291), in describing the contacts between the anorthosites and syenites of the Adirondacks, states that they are, in general, gradational, but when looked at in detail can be seen to be composed of "a sequence of subparallel layers, each one having approximately constant composition". Hødal (1945, p. 194) describes exactly similar relationships between the anorthosites and mangerites of the Vossestrand district of southern Norway.

Jotunites are best exposed in the Belleau-Desaulniers area on both sides of Loup river, approximately 6,000 feet north of Paillé lake. This particular locality provides two contrasting contacts of jotunites with mangerite. On the west side of the river mangerites overlie jotunites, whereas on the east side mangerites underlie jotunites. These two contacts are some 3,000 feet apart. The contact on the west side of the river is the same as that given in the general description of the jotunite-mangerite contact. There is much interlayering of jotunites and mangerites. In the bank of the river, the rock is composed largely of jotunite with, in a few places, layers of mangerite. However, higher up the bank and on the western side of the road, the amount of mangerite increases until the rock is composed entirely of massive mangerite. The feldspar phenocrysts that occur in the jotunites at this locality are fairly euhedral and show no signs of strain (Plate 1B).

The contact on the east side of the river is somewhat different. It is well exposed in a large outcrop on the road that branches off to a small lake east of the river. Here the rocks dip to the southwest and, as one proceeds to the northeast, norites are found to grade downwards into jotunites. Eventually, the mangerite is found underlying these other rocks. There is, however, very little interlayering of jotunite with mangerite, and phenocrysts of feldspar were found in the jotunite up to only a few inches away from the mangerite. The phenocrysts are, however, completely anhedral and badly strained.

Mangerites

The term "mangerites" was introduced by C.F. Kolderup (1903) to apply to a rock type that occurs at Manger in the Bergen district of southern Norway and, in his opinion, is intermediate between monzonite and gabbro. It is essentially a pyroxene-bearing monzonite in which the plagioclase is slightly more calcic than in normal monzonites. Such rocks are exceedingly common in the area, being estimated to constitute approximately 72% of the total Morin Series exposed.

The mangerites occur in a broad band that extends from just north of Souris lake at the eastern border of the area to Sacacomie lake. The band is approximately 15,000 feet wide and is composed almost entirely of

mangerites, with the exception of a few bodies of norite, already described, and some lenses of paragneiss that are interlayered with the mangerites at the western end of the band. The rocks dip gently to the south and overlie paragneisses of the upper part of the Grenville Series. A later, coarse-grained, pink, quartz monzonite marks the upper limit of the mangerites in the area. Between Souris lake and Eau-Claire lake, these two rocks lie in contact with each other along a fault. However, from Eau-Claire lake to Sacacomie lake, the relationships between the two are complicated by several factors. In the vicinity of Paillé lake, much faulting has taken place and a considerable amount of pseudotachylite has been developed. Mangerites, norite and quartz monzonite are all exposed at this locality and it was not possible, at the present scale of mapping, to work out completely the relationships between these rocks. Also, towards Sacacomie lake the normally pink quartz monzonite becomes brownish and is very difficult to distinguish from the mangerite. Consequently, from Loup river westward, the contact between mangerites and quartz monzonite is only approximate as mapped.

The mangerites are invariably gneissic and, in many cases, are difficult to distinguish from some Grenville gneisses. However, very few mangerites show any compositional banding, except for some lenses of jotunite. Therefore, if the outcrop is sufficiently large, this criterion can be used to distinguish mangerites from Grenville gneisses, which almost invariably are banded.

The mangerites are medium- to coarse-grained, light buff weathering augen gneisses. They are composed of greenish feldspar augen, surrounded by finer, granular feldspar, quartz, pyroxene and magnetite-ilmenite. The rock is so crushed that the augen constitute only about 20%. However, lenses of granulated feldspar indicate that the rock was originally composed largely of feldspar phenocrysts. Several types of phenocrysts appear to have been present, but granulation makes it difficult to determine their original proportions. The most common feldspar is a microperthitic orthoclase in which the exsolved plagioclase constitutes at least 35% of the total grain. Some augen of microperthitic orthoclase are rimmed with a thick layer of plagioclase (An_{32}). Other augen are composed entirely of plagioclase (An_{32}). The plagioclase in the augen exhibits very little twinning and contains very small opaque inclusions.

Quartz occurs both in thick lenses and as separate grains in the matrix. The lenses are in the granulated feldspar around the augen. Some of the lenses are sufficiently large to suggest that before deformation the quartz was in relatively large grains. The matrix between the feldspar augen and granular feldspar lenses includes a finer granular quartz along with pyroxene, feldspar and magnetite-ilmenite.

Both orthoclase and plagioclase (An_{32}) are present in the matrix with the mafic minerals. Clinopyroxene and orthopyroxene are present in approximately equal amounts. The orthopyroxene has a 2V of 52^{o}, which corresponds to approximately En_{60}, and is, therefore, similar to that in the jotunites. A brownish green hornblende is commonly present and appears to have formed as a replacement of pyroxene. Intergrown magnetite and ilmenite is an abundant constituent of the matrix. Apatite, in large rounded grains and in long thick prisms, is the most abundant accessory mineral. Zircon, which is also a common accessory, occurs both as anhedral and euhedral grains. These accessories are with the mafic minerals in the matrix of the rock.

It is almost impossible to determine exactly the mineralogical composition of the original matrix in which the feldspar phenocrysts were embedded, because of the difficulty of distinguishing granulated feldspar derived from the phenocrysts from feldspar belonging to the matrix. Nor is it certain how much of the quartz belongs to the matrix. However, although the mangerite as a whole contains only a small quantity of dark minerals, the original matrix must have contained a large amount of pyroxene and magnetite-ilmenite. The proportions of plagioclase to potash-feldspar would have been approximately equal. The amount of quartz is uncertain, but might have been about 10%. Apatite would have formed an abundant accessory mineral. If this matrix had been removed from the mangerite and crystallized as a separate rock, it would have resembled very closely the jotunites described above. It does not appear unreasonable, therefore, to interpret the lenses of jotunite, which commonly occur in the mangerites, as segregations of the last remaining liquid in the mangerites. The chemical evidence supporting this hypothesis will be discussed in a later section.

A chemical analysis of a typical mangerite from south of Cailly lake is given in column 7 of Table 3. This analysis is very similar to some of the analyses of the mangeritic rocks from the type locality in the Bergen district of southern Norway (Kolderup and Kolderup 1940, p. 97).

PETROGENESIS OF THE ANORTHOSITE-MANGERITE SUITE*

Rocks of the anorthosite-mangerite association have been found in many parts of the world, but there has been little agreement as to the actual relationship of the various members of this suite to one another. Some workers (Buddington 1939, p. 208; Miller 1929, p. 394), while recognizing the association of mangerites (referred to by them as syenites) with anorthosites, deny that there is a direct genetic relationship between

*For a critical examination of the problem, see: "Origin of the Anorthosite-Mangerite Rock in Southern Quebec," by A.R. Philpotts, Journal of Petrology, Vol. 7, No. 1, February 1966. - Editors

Table 3. - Analyses of Morin Series Rocks

1. Noritic anorthosite from Larose Lake syncline.
2. Norite from west side of Loup river, north of Paillé lake.
3 and 4. Norites from east side of Loup river, north of Paillé lake.
5. Jotunite from Burnt falls on Loup river.
6. Jotunite from north side of Paillé lake.
7. Mangerite from outcrop on old road west of Cailly lake.

	1	2	3	4	5	6	7
SiO_2	49.68	51.79	52.45	51.11	49.45	52.61	63.60
TiO_2	.40	1.30	1.21	2.50	2.95	2.60	1.30
Al_2O_3	22.60	17.14	16.95	15.07	14.28	14.26	14.94
Fe_2O_3	2.31	2.97	3.66	5.69	5.14	6.67	1.91
FeO	4.10	7.00	6.19	6.48	7.71	7.21	4.28
MnO	.06	.09	.11	.10	.17	.16	.11
MgO	6.41	7.90	6.71	5.47	5.39	2.41	1.19
CaO	9.91	6.70	8.14	8.44	8.62	6.41	3.66
Na_2O	3.30	3.03	3.35	3.59	3.57	3.39	3.49
K_2O	.61	.79	.78	1.33	1.52	2.54	5.03
P_2O_5	.09	.12	.31	.29	.64	.66	.49
H_2O+	.57	1.01	.57	.37	.32	.45	.32
H_2O-	.18	.12	.10	.10	.04	.05	.03
	100.22	99.96	100.53	100.54	99.80	99.42	100.35
Wt. Norm							
Q		1.85	2.43	2.30	.02	8.35	14.79
or	3.62	4.68	4.62	7.85	8.96	15.03	29.72
ab	27.90	25.65	28.32	30.37	30.21	28.69	29.53
an	45.07	30.82	28.93	21.09	18.47	16.19	10.27
wo } di	1.48	.70	4.00	7.95	8.51	4.86	2.06
en } di	1.03	.46	2.60	5.81	5.65	2.85	.84
fs } di	.32	.19	1.04	1.39	2.25	1.77	1.23
en } hy	4.26	19.21	14.05	7.82	7.78	3.16	2.12
fs } hy	1.36	8.23	5.53	1.87	3.11	1.96	3.12
fo } ol	7.48	-	-	-	-	-	-
fa } ol	2.62						
mt	3.36	4.31	5.30	8.24	7.46	9.68	2.78
il	.76	2.47	2.29	4.75	5.60	4.93	2.46
ap	.21	.28	.70	.66	1.45	1.49	1.11
	99.47	98.85	99.87	100.10	99.47	98.96	100.03

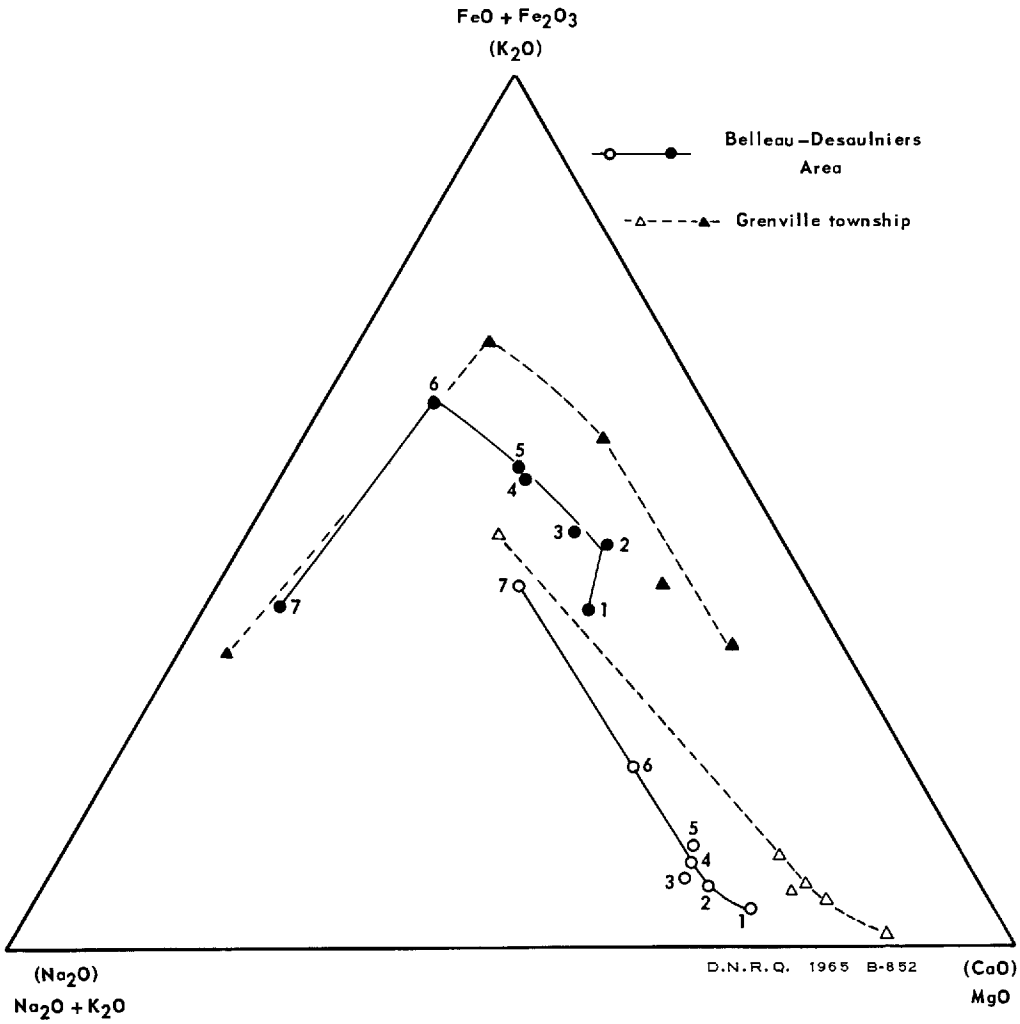


FIGURE 3

TERNARY VARIATION DIAGRAMS ($MgO - FeO + Fe_2O_3 - Na_2O + K_2O$ IN SOLID LINES, AND $CaO - Na_2O - K_2O$ IN DASHED LINES) OF MORIN SERIES ROCKS FROM THE BELLEAU–DESAULNIERS AREA COMPARED WITH THOSE FROM GRENVILLE TOWNSHIP

the two. Other workers, however, believe all of these rocks were derived from the same magma. Amongst these, however, there are differences as to the composition of the original magma. Bowen (1917, p. 242) believed that the "syenites" are late differentiates of a basaltic magma, but the large quantities of "syenite" make this hypothesis rather unlikely. Suggestions of a dioritic (Balk 1931, p. 401), granodioritic (Barth 1933, p. 302) or quartz mangerite (Osborne 1936b, p. 18) magma would appear to fit the proportions of the associated rock types more closely. Evidence from the present area supports the theory that all these rocks are comagnetic, having crystallized from a granodioritic magma that underwent strong crystal fractionation.

Table 4. - Bulk Compositions

	1	2	3
SiO_2	60.1	63.	62.7
TiO_2	1.3	.8	1.1
Al_2O_3	15.9	16.	19.0
Fe_2O_3	2.2	2.7	1.4
FeO	4.8	3.1	2.3
MnO	.1	.1	-
MgO	2.9	1.0	.8
CaO	4.8	3.3	5.4
Na_2O	3.4	4.5	4.2
K_2O	3.9	5.0	2.9
P_2O_5	.4	.4	.2
	99.8	99.9	100.0
Wt. Norm			
Q	10.7	10.	14.6
or	22.8	29.5	17.2
ab	28.8	38.2	35.6
an	16.8	9.5	24.8
di	3.7	3.6	1.4
hy	10.8	3.0	2.2
mt	3.2	4.0	2.1
il	2.4	1.4	2.1
ap	.9	.9	-
	100.1	100.1	100.0

1. Weighted average of chemical analyses of Morin rocks from the Belleau-Desaulniers area.
2. Weighted average of chemical analyses of rocks from the Diana complex of the northwest Adirondacks. (Buddington 1939, p. 103)
3. Weighted average of chemical analyses of rocks from the anorthositic body of southern Norway. (Barth, 1933, p. 301)

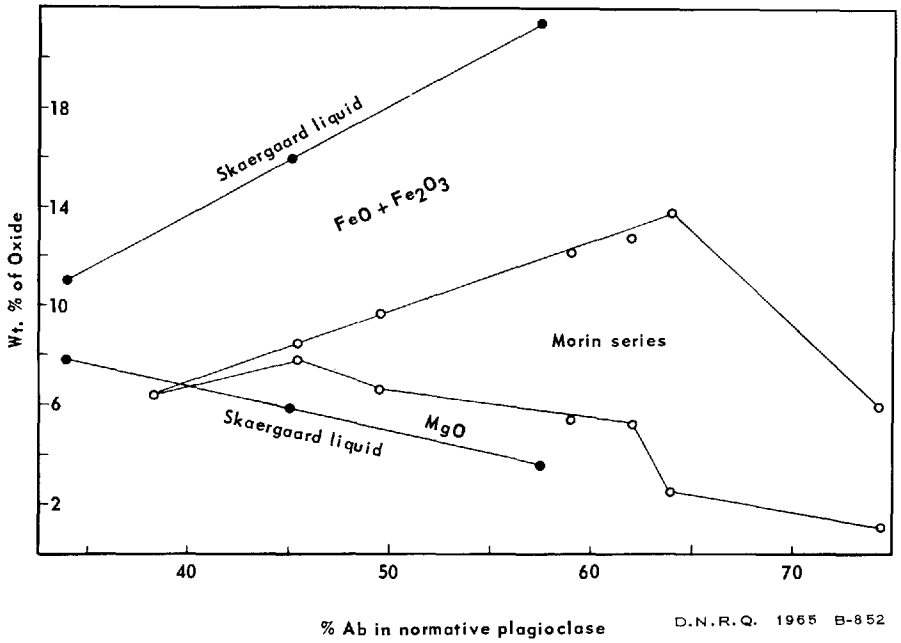


FIGURE 4

VARIATION IN $FeO + Fe_2O_3$ AND MgO PLOTTED AGAINST THE PERCENTAGE OF ALBITE IN THE NORMATIVE PLAGIOCLASE OF THE ROCKS, OF THE MORIN SERIES AND THE SKAERGAARD LIQUID

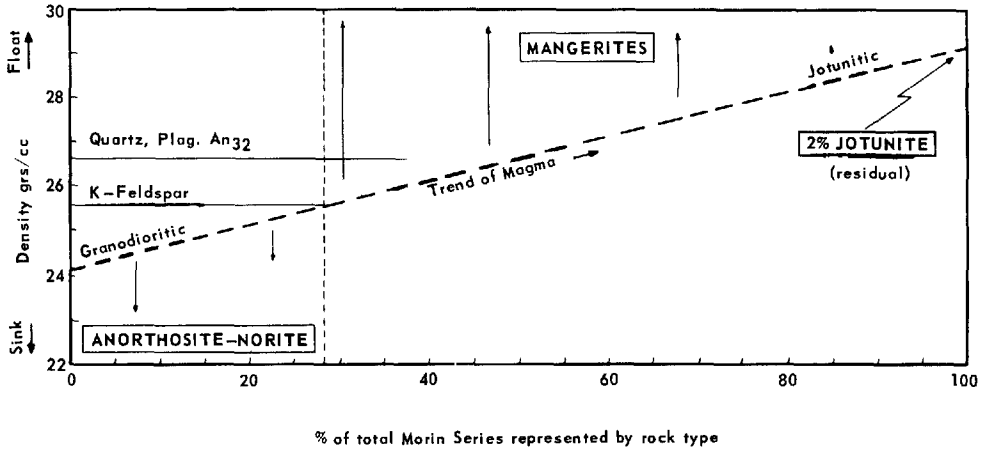


FIGURE 5

PROBABLE SEQUENCE OF EVENTS INVOLVED IN THE FORMATION OF THE MORIN SERIES. THE VARIATION IN THE DENSITY OF THE MAGMA IS SHOWN AS WELL AS THE ROCK TYPES FORMED (SHOWN IN BLOCKS).

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LATER PART OF MORIN SERIES

The last phase of the Morin Series consists of a coarse-grained quartz monzonite and a fine-grained granite. These rocks form part of a large discordant body that occurs to the east of Saint-Gabriel-de-Brandon and extends through the southern part of the present area. This body was first outlined by R.G. McConnell in 1880 (Ells, 1898).

The monzonite is coarse grained and generally pink weathering, although in a few places it weathers buff, and it is distinguished from the mangerites of the earlier part of the Morin Series only with great difficulty. The rock is porphyritic and the feldspar phenocrysts, which weather to give the rock its pink appearance, are surrounded by rims of white-weathering feldspar. A slight foliation is normally present, but may show only in large outcrops because of the very coarse grain size of the rock. The foliation is produced by an alignment of the many slightly augen-shaped feldspar phenocrysts.

The rock is composed of 50% oligoclase, 26% microcline microperthite, 12% quartz, 7% hornblende, 3% opaque minerals and 2% biotite, with sphene, apatite, zircon and pyrite as accessories. One of the most striking features of the rock is its rapakivi texture. The feldspar phenocrysts have a core of microcline microperthite surrounded by a rim of oligoclase (An_{25}) exhibiting only a small amount of albite twinning. The groundmass, which constitutes 56% of the rock, contains almost no potash-feldspar. The hornblende is pleochroic from a deep green through a brownish green to a pale yellow. The most abundant opaque minerals are ilmenite and magnetite.

An analysis of a sample of this quartz monzonite obtained from the roadcut at the southern entrance to the village of Saint-Alexis-des-Monts is given in column 4 Table 4. There is a great similarity between this and the analysis of the mangerite of the earlier part of the Morin series given in column 7 of Table 3. The major difference between these rocks is not chemical, but mineralogical, the older mangerite containing pyroxene, whereas the later monzonite contains hornblende and biotite. The quartz monzonite contains 0.25% barium oxide, which probably occurs in the feldspar as the celsian molecule.

Pink, quartz-feldspar pegmatites are associated with the quartz monzonite as small dikes 6 inches to 2 feet thick. Uraninite crystals are

present in some of the dikes, as for example in the one that cuts the norite in the roadcut on the west side of Loup river, at the southern boundary of the area. Many of the pegmatites in the vicinity of the major fault that passes through the southern part of the area have narrow margins of black aphanitic mylonite, suggesting that they were injected into faults.

Cutting the quartz monzonite at the eastern end of Eau-Claire lake is a small mass of fine-grained pink granite. The body is approximately 4 miles long and 1 1/2 miles wide and separates the quartz monzonite from Grenville amphibolites. The granite is extremely fine grained and very well jointed. Close to the margins of the body it is aphanitic and flow lines parallel the contact and wrap around inclusions. The granite is composed almost entirely of quartz, orthoclase and oligoclase with minor amounts of magnetite and hornblende. Many large xenoliths of the coarse-grained monzonite and of various Grenville rocks occur in the granite. Pegmatite dikes, some of which are composed almost entirely of quartz, cut the granite and surrounding rocks. These are well exposed on the southeastern shore of Eau-Claire lake.

AGE OF THE MORIN SERIES

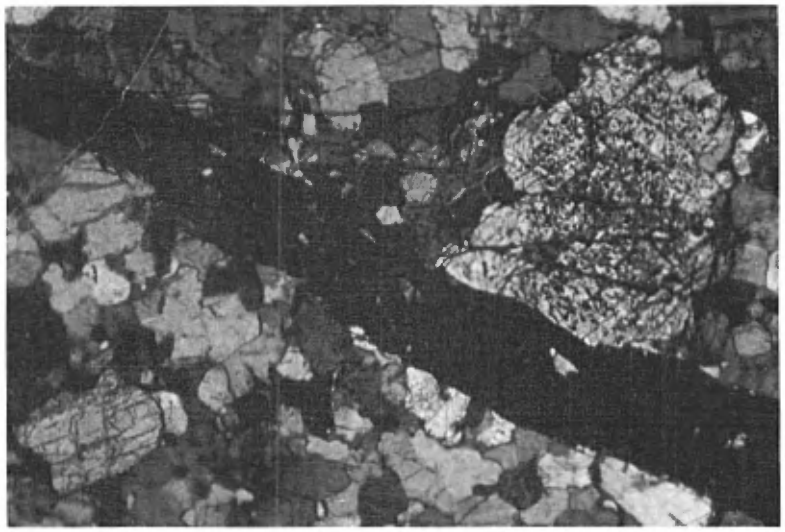
No absolute age determinations were made on the Morin rocks from the Belleau-Desaulniers area. However, biotites, developed around the magnetite-ilmenite grains in the earlier rocks of the series in Grenville township, gave potassium argon ages ranging from 946 to 927 million years. These biotites were probably developed during the closing stages of crystallization of the first part of the series. The ages in the two areas are probably similar.

The mode of occurrence of the later part of the series (discordant intrusives) suggests that it must have been intruded after the close of orogenic movements. However, as will be seen in the next section on pseudotachylites, it must have been intruded before 900 million years ago.

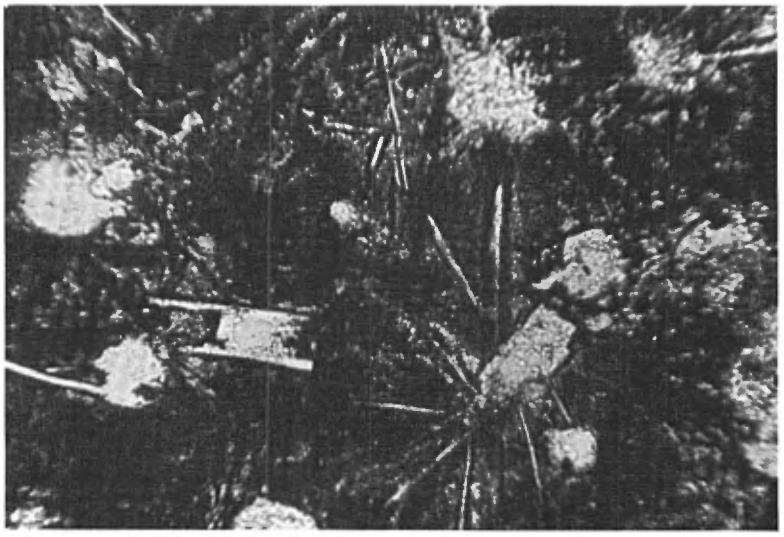
PSEUDOTACHYLITES*

Black, aphanitic and glassy rocks occur in small veins along the major northeasterly trending fault that extends through the southern part of the area. They usually have approximately the composition of the

* For details of these rocks refer to Philpotts, 1964.



A - Small dike of black glassy pseudotachylite cutting jotunite. There has been no displacement parallel to the dike, as can be seen from the position of the large grain of pyroxene which occurs on either side of the dike. The fragments in the pseudotachylite are of feldspar derived from the surrounding rock. Crossed nicols, x 30.



B - Aphanitic variety of pseudotachylite composed of feldspar microlites in an extremely fine-grained groundmass containing abundant small specks of magnetite. The "H"-shaped microlite of plagioclase contains a rounded core of potash-feldspar. Plain light, x 365.

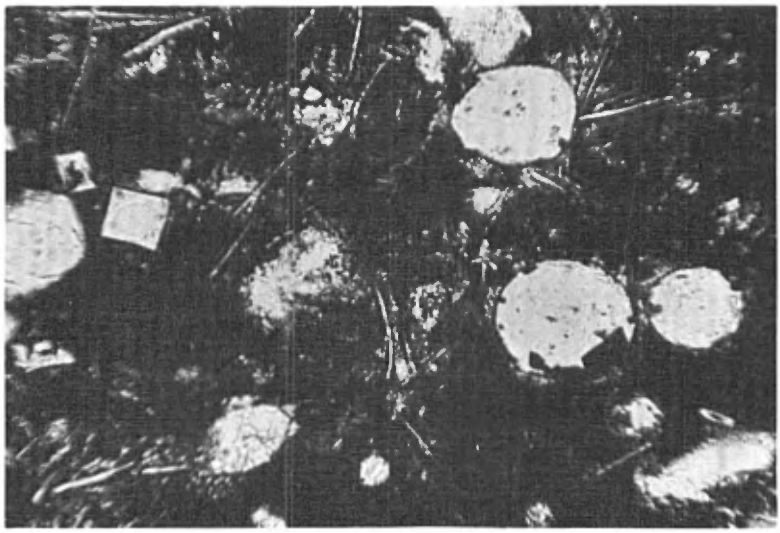
rock in which they occur, and appear to have formed in some cases by the extreme crushing of the country rock and in others by the melting of it. Similar rocks occuring at Parys, South Africa, were given the name pseudotachylite by Shand (1916, p. 199) because of their strong resemblance to true tachylite. Other names such as hyalomylonite, cryptomylonite (Scott and Drever, 1953) and flinty crush-rock (Clough, 1907) have also been applied to these rocks, but Shand's term seems the most appropriate for general use since it is descriptive but not genetic.

The fault with which the pseudotachylites are associated in the Belleau-Desaulniers area has been found to extend across the Shawinigan map-area, up Saint-Maurice river, along Mekinac lake, and from there branches into two faults that join again in Saint-Maurice river and follow it past LaTuque (Figure 7). In the present map-area pseudotachylites were found at four places: at the northwestern end of Souris lake; in the body of norite between Eau-Claire lake and Loup river; in the extreme southwestern corner of the area in an outcrop on the road leading from Saint-Alexis-des-Monts to Sacacomie lake; and at the eastern end of Paillé lake. This last locality shows the widest development of pseudotachylite in the area. A detailed search was not made along the entire length of the fault and it is possible that these rocks are present at many other localities in this zone.

The pseudotachylites occur in a variety of ways. In the fault zone, where brecciation has taken place, they form a matrix around the fragments. Farther away, where the rock has only been fractured, the pseudotachylite usually forms a network of small veins (Plate IIA), In a few places, single large dikes up to 8 inches thick were found (Paillé lake) cutting relatively undeformed rock. In the case of the network of veins and the dikes, it is quite certain that the pseudotachylite has been injected into the rock and has not been developed in situ. However, in the case where it forms the matrix of the breccia, it is not certain whether it has been injected or formed from the surrounding rock.

There are two clearly distinguishable varieties of pseudotachylite in the present area. The most abundant of these is a black aphanitic rock that breaks with a conchoidal fracture and gives a pronounced ring when struck with a hammer. It resembles fine-grained diabase, but can be distinguished from it by the very light grayish green to which it weathers, the diabase usually weathering dark. The other variety, which is black and glassy, was found only in dikes and networks of veins and never as the matrix of a breccia. The glass also breaks with a conchoidal

Plate III



Aphanitic variety of pseudotachylite containing amygdules of quartz. Small euhedral crystals of magnetite which project into the amygdule from the rim were probably formed before the quartz was deposited. The square, euhedral plagioclase grain has a rounded core of potash-feldspar. Plain light, x 365.

fracture, but is so well jointed in most cases that it crumbles on being hit. Both the aphanitic and glassy varieties are very magnetic and small fragments of the rock can usually be supported by a magnet.

The ages of three pseudotachylites from the east end of Paillé lake were determined by the potassium-argon method on the total rock samples. Analyses of these three pseudotachylites are given in Table 5. The first one, which is an aphanitic variety with a small amount of glass between the feldspar microlites, gives an age of 822 $\pm$ 40 million years. The second, almost entirely holocrystalline, is 904 $\pm$ 43 million years old. The third one is completely glassy and gave an age of 975 $\pm$ 46 million years. The average of these three values is 900 million years. These rock were, therefore, formed in the Precambrian and not long after the intrusion of the

Table 5. - Analyses of Pseudotachylite and Quartz Monzonite

1. Partly glassy pseudotachylite cutting jotunite at Paillé lake.
2. Completely crystalline pseudotachylite cutting jotunite at Paillé lake.
3. Completely glassy pseudotachylite cutting coarse-grained, quartz monzonite at Paillé lake.
4. Coarse grained, pink, quartz monzonite from roadcut at southern entrance to Saint-Alexis-des-Monts, Quebec. It also contains .09% S, .25% BaO. .09% SrO and .02% V_2O_3. Analyst, Z. Katzendorfer, Quebec Dept. Natural Resources.

	1	2	3	4
SiO_2	50.22	51.02	58.33	61.28
TiO_2	2.60	2.41	1.70	1.19
Al_2O_3	14.96	14.62	16.18	16.52
Fe_2O_3	6.42	5.82	2.69	2.75
FeO	5.89	5.34	4.95	2.62
MnO	.11	.13	.09	.09
MgO	2.33	2.17	2.10	1.39
CaO	5.77	5.62	4.20	3.79
Na_2O	4.34	3.88	2.61	3.98
K_2O	2.69	2.66	4.24	4.82
P_2O_5	.56	.84	.65	.44
H_2O+	.99	1.53	1.69	.36
H_2O-	.06	.06	.04	.06
CO_2	3.42	4.37	.36	.12
	100.36	100.47	99.83	99.41
Wt. Norm				
Q	2.20	6.40	14.58	11.22
C	-	-	1.12	-
or	15.92	15.70	25.04	28.50
ab	36.71	32.83	22.08	33.67
an	13.41	14.63	16.86	12.96
wo (di)	4.92	3.40	-	1.00
en (di)	3.58	2.50	-	.77
fs (di)	.88	.58	-	.12
en (hy)	2.22	2.90	5.23	2.70
fs (hy)	.55	.67	4.24	.44
mt	9.31	8.43	3.89	3.98
il	4.93	4.58	3.23	2.26
ap	1.28	1.90	1.49	1.01
cc	?	?	?	.27
	95.91	94.52	97.76	98.90

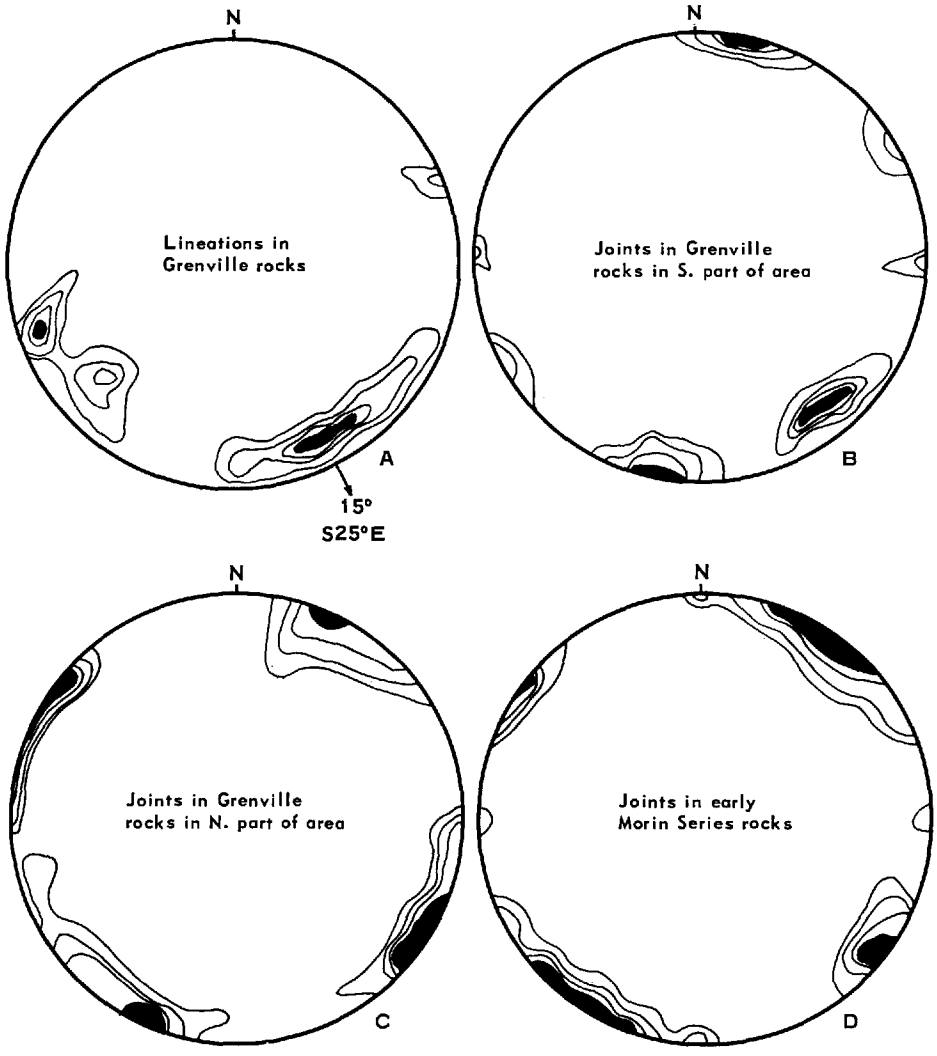


Figure 6

EQUAL AREA PROJECTIONS OF THE LINEATIONS (A), POLES OF JOINTS IN THE GRENVILLE ROCKS OF THE SOUTHERN PART OF THE AREA (B), POLES OF JOINTS IN THE GRENVILLE ROCKS OF THE NORTHERN PART OF THE AREA (C), POLES OF JOINTS IN THE EARLY MORIN SERIES IN THE AREA (D)

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Morin Series. With the exception of a tentative identification of glass in a pseudotachylite from the Gairloch district of Scotland (Park,1961, p. 548), the glassy pseudotachylite from Paillé lake is probably the oldest recorded undevitrified terrestrial glass. Geiss and Hess (1958) have determined the age of glass-bearing meteorites by the potassium-argon method to be over 4,000 million years.

The physical properties of the country rock are probably more important in the formation of pseudotachylites than the environmental conditions.

PLEISTOCENE

A thin veneer of till covers most of the area. However, it is only in the northwestern part and directly northeast of Eau-Claire lake that it is sufficiently thick to make outcrops scarce. Some of the valleys are filled with sand, which was probably deposited in small lakes following the retreat of the last ice sheet. Large deposits of such sand occur in the valley of Loup river at the western border of the area, at the northwestern end of Caribou lake, and around Wapizagonke lake.

Glacial striations are uniformly S.35°E. They are, however, not very abundant.

STRUCTURAL GEOLOGY

The rocks of the Belleau-Desaulniers area have undergone only moderate deformation, with the result that their structure is simple, with dips in the gneisses rarely exceeding 40°, and usually being 10°-20°. The area occupies part of the "quasi-plateau" region that is bounded to the south by the Ottawa fold belt and to the north by the Saguenay fold belt (Osborne,1936c, p. 413). Several northeasterly trending faults occur, the most southern of which is of major regional importance.

Folds

The area is underlain largely by an open syncline plunging to the southeast. Most of the area lies on the nose and northern limb of this fold, with the result that dips are generally to the south. The southwestern limb of the fold is exposed only along the western border of the area where dips to the east are common. In the extreme northeastern part of the area the rocks are flat or, in places, dip to the north.

Apart from the major syncline, there is only one other fold of significant size in the area. It occurs in the northeastern limb of the

syncline in the vicinity of Larose lake, and is of interest because, although it is a fold with considerable amplitude, it does not continue northward or westward through the rest of the paragneisses in the area. Instead, it ends abruptly to the north along a zone of sheared rocks that trends southeasterly along the valley entering the southeastern end of Barnard lake. To the west the fold also ends abruptly against several northeasterly trending faults that dip gently to the east under the fold. The fold is a syncline containing Upper Grenville paragneisses and anorthositic rocks of the Morin Series that have been thrust over the Lower Grenville amphibolites along the shear zone. The gently dipping faults on the western side of the fold appear to be intermediate between thrust and tear faults.

Lineations

Lineations are common throughout the area in all types of rocks. In those containing considerable amounts of quartz the lineations are usually due to the quartz being in rods or leaves, whereas, in those lacking quartz or containing very little, they are produced by the elongation of the ferromagnesian minerals or by the concentration of these minerals into strings within the foliation plane. In the coarse-grained igneous rocks, such as mangerite and quartz monzonite, the feldspar augen impart a lineation to the rock.

In Figure 6A the lineations in the rocks of the Belleau-Desaulniers area are shown on an equal-area projection. There are clearly two prominent directions of lineation: one plunging 15° in a direction S.25°E. and the other, 15° in a direction S.70°W. A third, less prominent lineation plunges 25° in a direction S.50°W. The southeasterly plunging lineation was found throughout the area and coincides with the axis of the major syncline, and is, therefore, a "b" lineation. The two westerly plunging lineations occur only in the northern part of the area, in particular north of a line passing through Shawinigan and Pembina lakes. The more prominent of these two (15° towards S.70°W.) forms a small segment of a girdle normal to the southeasterly plunging "b" lineation and may, therefore, be an "a" lineation. The reason for the "b" lineation being more prominent in the south, and for the "a" lineation being restricted to the north, may lie in the difference in the form of tectonic deformation between the two parts of the area. In the south, the stress was released by folding of the Grenville sedimentary rocks into a large syncline, with the result that a prominent "b" lineation was developed. However, in the northern part of the area, where the gneisses are in many cases horizontal, movement may have taken place with one layer of gneiss sliding over another producing an "a" lineation, although in places of minor folding a "b" lineation was also formed. There is also a possibility that the westerly plunging lineation is due to a later period of folding that took place at right angles to the earlier one.

It appears likely that the more steeply plunging southwesterly lineations (25° towards S.50°W.) were formed at a later date than those associated with the major southeasterly plunging syncline. Osborne and Lowther (1936, p. 1360) have found that, at Shawinigan Falls, there are two periods of deformation that have produced an earlier northwesterly trending set of folds (N.40°W.) and a later north-northwesterly trending set (N.20°E). The effects of the folding that produced the major syncline in the present area can be traced across the Shawinigan map-area (Béland 1961) to Shawinigan Falls, where the northwesterly trending folds referred to by Osborne and Lowther occur. The axis of folding changes slightly between these two areas, being N.25°W. in the Belleau-Desaulniers area and N.40°W. at Shawinigan Falls. The southwesterly lineation also shows a similar rotation. The joint patterns provide evidence on the age relationship of these different lineations.

In the Shawinigan Falls area, the northeasterly trending folds are restricted to the southeastern part of the area where they follow the direction of Saint-Maurice river. In the present area, the southwesterly plunging lineations are restricted to the northern part. This suggests that the later deformation took place along northeasterly trending zones that left large parts of the earlier deformed rocks unaffected.

The few lineations obtained in the mangerites of the Morin Series appear to bear a relationship to this later northeasterly trending deformation. Although the lineations in the mangerites were found to coincide approximately with the plunge of the large syncline, they were consistently in a more easterly direction and at right angles to the later southwesterly plunging lineations. Since the deformation in the mangerites is thought to have been formed during the intrusion of these rocks, it is possible that the southeasterly trending deformation was formed by the same movements that accompanied the intrusion of the Morin Series. The various joint patterns lend support to this hypothesis.

Joints

Two well-developed steeply dipping joint sets are common in most of the rocks of the area. However, their relationship to one another varies from one part of the area to another. The poles of the joints in the Grenville gneisses of the area south of Shawinigan lake are plotted in Figure 6B. One prominent set, which dips steeply to the northwest, lies normal to the "b" lineation shown in Figure 6A, and a weak set is developed at right angles to this. These are probably extension and release joints respectively. The second prominent set strikes S.80°W. and is, therefore, at an angle of approximately 45° to the extension joints. Another very weak set occurs approximately 45° on the other side of the extension joints. These diagonal joints may have been formed by shearing stresses set up during the folding.

The joints in the Grenville gneisses of the northern part of the area form two mutually perpendicular, vertical sets (Figure 6C). The northeasterly striking set probably consists of extension joints. They strike more northerly than those in the southern part of the area and dip vertically, which suggests that the tectonic axis swings slightly to the west and becomes horizontal. The diagonal sets occurring in the south are not present in the north. Instead, a very well developed set occurs at right angles to the extension joints. Although there are well-defined maxima in Figure 6C, there is a much broader range in the orientation of the joints in the northern part of the area than there is in the southern. This is probably due to the second period of deformation in the north. The joints normal to the extension joints were probably originally release joints that later became the extension joints of the second period of deformation.

The poles of the joints in the earlier part of the Morin Series (anorthosite-mangerite rocks) have been plotted in Figure 6D. Although these rocks occur in the southern part of the area and intrude Grenville rocks, the joint pattern of which is that shown in Figure 6B, they show the joint pattern characteristic of the rocks of the northern part of the area, where the second period of deformation has taken place. This suggests that the stress pattern that caused the joints in the early Morin Series is the same as the one that caused the deformation in the northern part of the area. This supports the hypothesis that the southwesterly trending tectonic axis in this part of the Shield was produced by a "Morin deformation".

Many of the joints in the area, particularly those with a northeasterly strike, have probably been taken advantage of by the faulting that affected large parts of the area.

Faults

The only prominent faulting associated with the orogenic disturbances in the area is that which took place along the northern and western limits of the small syncline east of Larose lake.

Four northeasterly trending faults occur in the northern part of the area: at the east end of Dickingham lake; the west end of Maréchal lake; the center of Caribou lake; and the center of Wapizagonke lake. They all strike approximately N.35°E. and dip vertically. They are right-strike slip faults with a horizontal displacement not exceeding 3,000 feet. The actual fault plane was seen only in the fault that cuts the large cliff on the east shore of Wapizagonke lake. Although the fault passing through Caribou lake shows virtually no displacement, a very pronounced topographic linear extends from it across the entire map-area, from Brodeur lake to the valley that extends towards Gaucher lake. A similar linear extends from the southern end of Wapizagonke lake to Larose lake. There is no displacement of the rocks on either side of this linear, but the zone is occupied by very closely spaced joints.

A northeasterly trending fault passes through the southeastern part of the area, following the valley of the Pic-Elevé lakes, the northwestern shore of Eau-Claire lake and the northern shore of Souris lake. It strikes apporximately N.45°E. for most of its length, but swings sharply east at Souris lake. Although this fault has very little topographic expression in the present area, there has been considerable movement on it. The width of the fault zone, which in places is several hundred feet, and the large-scale development of pseudotachylites at several localities along the fault indicate the severity of the movement that has taken place.

As mentioned earlier, this fault extends northeasterly across the Shawinigan area and up the Saint-Maurice valley (Figure 7). The fault may continue farther north along the Croche River valley, for a very strong topographic linear extends northward along this river. To the southwest, the fault may continue and join with the Sainte-Julienne fault in the New Glasgow area (Osborne and Clark 1960, p. 33), or it may join with the faults separating the Paleozoic rocks from the Precambrian Shield in this part of the St. Lawrence Lowlands. The fault has been mapped over a length of at least 100 miles and may be as much as 200 miles long. Because of its magnitude and geographical relationship to the Saint-Maurice river, it would appear appropriate to call it the "Saint-Maurice fault".

The general attitude of this fault is N.15°E., but, between the point where it leaves the Saint-Maurice 10 miles south of La Tuque and the southern part of the present area, it follows a large easterly convex arc. The strike of N.45°E., which the fault has in the present area, is, therefore, characteristic only of the lower part of this arc. A dip on shear planes within the fault zone could be obtained only at the north shore of Souris lake, where the fault strikes N.74°E. and dips 40° to the south. Slickensides at this locality plunge 38° in a direction S.30°E.

Since the bend in the trace of the fault plane is so sharp in the vicinity of Souris lake (Figure 7), it would appear unlikely that there has ever been any large strike-slip movement on the fault. In fact, if the plunge of this sharp angle in the fault plane were known, it would probably give a relatively accurate direction for the movement on the fault. It is possible to determine this direction approximately from the attitude of the fault at Souris lake and the attitude given by Klugman (1956, p. 5; N.5°E., dip 45°E.) for the fault at La Tuque. The line of intersection of these two parts of the fault plunges 35° in a direction S.40°E., which corresponds very closely to the direction obtained from the slickensides at Souris lake.

A small fault branches off from the Saint-Maurice fault at Saint-Mathieu and extends westward to Larose lake. It was possible to make an accurate measurement of the attitude of this fault in the small cliff on the south side of the road leading to Larose lake. It strikes N.80°W.

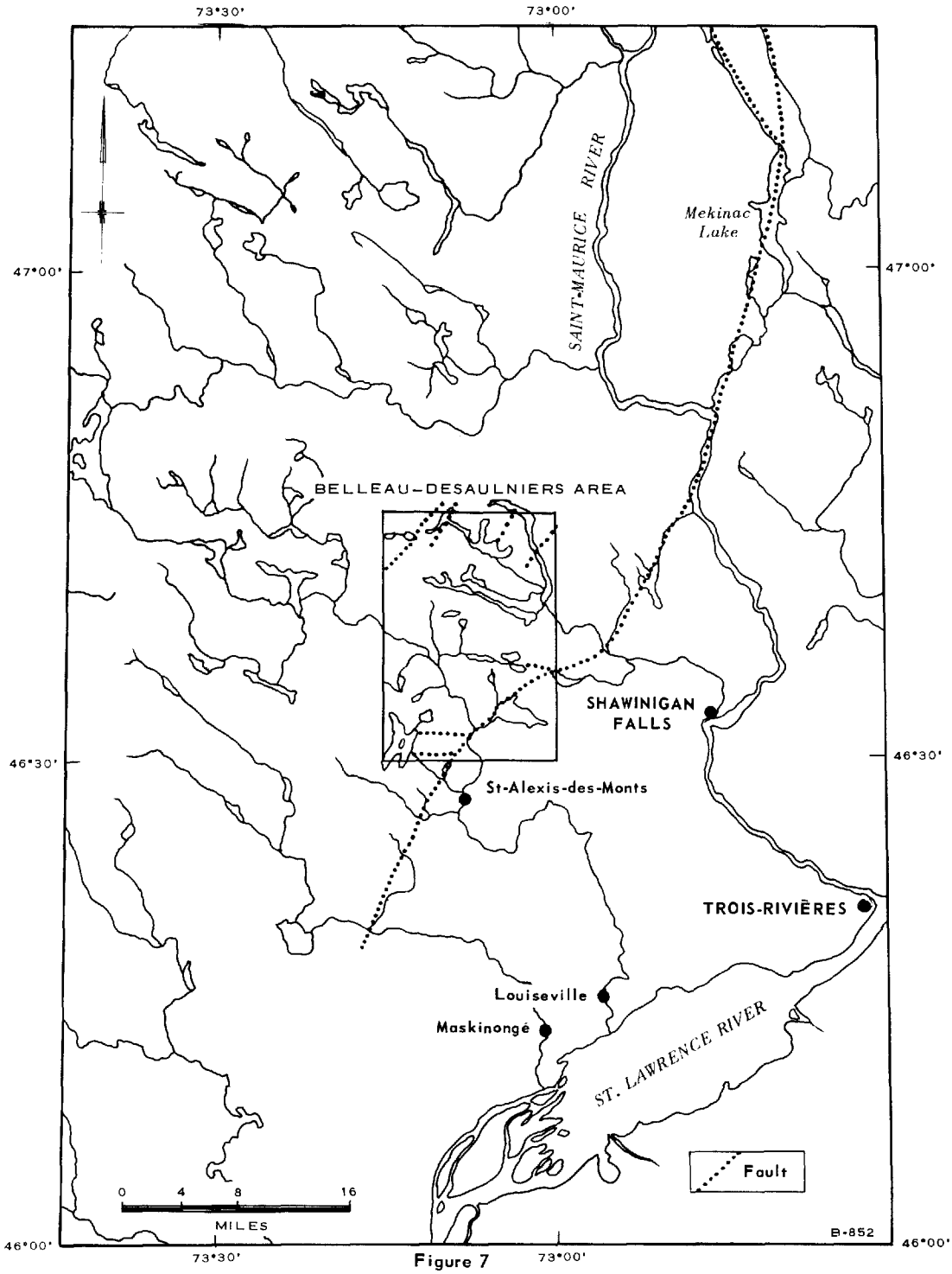


Figure 7

MAP OF THE LOWER PART OF THE SAINT-MAURICE RIVER, SHOWING THE MAJOR FAULT WHICH PASSES THROUGH THE SOUTHEASTERN PART OF THE BELLEAU–DESAULNIERS AREA. (COMPILATION FROM MAPS OF THE QUEBEC DEPT. OF NATURAL RESOURCES)

and dips 55° to the south. The line of intersection of this fault with the Saint-Maurice fault at Souris lake plunges 32° in a direction S.53°E, which again is very similar to the direction of the slickensides in the main fault. The drag in the paragneisses and the large mullion structures extending down the dip of this minor fault indicates that it is a normal dip slip fault (i.e., north side moved up). This small fault also has pseudotachylites associated with it and is undoubtedly of the same age as the Saint-Maurice fault. It is possible, therefore, that the Saint-Maurice fault is fundamentally a normal fault in the present area, and that the direction of slip plunges approximately 35° to the southeast. To the north and south of the present area where the Saint-Maurice fault strikes more northerly, the net slip would contain a fairly large strike slip component. Béland (1961) shows the fault on the Shawinigan map with the northwest side having moved up. It was not possible to determine the actual amount of movement that has taken place on the fault in the present area.

There has been more than one period of movement on the fault that branches off from the Saint-Maurice fault and extends to Larose lake. Traversing the mullion structures that plunge down the southerly dipping fault plane are slickensides plunging 10° in a direction S.77°E. and indicating a left strike-slip component. This second movement is not very severe and may have taken place at a much later date than the first.

Two other east-west-striking faults diverge from the Saint-Maurice fault in the present area. One of these leaves the main fault at Paillé lake and extends across to the northern end of Sacacomie lake. The largest development of pseudotachylites in the area was found near the junction of this fault with the Saint-Maurice fault. The other fault branches off at Pic-Elevé lakes and extends westward to the southern end of Sacacomie lake.

The pseudotachylites associated with the Saint-Maurice fault, and presumably formed during the severest movements on it, have an absolute age of 900 million years. The fault, therefore, must have existed at this time.

The coarse-grained quartz monzonite, which, with the exception of the granite, is the youngest rock in the area, is cut by the fault. However, in the vicinity of the fault, pegmatites associated with the monzonite commonly have a margin of black, aphanitic mylonite. It appears, therefore, that movement on the fault must have begun at the close of the intrusion of the monzonite.

Although the fault is essentially Precambrian, it is probable that a fault of such magnitude has had minor subsequent movements on it. If it extends to the southwest and joins up with the Sainte-Julienne fault

or with those that separate the Paleozoic rocks from the Shield, there must have been movements on it in post-Ordovician time.

ECONOMIC GEOLOGY

Sulfide mineralization has taken place in the body of anorthosite and norite directly east of Larose lake. Pyrite, pyrrhotite and pentlandite are the main sulfides present; there are also small amounts of chalcopyrite. Just to the east of the area in the same body of norite, notable concentrations of these minerals occur and preliminary work has been done on some claims at this locality by G. Simmons.

Some of the norite in the region of Souris lake and along the road to Larose lake has been badly shattered by movements associated with the Saint-Maurice fault. In these localities, the grains of magnetite-ilmenite in the norite have been replaced by pyrrhotite and pentlandite. The pentlandite occurs as small anhedral masses along the grain boundaries of the pyrrhotite and, in some cases, constitutes as much as 25% of the sulfide. The pyrrhotite itself has excellent cleavage, which suggests that it has a high nickel content. The plagioclase of the norite was the first mineral to be fractured and, consequently, it is traversed by many veins of pyrrhotite, pentlandite and chalcopyrite. The chalcopyrite occurs almost entirely in these fracture fillings in feldspar and only rarely as a replacement of the other sulfides and oxides. Veins of pyrite cut this mineralization and obliterate it in many places. Although some of the veins are fairly continuous, most of them are short gashes 2 to 3 inches long and 1/4 inch wide. Dark veins of pseudotachylite also cut the early mineralization. Fractures in the pseudotachylite are commonly coated with pyrite.

There are clearly two major periods of mineralization at this locality. During the first, pyrrhotite and pentlandite replaced grains of magnetite-ilmenite in the norite, and, during the second, pyrite was deposited in the many short gash veins that cut the earlier mineralization. On first examining the mineralization in the field, the writer considered the possibility that the pyrrhotite-pentlandite replacement of the magnetite-ilmenite grains was a very early phenomenon connected, perhaps, with the closing stages of the early part of the Morin Series. It was thought that the later faulting had remobilized the pyrrhotite and converted it to pyrite. However, when the polished sections were studied, it was found that there was no appreciable amount of sulfide present in the norites unless the rock was severely shattered. This indicates that the mineralization is associated with the faulting and not with the closing stages of crystallization of the norite. The mineralization occurred sporadically over an extended period of time and fresh veins occurred with each successive period of movement on the faults.

The association of the mineralization with the Saint-Maurice fault is an important fact in searching for further deposits. It is interesting to note that Klugman (1956, p. 5) states that the hanging-wall of the fault at La Tuque (Saint-Maurice fault) is mineralized. It is possible that the source of the ore minerals in the Belleau-Desaulniers area is the coarse-grained quartz monzonite believed to have been in its final stages of crystallization when the faulting began. The presence of magnetite-ilmenite grains in the rocks is also essential to the formation of the pyrrhotite-pentlandite mineralization. The jotunites, which contain up to 15% magnetite-ilmenite, would, therefore, appear to be the most likely rocks to be replaced. With these points in mind it is possible to point to several favorable localities for the occurrence of ore. The large body of norite occurring between Loup river and Douai lake is faulted into contact with the quartz monzonite along its northern side. This is a likely place for the occurrence of mineralization, but the large amount of sand that fills this part of Loup River valley makes the probability of finding an exposed mineralized zone very slight.

Uraninite occurs in many pegmatites, especially those associated with the coarse-grained quartz monzonite in the southern part of the area.

The extensive, coarse-grained, porphyritic, pink quartz monzonite in the vicinity of Saint-Alexis-des-Monts and in the southern part of the map-area would make a good building stone. It would be particularly suitable for an interior or exterior facing stone. Widely spaced joints, accompanied in many places by a horizontal primary foliation, would make the quarrying of the stone relatively easy.

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