THE GEOLOGY OF THE CANIMITI RIVER AREA
PONTIAC COUNTY, QUEBEC

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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INTRODUCTION

General Statement

The Canadian Shield is predominantly composed of rocks of Precambrian age. It contains numerous belts and isolated masses of volcanic and sedimentary rocks in which many of the gold and base metal deposits of Canada are found. These however, represent only a small part of the "Shield". The bulk of it is composed of gneisses and schists, believed to have been formed from ancient sedimentary, volcanic, and plutonic rocks, by metamorphism.

The close relationship between the "greenstones" and many ore bodies, has caused the prospector to neglect, or to pass hastily over the gneisses, schists, and granitic rocks, in his search for new areas of "greenstone". While geological investigation has been mainly concentrated in areas of present economic importance. A natural result of this neglect of the complex gneisses and granites, has been the development of a "feeling" that these rocks are barren, except for such minerals as mica, feldspar, apatite, molybdenite, etc. Little is known about the contact zones between the Keewatin-Timiskaming volcanic and sedimentary rocks and the surrounding gneisses. No one knows whether the ore deposits stop at the contact zones; but in this respect it is of interest to note, that the "Zinc-Lead Deposits" of Calumet Island, Quebec, the "Brucite Deposits" of Farm Point, Quebec, the "Lead Deposits" of Kingdon Mines, Ontario, the "Lead-Zinc Deposits" of Tetrault, Quebec, and the "Copper Deposits" of Sherritt Gordon in Manitoba, do not occur in "greenstones", but are associated with "Grenville type" metamorphic schists, gneisses, limestones, and quartzites.

Purpose of the Work

It was desired to investigate the area lying between the Keewatin-Timiskaming sedimentary and volcanic rocks mapped by Lowther (42) in 1935, and the area mapped by Wahl (71) in 1946, containing only granites, gneisses, and schists. With the hope of being able to shed some light on the ages and origins of the granites and gneisses, and possibly through them, to discover, some clue as to the relative ages of the Keewatin-Timiskaming rocks on one hand and the Grenville Rocks on the other. The ultimate aim being to determine the possibilities of finding ore in this and other similar areas.

Method Used in Surveying the Area

The rocks were mapped by means of pace and compass traverses, spaced at half mile intervals. Base maps on the scale of two inches to the mile, and aeroplane photographs, enabled the traverses to be planned, checked, and tied in to topographic features. All exposures on lake shores were examined wherever possible. Highway 58 has consecutive mileage signs, which give the distances from the town of Val d'Or, and these provided useful ties for the recording of road-side exposures.

Extent and Location of the Area

The area consists of roughly 200 square miles. It lies between latitudes $44^{\circ}30'$ to $44^{\circ}45'$, north, and longitudes $77^{\circ}00'$ to $77^{\circ}15'$, west; in the northern part of Pontiac County, and covers a part of the Senneterre-Mont Laurier provincial game reserve. The northern boundary of the sheet is approximately 41 miles south of Senneterre, a town some 300 miles northwest of Montreal.

Means of Access

The Senneterre-Mont Laurier highway (No. 58) passes diagonally through the southwest corner of the map sheet, and provides direct access by automobile from Montreal, (270 miles) and the towns of Val d'Or, and Senneterre (both 53.3 miles). The highway enters the area at mileage 53.3 (from Val d'Or) and leaves it at mileage 66.

The town of Senneterre is situated on the Canadian National Railways, Northern Transcontinental Line; Val d'Or is on a branch line, which runs between Senneterre and Noranda.

A daily bus service connects the town of Noranda, Val d'Or, and Senneterre, with the cities of Montreal and Ottawa, and passes through the area making flag stops where desired.

Aeroplanes on pontoons can be chartered at either Val d'Or or Senneterre for trips into those parts removed from the main water routes.

Previous Geological Exploration and Investigation of the Region

Robert Bell in 1887, (10) ascended from Lake Timiskaming to Grand Lake Victoria by way of Lake Kipawa, and the Dumoine River. He explored the headwaters of the Ottawa River, then crossed the divide into the Gatineau River watershed, and returned by this river to Ottawa. Later in 1895, he returned to Grand Lake Victoria, passing northward to explore the Bell River. (11)

Between 1907 and 1912, M.E. Wilson reported on many sections of northwestern Quebec, including the Kipawa-Grand Lake Victoria region. These are covered in a memoir published by the Geological Survey of Canada. (72) It contains the first comprehensive study of the complex gneisses in this region.

In 1932, L.V. Bell (12) reported on the complex gneisses in the Foch area. In 1933, J.A. Retty made a reconnaissance survey of the "Upper Gatineau Region". (54) Lowther mapped the "Villebon-Denain Area" in 1935. (42) Aubert de la Rue, made a reconnaissance of the Mont Laurier-Senneterre Highway in 1941, (26) and later in 1946, G. Wahl and F.F. Osborne reported on the complex gneisses of the Cawatose Basin. (71)

In 1946, Norman did detailed mapping of the Keewatin-Timiskaming volcanic and sedimentary rocks along their contact with the complex gneisses in Haig and Pershing townships. (48) (49) Tiphane continued this work in 1947, carrying the mapping further to the southwest. (67) (68)

Drainage

The area is just within the St. Lawrence River watershed and close to the Hudson Bay divide. It is drained by the Ottawa River, (of which Lake Soulier and Dozois are a part) and its tributaries, the Chochocouane and the Canimiti.

Travel Within the Area

The Ottawa, Chochocouane, and Canimiti Rivers afford excellent canoe routes; there are numerous rapids in the latter two rivers, and in two places on the Chochocouane, there are falls with drops of between 15 to 20 feet, but in most places portages have been provided and few are more than two or three hundred yards long. The Ottawa is entirely navigable for canoes within the area except for one place near the mouth of the Blind River.

In those parts removed from the main rivers, travel by canoe is difficult since the streams are shallow and have numerous small rapids; they are often filled with "windfalls", and portages where formerly provided have long since grown over. Canoes may be launched directly from either the Ottawa or Chochocouane bridges of Highway No. 58, for trips into the south or central parts of the area.

A good bush road maintained by the Canadian International Pulp and Paper Company,(1) extends eastwards from mileage 46 (from Val d'Or) on the highway, past the northeastern corner of the sheet as far as the Chochocouane and Denain Rivers. This gives easy access by canoe to the northern sections and eliminates the numerous portages which otherwise would have to be made in ascending either the Chochocouane or Canimiti Rivers.

<u>Population</u>

Temporary settlements are located at the Chochocouane River crossing of Highway No. 58, and are known

(I) Henceforth referred to in this thesis as the C.I.P. & P. Company road.

as "Murdock's" and "Paree's Camps". The inhabitants are local road construction and lumber company workers, and in all, probably number less than 200 persons at any time. There is a general store in which food may be purchased, but there is no regular accommodation for tourists. A small Indian encampment located on the banks of the river, contains only one or two families.

The Department of Lands and Forests of Quebec, maintains a district office here for the supervision of woods operations, and the Ottawa River Forestry Protective Association has a district headquarters where the highway crosses the Ottawa River.

The nearest tourist accommodation is at Camp d'Or Val, some 8 miles south of the Ottawa River along the highway, and outside the area.

Climate

The climate is rigorous, with short but hot summers during which there is a moderate rainfall. The winters are cold with abundant snow. After the sun sets in the summer, the nights frequently become cool, and frosts are not unknown. A more elaborate discussion of the climate is given in the report by Wahl if further information is required. (71)

NATURAL RESOURCES

Pulp Wood Cutting and Lumbering

There are large tracts of spruce, and smaller stands of white pine, red pine, and jack pine. The northern two thirds of the area are under lease to the Canadian International Pulp and Paper Company, and the Southern part is leased or owned by the C. and G. Dent Lumber Company. Their mill having a capacity of some six million board feet per year, is on the Camatose River, about 24 miles south of the boundary of the present area.

Much of the forest along the eastern boundary has been burnt within the last forty years, and the area is now covered by a heavy growth of white and yellow birch, poplar and mountain maple.

The spruce in the area is healthy and relatively free from blights, but the white pine in many cases is suffering from a trunk rot, and many fine trees of large size were found broken off at the base and completely rotted away inside.

A noteworthy example of the natural reforestation of white pine occurs along the southern boundary of the sheet, between the east and west arms of Lake Soulier, in the Dent Lumber Company limits.

Farming

The area is not suitable for farming since the only lowlands are underlain by sandy soils, or moisture retaining clays, and because there is danger of destructive summer frosts.

Power

Neither the Chochocouane nor the Canimiti Rivers have sites capable of providing more than a few thousand horse power. But a large power dam is being constructed at the "narrows" on Lake Dozois (Big Birch Lake), to the west of this area, and will have a capacity of approximately 75,000 H.P.

The Dozois Lake dam when closed, will raise the water in the Ottawa River and its tributaries in the area, from the 1105 foot to the 1135 foot level, and will turn much of the southern part of the area into a vast swamp. (A map showing the area to be inundated accompanies this thesis.)

Game

The map sheet is a part of the Mont Laurier-Senneterre provincial game reserve, hunting is prohibited, but fishing is permitted in season. The rivers, streams, and lakes, are plentifully stocked with fish amongst which are the great northern pike, white fish, and the pickerel or dore; no trout were seen but many of the lakes and streams in the eastern half of the sheet, with their rocky or sandy basins and clear cool water, are well suited for these fish.

Bear are numerous and at times a great nuisance to campers, since they are readily attracted by unburied refuse, or food not properly cached.

Beaver are found, and probably one-fifth of the small lakes in the area owe their existence to beaver dams. One dam observed was at least 125 feet long and at the centre of the stream, was retaining a wall of water about 5 feet in height.

Moose are not plentiful and unless they are given more protection, will suffer the same fate as that of the beaver. In this respect, it should be mentioned that the Game Wardens have carried out their duties with the utmost diligence, but are handicapped by an area which is too large to supervise, and by the inability of the public to realize what the extinction of these fine animals would mean.

Partridge are exceptionally plentiful, while fox and muskrat were occasionally seen in the various parts of the area.

GEOLOGY

Introduction

The rocks of the area are predominently gneisses and granulites (I) whose original compositions and structures have been so altered by metamorphism that their origins are obscure. Sharp contacts appear to be non-existent, and metamorphism has produced a similarity in appearance which makes mapping off formations extremely difficult.

It was decided after considering the high grade of metamorphism prevailing in the rocks, that the only feasible method of classification would be on a purely mineralogical basis. (i.e., according to the minerals identified in the handspecimen; thus a gneiss would be called a "biotite, feldspar, quartz, gneiss", if it contained all those minerals.) It was hoped that in the manner of Barrow (9-pp.274-290) zones could be delimited which would throw light on the origins and compositions of the original rocks.

The mapping was carried out using biotite, garnets, hornblende, and pyroxenes as index minerals; but it was

(1) The term is used with reference to their granular appearance, and without implication of origin or composition.

found that the garnets overlapped into the biotite and pyroxene-bearing rocks, and so it was necessary to restrict the garnet gneisses to all those rocks containing 5 percent or more of garnets and less than 5 percent of hypersthene.

The map which accompanies this thesis shows those areas where rocks containing a predominant index mineral occur, but it does not exclude the occurrence in small amounts of rocks in which there are other index minerals.

Banding or layering and foliation (see definition of these terms under "Structural Geology") have been found to conform with each other everywhere within the area; and their attitudes are represented on the accompanying map by strike and dip symbols. Mica and chlorite schists are rarely found, and bedding has not been definitely recognized, although it is thought to exist.

GEOMORPHOLOGY

Topography

The maximum relief so far recorded within the area is 658 feet and is between the Kanimiti geodetic station (elevation 1763 feet), which is one mile east of the south tip of Gremilin Lake in the west central part of the sheet, and the Ottawa River at its junction with the Chochocouane (elevation 1105 feet). The average relief is 200 feet, but in a few localities such as west and southwest of Elbow Lake, and along the eastern boundary, some hills rise to heights of from 350 to 400 feet above the adjacent valleys.

In general the surface is one of contrasting elevations and depressions, with numerous small, but few extensive lowlands. Many of the hills have pronounced elongations with marked trends in a north or north-easterly direction. These trends are reflected in the courses of streams and lakes, being more pronounced in some sections than in others. The hills, whether of the elongated or irregular pattern, have steep north-to-west-facing slopes characterised by numerous scarps, rising above valleys containing either lakes or streams. In contrast the back slopes of these hills are less steep and show few rock exposures. (See Plates Nos. 1 and 2)

The most extensive lowlands in the area are east of the Chochocouane River in the central and southern parts of the sheet. These are sand plains covered by young jack pine. Spruce muskegs are best developed along the northern reaches of the Canimiti and Chochocouane Rivers and along the south bank of the Ottawa west of the highway.

Explanation of Topography

A view of the region from one of the higher ridges in the area shows numerous hills dotting the country, most of which are approximately equal in elevation. This rough accordance probably represents the "Laurentian peneplane", which Cooke believes was elevated high above the sea during the Pliocene, and was accompanied by faulting. (22-p.51) (See Plates Nos. 3 and 4)

The elongated hills with steep and rocky west to north sides, and gentle, soil covered, east to south facing back slopes, are undoubtedly a reflection of underlying rock structures. The steep scarps are in many cases composed of well foliated, and at times plated gneisses, having strikes parallel to or nearly parallel to the long axes of the hills, and dips going in the direction of the more gentle back slopes.

Some hills, in particular the higher ones, have sill-like slightly foliated or unfoliated masses of acidic igneous rocks; these also strike roughly parallel to the trends of the ridges, and dip in the direction of the back slopes.

At the bases of some scarps, sheared-looking "flaser" gneisses with pseudo-slickensided surfaces have been found which may indicate that some of the valleys and the adjacent hills are the result of erosion along zones of faulting. Lowther (42-p.51) found that in the northern part of his area similar scarps strike transversely to the direction of recognizable bedding; which is undoubtedly proof of their fault origin in the adjacent area to the north.

Wilson (72-p.39) has discussed the linear valleys of the region in some detail, and cites evidence to show that they must be the result of faulting which occurred between post-Silurian and pre-Pleistocene times. However, serious consideration should be given to the possibility that some of these valleys may have arisen by differential erosion as between limestone or garnet gneiss on one hand, and the more resistant granite rocks that frequently underlie the ridges. In this respect it should be pointed out that experience in making thin sections of highly garnetiferous rocks indicates that the garnet gneisses though hard, are very friable, by virtue of the fractured nature of the garnets.

In addition to the regularly oriented hills, there are irregular or round hills, which appear to be in places where faulting or jointing does not coincide with the strike of the foliation, or where the foliation directions form folds. A good example of this may be seen north of the Kanimiti geodetic station, in the west central part of the sheet. Other irregularly shaped hills are caused by the erosion of homogeneous rocks, such as the syenites, that underlie much of the southeastern corner of the sheet. Here the hills are relatively low, and well rounded by glaciation, but there is still an overall pattern which suggests faulting or jointing.

The noteworthy absence of numerous glacial stoss and lee forms on the hills of the area, can only be explained by the attitudes of the underlying rock structures. It is thought that the ubiquitous banding of the rocks probably acted as reinforcing, giving them a resistance which prevented their breaking along joint planes. This would tend to arrest the formation of the lee forms, while the northeasterly strikes and southeasterly dips of the foliations and banding, would present a strong front to the ice movement from the north, and so decrease the tendency for the ice to carve stoss slopes.

In the northeast part of the sheet, just east of the Elbow Lakes and south of the fault shown on the accompanying map, there is a fold-shaped hill that may represent an individual garnetiferous formation. The outlines of the hill have been shown on the map; but only coloured in those places where exposures were observed.

The trends of rivers, streams, and lakes, to a large extent conform with that of the foliation and banding in the various parts of the sheet, as may be confirmed by a glance at the accompanying map. But Lake Tombbah, Gabbro Lake, Lac des Montagnes, the Ottawa River west of the highway, and the eastern parts of the Elbow Lakes, have trends which are nearly east-west, and disrupt the general northeasterly trend of the area. These show a marked coincidence in trend with the strikes of the known or suspected faults and are believed to follow fault zones.

Those portions of the Ottawa River which were transverse to the direction of the ice movement, and parallel to the rock foliations, must undoubtedly be pre-glacial. The position of Lake Soulier is interesting for the manner in which it curls around the hornblende syenite stock; and it requires little imagination to visualize its formation in an early geological period, as a result of differential erosion along the contact between the syenite and the surrounding gneisses.

The Canimiti River on the other hand, for some two or three miles below the Elbow Lakes, wanders over flat muskeg areas underlain by clay and moraine. It passes between small hills or ridges and then takes up a predominant southerly course, becomes narrow, and has numerous bedrock rapids. This youthful aspect of the southern part of the river valley probably indicates that here, it is of post-glacial origin.

The northern part of the Canimiti enters Elbow Lake through a long straight southwesterly trending valley, which is directly in line with another that encloses the long southwest arm of the lake; and it seems possible that the Canimiti may formerly have continued on to the southwest. This course may have been blocked by an eastwest fault. A suspected fault of this nature is indicated on the accompanying map at the eastern end of the Elbow Lakes.

Pleistocene

During the Pleistocene, the area was undoubtedly covered by ice, as evidenced by the large erratics and striated surfaces that are to be seen on a few of the higher hills. Few good striae were observed, but those seen indicated an ice movement of from south to S 10^{o}E.

The Ottawa and Chochocouane Rivers occupy the broadest valleys in the area, in which much moraine was deposited. Both rivers in places upstream from natural barriers such as rapids, have aggraded their beds and built levees, behind which there are small lakes and swamps.

West of the Chochocouane, just above its junction with the Ottawa River, there are several sinuous esker-like forms, one of which splits into two branches towards the south end, while to the north it tapers out and terminates against a hill. No detailed examination was made, but it is possible that these are crevasse fillings. (32-pp.410-16) In addition, there is a perfectly circular, dome-like hill which consists of water-worn pebbles and sand; this is thought to be a deposit formed by a "moulin" in stagnant ice. (41-pp.298-9)

The size of the Ottawa River Valley in this vicinity, and the way it lies transverse to the direction of the ice movement, indicate that it must be of pre-glacial origin.

Fluvio-glacial deposits are found locally throughout the area. They are well stratified sands and gravels with marked cross-bedding, or poorly sorted sands and gravels with many large erratics scattered throughout. The cross-bedding shows no consistent direction of formation, indicating shifting currents. Gravels in some places, form thin and narrow lenses of well-water-worn pebbles. Possibly, these are the result of some temporary torrential current, coming from a stagnant ice front. Large boulders appear to be more numerous in the less stratified deposits of finer grain, but which nevertheless have some cross-bedding, and these are generally thought to have been derived by ice rafting in post-glacial lakes.

A small sand plain occurs in the northeast corner of the sheet along the C.I.P. & P. Company road, and another much larger one lies to the east of the Chochocouane River in the central part of the area. Between Lakes Tombbah and Soulier, the country is strewn with much morainic material. An esker which starts in the node of Cultus Creek, extends southwards for about a mile and terminates in an area containing many erratics and a few small sand plains.

REGIONAL GEOLOGY

Lowther (42), and Tiphane (67), (68), mapped the area to the north,and have shown it to be underlain in the northwest half by Timiskaming and Keewatin-type sedimentary and volcanic rocks, many of which are altered to amphibolites, and intruded by hornblende syenite. There are in addition, muscovite and/or biotite bearing pegmatites. The southeast portion contains only biotite and garnet gneisses, that are a continuation of those found in the present area. Tiphane considers the boundary between his gneisses and the Keewatin-Timiskaming rocks to be a fault zone which extends diagonally across his sheet in a northeasterly direction.

Wahl (71) reported on the area to the south where the rocks are predominantly biotite, biotite garnet, and biotite hornblende paragneisses, along with biotite and hornblende-bearing granite orthogneisses. In addition, there is a large quartz syenite intrusive that extends across the northern boundary into the southeast corner of the present area. He found one small exposure of Grenville type limestone and quartzite, and another containing sillimanite gneiss. (71-p.6) This find is of importance, inasmuch as it shows that metamorphosed sedimentary rocks are present in the region, some of which may be of Grenville age.

Retty (54) carried out a reconnaissance survey to the east, and reported biotite and garnet gneisses, granites, granodiorites, and a few small patches of Grenville type limestone and quartzite.

The geology of the Canimiti River area is in marked contrast to these areas; no Grenville type limestones, quartzites, or sillimanite gneisses have been found, and orthogneisses are only known in a few small exposures. Volcanic and sedimentary rocks have not been found, but their metamorphic equivalents are undoubtedly present amongst the gneisses and granulites. On the other hand, composite or hybrid gneisses are numerous and are characterized by small amounts of a "sanidine-anorthoclase" mineral, while hypersthene, which has hitherto not been reported in the rocks of the surrounding regions, is ubiquitous throughout the area.

As in the other areas, save Wahl's, there is a structural trend in a northeasterly direction which is reflected in the topography. It is particularly noteworthy for its rough parallelism to the suspected fault zone between the Keewatin-Timiskaming rocks and the gneisses. (See Regional Map)

GENERAL GEOLOGY

The rocks in the area are biotite, biotite garnet, and hypersthene gneisses and granulites[(1)] thought to have been formed by the metamorphism of pre-existing volcanic and sedimentary rocks. Composite rocks which have resulted from igneous injections and metasomatism of pre-existing rocks, have both igneous and metamorphic characteristics, and display gradations into the other metamorphic facies.

Metamorphism has been of such a grade that schists could not develop. Granoblastic textures with a slight directive structure are the rule; but in restricted zones

(1) The term is used with respect to their granular appearance, and carries no implication of either origin or composition. However, there is a definite similarity to those described by Adams (1-pp.78-82) from the Grenville area.

there occur plated, or "flaser" pegmatites and gneisses, which are thought to be the equivalent of the sheared zones found in other less metamorphosed regions.

Hypersthene granulites are well represented along the eastern boundary between Lac des Montagnes and Lake Tombbah, and also in the southwest corner of the sheet. Here, however, they are more strongly foliated and contain some mafic inclusions or layers and zones of garnet gneiss.

Garnet gneisses occur throughout the area but are particularly common in the localities to the west of the Chochocouane River. They grade into or are intermixed with both hypersthene and biotite gneisses and granulites.

The biotite gneisses are generally restricted to those areas east of the Chochocouane, where discontinuous zones between one and two miles in width, form a belt which extends from the south and central part of the boundary, diagonally northeastwards up to and beyond Lac des Montagnes. Another area is found in the very southeast corner of the sheet near the Blind River. These rocks as a group are much injected by igneous material and contain numerous small exposures of pink "flaser" or "augen" gneiss. Garnets are nearly always present, but in minor quantities (less than 5%).

Composite gneisses are most common in the northern part of the area. They are medium to coarse grained igneous textured rocks, having compositions approximating quartz diorite, and grade into finer grained, and often well-banded rocks rich in hypersthene and garnets. The banding is in part due to pegmatitic injections along bedding or planes of foliation, and in part, to original variations in composition from layer to layer. (See Plates Nos. 9, 10, and 11)

A short distance beyond the western boundary in the northwest corner of the area, there are some small exposures of "greenstone" that may be sedimentary or volcanic rocks; yet they could be disrupted dykes. They are considered to be younger than the adjacent highly metamorphosed gneisses, by virtue of their much lower metamorphic grade, but they are definitely older than the red quartz diorite and syenitic pegmatites which are seen to intrude them. It is not improbable that their positions could be the result of faulting, or of an unconformity.

It is thought that some of the "greenstones" may have been incorporated into the composite rocks that are found in the vicinity of Composite Lake. Their proximity to the Keewatin-Timiskaming rocks, suggests that they are of similar origin and age.

The earliest intrusives are the white to grey quartz diorites and associated grey to pale pink pegmatoid and pegmatitic sills and dykes. There are no large masses, but they appear to underlie the whole area, and to have provided the material for most of the lit-par-lit injections.

Massive igneous rocks from hypersthene gabbro through quartz diorite to quartz syenite, form the largest individual intrusive bodies in the area. These are only cut by their associated syenitic and granitic pegmatites; all the more acidic members of this group including the pegmatites are characterised by their pink to reddish colour. Tiphane (67) considers the syenites of the area mapped by him to be post-Timiskaming, and since those in this area have a similarity in trend and composition, they are tentatively considered to be of the same age.

There are several small exposures of a medium grained mottled green and grey, massive rock in the vicinity of Gabbro Lake; these may be either hornblende gabbros or amphibolites.

One late coarse grained granitic dyke cuts the composite gneisses and is unlike anything seen elsewhere in the area, but a similar dyke occurs outside the northwest boundary on the highway near McLaurin Lake, where it intrudes amphibolitic and garnetiferous gneisses.

A few basic dykes have been found, some of which have been only weakly metamorphosed; but little is known about their associations and origins save that they transect the gneisses and granulites.

Basic layers, lenses, and inclusions, are found in the granulites and gneisses, some undoubtedly represent early intrusives that have been pinched or rolled out during the deformation of the enclosing rocks, but others are probably of agglomeratic or conglomeratic origin. An analysis of one relatively large mass indicates that it was probably a peridotite. One "relic" dyke is now recognised only in outline, and by remnants of basic material at its centre. It shows that some basic dykes pre-date metamorphism, and intruded already banded rocks. In addition, it demonstrates that fluid action must have played a major role in the transformation of the rocks in the area.

The rocks have been strongly folded by regional stresses, and faults, though only proved in two instances, are probably widespread. This is suggested by the common regional trend of the topography and foliation, and by the presence both in place, and as erratics, of numerous "flaser" gneisses.

A table of the rocks found in the area is given below and a geological map showing the distribution of rock types is in the pocket at the back of the thesis.

TABLE OF THE ROCKS OF THE AREA

PLEISTOCENE and RECENT	Sands and Gravels

PRECAMBRIAN
Post-Timiskaming?

Basic Dykes:		Metadiabase, augite porphyry, metagabbro?
Pegmatites	1.	Quartz diorite, syenite, granite, pink red and brown colours, medium to coarse grained
	2.	Granitic, coarse grained and grey green
Aplites and (Quartz porphyry dykes.?)		
Quartz diorite, granodiorite, hornblende syenite, quartz syenite		
Gabbro	1.	Hypersthene gabbro
	2.	Hornblende gabbro (amphibolite)?
Composite Gneisses	1.	Well banded may contain either or both hypersthene and garnets and grade into type 2a
(assoc. with late quartz diorite)?	2.	Massive igneous textured, may contain mafic bands, possibly assimilated "greenstones", composition approximates to quartz diorite,
	2a.	Massive igneous textured grades into type 1. contains "sanidine-anorthoclase"

\- - - - - - - - - - - - Intrusive Contact - - - - - - - - - -

"Greenstones"? or Dykes?	Outside northwest boundary

\- - - - - - - - -Unconformity ? Fault Contact ? - - - - -

Quartz porphyry dykes?

Quartz diorite orthogneiss, quartz diorite, granite stocks and associated pegmatoid and pegmatitic (lit-par-lit) sills, pink pegmatite "flaser" and "augen" gneisses, graphic pegmatite

TABLE OF THE ROCKS OF THE AREA (cont'd)

Composite gneiss, no large exposures, mostly lit-par-lit injections
Basic dykes or sills - rich in hypersthene (peridotites?)

- - - - - - - - - - - - - - Intrusive Contact - - - - - - - - -

PARAGNEISSES (in part)

Microcline, plagioclase, quartz gneiss.
Biotite, quartz, feldspar gneiss.
Biotite, garnet, feldspar, quartz, gneiss.
Hypersthene, quartz, feldspar, biotite, granulites and gneisses.
Hypersthene - augite - hornblende rocks (layers or sills). Small masses, in part believed to have been sedimentary rocks.

PETROLOGY

PARAGNEISSES
(in part)

Hypersthene - Augite - Hornblende, Rocks (Layers, Sills and Inclusions)

Description

These are dark green, massive, fine to medium, coarse grained rocks, consisting essentially of hypersthene, augite, and hornblende in various proportions; a few types may contain biotite, sericite, chlorite and carbonates.

Occurrences

One variety outcrops on the east bank of the Canimiti River, about 3 miles above its junction with the Chochocouane. It contains large porphyroblasts of hypersthene, (up to 1.5") in a medium grained groundmass of hypersthene, augite, and hornblende. (See Plate No. 15) It is a layer or lens about 125 feet thick, but otherwise of unknown extent. The coarsest facies is at the centre of the mass. This decreases in grain size towards the only visible contact with the garnet gneisses. Near the contact the porphyroblasts disappear, hornblende becomes the predominant mineral, and the rock grades into the gneisses over a distance of a few inches. The contact strikes N 60°E, and dips 50° southeast. An analysis of this rock is given in Table 1.

Two miles north from the junction of the Canimiti River with the Chochocouane, there is a questionable shear zone some 10 feet wide in the bed of a small creek, which strikes west and dips to the north at 50° to 60°. The rocks are green, very micaceous, and slightly chloritic, yet contain much coarse hypersthene, and are not real schists. (See Plate No. 16) It is thought that the aforementioned coarse grained porphyroblastic rocks and those in the shear zone were formerly the same, but formed different facies as a result of different types of metamorphism; the former thermal, and the latter dynamic.

Near the suspected fault zone at the east end of the Elbow Lakes, a small exposure contains a green micaceous, hypersthene rock interbanded with biotite gneiss. The banding strikes N 20°E, and dips 25° to the southeast. The rock appears to be a schist, but it contains mica only on certain planes; while the greater part of the rock consists of a green pyroxene. A thin section of this rock showed hypersthene (65%), augite (20%), and biotite (10%), with accessory amounts of quartz and plagioclase An_{40}.

Basic layers or lenses are found in the granulites and gneisses south of the Nose Lakes in the southwest corner of the sheet. They are of two types; one is brown to dark brown, medium grained, and is essentially composed of a dark brown hornblende, with lesser amounts of augite and/or hypersthene; (Plate No. 17) the other is green to dark green, fine to medium grained, and contains hypersthene, augite, hornblende, biotite, plagioclase, and accessory quartz. Both types occur as narrow isolated layers or lenses, rarely more than a few inches in thickness, and seldom of great length. The latter type is more common and has also been found as small elliptical masses in the granulites that resemble volcanic bombs. (See Plate No. 19) In all the observed exposures, the bands are conformable to the foliations of the enclosing rocks.

In the same area south of the Nose Lakes an exposure of coarse reddish hypersthene-bearing pegmatite, contains numerous irregular shaped but rounded inclusions of a green fine to medium grained hypersthene bearing rock, similar to those occasionally found in the granulites. Approximately one-half mile east of here, another exposure shows a pink non-biotitic medium grained pegmatite lying beneath some narrow even banded biotite gneisses or granulites. The contact between these rocks and the pegmatite is slightly irregular, and at one place there is a dark green hypersthene-rich inclusion, very similar to those described above; but whether this rested in or on the pegmatite could not be determined. It is possible that these exposures represent unconformities along which pegmatites were intruded.

A dark brown, medium grained, micaceous hornblende-pyroxene band or lens, crosses Highway 58 some 400 yards north of Gabbro Lake; it is roughly 10 feet wide and of unknown length, with a foliation that strikes N 5°E and dips 50° east. On the south side of this band the rocks are garnetiferous, while on the north side, the next few exposures are granulites with numerous dark green hypersthene-bearing layers, that are roughly parallel to the foliation of the enclosing rocks, but in places have a disrupted or brecciated appearance. (See Plate No. 14) A syenitic pegmatite intrudes these rocks, and it is not known whether it intersects the pyroxene bands, but it may possibly be responsible for the brecciation.

In the southeastern part of the area, one half mile south of Lake Tombbah, an exposure of dirty grey green granulite, contains a narrow, but extremely fine grained green band, that parallels the weak foliation of the granulites and has a strike of N 25°E, with a gentle eastward dip of only a few degrees. A thin section of this band contains hypersthene (35%), plagioclase An_{40-45} (45%), quartz (10%), biotite (10%); with augite, hornblende, and magnetite as accessories.

On the eastern boundary of the sheet, four miles north of Lac des Montagnes, there is an exposure of a massive, medium grained, light green rock which strikes north and dips east at 40°. A thin section of this rock approximates in composition to the band described in the previous paragraph; but contains more augite, and has tremolite and quartz as accessories. These rocks may have been either basic intrusive sills or calcareous sedimentary layers prior to the onset of metamorphism.

Petrography

These rocks are medium to coarse grained in thin section, with textures that can only be called granoblastic but of irregular grain size. Some show slight directive textures, and the coarser grained varieties are often poikiloblastic. Hypersthene, augite, hornblende, and occasionally biotite, are the essential minerals; while olivine, carbonates, quartz and plagioclase are the accessories. However, the carbonates and olivine are only found in the coarser grained varieties, and plagioclase An_{32-45} may be an essential mineral. Opaque oxides and sulphides were seen as accessories in only a few sections.

The hypersthene is near bronzite in composition having a negative $2V=60^{\circ}-70^{\circ}$, parallel extinction, a good (010) cleavage, and a very faint pink pleochroism. It forms very large subhedral crystals (up to 30 mm) which frequently enclose the other minerals. (See Plate No. 49)

The augite, biotite, and hornblende, are the normal varieties, usually anhedral, rarely subhedral, and seldom larger than 10mm; in the southern parts of the area they vie with hypersthene for predominance.

Secondary alteration is negligible, but the hypersthene in some thin sections of rocks from the southern part of the area, shows a limonitic alteration along the cleavage planes, while the crystals have serrated outlines.

Crystals of carbonate large enough to obtain a good optic axial figure were found in a few thin sections, but whether these are of primary or secondary origin is not known.

Structural Relationships

Mafic layers or lenses occur chiefly in the hypersthene bearing rocks, and are invariably parallel to the foliation. In only a few places was evidence seen to indicate that they could have been caused by the disruption of larger amphibolitic bodies or sills, such as those described by Adams (2-p.76) in the "Haliburton and Bancroft Area". (See Plate No. 14)

There are three distinct shapes, the ribbon or layer, the lens or pod, and the small rounded "bomb-like" inclusion, of which only three were found in the granulites; though others occur in the pegmatites associated with them.

The contacts of the smaller and finer grained varieties are clear cut, while those of the coarser and sometimes porphyroblastic types appear to be gradational in some occurrences, yet sharply defined in others.

A striking feature is the rarety of these bands, and few exposures exhibit more than one lens or pod. The best example of their multiple occurrence is on the highway north of Gabbro Lake. (See Plate No. 14)

Few if any of the finer grained ribbons or layers show pinching or swelling along their strikes, but taper out gradually.

The small "bomb-like" inclusions that are found in the granulites appear to be isolated examples having similar compositions to those of the mafic layers. They are not the result of spheroidal weathering since their mafic content is much greater than that of the rocks in which they are included.

The coarse grained facies are found as larger bodies, and some of these were seen to be thick, short pods.

Origin

An analysis of the coarse porphyroblastic hypersthene-augite - hornblende rock from east of the Canimiti River is given below in table 1.

TABLE I

SiO_2 -------	45.79%	
TiO_2 -------	00.36	
Al_2O_3-------	06.97	
Fe_2O_3-------	00.77	
FeO---------	09.74	
MnO---------	00.82	
MgO---------	26.75	
CaO---------	04.39	
Na_2O--------	00.54	(Specimen No. 82-12)
K_2O---------	00.22	
P_2O_5--------	00.003	
H_2O---------	01.55	
H_2O---------	00.09	Analyzed by the Laboratories of the Quebec Department of Mines.
S ---------	00.40	Analysts, H. Boileau, and J. Gagnon.
BaO---------	00.00	
Cr_2O_3-------	00.37	Specific gravity - 3.26
ZrO_2--------	00.00	
NiO---------	00.14	
	98.90	

The low silica alumina and alkalies, and the high magnesia, in addition to the chromium and nickel are features found only in rocks such as pyroxenites and peridotites. In any event it must be concluded that the analysis is that of an ultra-basic rock. This is substantiated by its high specific gravity.

The small bomb-like inclusions may be sheared and rolled out dykes or sill fragments, but their isolated occurrences in the granulites with which they are chiefly associated, points to their being accidental inclusions such as might be found in sedimentary rocks. Their presence in greater numbers in one pegmatite suggests that the latter may have been intruded along a bed of conglomerate; yet they could be caused by the brecciation and rolling out of a dyke engulfed in the advancing pegmatite. In the absence of any evidence to show that there has been much brecciation and disruption of dykes or sills, (only one early dyke is known, see page 55) it must be concluded that those inclusions in the granulites at least, are conglomeratic or agglomeratic in origin.

Undoubtedly some, if not all, of the finer grained mafic layers are sills, injected at an early period, and under very different conditions from those of the recognised and little altered basic dykes, which cut the banding of the gneisses and granulites.

Hypersthene Gneisses and Granulites

Description

These are fine to medium grained, green to rusty brown rocks, depending upon whether they are fresh or weathered. They are composed of hypersthene, plagioclase, quartz, and biotite, with at times, varying amounts of garnet. The term granulite is used with reference to their granular appearance, without implication as to composition or origin. All medium grained granular and gneissose rocks with hypersthene in excess of 5 percent are included in this group. Plate No. 18, shows some typical specimens of these rocks.

Occurrences

Southeast of the Nose Lakes in the southwest section of the sheet, there are many foliated granulites containing hypersthene layers or inclusions. The strikes of both the layers and foliation vary throughout this locality and appear to indicate folds in much the same manner as those of normal sedimentary or volcanic formations. A good example is to be seen east of the little lake at lat. 47°30' north and long. 77°11' west; here a closed fold some 30 feet wide in cross-section, plunges N43°E at 30°, and is slightly overturned to the southeast.

The layering is caused by very small mineralogical differences in a light grey-green to green granulite; while the presence of one narrow dark hypersthene band conformably folded with the others, accentuates the layered or bedded appearance of the rocks in the fold.

Hypersthene granulites constitute many of the high hills along the eastern boundary to the south of Lac des Montagnes, and are relatively massive, (See Plate No. 18) but occasionally interbanded with zones of garnetiferous rocks, and injected by coarse grained pegmatite dykes, some of which are 4 to 5 feet thick. Thin sections of the granulites from this vicinity show plagioclase An_{38} (60%), hypersthene (15%), quartz (15%), and biotite (10%); accessories are garnet, magnetite or ilmenite, and sulphides.

Along the east side of the Canimiti River above its junction with the Chochocouane, there are hills with prominent west facing scarps which are essentially composed of massive granulites and garnet gneiss. A thin section from a representative specimen, shows that garnets and hypersthene are each present in amounts of around 15%.

In the north and northwest parts of the sheet, hypersthene and garnet bearing gneisses are numerous but the more massive unfoliated types are absent. They are more intimately injected by igneous material than those previously described, so much so, that in places they are seen to grade into coarse granoblastic and apparently igneous rocks, which are referred to in this thesis as the "composite gneisses". Here marked layering or banding is seen in many places, and appears to have resulted from narrow igneous injections along parallel planes, or from compositional differences in the original rock. (See Plates Nos. 10 and 11)

Petrography

These are fine to medium grained, granoblastic rocks, and although a foliation is usually seen in hand specimens, it is rarely noticeable in thin section. (See Plates Nos. 35, 36, and 38) They contain plagioclase An_{32-40}, hypersthene, quartz, and biotite; in addition some sections have large amounts of garnet. The common accessories are garnet, magnetite and/or ilmenite, sulphides, and occasionally apatite.

The hypersthene occurs as subhedral to anhedral elongated wisps and shreds; it is colourless to faintly pleochroic in pale pinks and yellows, with a parallel extinction and a negative $2V=60^o-70^o$. Some crystals have small extinction angles of a few degrees, whereas one or two were observed of around 22°, suggesting the presence of clino-hypersthene. The optic axial angle according to Winchell (74-p.218) indicates a content of 32 percent for the hypersthene molecule, yet the faint pleochrism is that of bronzite.

The plagioclase grains are anhedral. They display infrequent albite and more frequent pericline twinning and are clear and fresh in appearance. Extinctions on (010) and (001) are between 14°- 20°, giving compositions of An_{32-40}; but in those rocks containing large quantities of hypersthene, the plagioclase has extinction angles on 010=26°, and positive 2V's, indicating compositions of between An_{45-48}.

Garnets and hypersthene when found in the same section are generally separated by other minerals though exceptions are known. (See Plate No. 38) The garnets are subhedral dodecahedra, colourless, well fractured, contain inclusions of both quartz and feldspar, and are isotropic.

Quartz anhedra are present in proportions of from 10-20%, and embay all the other minerals, giving the impression of having been introduced; but this could be caused by the melting or solution of original quartz, resulting in a local redistribution in the parent rock.

Some crystals show fracturing and undulatory extinction, but most of the quartz is clear and unstressed.

Structural Relationships

A most notable feature is the apparent restriction of these rocks to the present area. Wahl has reported no hypersthene-bearing rocks from his area, and neither have Retty and Lowther. However, they undoubtedly extend to the northeast into Retty's area.

The occurrences of basic hypersthene bands or layers and inclusions, appear to be restricted to these hypersthene rocks. They are less intensely injected by acidic material than the other gneisses, and are more massive. In some instances they are thought to be transitional into the garnet gneisses.

Small folds outlined by banding are not uncommon.

Biotite Garnet Gneiss

Description

These are fine to medium coarse grained rocks, which are grey green to green on fresh surfaces, but a light yellow brown when weathered. (See Plate No. 21) Some are massive but most are foliated or banded. (See Plate No. 22) The recognizable minerals are pink to red garnets, feldspar, quartz, and biotite. Only those rocks containing garnets in excess of 5% and negligible amounts of hypersthene (less than 5%) are included in this group.

Occurrences

Immediately south of the old highway bridge over the Ottawa River, there are many exposures of these rocks which display excellent banding. The strikes in this locality are variable, but generally in a northeasterly direction, whereas the dips a few hundred yards south of the bridge, are low towards the southeast, but steepen northwards as the Ottawa River is approached. The bands are pegmatoid quartz diorite and in some places constitute 70% of the rock in the exposures. A thin section of these gneisses shows plagioclase An_{34} (50%), garnets (15%), quartz (25%), and biotite (10%).

North of the old highway bridge over the Ottawa River, about 1000 feet along the highway, there is a green, foliated, fine to medium grained garnet gneiss; here injection banding is much less apparent than in the exposure previously described, but the rock has a strongly plated look which is very suggestive of some argillaceous rocks. (See Plate No. 5) In thin section, this rock contains plagioclase (50%), quartz (10%), garnets (15%), and biotite (20%). The adjacent exposure further north is a massive, but slightly foliated, green, hypersthene granulite, with little or no acidic banding. This rock contains plagioclase An_{30} (50%), hypersthene (15%), quartz (10%), biotite (20%), and garnets (5%). The presence of garnet and hypersthene bearing rocks in adjacent exposures is of interest and will be discussed later under the "Origin Of The Granulites and Gneisses".

Banding of a different type is to be seen in the narrow garnetiferous zone, shown on the accompanying geological map, at the western end of Lake Tombbah. (See Plate No. 9) The bands are 1 to 2 feet thick and somewhat contorted; granitic material alternates with green layers consisting of biotite, plagioclase, quartz and abundant red garnets; some of the latter are about one half inch in diameter. These rocks typify the migmatites so frequently described by Sederholm.

Another garnet zone occurs at the eastern end of this lake, and specimens from here have 40% of garnet. (See Plate No. 20) A thin section of this particular rock shows plagioclase An_{31}, (45%), garnets (15%), quartz (15%), and biotite (20%), with accessory microperthite, sanidine or anorthoclase, magnetite, and sulphides. The low garnet content recorded in this thin section is believed to be caused by their loss during grinding and polishing.

A fine grained brown band in which no minerals could be identified megascopically, is included in a massive gabbro exposured in the north central part of the sheet. The band is vertical, and 2 feet wide at the bottom, and bulges to 3 feet at the top. It strikes N 30°E. and in this respect conforms to the strikes of the other gneisses in that vicinity. Under the microscope, it is seen to have plagioclase An_{38}(35%), garnets (20%), hypersthene diopside and hornblende combined (25%), quartz (5%), and iron oxides (15%), (See Plate No. 40). The gabbro shows no chilling at the margins and has less than 10% of garnet.

An analysis of this rock is given in Table 2, but provides no clue as to its origin. The high titanium and iron content can be accounted for by its presence in the gabbro.

TABLE 2

SiO_2	-	49.78	
Al_2O_3	-	13.44	
Fe_2O_3	-	4.94	(Specimen #111-8)
FeO	-	12.99	
MgO	-	3.85	(Analyzed in the Laboratories of the Quebec Department of Mines.)
CaO	-	7.27	
Na_2O	-	2.16	
K_2O	-	1.30	Analysts - H. Boileau J. Gagnon.
H_2O	-	0.56	

TABLE 2 (Cont'd)

H_2O	-	0.10
TiO_2	-	2.96
P_2O_5	-	0.27
MnO_2	-	0.24
CO_2	-	6.00
S	-	0.02
		105.88

A grey-green, massive, buff-weathering variety of garnet gneiss is found throughout the north central and central parts of the sheet, to the west of the Canimiti River. The banding is sparse and restricted to the occasional narrow acidic stringer in and alongside of which the garnets may be numerous. In the massive rock away from the injected material the garnets may be plentiful, but are small and can be easily overlooked. Certain sections of these rocks give the appearance of having been "soaked" by acidic material, and on a fresh surface are a light grey-green, and contain some sulphides, mostly pyrrhotite. (See Plate No. 24)

The strikes of the foliations and banding in the garnet rocks northeast of Gabbro Lake indicate the presence of a large fold. This is cut by one of the only proven faults in the area. The position of this fault agrees with the results obtained by Cadell (18) in his small scale experiments with the folding of bedded formations; in that the fault seems to start or end in a fold.

A most distinctive garnet gneiss occurs in two exposures at the eastern end of the Canadian International Pulp and Paper Company road, in the north of the area. It is a light grey, medium grained, granitic looking gneiss, and consists of fine layers of pink garnets in a groundmass of feldspar, quartz, and sparse biotite. (See Plate No. 22) A thin section shows it to contain; plagioclase An_{40-45} (70%), garnets (15%), quartz (10%), and biotite (5%). The two exposures are about 1 mile apart and lie to the north of a fold-shaped hill from which they are believed to be separated by an east-west trending fault. This fault is indicated on the aeroplane photographs by a break in the topography, and by the occurrence of a "sheared" hypersthene-augite-hornblende rock in the vicinity of the "topographic break". In view of the position of these exposures at the extremities of the fold-shaped hill, it is possible that they represent the same formation duplicated by folding. The hill itself was found to contain garnetiferous gneiss in those places crossed by traverses, but none of a similar nature to those just described.

A garnet gneiss of more than ordinary interest occurs on the highway at mileage 58. This is highly injected by lit-par-lit sills of pegmatoid quartz diorite which carry "sanidine-anorthoclase" minerals. (See Plate No. 22) It is fully described in a later section under "Early Pegmatites".

Petrography

Under the microscope, these rocks are fine to medium grained and granoblastic, with occasional porphyroblasts of garnet; directive textures are poorly developed or absent. The essential minerals are plagioclase, garnet, biotite, and quartz; the common accessories are magnetite, and sulphides, with occasionally hypersthene, apatite, and zircon. The latter occurs as inclusions in biotite and is surrounded by pleochroic haloes.

Alteration is not common, but one thin section from east of the Chochocouane River shows distortion of biotite metacrysts, and contains some chlorite, epidote, sericite, and carbonates.

The garnets are subhedral to anhedral dodecahedra and contain numerous inclusions of rounded quartz; while hypersthene, biotite, and sulphides, are seen as inclusions or filling fractures in the garnets, and are thus considered to be late-formed minerals. (See Plates Nos. 38 and 39)

The biotite is pleochroic in brown and is the mineral most prominent in establishing the gneissose structure. It frequently occurs as clusters around the garnets, indicating a close relationship between the two minerals. One thin section from east of the Chochocouane, shows a few crystals of biotite with strained or bent lamellae.

The plagioclase has compositions of An_{30-36}, except in the two instances previously described. Twinning of the albite, pericline, and Carlsbad types are found, but are rarely well developed.

The quartz is characteristically anhedral and apparently embays and replaces all the other minerals except biotite. It is generally clear but undulatory extinctions and fractures are occasionally seen.

Potash feldspars only occur in minor quantities in a few thin sections as microperthite, and as a "sanidine-anorthoclase" mineral. The optical properties of the latter are; a negative $2V=30^{\circ}-40^{\circ}$, a very low birefringence, a refractive index less than that of Canada balsom, and a faint twinning after the albite law. In many respects, the crystals resembled microperthite, inasmuch as they have a faint wavy appearance caused by the irregular interlamination of two minerals with different refractive indices. The birefringence is so low that the apparent aggregate is nearly opaque between crossed nicols.

Structural Relationships

The garnet gneisses have no contacts or visible boundaries, and grade imperceptibly into the biotite gneisses, and possibly into the hypersthene-bearing rocks.

They contain abundant acidic material in the form of lit-par-lit sills. These appear to have intruded along some preferred channels, such as might have been provided by closely spaced bedding, or slaty cleavage. (See Plate No. 5)

The strikes of the foliations and of the injection banding, outline major fold patterns more suggestive of large sedimentary or volcanic formations than of flowage (Ptygmatic) folding. A good example of this apparent folding is shown on the accompanying geological map north-east of Gabbro Lake.

Biotite Gneiss

Description

These are fine to medium grained, grey-green to green rocks, and are gneissose to sub-schistose in the hand specimen, but in some places they are relatively massive. (See Plate No. 24) Biotite, feldspars, and quartz are the common minerals, and in the typical example biotite predominates over all save feldspar, though all variations may be found between rocks rich in biotite, and granitic rocks in which feldspars and quartz are the only minerals. Garnets are usually present, but only those gneisses with less than 5% of garnet are considered in this thesis to be biotite gneiss.

Occurrences

These rocks are mainly confined to an area in the southeast corner of the sheet, and to a discontinuous belt one to two miles in width that extends from the central part of the south boundary, northeastwards up to and beyond Lac des Montagnes.

The fine grained sub-schistose variety are best developed on the south shores of Lac des Montagnes and are almost identical to those found in the "Villebon-Denain" map sheet of Lowther.(42) (See Plate No. 23) Elsewhere as in the vicinity of the Blind River, the biotite is usually much coarser though often not so plentiful or as evenly distributed, and much igneous material has been injected as lit-par-lit sills of quartz diorite to granitic compositions, and lenses of "pink granite pegmatite". Exceptionally fine parallel banding is occasionally seen in which layers of coarse biotite alternate with others composed of quartz and feldspar.

Between Cultus Creek and the Chochocouane River there are numerous exposures composed of different varieties of biotite gneiss; these vary with increasing quantities of injected material, from greenish, medium-grained, sub-schistose, biotite rocks, to lenses of granite or pegmatite, with a low biotite content. A thin section of a typical biotite gneiss from this area contained biotite (30%), quartz (8%), plagioclase An_{33}, (62%), with accessory garnets, and magnetite.

On the highway 1000 feet south of the old bridge over the Ottawa River there are well banded biotite and garnet gneisses. The bands are apparently the result of injection by quartz diorite pegmatoid material along some pre-existing closely spaced parallel planes in the original rock. (See Plates Nos. 7 and 8)

In the same locality the excavations for the abutments of the new highway bridge over the river, showed good vertical sections of these gneisses. The section on the south bank of the river contains highly foliated gneisses rich in biotite, which are only moderately banded by igneous material. The strike of the layering is parallel to the river, and dips to the south at 40°. The north abutment section is in strong contrast to the former;

here 80 per cent of the exposure consists of a white to pink, medium to coarse grained quartz diorite, in which there are a few narrow bands of biotite and the occasional lens of hornblende. Biotite gneiss comprises the top of the section, and is well injected or "soaked" by the quartz diorite. Contorted roots of the biotite gneiss sweep down into the intrusive, becoming weaker and fewer as they descend, until finally they die out, leaving only the massive quartz diorite in which biotite is rarely seen. (See Plate No. 26)

It is this intrusive which appears to have provided the acidic material for the lit-par-lit injections seen in the gneisses of this locality. Microscopically it contains only plagioclase An_{30} and quartz, with very minor quantities of biotite.

The contrasting rock types in these exposures suggest that the Ottawa River in this vicinity may occupy a fault.

Petrography

In thin section these are fine to medium-grained rocks with a texture that varies from granoblastic to gneissose. The essential minerals are; Plagioclase An_{30-33}, biotite, and quartz; while garnets, apatite, magnetite, and sulphides are the common accessories.

The biotite is the usual brown pleochroic variety and commonly subhedral.

The plagioclase is subhedral to anhedral and displays infrequent albite and pericline twins that are seldom clear or sharply defined, but which nevertheless show little alteration.

The quartz is in anhedra of all sizes and rarely shows fractures or strain shadows.

Alteration is absent or negligible.

Structural Relationships

These are the most injected rocks of all the paragneisses, and grade into granitic rocks on one hand and into garnet gneisses on the other.

Locally they exhibit good layering in which bands of biotite alternate with others of feldspar and quartz.

Microcline-Plagioclase-Quartz Gneisses

Description

These are light grey, medium grained, gneissose rocks, that to the eye contain feldspar, quartz, and accessory biotite.

Occurrences

This rock was seen only on the north shore of the little lake that lies due north from the eastern end of

Lake Tombbah. It is finely foliated and slightly contorted, and in one place bends snuggly around the nose of a protruding body of massive hypersthene granulite. The contact between these rocks was not observed, but the foliation in the microcline gneiss appears to conform to the shape of the granulite.

An amphibolitic band is enclosed in this rock, and over part of its observed length transects the foliation. It is about 2 feet thick and has margins whose mafic content approximate that of the enclosing gneiss. However, the dark minerals increase towards the centre, at which place there are several mafic hornblende-pyroxene lenses some 6 to 10 inches long, arranged in line along the strike of the band. This band is undoubtedly the relic of a once more mafic dyke which was altered by fluids during the metamorphism of the rocks. The significance of this occurrence is far reaching; since it indicates that the foliation of the gneiss must have been formed prior to metamorphism, and is possibly of sedimentary origin. Furthermore, it demonstrates that the metamorphism of these rocks involved a process of replacement.

Petrography

Microscopically the gneiss is granoblastic, with only feeble traces of a directive texture. It consists of microcline, plagioclase, and quartz, biotite is the only accessory.

Fresh, well twinned microcline is present in amounts of around 15%, but the quantities of the other minerals could not be estimated since the plagioclase is clear and untwinned, and difficult to distinguish from the quartz.

ORIGIN OF THE GRANULITES AND GNEISSES

There is little direct evidence to show what the biotite, garnet, and hypersthene bearing rocks were before they were metamorphosed; what there is, is mostly of an indirect nature.

In the area to the north Lowther states; "there is a gradation eastwards from the normal Temiscamian greywackes to a coarse grained garnetiferous gneiss". (42-p.49) To the south Wahl found one exposure which has a garnetiferous schist between a layer of limestone and of quartzite; the position of the schist between rocks of undoubted sedimentary origin implies that it must have been a shale or impure arenaceous rock, and points to a similar origin for the other garnet rocks of the region. (71-p.6)

Layering which undoubtedly developed from sedimentary bedding (See Plates Nos. 10 and 11) is found in many places, while inclusions in granulites and pegmatites could be xenoliths in extrusives or intrusives, disrupted dykes, or of agglomeratic, or conglomeratic origin.

The mineralogical compositions of ten thin sections of both the hypersthene granulites and the garnet gneisses were estimated and an average determined for each rock; from these the chemical compositions were calculated, and are given below in Table 3 along with chemical analyses of shales, slates, andesites and two greywackes.

It should be pointed out that the average garnet content in the gneisses represented by analysis 2, Table 3, is 16.5%, but that rocks with as much as 40% of garnet are known. In such instances it is felt that analyses would show much larger amounts of alumina, only reconcilable to gneisses derived by the metamorphism of aluminous sedimentary rocks.

TABLE 3

	1.	2.	3.	4.	5.	6.	7.
SiO_2	61.71	61.74	58.38	61.74	61.96	61.59	61.12
Al_2O_3	19.34	19.24	15.47	16.54	17.20	19.47	17.65
Fe_2O_3	4.23	5.44	4.03	2.73	1.42	1.96	2.89
FeO			2.46	3.63	4.49	3.07	2.40
MgO	3.00	3.54	2.45	2.99	3.27	1.09	2.44
CaO	4.33	3.11	3.12	1.07	1.00	2.60	5.80
Na_2O	4.72	4.13	1.31	2.57	5.27	3.32	3.83
K_2O	1.12	1.68	3.25	3.15	2.04	2.58	1.72
$\frac{Al_2O_3}{K_2O+Na_2O+CaO}$	1.89	2.15	2.01	2.43	2.05	2.29	1.55

Note: The less common elements have not been included.

1. Hypersthene granulites, "Canimiti River Area", Quebec, calculated analyses.
2. Garnet gneisses, idem.
3. Average of composite analyses of 78 shales, Clarke, F.W., "Data of Geochemistry", U.S.G.S. Bull. No. 770, p.631.
4. Average of 22 analyses of slates, idem.
5. Analyses greywacke matrix Gowganda formation conglomerate, "Onaping Map Area", Collins, W.G., G.S.C., Mem. 95, 1917, p.65.
6. Analyses of conglomerate greywacke matrix, Hastings series, "Precambrian Geology of Southeastern Ontario" Miller, W.G., and Knight, C.W., O.B.M., 1914, p.87.
7. Hornblende Andesites (Composite analyses) "Igneous Rocks and the Depths of the Earth", Daly, R.A., p.16, McGraw Hill Book Company Inc., 1933.

The chemical analyses included in Table 3 above, were chosen for purposes of comparison because they represent rock types having the nearest approximate compositions to those of the calculated analyses of the Canimiti River rocks.

Chemical compositions were also calculated for the biotite gneisses, but have not been included in the table because too few thin sections were available with which to obtain reliable averages; however, as a matter of interest, they were found to contain 62.90% silica, 21.19% alumina, 4.22% calcium, 5.19% soda, and 2.24% potash, while the combined magnesia and iron was 3.84%.

The obvious features about the compositions of the Canimiti River rocks in Table 3 above (Columns 1 and 2) are their similarities to each other, even in alumina, and the occurrence of this element in quantities greater than that found in either the shales or slates (Columns 3 and 4) but in amounts equal to that contained in one greywacke (Column 6). The greywackes show an excess of soda over potash as do the andesites granulites and gneisses; this when found in metamorphic rocks is normally considered to be evidence suggesting an igneous origin, but it is certainly not applicable to metamorphic rocks derived from greywackes. There are roughly equal amounts of magnesia and iron in all the rocks except the conglomerate (Column 6); whereas the slates, greywackes, and conglomerates contain less calcium; however, the shales (Column 3) have equivalent amounts of this element to that found in the granulites and gneisses. The igneous origin of the andesites is only signified by their higher calcium content. A calculation of the ratios of alumina to lime and alkalies, in all these rocks, shows that the andesites, the igneous rocks, have a ratio of 1.55 whereas all the others have ratios of between 1.89 to 2.43; of interest but not necessarily of diagnostic value is the fact that the garnet gneiss has a ratio higher than that of the shales and greywacke in columns 3, and 5.

Chemical analyses of two garnet gneisses from the Canimiti area were made by the laboratories of the Quebec Department of Mines; these are given below in Table 4.

TABLE 4

		1		2	
SiO_2	-	63.50	-	66.24	
Al_2O_3	-	17.32	-	15.42	
Fe_2O_3	-	1.06	-	0.76	
FeO	-	5.40	-	5.40	
MgO	-	3.68	-	3.21	Analysts H. Boileau and
CaO	-	2.64	-	3.15	J. Gagnon.
Na_2O	-	3.21	-	3.19	
K_2O	-	1.85	-	1.43	
TiO_2	-	0.66	-	0.61	
		99.32		101.41	

1. Light grey-green, banded garnet gneiss shown in plate No. 22 (specimen No. C.I.P.-17) garnets 15-20% of rock.

2. Massive medium grained, dark green garnet gneiss. Garnets only 10-15% of rock. (Specimen No. R.I.-22)

A comparison between the analyses in Table 4, and the calculated average composition for the garnet gneisses shown in Table 3, indicates that the calculated analyses are most probably a close approximation to the average composition of the garnet gneisses in the area. Moreover a point of exceeding interest, is that the chemical analysis of the garnet gneiss in Table 4, column 1, has an alumina to calcium and alkali ratio of 2.2, which is slightly higher than that of the calculated composition in Table 3. The gneiss in column 2, Table 4, has a high silica content and an alumina to calcium and alkali ratio of 1.9. The latter is still too high for that of most igneous rocks, as shown by a perusal of the igneous rock compositions given by Daly in his "Igneous Rocks and the Depths of the Earth". The analyses strengthen the contention that most of the garnet and probably the biotite gneisses, are metamorphosed sedimentary rocks; possibly muddy sandstones or greywackes.

The occurrence of hypersthene rich rocks in close proximity to others characterized by garnets, suggests that there must have been some difference in the nature of the parent rocks. Though faulting for which there is no proof, could have placed these contrasting facies in adjacent positions. The alumina to lime and alkali ratio for the hypersthene granulites (1.89) is lower than that of the garnet gneisses (2.15), but comparable to that of the "Greenstones" (1.90). Therefore, it seems reasonable to consider that both these rock types were probably derived from mafic greywackes or even tuffs.

EARLY IGNEOUS INTRUSIVES

Introduction

Throughout the area there are small lenses and many closely-spaced, narrow sill-like injections, ranging from granite to quartz diorite, some have associated pegmatitic facies only identifiable by their coarse grain and considerable tenor of quartz.

Large intrusive masses of these rocks are not found, yet the injected acidic material in some places is so great that the rocks are now of a "composite" or "hybrid" character.

Quartz Diorite Orthogneiss

Description

These are medium to coarse grained massive rocks mottled in grey and green, and are composed essentially of feldspar, biotite, and quartz, with locally some hornblende. The rock is decidedly gneissose and has a gnarled or knotted appearance. (See Plate No. 25) The biotite is plentiful and is concentrated in ill-defined layers.

Occurrence

These rocks underlie a small group of islands in the eastern part of Lake Tombbah and were the only exposures of orthogneiss seen in the area. They are highly contorted with a marked gneissic structure and contain inclusions of a dark hornblende-pyroxene rock in all stages of digestion, from that of sharply angular fragments rich in mafic minerals to poorly defined ellipsoidal patches with sparse hornblende, which grade imperceptibly into the less mafic quartz diorite. (See Plate No. 6)

Thin sections of this gneiss and of a moderately digested inclusion show that both contain plagioclase An_{31}, biotite and quartz, but that the inclusion has in addition 20% of a green hornblende.

No constant strike or dip could be recorded for these rocks owing to their contortion, but the longer axes of the moderately digested inclusions plunge at 35° to the east.

Petrography

Microscopically these are medium to coarse grained hypidiomorphic granular rocks, with only the suggestion of a directive texture. The essential minerals are plagioclase An_{29-31}, quartz, biotite, and occasionally hornblende. The accessory minerals are apatite, zircon, magnetite, and sulphides.

The plagioclase is anhedral to subhedral and rarely twinned or altered; twinning when seen is after the albite or pericline laws.

The biotite is the brown pleochroic variety with a negative $2V=0^{\circ}$, and a parallel extinction. The crystals are subhedral, lath-shaped, and fresh.

The quartz is always anhedral and appears to replace the other minerals.

The hornblende is subhedral with good cleavages at 56° and 124° on basal sections. It is pleochroic in green and greenish brown, has $Z \wedge c = 22^{\circ}$, a negative $2V=75^{\circ}$, and a dispersion of $P > V$. In appearance it is fresh and unaltered, but contains the occasional small zircon around which there are weak pleochroic haloes.

Apatite is the most abundant accessory and is in euhedral laths, while the magnetite occurs as small irregular blobs.

Quartz Diorite

Description

This is a massive medium to coarse grained, grey rock, in which the only minerals are feldspar, quartz, and minor amounts of biotite. (See Plate No. 26)

Occurrences

The quartz diorite, revealed in the abutment excavation for the new highway bridge over the Ottawa River, shows itself as a massive intrusive lying below a thin cover of biotite paragneiss. There is a transitional zone between the two rocks, and the biotite gneiss loses its identity as it passes through this zone; becoming more injected and "soaked" until finally its former presence is only made known by the occasional contorted streak or schlieren of biotite in the massive quartz diorite. There appears to have been no rending or tearing of the biotite gneiss by the intrusive, the invaded rocks have not been flattened back tightly against a sharp contact, but rather there is the impression that the biotite gneiss has been growing, and has sent long sustaining roots down into the intrusive. The rocks of the contact zone could be described as orthogneisses if seen only in plan, but the evidence shown in this section, makes it evident that where such gneisses are found, there are massive intrusives at no great depth. Because of this, a small body of "orthogneiss" that lies north of the Ottawa River, between the new and old highways, has been classified as massive quartz diorite.

The vast numbers of quartz diorite pegmatoid sills seen throughout the area, imply that there is a large batholithic mass, or a large number of smaller stocks at no great depth.

Petrography

In thin section this rock is hypidiomorphic granular and consists of plagioclase An_{30} (85%), quartz (15%), and accessory biotite.

The plagioclase is clear and untwinned, and shows no alteration.

The quartz is in the customary anhedra and is neither fractured nor strained.

Granite (Anorthoglase Bearing)

Description

These are medium grained, pink to grey massive rocks, which in the hand specimen are composed of quartz, feldspar, and biotite. Garnets are common in the more contaminated facies.

Occurrence

They have been found in only two localities, the first is in the west central part of the area, three quarters of a mile to the east of Gabbro Lake, where they appear as random masses of unknown size and shape, contaminated by hypersthene and garnet gneisses; and secondly, south of Beak Lake where similar rocks form a strong east-west trending ridge. Here the granite has intruded the gneisses as sills; the largest seen was some 15 feet thick and has an east-west strike and a dip of 65° to the south. There is a noticeable increase of grain size towards the centre of the sill but no marginal chilling. In some places large elongated quartz crystals show a marked lineation which plunges N 85°E at 50°.

Petrography

In thin section these are medium grained granitoid rocks, and consist of subhedral to anhedral microperthitic orthoclase and microcline (60%), anhedral quartz (28%), plagioclase (5%), with accessory anorthoclase, zircon, and occasionally garnets and biotite.

The microcline is of two ages; the earliest is perthitic and in large anhedral crystals (up to 6mm). Between crossed nicols the microcline twinning is hazy and indistinct, while superposed on this is a wavy appearance caused by irregular alternating layers of two different minerals with different refractive indices. One mineral has an index lower than that of Canada balsam and is orthoclase or microcline; the other has a higher index, though whether it is higher than balsam could not be determined, but it is believed to be a plagioclase. The second and later age of microcline crystals are small, display clear cross-hatched twinning, and are interstitial to the larger crystals of perthitic microcline and orthoclase.

The orthoclase is in large anhedral crystals and may be clear or perthitic, with numerous small lens-like inclusions of plagioclase, or it may have the wavy surface between crossed nicols similar to that found in the microcline perthite.

The quartz is in the customary rounded but irregular anhedra of all sizes and may show strain shadows, but is more often clear and undistorted, and seems to replace the other minerals.

The biotite is the normal brown variety, with a negative $2V=0^{\circ}$, and contains a few zircons with pleochroic haloes.

A colourless mineral with a very low birefringence, a refractive index less than balsam, and a negative $2V=30-40^{\circ}$ was identified as anorthoclase.

Myrémekitic and vermicular intergrowths of quartz and plagioclase feldspar, and micrographic intergrowths of quartz in orthoclase can be seen in a few small interstitial patches.

No alteration except traces of sericite and/or carbonates was observed.

Quartz Porphyry Dyke

Description

This rock is pale pink to light grey and fine to medium grained. It consists of quartz phenocrysts up to 12 mms in length, in a groundmass of feldspar and quartz. Disseminated sulphides, garnets, and biotite, occur in small amounts.

Occurrence

Only one exposure was found and this occurs on the highway, approximately 1500 feet north of the old bridge over the Ottawa River. Here a dyke 4 feet wide, strikes east and dips 55^{o} to the south, cutting across the layering of the enclosing hypersthene granulites, which strike N 10^{o}E and dip east at 45^{o}. There are poorly developed joints in the dyke and the surfaces of these may be covered with a red oxide. Disseminated sulphides are found in the rock, and also as very minor concentrations along or near the joints.

The quartz crystals show an increase in grain size towards the centre of the dyke and have a lineation which plunges eastward at 45^{o}.

Age

The manner in which this dyke cuts the foliation of the enclosing granulites, and its clean cut contacts, as well as its massive character, suggest that it is probably the youngest of the early acidic intrusives. However, the possibility that it may be a late aplitic differentiate of the syenites should not be discounted.

EARLY PEGMATITES

Quartz Diorite to Granite Pegmatites

Description

The pegmatites associated with the early quartz diorite intrusives are medium to coarse grained (2-10mm.) and range in colour from white to pink, and grey to grey green. To the eye they are essentially composed of feldspars and quartz, but a few have small amounts of biotite and garnet. The earliest of these resembles an even grained pegmatitic quartz vein; the later ones are very coarse grained and typically pegmatitic, but are not numerous. (See Plate No. 27)

Occurrences

The simple quartz feldspar pegmatites are found throughout the area and constitute most of the igneous material in the lit-par-lit injections. An outstanding example is to be seen in the rocks along the highway south of the old Ottawa River bridge. (See Plates Nos. 7 and 8) A thin section of a sill from here contains plagioclase An_{27} (50%), antiperthitic plagioclase (10%), and quartz (40%). About one and three quarter miles west of the highway and 600 yards north of the southern boundary, a similar but more glassy pegmatite (See Plate No.27) roughly 10 inches thick, shows no chilled margins. It is cut by a very coarse grained (20mm.) white feldspar pegmatite, (See Plate No. 27) which has a low quartz content and the occasional book of biotite. The remarkable features of this dyke are its strongly chilled contacts and the rapid coarsening of its crystals away from the margins, while it has numerous small offshoots which behave in a similar manner. A specific gravity determination of the feldspars showed them to be plagioclase An_{18}; whereas similar determinations of the feldspars in the more glassy dykes indicate compositions of An_{32}.

East of the Chochocouane River in the central part of the area, a medium to coarse grained glassy plagioclase quartz pegmatite sill, some 5 inches thick, intrudes garnet gneisses. The feldspars are rounded and fairly coarse (5mm.), and on a weathered surface give the sill a porphyritic appearance. There is a slight but noticeable decrease in the size of the feldspars towards the contact, along which there is a strong concentration of red garnets. Small quantities of a sulphide, presumably pyrrhotite, occur as slickensided plates both in the sill and the gneiss. The enclosing gneisses are fresh and suggary, and appear to have been "granitized" by the injection of fluids.

At mileage 58 on the highway, an exposure of garnet gneiss is highly saturated with a grey pegmatitic material, in the form of closely spaced parallel sills. (See Plate No. 22) The banding is imperfect because the injected material has broken through, and disrupted the separating layers of garnetiferous gneiss. Transgressing the gneiss is a dyke of grey pegmatite which seems to have been the source from which the material in the sills was derived. The dyke strikes N 55°E and dips northwest at 30°, whereas the gneisses strike N 35°E and dip southeast at 45°.

Petrography

In thin section these rocks are medium to coarse grained and granitoid. The essential minerals are microperthite, antiperthite, plagioclase An_{18-32}, and quartz. The accessories are orthoclase, microcline, biotite, garnets, and a soda-potash feldspar referred to in this thesis as "sanidine-anorthoclase". However, the only consistently essential minerals are quartz and plagioclase.

The microperthite is the normal type with the wavy-looking surface when seen between crossed nicols. The rods of albite are not so well developed, nor as clear cut as those seen in the microperthite of the hornblende syenite, and have a lower birefringence. The impression is gained that the albite("Waves" with higher refractive indices than orthoclase or microcline and lower than that of quartz) had been in the process of separating from the potash feldspar (microcline or orthoclase?) but that this process had not been completed.

The plagioclase is in anhedra, fresh looking and moderately twinned after the albite law; though these have a faded appearance. The extinction on the section simultaneously perpendicular to (010) and (001) = 10^{o}- 13^{o} giving a compositional range of An_{28-31}; specific gravity determinations previously quoted gave An_{32}. Whereas that in coarse grained late pegmatite has the higher sodic composition of An_{18}.

Antiperthitic plagioclase is best developed in the more quartz rich, pegmatoid sills near the Ottawa River. Large crystals of plagioclase An_{31} enclose many small patches of feldspar with lower refractive indices than that of Canada balsom. They have a negative 2V= 75^{o}-80^{o}, and must be orthoclase. The small patches are in places partly bounded by twinning planes, but more generally have very ragged outlines and appear to follow fractures. One of the small orthoclase patches seen in Plate No. 45, shows the start of the formation of micro-perthite. These are undoubtedly developments from within the crystal itself, and unrelated to any replacement phenomena. It is to be noted that the albitic (higher refractive index than the containing orthoclase) lamallae (?) are parallel to the strongest diagonal cross-fractures in the plagioclase. This suggests that both the antiperthitic orthoclase, and the microperthite may be ex-solution phenomena caused or aided by stress.

The dyke on the highway at mileage 58, contains antiperthitic plagioclase, quartz, and minor amounts of orthoclase and microperthite. The sills from this dyke, which intimately intrude the garnet gneiss, contain little antiperthite or orthoclase, but more microperthite, and show small interstitial crystals of myrmekite, and are more contaminated by garnets and biotite. They have in addition about 3% of a mineral believed to be a potash-soda feldspar which because it has optical properties that vary between those of sanidine and those of anorthoclase, is referred to in this thesis as "sanidine-anorthoclase".

The "sanidine-anorthoclase" has a negative $2V=10^{\circ}-30^{\circ}$, a very low birefringence, and a refractive index less than that of balsam. The crystals are glassy clear, but some have undulant surfaces when seen between crossed nicols indicating that there are probably two substances present, that have different refractive indices. They may contain tiny inclusions of plagioclase that are occasionally twinned and by their extinction angles indicate a composition of An_{36}. It was found that the crystal or part of a crystal which has the most inclusions of plagioclase, also has the largest optic axial angle.

The origin of this mineral is discussed in a later section on the "Paragenesis of the Minerals".

The quartz is characteristically anhedral and in crystals of various size. It frequently contains clouds of small hair-like microlites which may or may not show directive tendencies: but whose compositions could not be determined. Wilson (73-p.122) has noted similar hair-like inclusions in the sillimanite-garnet gneiss of the Maniwaki area, and notes that they are very common in the quartz of the Grenville rocks.

Pink Granite Pegmatites (Augen Gneiss and Flaser Gneiss)

Description

These are pale pink to pink, medium to coarse grained rocks. One type contains large eyes of pink or green feldspar and lenticular streaks of biotite, in a fine to medium grained ground mass of feldspar and quartz. It is referred to as "augen" gneiss. (See Plate No. 28) The other type has a highly foliated or plated appearance, consists of quartz and feldspar, and is referred to as "flaser" gneiss. (See Plate No. 29) The quartz in the latter type may be in "pencils" several inches long, and display preferred orientations of their longer axes.

Occurrences

The "augen" gneisses are most commonly found intruding biotite gneiss, and are usually lens shaped bodies of small size, which contain inclusions or schlieren of biotite, or biotite gneiss. A good exposure of these rocks is to be seen on the old part of the highway, one half mile south of the Chochocouane River, where an "augen" pegmatite conformably intrudes biotite gneiss.

The "flaser" gneisses are found throughout the area in what are believed to be fault zones. The best example occurs two miles northeast of Gabbro Lake where a narrow 1.5 foot "flaser" gneiss cuts garnet gneiss transverse to its banding. A fault movement in and along the dyke has resulted in a well banded and highly garnetiferous rock being placed opposite a poorly banded, moderately garnetiferous one. The "flaser" gneiss along which the fault movement has occurred is well plated, and shows a few small drag folds as further evidence of movement.

Petrography

"Augen" Gneiss

Microscopically these are medium to coarse grained inequigranular rocks consisting of plagioclase An_{30-40}, (55%), microcline (25%), microperthite and orthoclase (10%), and quartz (10%). Biotite is the only accessory, but carbonates and sericite were seen in a few sections. There is no suggestion of a directive or "augen" structure.

The plagioclase, orthoclase, and perthite, are found as relatively large anhedra and show a low powdery alteration product, which is probably sericite, and/or carbonate, and is more plentiful on the plagioclase crystals.

Twinning is rare and the compositions of the plagioclase could only be roughly determined by their refractive indices, which were greater than that of balsom, and by the sizes and signs of their optic axial angles.

The microcline seldom occurs as large crystals and those seen contained highly distorted or deteriorated cross-hatched twinning, as if consolidation had arrested some transformation process. There are small second generation crystals of microcline which are subhedral to anhedral, distinctly twinned, fresh, and interstitial to the other feldspars.

The quartz is characteristically anhedral and similar to that found in the other rocks of the area. It appears only in the fine grained interstices, embaying and apparently replacing the feldspars.

A few small interstitial patches contained myrmekitic intergrowths of quartz and plagioclase, in which the quartz shows a common crystallographic orientation by its simultaneous extinction between crossed nicols.

One section taken from the exposure on the highway south of the Chochocouane River contained one small crystal of anorthoclase.

"Flaser" Gneiss

Only one thin section of these rocks was seen. It was not considered to be representative since it was taken from the margin of a "flaser" gneiss and was contaminated by biotite. However, it showed a strong directive texture in which most of the minerals, even orthoclase and quartz, participated.

Origin of the Structures

The "augen" structure is undoubtedly the result of differential movements which caused granulation, and the migration of some material according to Riecke's principle.

The "flaser" pegmatite dyke northeast of Gabbro Lake, occupies a fault. But whether its structure was imposed during and/or after its consolidation could not be determined. A few small drag-folds outlined in its foliation only prove that there was movement in the dyke after the platy (flaser) structure had been formed. As a group these rocks are important since they indicate zones of faulting and lesser differential movements, in rocks which are believed to have been at very high temperatures. They are undoubtedly the equivalent of the "shears" found in the lower grade metamorphic rocks of other areas.

Age

In the vicinity of Gabbro Lake, pink pegmatites were seen cutting the white pegmatoid and pegmatitic, Lit-par-lit injection banding. They are therefore post-quartz diorite pegmatite, and probably pre-hornblende syenite, since the pegmatites associated with the latter intrusives are much richer in alkaline feldspars.

Graphic Granite Pegmatite

Description

This is a pink medium to coarse grained rock composed of quartz and feldspars. The quartz is disposed between the feldspar crystals as streaks and lines which resemble semitic characters.

Distribution

Only one small exposure was found and this occurs immediately to the east of Lac des Montagnes. In this vicinity much granitic and pegmatitic material has been intruded into the biotite gneisses and has resulted in the formation of many curious facies, most of which appear to be rich in potash feldspars.

Petrography

In thin section the rock is coarse grained, roughly equigranular, and consists of perthitic microcline (60%), orthoclase (15%), quartz (20%), plagioclase of undetermined composition (5%), and microcline (5%). Accessories are absent but the plagioclase displays weak though noticeable sericitic alteration.

The perthitic microcline shows a ripple-like surface between crossed nicols, superimposed on a distorted or deteriorated microcline twinning. Small but fresh microcline crystals also occur and are apparently replacing the larger potash feldspars.

The quartz is in the customary irregular but rounded grains, and embays all the other minerals except the small fresh microcline crystals.

GREENSTONES ?

Description

These are fine grained, dark green, massive and foliated rocks. The only recognisable minerals are biotite and/or chlorite, and an occasional garnet. Some specimens contain small streaks or inclusions of acidic material, while others show many minute acidic "sill-like" layers.

Occurrences

There are no known bodies of this rock within the area, but five small exposures were found outside the northwest boundary and their positions are shown on a supplementary map which accompanies this thesis.

The most important of these exposures is 4000 feet east of the highway on the southern boundary of Freville township. It is on the side of a steep west facing ridge that rises some 250 feet above the adjacent valley. The exposure is not continuous but comprises a group of small ledges which protrude through a talus slope. They were traced along a strike of N 5^{o}E for about 200 feet, but may extend further. Their layering, when apparent, dips to the east at 15^{o} to 35^{o}. The width of the zone could not be determined because of the abundant talus. Some of these "greenstones" break with a sub-schistose fracture which has a chloritic and slickensided appearance. (See Plate No. 30) A few are very finely banded by acidic material. At one place they are intruded by a coarse grained rusty brown hypersthene-bearing pegmatite similar to those associated with the hornblende syenite intrusives, (See Plate No. 32) though elsewhere no contacts were seen.

There are no other exposures on the hill below the "greenstones", but lying above and separated from them by some 30 feet of talus, there are large exposures of medium to coarse grained composite gneisses, the layering of which is conformable to that of the "greenstones". An explanation is needed for this relationship. Why should rocks so intensely injected and metamorphosed apparently overly such rocks as the "greenstones", which are of low metamorphic grade?

On the far side of the valley about 800 feet west of the above exposure, and against the muskeg that covers the valley floor, there is a small exposure of a fine grained green rock containing porphyroblasts of acidic material. It has a foliation which strikes north and dips to the east; but whether it is a metamorphosed igneous or sedimentary rock was not ascertained. The position of this exposure and its nature, suggests the possibility that "greenstones" may outcrop under the muskeg in the valley.

There is another exposure of "greenstone" on the west bank of the stream that flows from the southwestern end of Composite Lake, some two hundred yards downstream from the lake. It is roughly 25 feet by 15 feet in size, and is fine grained and massive, with only a weak foliation that strikes N 15^{o}E and dips east at 45^{o}. Microscopically, it is similar in all respects to the rocks previously described. It contains small porphyroblasts of garnet (10%) set in a very fine grained ground mass of plagioclase An_{28}, quartz, biotite, muscovite or sericite. In addition to small quantities of carbonates and chlorite. The texture is strongly directive and flows around the garnet metacrysts. (See Plate No. 46) A much smaller exposure occurs only 100 feet north of here. It is a highly plated green rock which has been injected by a multitude of narrow sills of acidic material. The foliation strikes N 10°E and dips east at 40°, conformable to the structural trend of that vicinity. On the eastern side of the stream valley, there are steep scarps composed of well banded composite gneisses. These contain many mafic layers having strikes of from north to N 15°E, and dips to the east of 40° to 55°.

The acidic layers in some composite gneisses and "greenstones" from this locality, are pink to reddish in colour, suggesting that they are injections related to the red quartz diorite stock, which lies only a short distance to the northeast of Composite Lake.

Petrography

In thin section these rocks are all fine grained, and have a strongly foliated texture which flows around metacrysts of garnet. They consist of plagioclase An_{28}, garnets, quartz, biotite, muscovite and/or sericite, with accessory amounts of carbonates, chlorite, magnetite, and sulphides.

The plagioclase are in small anhedra and rarely twinned. In some instances moderate amounts of chlorite, sericite and/or muscovite, and carbonates, are found as alteration products of the biotite and feldspars.

Brown hornblende was found in a thin section of the highly injected and plated "greenstone" and is accompanied by biotite, but chlorite sericite and carbonates are lacking. The crystals are subhedral laths and have extinctions of $Z \wedge c = 20^{\circ}$. They were too small for the accurate determination of their other optical properties.

Those thin sections containing hornblende have small fresh-looking, poorly twinned feldspars.

The quartz is the normal variety and is clear and unstressed, but in the more layered types forms long narrow lenses which parallel the foliation. It is thought to be the result of injection and/or replacement.

The garnets are the normal subhedral dodecahedrons, and usually fractured. Sulphides and/or magnetite occasionally occur in these fractures.

Origin

Tiphane[I] found similar "greenstones" in the gneisses to the north of this area, and thinks they are metasedimentary or metavolcanic rocks, but at first, he was inclined to believe them to be disrupted dykes.

In the present area no dykes have been found which compare with the "greenstones" in either composition, grade of metamorphism, or structure. (Sub-schistose and slightly chloritic in some places).

The mafic nature of the composite gneisses adjacent to the "greenstones" near Composite Lake, may have arisen

I Personal conversation.

by the assimilation of "greenstones". Such a possibility cannot be discounted, for ultrametamorphic processes have converted biotite, garnet, and hypersthene granulites and gneisses into coarse composite rocks, only a short distance to the east of this locality.

The "greenstone" exposure on the south boundary of Freville township which has layering conformable to that of the adjacent composite gneisses, is in places sub-schistose. (See Plate No. 30) This relationship is best explained by faulting. It is granted that the "greenstone" could be a faulted dyke, but again the low and high grades of metamorphism might imply the existence of an unconformity, along which faulting had taken place.

A specimen of "greenstone" was analysed in the Laboratories of the Quebec Department of Mines, and the results are given in Table 5.

TABLE 5.

SiO_2	-	59.81%
Al_2O_3	-	17.06
Fe_2O_3	-	4.97
FeO	-	1.54
CaO	-	3.23
MgO	-	4.12
K_2O	-	1.83

TABLE 5 (Cont'd)

Na_2O	-	3.88	(Specimen No. 106-9.)
H_2O	-	1.78	Al_2O_3/ K_2O-Na_2O-CaO Ratio = 1.90
H_2O	-	0.09	
TiO_2	-	0.69	(Analysts, H. Boileau and J. Gagnon.)
P_2O_5	-	0.18	
MnO	-	0.08	
CO_2	-	0.38	
S	-	0.30	
		99.99	

The composition of this rock approaches that of an andesite, but the calcium is too low, and the magnesia is too high. However, magnesia might have been added and calcium subtracted during metamorphism. On the other hand the alumina to calcium and alkali ratio is 1.90, which is too high for an igneous rock, (andesites 1.55) and more compatible with the other paragneisses of the area (ratios 1.89-2.23).

Osborne thinks that these rocks were immaturely weathered sediments similar to the Timiskaming greywackes to the north, which were derived from andesitic and basaltic rocks, and that during their transportation,

I Personal conversation with F.F. Osborne, Professor of Geology, Laval University.

calcium and some magnesia were removed by solution. This appears to be a reasonable conclusion.

Age

The "greenstones" are intruded by a coarse, brown to dark brown hypersthene bearing pegmatite of the type associated with the syenites. Therefore, they are undoubtedly pre-syenite, and in view of their low grade of metamorphism possibly post-early quartz diorite.

LATE INTRUSIVES (Post Timiskaming?)

Hornblende Gabbro (Amphibolite?)

Description

These are medium grained massive rocks that are mottled in green and grey, and to the eye contain feldspars, hornblende, and less numerous garnets. In a few places there may be a weak linear arrangement of the hornblende crystals.

Occurrences

There are several exposures of these rocks nearly all of which are in the vicinity of Gabbro Lake. The two best examples are along the highway, one at mileage 53.5, (See Plate No. 13) and the other right beside the lake. This latter exposure appears to be part of a large dyke or lens-shaped mass which can be traced intermittently southwestwards along the north shore of the lake. A search of the south shore failed to reveal any extension of it in that direction, while northeast of the road attempts to find it were equally fruitless.

The most southerly exposure on the lake shore displays an easterly lineation of its hornblende crystals. The longer axes of the crystals parallel the longer axis of the lake and suggest the possibility of the latter occupying an easterly striking fault zone. The occurrence only a few miles to the northeast of a fault having a similar trend lends emphasis to the idea. However it could be that the rock is a sill-like mass controlled by folding, in which case it may continue under the lake and follow its channel to the northwest. On the other hand, the rock may only occur as lenses of small length, and erratic distribution.

Petrography

In thin section the rocks are medium grained and granoblastic. They consist of plagioclase An_{45-47} (50%), brown hornblende (35%), garnets (10%), biotite (5%), with only a few small accessory grains of magnetite.

The feldspar crystals are water clear and fresh, with subhedral to anhedral outlines. Albite and pericline twinning are moderately well developed and give maximum extinctions on the section perpendicular to (010) - 27°.

The hornblende is in subhedral to anhedral laths. It is pleochroic in greenish browns and browns, and has a negative $2V=70^{\circ}$, an extinction angle of $Z_{\wedge}c=16^{\circ}$, and displays good basal cleavages at 124° and 56°.

The garnets are found as small euhedral to subhedral crystals in and around clusters of hornblende, and some appear to have a very weak birefringence.

Under the microscope these rocks are more like amphibolites than gabbros, and compare favourably with those described by Adams (2-pp.104-6), and shown to have been formed by the metamorphism of limestones.

Hypersthene Gabbro

Description

These are massive, mottled green and grey granitoid rocks. They contain pyroxenes, feldspars and minor amounts of garnet.

Occurrences

West of the Canimiti River some four miles above its junction with the Chochocouane, there are numerous massive exposures of these rocks; the largest seen was about 400 feet by 200 feet in dimension. Vertical joints that strike S 55°E, and an intermittent lineation of the hornblende crystals in a direction of N 75°E, were the only observed structures.

An interesting exposure was found 4500 feet due south from the southwest corner of Champrodon township; here a very fine grained slightly foliated and very garnetiferous band of gneiss about 2 to 3 feet in width, is enclosed in massive gabbro. The band stands vertically within the gabbro, and neither rock shows any change of grain size at the contact. Whether this is an included metamorphosed sediment or a dyke could not be determined. (See analysis of this rock under "Biotite Garnet Gneiss")

Petrography

Microscopically these are medium grained hypidiomorphic granular rocks, containing plagioclase An_{45-50} (40%), hypersthene (15%), hornblende (10%), augite (25%) and garnets (10%). Biotite, zircon and magnetite or ilmenite are the accessory minerals.

The plagioclase is in both large and small subhedral to anhedral crystals and shows good albite pericline and occasionally carlsbad twinning, with a maximum extinction on (010) and (001) = 30°, and a positive 2V. Zoning is found but the compositions of these crystals were not determined.

The hypersthene is in anhedral crystals or aggregates of small crystals and rarely larger than 2mm. in length; it has a parallel extinction and a faint pleochroism in pale pinks and yellows.

Hornblende is seen as an alteration product of augite and is the brown pleochroic variety having a maximum extinction of $Z \wedge c = 18^{\circ}$.

The augite is colourless subhedral to anhedral and shows the rare basal section with two cleavages intersecting at 87°; one such section displayed twinning on the (100) face. The sign and size of the optic axis could not be determined, but the extinction of $Z \wedge c = 44^{\circ}$.

The garnets are small and have not their customary subhedral to euhedral outlines. They are very irregularly distributed suggesting that they are late formed minerals, possibly the results of contamination. In some instances, they seem to have replaced the augite and plagioclase inasmuch as they embay these minerals, yet in other places their faces are bounded by both augite and plagioclase cleavages.

Biotite, zircon, and magnetite or ilmenite, are the only accessories. The zircon is invariably found as inclusions in the augite, while the biotite is apparently the result of the alteration of either augite or hornblende.

Age

In all the exposures of these rocks so far observed, no contacts were seen with the surrounding gneisses, nor were any rocks seen to intrude them. Structurally they are massive, and they appear to have escaped the effects of the strong forces which were so active elsewhere. Thus the fact that the early quartz diorites, granites, and late pegmatites, have not been found intruding the hypersthene gabbros, suggests that they are younger intrusives: possibly differentiates from the same magma that provided the syenites.

Quartz Diorite (Red)

Description

This is a medium grained pink to reddish granitoid rock, composed of pink to red feldspars, and quartz, with only minor amounts of mafic minerals, chiefly biotite.

Occurrences

East of Lake Numance in the northwest corner of the sheet, there is a large north-south trending ridge which has a core of pink to reddish quartz diorite. The western flank of the ridge is steep and there are many rock scarps which consist of layers of interbanded quartz diorite and pyroxene-bearing gneisses; the strike of the banding is between north to N 10^{o}E while the dip is 60-70^{o} towards the east. The scarps are smooth faced, yet have trough-like crenulations which plunge N 70^{o}E at 60^{o}. Above the scarps the rocks become massive quartz diorite, and banding is rarely seen.

The eastern margin of the intrusive is against foliated pyroxene-bearing gneisses and granulites which contain a few small lenses of coarse grained "hypersthene - augite - hornblende" rock, similar to those previously described. As the intrusive is approached from the east, the marginal granulites become well banded as a result of the concentration of mafic and acidic material into alternate layers. Some of this layering is undoubtedly caused by lit-par-lit injections of quartz diorite, but part may be original banding.

The long straight front of the western side of this ridge; its steepness, the plated and slightly slickensided appearance of the rocks near the base; in addition to the way in which they dip east under the ridge, is considered to be undeniable evidence of faulting along this zone.

Only three exposures were found between the base of the ridge and Lake Numance; one contains foliated quartz diorite, while the other two are massive medium to coarse grained pyroxene - hornblende rocks that have some acidic bands and appear to grade into quartz diorite. The strikes and dips of their foliations are conformable to those of the other rocks in this locality.

As a matter of record, it should be mentioned that at the base of the large ridge, angular fragments of a hard but plated and slightly injected "greenstone" were found; where they came from is not known, but their presence in the talus and their plated appearance indicates that they were probably scaled from the base of the ridge.

Petrography

Microscopically the rock is hypidiomorphic granular, and consists of plagioclase An_{30} (80%), and quartz (15%). Hypersthene is the only accessory mineral, but some hand specimens also contain biotite.

The plagioclase is fresh and rarely twinned after the albite law, and shows little alteration. One crystal displayed a very minute perthitic development of either a less calcic plagioclase or a potash feldspar.

The hypersthene is only in very small irregular crystals that have the usual parallel extinction, and are slightly pleochroic in pale yellow and pink.

The quartz is in the customary anhedra of varying sizes, and shows little fracturing or distortion.

Age

This stock is not known to be intruded by any other rock and so might belong to the early period of intrusion or be roughly contemporaneous with the syenites and granodiorites. Its pink to reddish colour suggests that it is possibly related to the latter, for the early granitic rocks in the area are grey or white and contain no hypersthene; whereas this mineral is common in the younger syenitic intrusives. Moore (46-p.133) conducted a survey of the granitic intrusives which occur in the Canadian and Scandanavian "Shields", and found that in all cases the reddish coloured granites were the youngest.

It must be admitted that there is insufficient evidence as to the age of this intrusive, but until more conclusive proof is forecoming, it will be treated as contemporaneous in age with the syenites and granodiorites.

Hornblende Syenites, Quartz Syenites, and Granodiorites.

Description

These are medium to coarse grained granitoid rocks mottled in pink and green, and consisting of mauve to pink feldspars, dark brown hornblende, hypersthene and quartz. Some facies have little or no quartz while others may have an abundance of mafic minerals. (See Plate No. 31).

Occurrences

There are two large stocks and a number of small exposures in the southeastern and eastern portions of the area. The largest is on the south boundary and underlies the region between the arms of Soulier Lake; it extends southwestwards into the territory mapped by Wahl and is described by him in his report. (71)

In plan this stock is ellipsoidal with a longer axis that strikes in a northeasterly direction, and including that part which protrudes into Wahl's area, is roughly 4 to 5 miles long and 1 to 2 miles wide. It was seen in many places along the southern boundary of the sheet, but further to the north no exposures were found and it was only possible to roughly delimit its extent by recording the changes in abundance of syenitic erratics and those of gneisses.

There are two distinctive facies in this intrusive; the commonest is the mottled pink and green variety, that contains feldspar hornblende and quartz (5%), the other is a rich pink colour, has no hornblende, and is composed entirely of feldspars with 10 to 15% of quartz. This latter type is inequigranular and contains some large mauve phenocryst of felspar, and is undoubtedly a pegmatoid facies.

Foliation within the intrusive is not noticeable, but there is a tendency for the marginal zones to have well banded hornblendic gneiss which may be contaminated or sheared syenites, or have resulted from lit-par-lit injections of syenite into the adjacent rocks. The strikes of these layered zones in part conform to the long axis of the intrusive. Near the west arm of Soulier Lake the lineation plunges S45°E at 55°, whereas within the main mass it plunges N60°-90°E at between 10°-25°.

The other large syenite intrusive is in the east central part of the area north of Lake Tombbah. It is also elongated, being 2 miles long by 1 mile wide, with its longer axis trending in a northeasterly direction. In appearance it is similar to the quartz syenite previously described, but is intruded by a greater number of very coarse grained reddish brown pegmatites, and also by a few fine grained aplitic dykes. The latter in places form selvages around the coarser pegmatites and branch off as small individual dykes. In thin section the aplites were seen to consist of microcline (50%), quartz (40%), and plagioclase An_{30} (10%).

At the southern end of this body, and just west of Lake Tombbah, there is a small exposure in which a medium grained reddish pegmatite, bearing quartz and magnetite, intrudes a mafic facies of the quartz syenite. A half mile south of here, there is an exposure of mafic syenite that grades into the normal hornblende-bearing variety. This is in places well foliated and banded and resembles the marginal basic gneisses found elsewhere in association with the other intrusives of this group.

The stock just described has in places a mineralogical composition between that of the hornblende syenite and the (red) quartz diorite, and since it contains between 10 and 15 percent of potash feldspars, it approximates the composition of a granodiorite.

Petrography

In thin section the hornblende syenites from the southern boundary are hypidiomorphic granular, medium to coarse grained rocks, and are essentially composed of microperthite (45%), microcline (20%), plagioclase An_{10-15}

and An_{25-30} (25%), quartz (5%), and hornblende (5%). The accessories are anorthoclase, augite, magnetite and sulphides. In addition some small relic crystals believed to be hypersthene were also seen. This was confirmed by the finding in a few hand specimens of small rusty weathering crystals of hypersthene similar to that so prevalent in other rocks of the area.

Wahl found some aegirine - augite in this rock, but none was observed in the thin sections of the syenite from this area. It is possible that some of the relic crystals mentioned above are resorbed aegirine - augite.

The medium grained pegmatitic facies found with the hornblende syenites, differs from these latter rocks by the absence of mafic minerals, greater amounts of microcline, less microperthite, a greater ratio of albite to oligoclase, and a higher quartz content. On the other hand, the stock north of Lake Tombbah in places contains little microperthite, low microcline and/or orthoclase, and is predominantly composed of plagioclase An_{30-35}, with in addition some hornblende and 10% of quartz.

The relationships between the microperthite, albite, and oligoclase, are of interest; the microperthite is in anhedra of medium and large size, which show albite developing as lenses and rods within the crystals and also as reaction rims apparently replacing the microperthite. (See Plates Nos. 50 and 51) The plagioclase An_{25-30} shows little alteration but in places has been albitized and occasionally displays partly zoned crystals.

Anorthoclase is found replacing plagioclase An_{25-30}, (See Plate No. 52). This mineral is distinguished by its low birefringence, and a $2V=45^o-55^o$. The inclusions which it contains are reminiscent of those seen elsewhere in the "sanidine - anorthoclase". (See Plate No. 53)

The hornblende is in irregular but at times lath-like crystals, and is the yellow brown to brown pleochroic variety, with an absorption of $Z>Y>X$, and an extinction of $Z\wedge c=15^o$, the $2V=65^o-75^o$ and is negative.

The augite crystals are small and resorbed and defied accurate determination, but are non-pleochroic, with an extinction of $Z\wedge c=44^o$.

A few small crystals of hypersthene were recognized by their pale pink and yellow pleochroism, and their parallel extinction.

The quartz is clear and unstrained and apparently replaces the other minerals.

<u>Age</u>

The age of these rocks is post-early (grey) quartz diorites, granites and pegmatites, since none of these early intrusives are known to cut them. On the other hand, pegmatites of a type commonly associated with the quartz syenites, do cut the "greenstones" found on the southern boundary of Freville township. The syenitic stocks have trends similar to those in the area to the north. (42) (67) (68) They intrude the granulites and gneisses which are believed to be of Timiskaming age. Hence, they are probably post-Timiskaming, and for reasons quoted elsewhere, pre-Cobalt, though a Killarney age cannot be entirely discounted. (See Page 204)

LATE PEGMATITES

Quartz Diorite, Hornblende Syenite, Quartz Syenite and Syenite Pegmatites

Description

These are coarse to very coarse grained, pink to reddish brown rocks. In the hand specimen, they consist of mauve to reddish feldspars, with the occasional crystal of hypersthene and/or hornblende. Some types may contain a mauve or opalescent quartz, and magnetite is occasionally seen in small amounts.

Occurrences

On Highway 58, within a few hundred yards of the western boundary of the sheet, there is a small exposure of pink to reddish pegmatite which is composed entirely of reddish to mauve feldspars. (See Plate No. 33) Small sills of this material may be seen intruding the hypersthene granulites in the immediate vicinity. Microscopically they consist of microperthitic felspars, with only accessory zircon, apatite and plagioclase.

Reddish to brown hypersthene and/or hornblende-bearing pegmatites intrude the hornblende syenite stock which lies on the southeastern boundary, and the granodiorite north of Lake Tombbah. No thin sections were made of these rocks, but their very coarse mauve feldspars are undoubtedly potash rich varieties. In one instance at the western end of Lake Tombbah a medium to coarse grained reddish pegmatite was seen to contain much disseminated magnetite.

A noteworthy feature is the frequent occurrence of these pegmatites in the more mafic and banded facies of the syenites, but when found within the more massive and granitoid exposures of these rocks, they have only minor amounts of hypersthene and/or hornblende.

Intruding the "greenstones" which lie on the southern boundary of Freville township, there is a reddish brown to dark brown, coarse grained pegmatite of unknown dimensions. It contains coarse reddish brown feldspars, crystals of an unidentified pyroxene, and disseminated iron oxides. (See Plate No. 32)

On the C.I.P. & P. Company road in the northern part of the area, three miles east of the Canimiti River bridge, the composite gneisses are intruded conformably by reddish, medium to coarse grained sills containing red to mauve feldspars, and opalescent quartz. There is also the occasional crystal of a light brown weathering hypersthene. Microscopically these contain plagioclase An_{29} (55%), antiperthitic plagioclase (10%), and quartz (35%), with only accessory biotite. Hypersthene is undoubtedly present in small amounts, but was not seen in thin section.

One half mile outside the western boundary of the sheet along Highway 58, there is an exposure of a medium to coarse grained dark green rock. This contains green feldspars, dark brown pyroxenes and/or hornblende, and the coarser facies have a pegmatitic appearance. Short distances to the north and south of here there are other exposures of these massive rocks. A thin section showed orthoclase and microperthite (15%), antiperthitic plagioclase An_{27} (75%), and quartz (10%). The accessories are hypersthene and biotite, but in the hand specimen the mafic minerals are much more prominent than the thin section indicates.

Petrography

Under the microscope, the textures of these rocks are hypidiomorphic granular to inequigranular. Plagioclase An_{27-33} is the commonest mineral except in the alkaline variety, and is moderately well twinned and little altered. In the quartz diorite type of pegmatite found as lit-par-lit injections in the northern part of the area, orthoclase is absent or accessory, except as replacement or ex-solution crystals of small size in antiperthite.

The end product in the differentiation of the pegmatites associated with the late intrusives, is probably represented by the syenitic type found on the highway near the western boundary. All the feldspars are microperthites of large size, and have undergone albitization, while apatite so characteristic of alkaline pegmatites, is seen in accessory amounts. It is in the customary laths, and shows good hexagonal basal sections. Quartz which is so abundant in the other pegmatites, is absent.

Age and Origin

The occurrence of the potash rich varieties within the hornblende syenites, leaves little doubt but that they are late differentiates of these intrusives. They are younger than the "greenstones" since they intrude them, but those containing minor quantities of potash feldspars may be related to the early quartz diorites or the syenites.

COMPOSITE OR HYBRID ROCKS

Description

There is no adequate description for these rocks; they can be grey green to dark green, medium to coarse grained and massive, yet well banded by mafic layers, or they can be fine to medium grained and well banded as a result of injection or original composition, and contain hypersthene or garnets, or hypersthene and garnets. By transition they can grade into foliated yet coarse textured rocks, containing the occasional large porphyroblast of plagioclase, which in all respects appear to be of igneous origin. In short, they appear to represent that stage in metamorphism when near surface structures and textures are being obliterated,as the rocks are made ready for their assimilation into an expanding magma.

Occurrences

The northern parts of the area seem to have more of these complex rocks than the other sections, and many good exposures can be seen along the C.I.P. & P. Company road.

The coarser grained varieties are invariably located near the tops of small hills, and consist of reddish to green feldspars, pink to mauve quartz, biotite, coarse dark pyroxene, and various amounts of garnet. (See Plate No. 34) In thin section they show microperthite (0-10%) and/or orthoclase, plagioclase An_{27-33} (50-60%), biotite (5-15%), quartz (10-20%), garnets (0-10%), hypersthene (0-5%); while "sanidine - anorthoclase", antiperthite, magnetite, and sulphides are the accessories. The mauve quartz commonly occurs as crystals blebs or small stringers containing in places a few specks of sulphide, yet small fractures or joints are found in which there are equal concentrations of quartz and sulphide. These coarse grained rocks are seen to grade into medium grained light brown foliated varieties, which contain injection banding, and have either or both garnets and hypersthene.

Three quarters of a mile east of Composite Lake along the road, there are well-banded composite hypersthene rocks of medium grain, in which the banding appears to be in part the result of the injection of pegmatitic material, and partly inherited from the original rock.

(See Plates Nos. 10 and 11) There is a variation in grain size and colour which cannot be directly attributed to the intruding pegmatites, but must have resulted from selective pneumatolytic or hydrothermal action along preferred channels, such as might have been provided by sedimentary bedding. Some bands contain garnets, while others have both garnets and hypersthene, and in addition there is the occasional dark pyroxene-hornblende inclusion that may contain sulphides (pyrrhotite) in sufficient quantities to deflect a compass needle. In thin section, these gneisses are fine to coarse grained and contain plagioclase An_{27-30}, antiperthite, hypersthene, biotite, garnets, and quartz.

South of Composite Lake, the exposures along the road are of a medium to coarse grained, green to dark green rock, in many respects similar to the coarse textured rocks described previously. But here mafic bands (See Plate No. 12) are so numerous that in places they constitute 70 per cent of an exposure. These rocks form steep scarps on the east side of the creek which drains Composite Lake at its southwest end, and are intruded in a lit-par-lit fashion by medium grained material of quartz diorite composition. The foliation and banding strike to the north and dip east at 50° to 60°. Two small exposures of "greenstone" occur on the west side of the creek and have layering conformable to the above. One is much injected by a quartz diorite similar to that which intrudes the composite gneisses. The concentrations of mafic banding in these rocks and their proximity to the "greenstones" suggests the possibility that the mafic bands are assimilated or metamorphosed "greenstones".

The composite rocks from this vicinity contain plagioclase An_{32-35}, biotite, quartz, and accessory augite, hornblende, hypersthene, apatite, magnetite or ilmenite and sulphides.

Petrography

These rocks are granoblastic, consist of plagioclase An_{27-35}, quartz, hypersthene, garnets, biotite, and orthoclase or microperthite. However, plagioclase and quartz are the only two consistently essential minerals, whereas apatite, "sanidine-anorthoclase", zircon, magnetite, and/or ilmenite and sulphides are usually the accessories.

The mafic bands so common in the rocks around Composite Lake are composed of fine grained aggregates of biotite, hypersthene, augite, hornblende, quartz, plagioclase and garnet, in a coarser grained plagioclase quartz aggregate. (See Plates Nos. 47 and 48) They are identical in many respects to the well banded composite hypersthene garnet gneisses which are found along the road to the southeast of Composite Lake.

Orthoclase is rarely seen and is only identified by its refractive index (lower than balsom) and its negative optic axial angle.

Microperthite is in anhedral crystals of medium size and quite common in amounts of up to 10%, though in a few of the coarser rocks there may be more. It is rarely as well developed as that seen in the hornblende syenites, which suggests that it and the accompanying metamorphism are associated with the early period of intrusion.

Antiperthite is not present to any extent in the finer grained varieties, but is more common in the coarser but less potassic rocks, though it is not as well developed as that seen in the quartz diorite sills near the Ottawa River.

The "sanidine - anorthoclase" is clear, colourless, dark and ~~opaque~~ between crossed nicols. It has a negative $2V=15^{\circ}-30^{\circ}$, and contains inclusions of twinned plagioclase. (See Plate No. 53) It embays and appears to replace the larger twinned plagioclase. The latter in one instance shows myrmekitic intergrowths at its contact with the "sanidine - anorthoclase", yet these do not extend into the potash mineral.

The plagioclase is in large and small crystals and moderately twinned after the albite law. The extinction angles on (010) indicate compositions with a range of An_{27-33}. The twinning is sharp but hazy, indicating that it has been undergoing resorption.

The hypersthene is the normal anhedral variety with a very faint pink to green pleochroism, and a parallel extinction. It contains in places a dark powdery opaque substance in the cleavages and around its borders, which is probably caused by decomposition and the formation of iron oxide. This mineral is much more plentiful than the thin sections indicate, for it is crumbly and readily removed by abrasion during the grinding of the thin sections.

The augite is only found as very small anhedra in the finer grained and banded types. No proper identification was possible, but its lack of pleochroism and an extinction angle of $Z_{\wedge}c=44^{o}$, served as identification.

The hornblende is the normal brown pleochroic variety with a $Z_{\wedge}c=22^{o}$ and a positive elongation. It occurs in small laths and clusters only in the mafic rocks south of Composite Lake, associated with garnets, biotite, augite, and hypersthene, (See Plates Nos. 47 and 48).

The garnets are anhedral to subhedral dodecahedrons of all sizes, and are opaque between crossed nicols, often fractured, and contain inclusions of quartz, feldspar, biotite, and sulphides.

The quartz is in the usual anhedrons, generally clear and unstressed; but occasionally shows undulatory extinction and fractures. In some sections, it appears to be in long interstitial lenses and to replace the plagioclase.

The occurrence of mauve to opalescent quartz in this vicinity is worthy of mention, since it is similar to that found in the albitic intrusives associated with the gold deposits of the Bourlamaque area, Quebec.

Origin

This will be considered in a later section on "The Mode of Emplacement of The Igneous Rocks and Their Associated Phenomena".

GRANITE DYKE (PEGMATITIC)

Description

This is a coarse grained mottled grey and green rock containing coarse light grey feldspars, dark green pyroxene, rose quartz, and biotite. The feldspars are large, but of consistent size (10-20mm.) and make up 70% of the rock. The mafic minerals and the quartz are smaller and interstitial.

Occurrence

Only one such dyke was found within the area, and this occurs on the C.I.P. & P. Company road, roughly two miles east of Composite Lake. It is 4 to 5 feet wide and cuts coarse grained but slightly foliated and banded composite gneisses which strike N 15°W, and dip gently to the northeast, whereas the dyke strikes N 10°E and is vertical. The margins have a finer grain than the centre of the dyke but are not chilled, while in appearance it is fresh and unsheared, though small striated plates of sulphides were seen on some crystal faces and these appear to have been caused by slight differential movements. Another similar dyke was seen on the highway near McLaurin Lake outside the western boundary, where it intrudes amphibolites and garnet gneisses.

Petrography

In thin section this rock is hypidiomorphic inequigranular and contains microperthite (60%), quartz (30%), hypersthene and biotite (10%), while plagioclase of an unknown composition and microcline are the accessories. Alteration is negligible or absent.

The quartz, plagioclase, and biotite, are found as small crystals and aggregates of crystals, interstitial to the potash feldspars.

The microcline is in small fresh crystals and shows good cross-hatched twinning.

The hypersthene is in the occasional anhedral crystal and is recognized by its parallel extinction and weak pleochroism.

There are a few small interstitial patches which display myrmekitic intergrowths of quartz and orthoclase or albite.

Age and Origin

The acidity of this dyke and its coarse grain, along with its abundant microperthite suggest that it is related to the syenite pegmatites: while the manner in which it cuts sharply across the composite gneisses, as well as its freshness, indicate that it is one of the youngest acidic intrusives in the area.

BASIC DYKES

General

Basic dykes are not numerous in the area, but many of the inclusions or bands found in the granulites and gneisses may be metamorphosed and disrupted dykes or sills. A relict structure of what was undoubtedly a basic dyke has been described with the "Microcline - Plagioclase - Quartz gneiss.

Metagabbro

Description

This is a dark green, medium grained, rusty weathering rock, which in the hand specimen consists of pyroxene, hornblende, and minor amounts of feldspar.

Occurrences

Four miles due east from the Canimiti River crossing of the C.I.P. & P. Company road, on the eastern side of a little lake at that place, there is a scarp of garnet gneisses in which there are some small sills of this rock.

On the eastern bank of the Canimiti River where it leaves the Elbow Lakes, there are more of these rocks which appear to be disrupted sills. They are enclosed in contorted hypersthene-bearing gneisses, that have a northerly strike and an easterly dip of 80°.

Petrography

Microscopically the rocks are inequigranular and of medium to coarse grain; and contain augite (35%), hornblende (30%), hypersthene (25%), and plagioclase An_{45-48}, (10%). The accessories are apatite, zircon, quartz, and magnetite, in addition to a deep amber coloured mineral with a high refractive index, and low birefringence, which was not identified. Biotite and garnets are present in one thin section in equal amounts of about 10%.

The composition of the feldspars could not be determined since they are covered by a powdery opaque alteration product believed to be hematite.

The pyroxene was probably augite but is now only seen as relic crystals.

Hornblende is the most prominent mineral, and is pleochroic in browns, with Z = brown, Y = yellow brown, and X = yellow green. The extinction angle $Z_{\wedge}c=18^{o}$. This mineral has undoubtedly formed at the expense of the pyroxene.

The garnets are in the form of small anhedra and occur as clusters associated with the biotite.

The biotite is the brown pleochroic variety and forms peripheral clusters around the magnetite or ilmenite and the sulphides.

<u>Augite Dyke</u>

<u>Description</u>

This is a dark green, fine grained rock in which pyroxene and feldspars are the only recognisable minerals.

<u>Occurrences</u>

There are four or five dykes of this rock cutting the banded hypersthene garnet gneisses exposed at the long rapids on the Chochocouane River, three quarters of a mile south of its junction with the Canimiti. The dykes are between 2 to 6 feet wide and have strikes which vary from north to N 70°E, while their dips although more often to the southeast are not consistent. There is a slight increase in grain size towards the centres, but no strong chilling along the contacts, and foliation is negligible or absent.

Petrography

In thin section these are a fine grained aggregate of augite (40%), hornblende (20%), plagioclase An_{37} (28%), hypersthene (5%), and quartz (10%); garnet is the only accessory, but small quantities of carbonates and epidote are found as alteration products.

The augite is non-pleochroic and pale pink in colour, has a $Z \wedge c = 40^\circ$, and shows some alteration to epidote. It is occasionally seen as relatively large well formed phenocrysts, a few of which have twinning on the (122) or (011) face.

Other Basic Dykes

A fine to medium grained brittle dyke of dark green colour was seen on the C.I.P. & P. Company road just east of the 77°05' meridian; it appears to strike

N 10^{o} E and to have a vertical dip. Near the only observable contact it becomes finer grained and breaks with a subconcoidal fracture. The width could not be determined but the exposure is roughly 15 feet wide across the strike.

Ages of the Basic Dykes

Since the metadiabase and the augite dykes cut the gneiss banding and are undeformed, they must have been intruded after or at the close of the major period of deformation and metamorphism, and possibly later than the syenites and their associated pegmatites. The metagabbros on the other hand which only occur as sills and are metamorphosed, probably belong to the earliest period of igneous intrusion. Pre-metamorphic intrusion of basic material is clearly indicated by the "relic" dyke which cuts the microcline - plagioclase - quartz gneiss north of Lake Tombbah.

PARAGENESIS OF THE MINERALS AND THEIR SIGNIFICANCE

Biotite

The associations of this mineral are of the utmost significance, for nowhere save in recognisable igneous rocks and in some composite gneisses is it seen to have formed at the expense of either hornblende or pyroxene. The biotite gneisses contain no hornblende, relic crystals of hornblende, nor biotite pseudomorphs of hornblende, as might be expected if these rocks had been derived by the metamorphism of basic intrusives or extrusives. Total obliteration of such evidence would require low temperature stress conditions and a plentiful supply of water. (37-p.312) This would have undoubtedly led to the formation of chlorite in addition to biotite, but the former mineral is lacking, and the rocks display little evidence in their minerals of low temperature stress effects.

On the other hand it is generally accepted that an abundance of biotite, such as is found in the biotite gneisses, must have been formed at the expense of pre-existing alumino-silicates like chlorite and sericite, minerals which in their turn were derived from the regional metamorphism of muddy sediments. (37-pp.209-218)

Harker states that biotite is stable into the higher grades of metamorphism, and that "it is often very evident that as we pass the highest grade of metamorphism, biotite dwindles and disappears. The potassic part goes to make orthoclase with some alumino-silicate, while the ferromegnesian part gives rise to hypersthene or possibly garnet". (37-p.57)

Grubenmann (35-p.60) in his table of the depth zones, shows biotite and orthopyroxenes as being stable in the "kata-zone". But reason would demand that biotite cease to exist in very deep, hot zones, through loss of the (OH) radical.

Biotite occurs in nearly all the rocks except some pegmatites, but its quantities decrease in the more metamorphosed types. However, even in the biotite gneisses it is rarely found in amounts of over 30%, and nowhere in the area have true schistose rocks been seen. This is taken to indicate that the rocks were formerly at such high temperatures that biotite, a stress mineral, was unstable, and that such schistose rocks as were present had been transformed into garnet or hypersthene bearing gneisses. Though it could be that there were no rocks in the area, appropriate in composition for the formation of abundant biotite.

Microscopically, the biotite shows a close relationship to the garnets, and it is not uncommon to see clusters of biotite and garnets in the same thin section. In some instances, the biotite appears to be penetrating the garnets, (See Plate No. 39) and it is quite possible that retrograde metamorphism has caused the development of some, while in a few instances, contorted lamellae indicate that stresses have not been entirely lacking.

Zircons with pleochroic haloes are frequently found as inclusions in the biotite of the garnet and biotite gneisses. Henderson, of Dalhousie University, investigated the haloes from different localities. He concluded that the zircons and radio active material had been introduced into the biotite by solutions. (38)

Bain (6-p.655) gives an analysis of the biotite from the biotite gneiss of Chatham Township, Quebec. This shows that the Grenville biotite in that locality, carries equal amounts of potash and soda (3.07% and 3.12%), and much magnesia and iron (9.22% and 15.53%), in addition to alumina and low calcium (22.32% and 2.73%).

A significant amount of soda if present in the biotite of the area, might explain the abundance of microperthite in the more differentiated intrusives, since it is believed that the igneous rocks advanced by "assimilating" the gneisses in their path. In this way, they could have obtained large amounts of soda and potash for the formation of microperthite.

Garnet

This mineral is found in most of the gneisses of the area to a greater or less extent, and varies in colour from pale pink to deep red.

Five specific gravity determinations on the pink garnets in the light coloured garnet gneiss shown in Plate No. 22, gave an average of 3.80, and have refractive indices of 1.76 to 1.77. Qualitative tests show that they contain moderate quantities of iron: according to Winchell (74-p.176) these are pyralspite garnets, consisting of pyrope and almandite, with minor quantities of grossularite. A check with the more recent work of Fleischer (31-p.754) indicates an approximate composition of pyrope 43%, almandite 40%, grossularite 8%, andradite 5%, and spessarite 1.50%. This garnet gneiss comes from the eastern end of the C.I.P. & P. Company road.

Four specific gravity determinations were made on the deep red garnets from the sample shown in Plate No. 21. This comes from the western end of the C.I.P. & P. Company road. The average specific gravity for these garnets is much higher being 4.02. Qualitative tests gave good reactions for iron, but no refractive indices tests were made. Winchell's chart (74-p.176) shows that the specific gravity is that of a spessarite, almandite garnet with lesser amounts of pyrope.

The accuracy of these determinations is at the best only an approximation since the garnets usually contain inclusions of quartz, feldspar, and occasionally biotite. (See Plate No. 39) However, care was taken in the choice of the grains which were first inspected under the microscope in order to select those of the greatest purity.

In thin section the garnets are subhedral to anhedral, of all sizes, fractured, and opaque between crossed nicols. Inclusions of quartz and feldspar, presumably plagioclase, are common and appear to be the result of replacement. Biotite hypersthene and garnets are seen to be intimately associated in the finer grained composite gneisses in the north of the area. It is believed that in these rocks the garnets and hypersthene have formed at the expense of the biotite. However as previously described, biotite is seen to embay or penetrate the garnets in some instances, (See Plate No. 39) and it is quite possible that some biotite is the result of retrograde metamorphism, or that the garnet has grown around the biotite.

Bain (6-p.664) has described such an occurence in the Grenville rocks of Chatham township, and ascribes it to late lateral stresses caused by mountain building that fractured the garnets, which were then changed to chlorite and biotite in the presence of late magmatic waters.

Harker believes that almandite garnet is a stress mineral and characteristic of regional metamorphism, but that with a notable proportion of spessarite, it becomes stable under high temperature conditions. (37-pp.54-55) However, he states that exceptions are known where almandite garnets appear in the inner aureole of some intrusives. In connection with this it can be pointed out that garnets are found in the composite rocks of this area and these must have undoubtedly had some mobility. Further, they are frequently found in the quartz diorite dykes and sills, and are very numerous in the more massive migmatitic injections of Lake Tombbah. (See Plate No. 9) This would imply that the garnets in the rocks of the area are in part, at least, stable under antistress conditions, and possibly of a spessarite bearing variety, or are an anomolous occurrence similar to that referred to by Harker.

Eskola (27-p.173) says that the garnets of the eclogites are principally almandite and pyrope with only minor quantities of grossularite. He makes no mention of there being any high spessarite content, and it is of interest to note that in chemical components they are similar to those in the present area.

That the garnets have been derived from the alteration of biotite by increase in grade of metamorphism cannot be doubted, since biotite gneisses grade imperceptibly into the garnet gneisses: also biotite has the appropriate chemical composition necessary for the formation of the particular garnets of the area. In addition, support is found in the estimated mode average of biotite in the various gneisses. These are as follows: biotite gneiss, 20%, garnet gneiss, 15%, hypersthene granulites, 9.8%. No average estimate was calculated for the composite gneisses of coarse grain, but these have about 5%. Assuming that all these gneisses are facies of the same original rock, then biotite must have been removed or altered, and what could be more logical than the formation of garnets from the liberated magnesia, iron and alumina.

It is quite probable that some garnets have resulted from the metamorphism of intermediate or basic igneous extrusives as described by Harker. (37-pp.283-295) They are usually accompanied by mafic minerals such as hornblende, a mineral known to occur with garnets only in some layered composite gneisses, which because of their layered structure are considered to be of sedimentary origin.

Bruce (16-pp.27-40) in the western part of the "shield" found examples of garnetiferous gneisses of both igneous and sedimentary origin, while Ambrose has shown the progressive kinetic metamorphism of greywackes through biotite gneiss to garnet gneiss (5-p.285).

The formation of almandite (76.75%), pyrope (17.43%), grossularite (5.22%), garnet rock, from the Grenville limestone of Chatham township, Quebec, is described by Bain. (6-pp.650-668) He shows that "pegmatitic influences of the Laurentian granite" have metamorphosed the Grenville limestone, giving skarn, feldspar-garnet rock, biotite garnet gneiss, and biotite gneiss. It is hard to believe that the biotite, and biotite garnet gneisses have resulted from the metamorphism of a limestone; it seems more logical that they should have developed from a lime rich shale. However, the important point is that rocks rich in lime have given not lime rich garnets, but iron magnesian ones, with only a low lime content. Further it shows that lime rich rocks can lose their lime and thus their identity, under the influence of strong metamorphism accompanied by replacement. This is a most important phenomenon to remember, in view of the fact that the Canimity River area is situated in the "no man's Land" between Grenville and Timiskaming type rocks, where limestones may formerly have existed.

Hypersthene

This mineral occurs in nearly all the rocks of the area except the biotite gneisses and the quartz diorite intrusives. It is best developed in the composite gneisses and the late syenitic pegmatites. When fresh it is brown to dark brown, but weathers readily to a rusty brown oxide. In thin section it is faintly pleochroic in yellows and pinks, and in some crystals it appears to be nonpleochroic. The cleavages are rarely well developed, while the crystals are anhedral to subhedral with in places highly serrated outlines. They are often coated with a dark powdery substance that is presumably an iron oxide resulting from decomposition. The 2V is between 60°-70° and negative. This was not measured accurately and may be larger as is probably the case, otherwise there is ambiguity between it and the faint pleochroism, which is that of bronzite or low iron hypersthene with a 2V of between 70°-90°. (74-p.218)

Hypersthene and garnets occur in the same rock, but in those thin sections where they are seen to be intimately intermixed (See Plate No. 38) neither are well developed. But when separated or alone, they tend to form larger crystals with more characteristic outlines.

Large hypersthene crystals are found more consistently in the coarse grained composite gneisses, the porphyroblastic hypersthene - augite - hornblende layers or lenses, and in the coarse grained pegmatites; whereas the coarsest garnets are seen in the more feldspathic sills, that intrude the garnet gneisses. Since the hypersthene occurs in what are undoubtedly the most highly metamorphosed rocks in the area, it is possibly stable at higher temperatures than garnet, and probably derives its iron magnesia and silica from the decomposition of the latter with continued increases in temperature. Some evidence to support this contention is to be found in Plate No. 38 in which hypersthene may be seen forming along fractures in a garnet.

Brauns (14-p.60) believed that the hypersthene and cordierite in the rocks of the Laach Lake Region obtained their iron and magnesia from the biotite garnet and magnetite of biotite garnet gneisses.

Harker (37-pp.57-58) says that hypersthene orthoclase and cordierite are formed in the high grades of metamorphism, and that "if biotite is present, it is seen to be in the process of destruction". No cordierite is found in the metamorphosed rocks of the area and potash feldspars though present are not abundant. It is possible that Harker's conception of the metamorphic processes (37-p.250) is at times in error, through his refusal to admit that moderate quantities of material can be added or subtracted by fluids during metamorphism. The absence of the minerals which he associates with the hypersthene stage can be explained through the removal of potash and alumina by solvents, since these elements were probably not in equilibrium with the quartz diorite intrusives, but only with their pegmatites near the end stages of consolidation. In all probability these elements formed feldspars, leaving no alumina for the formation of cordierite.

"Sanidine-anorthoclase"

This name has been given to a colourless glassy anhedral mineral which is found in accessory amounts in the potash-rich quartz diorite pegmatoid sills, in the coarse composite rocks, occasionally in the garnet gneisses, and in some fine to medium grained granites. The latter are contaminated by garnets and biotite absorbed from the surrounding gneisses.

The optic axial angle has a range of from 10^{o}-55^{o} and varies from crystal to crystal, and in different parts of the same crystal. It is negative and the optic axial plane appears to be parallel to (010). This mineral frequently contains inclusions of twinned plagioclase which by their extinction angles indicate compositions of An_{32-36}. These inclusions show a peculiar relationship to the size of the optic axial angle of the "sanidine-anorthoclase". Where they are numerous the angle is at a maximum (45°-55°) but where they are few or absent the optic angle becomes very small (10°-15°). Winchel (74-p.367) gives an optic axial angle for anorthoclase of from 42°-52°, while Iddings (40-p.234) quotes angles of up to 13° for sanidine. Therefore the optic axial angles of sanidine and anorthoclase are respectively similar to the minimum and maximum of those in the "sanidine-anorthoclase". This suggests the possibility that the latter may be an isomorphus mineral or a solid solution composed of orthoclase and albite molecules in variable proportions.

The inclusions might be construed as indicating a state of supersaturation in those crystals or parts of crystals with respect to the plagioclase molecule; or that re-solution of plagioclase by the "sanidine-anorthoclase" was taking place at the time of consolidation, but that continually diminishing temperature, and therefore diminishing diffusion, restricted the enrichment of the crystals to those parts in immediate contact with the plagioclase. The size of the optic angle would thus be expected to vary in different crystals, and in different parts of a crystal if it were not homogeneous. If this explanation holds true, then an optic angle of say 27° could mean that the crystal composition was roughly Or_1 Ab_1, since this angle would represent a mean between those of sanidine (13°) and of anorthoclase (42°). The plagioclase inclusions have random orientations and bear no resemblence to the rods of albite in the microperthite which are believed to have formed by ex-solution, and their compositions are more calcic.

In the same rocks containing "sanidine-anorthoclase", albite and potash feldspars were being released from solid solution to form microperthite. It would be a contradiction to have oligoclase-andesine feldspars forming at the same time.

In the hornblende syenites which contain abundant microperthite, plagioclase An_{25} has reaction rims of albite, and it is also replaced by anorthoclase. (See Plates, 50-52)

Late replacement of plagioclase by potash feldspars is quite common and has been described by Reynolds (55-p.213-14) and others from areas where "granitization" has occurred.

There can be little doubt but that the "sanidine-anorthoclase" was replacing the oligoclase-andesine feldspars in those rocks in which it occurs.

Makinen (43-pp.121-184) has shown that the high temperature form of albite is probably miscible in all proportions with sanidine, and thinks the high temperature form is monoclinic. Winchell refers to this as the "sanidine-barbierite" series and says they are only stable at temperatures above 900°C (74-p.355). The name barbierite was given by Schaller to a sanidine from Norway containing 4.92 percent soda and 6.75 percent potash, which was considered by him to be monoclinic (59-pp.40-41).

Vogt believed that there is no such thing as monoclinic albite and considered barbierite to be a "mistake" (70-p.18). He thought, however, that a high orthoclase content caused monoclinic symmetry to be approached. He also took exception to Alling proposing the use of the name anorthoclase for all compositions ranging between 70% orthoclase: 30% albite, to 20% orthoclase: 80% albite, and stated that he would like to know if a mineral in this group carrying 35% of orthoclase existed. He quoted Rosenbusch's limits for anorthoclase as being between 20- to 30 percent orthoclase (70-p.14).

It is not known whether the "sanidine-anorthoclase" in this area is monoclinic, but the range of its optic axial angle indicates that it probably represents a continuous orthoclase - albite series hitherto suspected but not observed.

Tridymite and alkaline pyroboles fill cavities in the lithoidal rocks associated with the anorthoclase bearing pantellerites on the island of Pantelleria, (80-pp.94-97) and since tridymite is stable between 870°-1470°C., this implies that anorthoclase is also stable somewhere within these temperatures.

Makinen (43-pp.126-7) showed that mixtures of microcline and albite do not fuse together until 1300°C. in a dry melt. This suggests the maximum temperature for the formation of anorthoclase. However it is generally accepted that the presence of volatiles reduces considerably the crystallization temperatures of minerals.

Brauns (14-p.33) found that the volcanic bombs of the "Laach Lake Region" contain sanidine in which there are inclusions of corundum, and that the quartz which surrounds the sanidine appears to have melted. However, he did not believe that the temperatures within a volcano ever approximated the fusion temperature of quartz.

Day and Shepherd measured the temperature of the Kilauean basaltic lava, and found it to be about 1000°C. (25-p.601).

Acidic lavas are believed to be molten at lower temperatures, because of a greater volatile content. But gaseous transfer of heat from depth might make the lava hotter than the magma at depth. However, if these conditions are allowed for by reducing the figure given by Day and Shepherd to 870^{o}C, this can probably be accepted as the lower limit for the consolidation of the "sanidine-anorthoclase". Vogt (70-p.65) was of the opinion that granites solidify between 850^{o} to 880^{o}C.

The potash for the formation of the "sanidine-anorthoclase" was probably derived from biotite. Braun (14-pp.57-58) believed that his sanidinites, containing cordierite, biotite, hypersthene, sanidine, anorthoclase, spinel, and corundum, were derived by the pyrometamorphism of biotite garnet staurolite sillimantite orthoclase plagioclase schists and gneisses.

High temperature potash feldspars have been reported from two other localities in the "Canadian Shield". Cooke (23-p.105) describes a large intrusive of "purplish red feldspar porphyry" in Duparquet township Quebec, in which the phenocrysts are anorthoclase. The description of these feldspars is similar to those in the more pegmatitic facies of the hornblende syenite in the present area, which contain the occasional grain of anorthoclase. (See

Plate No. 52) Mawdsley (44-p.23) found small amounts of "anorthoclase or orthoclase" as perthitic rods in the andesine of the St. Urbain anorthosite.

In the occurrences referred to above, it is probably safe to assume that the anorthoclase in the "red porphyry" was an early formed mineral, whereas that in the rocks of St. Urbain must have crystallized late, as did the anorthoclase in the Canimiti River area. This is interesting since the two latter occurrences are both in the Grenville province.

Hope-Simpson (64) has described sanidine from the middle Devonian rocks of Gaspe, where it occurs in the mesostasis of metamorphosed intercalated siltstones and marls (porcellanite) as well as in veins. He makes an interesting reference to Eskola (27-p.162) in which the latter states that no garnets are stable in the sanidinite facies. This conflicts with Harker's statement (see under garnets) that certain varieties of garnet are stable in the inner aureoles of some intrusives. The evidence from such areas containing sanidine and anorthoclase as described by Braun (14) and Brogger (15) supports Eskola's contention. Yet the instances referred to by Harker are probably associated with potash-poor intrusives, or as in the present area only the initial stages of the sanidinite facies were attained before consolidation took place. In this respect, it can be stated, that in the coarse composite rocks "sanidine-anorthoclase" has not been observed in the same thin section with garnets, but the samples from which the thin sections were cut contain garnets. One thin section of a fine to medium grained garnet gneiss did show a few crystals of anorthoclase. The only plausible explanation is that the rocks of this area had not fully attained the grade of the sanidinite facies.

In the porcellanites, Hope-Simpson found that sanidine and carbonates had replaced diopside and that stress minerals are lacking. He considers the associated copper deposits to be xenothermal (high temperature low pressure).

The "sanidine-anorthoclase" is most plentiful in the quartz diorite to granite sills which inject the more garnetiferous rocks and in the coarse grained composite gneisses. It is an interstitial mineral of variable composition and has probably arisen through the selective replacement and/or solution of the albite molecule from the surrounding plagioclase, since it is prominent only at the contacts of the <u>lit-par-lit</u> sills, and in the coarse composite gneisses. It is possible that potash, alumina, and soda, were derived from biotite during the transformation of its constituents into garnet with rising temperatures. This is suggested by the absence of "sanidine-anorthoclase" in the biotite gneisses, even though they are intruded by much igneous material, and by the fact that Bain (see under biotite) found a high soda content in the biotite from the Grenville gneisses in Chatham township.

Microperthite (orthoclase or microcline?)

This mineral occurs to a greater or less extent in most of the acidic intrusives and is always present in those which contain "sanidine-anorthoclase".

It is well represented in the quartz diorite lit-par-lit sills which inject the more garnetiferous gneisses, whereas it seldom occurs in those that intrude the biotite gneiss.

The hornblende syenite intrusive in the south-east part of the area has up to 45% in some thin sections. The granite dyke (pegmatitic) in the north of the area is almost entirely composed of microperthite and quartz, with only minor amounts of hypersthene, biotite, plagioclase and sulphides.

The composite gneisses have minor amounts (0-10%)

and the fine to medium grained massive garnet gneisses contain only an occasional crystal. One thin section of the latter has small anhedra of both anorthoclase and microperthite. The anorthoclase has a very low birefringence and an optic axial angle of between 45°-55°. The surfaces of these crystals have an undulating appearance when seen between crossed nicols, and it is only by incessant searching that optic axial figures can be obtained. The microperthite on the other hand has only achieved its characteristic rod-like structure in a few crystals and these have a birefringence that is relatively much higher than anorthoclase. There are however, crystals that are undoubtedly microperthite, in which the rods appear not to have completed their seggregation; and are broad blurred bands that follow roughly the (001) or (010) directions in the host feldspar. It is to be noted that the birefringence in these crystals approximates that of anorthoclase. They maintain a nearly constant low birefringence during a 360 degree rotation of the microscope stage, indicating that the section must be normal to an optic axis, yet no optic figure could be obtained. The only implication possible from this, is that homogeneity within the crystals has been disrupted by a process of ex-solution which was not completed due to a too rapid loss of heat. From this it would appear that these particular microperthitic structures have arisen through the ex-solution of albite from anorthoclase.

Shand (63-p.17) quotes Dittler and Kohler to the effect that microperthite when heated to 1000° centigrade reverts to "soda-orthoclase", (anorthoclase). This he states was confirmed by Spencer, who has shown that microperthite can be dissolved and reprecipitated without difficulty. Most of the solution takes place between 350° and 750° centigrade, and ex-solution is very easy to achieve.

Further support is given by the following quotation from Dana:

> "X-ray studies have shown that orthoclase at high temperatures may hold in crystal solution other feldspar molecules (chiefly albite), which at these temperatures seem to possess the same monoclinic lattice as orthoclase. On cooling, however, unstable conditions may result, and the dissolved molecules may separate and show their normal triclinic lattices. This accounts for the intimate intergrowth of different feldspars shown in the perthites. (24-p.540)

Microperthite by itself is common in the rocks of the area, but "sanidine-anorthoclase" rarely occurs unaccompanied by microperthite. This is strong circumstantial evidence for the conclusion that microperthite has been derived from a mineral belonging to the "sanidine-anorthoclase" series by some process of ex-solution.

Alling has made an exhaustive study of the perthites and considers that they are of two types: in the first the albite lamallae are believed to have separated out from the orthoclase by ex-solution at high temperatures, in the second, the albite is thought to be the result of replacement at moderate to low temperatures. The criteria for the identification of the distinctive types is given below:

"Ex-solution. Those blebs with comparatively uniform shape, relatively small in size, stringlets, strings and rods, with a definite orientation, usually parallel to 100 or nearly so; plus 6.5° to -6.5° to 010; parallel to 001; or parallel to 110, which have no connection with the margin of the grain of the host and which avoid zones near inclusions of quartz, are regarded as due to ex-solution. The distribution of the rods is a particularly useful criterion. They avoid the margins and zones around quartz inclusions. Ex-solution blebs are more abundant and larger near neighbouring grains of feldspar and farther away from the grain boundaries in contact with quartz, and at the same time they are smaller in size. The stringlets and strings are less restricted in distribution than the rods.

Replacement. These perthitic guests are larger (films, bands, plumes, and patches), more irregular in shape, do not maintain the same degree of uniformity in orientation, do more obvious cutting of the host, and frequently occur in the margins, sending tongues into the host. In contrast to the behaviour of the ex-solution blebs around inclusions, replacement perthite films, bands, and plumes surround such inclusions." (4-p.163)

According to these criteria the microperthites of the syenite are the high to moderate temperature ex-solution type. (See Plate No. 51) Yet in some instances the microperthite is saturated with albite droplets and stringlets. These seem to have been squeezed or seeped out to the margins at which place the albite appears to have replaced its host. (See Plate No. 50)

In one thin section, anorthoclase is seen replacing plagioclase An_{25}, (See Plate No. 52) and there is a partly zoned plagioclase An_{25} which has a rim of albite. From evidence seen in this thin section and others, it could be construed that plagioclase An_{25} was the last continuous member of the plagioclase group to form in the syenites. It was apparently followed by anorthoclase rather than albite, but with continued cooling albite and orthoclase were released from the anorthoclase by ex-solution to form microperthite.

The strongest argument for a break in the continuity of the plagioclase series is to be seen in Plate No. 52, which shows anorthoclase replacing oligoclase. In those sections showing strong albitization, microperthite is abundant, and both it and plagioclase An_{25} have been replaced by albite. It is to be noted that the more acidic and coarser facies of the syenites have the most microperthite and quartz hence the most albite. Possibly they represent the root areas of former syenitic pegmatites, similar to that seen on the highway near the western boundary which contains only microperthite, albite, zircons, and apatite. According to Schaller (85-p.149) this would be a complex pegmatite formed as a result of the replacement at high temperatures of potash feldspar by albite. Such a mineral succession would be in accord with the interpretation presented above.

Pegmatites are of frequent occurrence in the syenites indicating that these intrusives were plentifully supplied with volatiles in the closing stages of consolidation. Hence in the absence of proof to the contrary, any late process such as that of albitization must be attributed to a deuteric action within the syenites, whereby residual solutions or a rest magma rich in soda reacted with the already consolidated portions albitizing their feldspars.

Why microperthite should have been deposited before albite is a matter for conjecture. Perhaps at the albite stage both albite and orthoclase were present in the intrusive in eutectic proportions, (63-p.17) which at depth and at high temperatures led to the formation of a soda rich anorthoclase, but upon cooling the differences in crystal structure between the soda and potash molecules in this mineral caused them to separate. On the other hand the acidic plagioclase might have been withdrawn to a remote part of the magma causing enrichment in orthoclase and the simultaneous crystallization of orthoclase and albite. Later the albite rich fraction was intruded and replaced the microperthite and more calcic plagioclase.

The occurrence of antiperthite in the early quartz diorite pegmatoid sills and the absence of albitization, suggests that for some reason potash had started to accumulate and separate out early in the magma underlying the area. The absence of potash feldspars in the early quartz diorite stocks as opposed to their presence in the associated pegmatoid sills, might be accounted for by magmatic differentiation, or by the sills passing through rocks richer in potash than in soda, from which they derived potash for the formation of orthoclase.

While doing field work in the Levack gneisses along the contact of the Sudbury Irruptive, the author observed evidence indicating that granitic sills had been modified by the rocks which they had intruded. In one locality consisting of biotite-feldspar-quartz gneisses, intrusive sills contain only quartz and feldspar; while in an adjacent wide band of amphibolites the sills carry an amphibole in addition to quartz and feldspar.

Microcline

Relatively large crystals of microcline microperthite are found in a graphic granite pegmatite near Lac des Montagnes. The characteristic twinning is much deteriorated, presumably as a result of the formation of the perthitic structure by the ex-solution of albite. In marked contrast to these, there are small interstitial crystals of microcline in which the cross-hatched twinning is remarkably clear. Similar small microcline crystals are found in the hornblende syenites where they display the same interstitial relationship to the large crystals of microperthite, but are also accompanied by quartz and plagioclase. They make up 15 per cent of the microcline-plagioclase-quartz gneiss which is found in the section to the north of Lake Tombbah. The rock is equigranular and the microcline crystals are distributed uniformly throughout. The rock is believed to be a paragneiss, and this contention is afforded some support by the absence of the interstitial relationship which the microcline usually displays in the igneous rocks. However, in contradiction to this, one very small aplite which intrudes the syenites, contains nothing but microcline, plagioclase and quartz.

The microcline in the intrusives of the area is undoubtedly a late formed mineral, and in this respect, agrees with the contentions of Makinen (43-p.139) and Alling (3-p.59) that it is the stable low temperature form of potash feldspar.

Quartz

The granulites and gneisses all contain this mineral in abundance (15 to 30%). It is interstitial in some rocks such as the quartz syenites and pegmatites, or interwoven in a granoblastic aggregate with the other minerals as in the granulites and gneisses. Optically it has in places undulatory extinctions, and shows fractures. It is characteristically anhedral and embays all the other minerals except biotite. In some granitic sills, especially those intruding the more garnetiferous gneiss, the quartz may contain a multitude of hair-like inclusions of unknown composition, these can have random or lineated orientations. Wilson has noted that such inclusions are common in the quartz of Grenville paragneisses. (73-p.122)

The presence of large irregular grains, blebs, and small veinlets of quartz, in the coarse grained composite rocks, indicates that silica must have been mobile. But whether it was derived from the host rocks by selective fusion or introduced by intrusives is not known.

Antiperthitic Plagioclase

This mineral occurs in the composite gneisses, and in the quartz diorite pegmatoid sills, but it is not found in those rocks which have abundant potash feldspar. It is thought to represent ex-solution of potash feldspar from plagioclase, similar to the release of albite from solution with potash feldspar. Within one of the patches of potash feldspar shown in Plate No. 45, a few tiny lamallae can be seen with the aid of a hand lens. These have refractive indices greater than that of the enclosing potash feldspar and are therefore plagioclase, probably albite. The explanation of why perthitic inclusions are found within antiperthitic inclusions is difficult, but must needs be accounted for by either exsolution or replacement. Cheng (19-p.141) thinks antiperthite is caused by "the simultaneous rythmical crystallization" of plagioclase and orthoclase "or the replacement of plagioclase by orthoclase." Buddington has referred it to unmixing during deformation (17-p.133)

Myrmekitic and Vermicular Intergrowths of Quartz and Plagioclase or Orthoclase.

These occur as small interstitial grains in the garnet gneisses adjacent to pegmatite sills, in the coarse grained composite gneisses, and in intrusives such as the anorthoclase bearing granite, where the presence of garnet shows that the intrusive has probably been contaminated by included material. In short they are found only in rocks which show evidence of having contained, or been acted upon by fluids (60-p.70) and contain some potash feldspars. Authors such as Cheng (19-p.140-2) Reynolds (55-p.213-4) and Vogt, (70-p.94-5) found that vermicular intergrowths similar to these occur interstitially between large crystals of potash feldspar and plagioclase, but only one such occurrence was noted in the rocks of the area.

Opinions as to the origin of these structures range from the replacement of oligoclase by orthoclase, thus releasing quartz from the plagioclase, which in turn replaced the orthoclase forming the vermicular intergrowths of quartz and orthoclase, to the straight replacement of orthoclase by a eutectic solution of plagioclase and quartz.

Alling has discussed the evidence as to the origin of these textures and sums it up by saying: "that it seems to me that the intergrowths of eutectic appearance may be the products of various processes known as contemporaneous crystallization, partial assimilation, hydrothermal replacement, and ex-solution. It is not always possible, and perhaps not even wise, to assign a single explanation to a given intergrowth." (3-p.171) All that can be said with certainty, is that mymekitic intergrowths only occur in those rocks which have been injected by igneous solutions.

METAMORPHISM

No simple process can be invoked to account for the changes in the rocks. There are no well defined boundaries between the various metamorphic types, and no established spacial relationships between grade of metamorphism and the larger intrusive masses.

Most of the gneisses and granulites have been injected by igneous material to a greater or less degree, though many of the hypersthene and some garnet granulites are relatively massive, with but few injection bands. Chilled margins are seldom seen, which probably means that the gneisses had been pre-heated prior to their intrusion by the igneous material.

The lack of strain in the minerals, and the absence of schistosity in the rocks, as well as their granoblastic textures, is remarkable, in view of the fact that folding and gneissic foliation are so prevalent. This suggests that during the end stages of the last orogeny, elevated temperatures and/or the presence of solutions caused the rocks to act as a plastic mass, prohibiting the transmission of directional stresses, and aiding recrystallization. As a result the effects of any pre-metamorphic deformation would have been erradicated. On the other hand the freshness of the minerals in all the rocks save some intrusives, implies that there must have been a poverty of solvents or gases. Perhaps the original rocks were dry, or contained fluids later removed, when the rocks were depressed into deep seated regions of high temperature. It seems logical to assume that such conditions would cause any fluids or volatiles to migrate upwards into the higher levels of lower temperature. This upward migration of solutions could pass like a wave, causing rapid recrystallization of the minerals in the rocks in their path, and leaving behind, after they had passed, a predominance of anhydrous minerals.

The plagioclase in the gneisses, granulites, and quartz diorite intrusives, is with but few exceptions in the oligoclase-andesine range. This apparent equilibrium between host rocks and intrusives can hardly be considered a chance happening. It may have resulted from; (1) diffusion in the solid state at high temperatures, or (2) the presence of solvents in the pores of the original rock, which were later augmented by others coming from intrusives, (3) the original rocks having a similar composition, and the magma was generated by the fusion of these rocks, or it achieved a similarity in composition by their assimilation.

The rocks are believed to have been at high temperatures and some diffusion may have occurred, but the likelihood that all the rocks had plagioclase of the same composition seems most improbable. However, conclusive proof that fluids were present during some stage of metamorphism is shown by; (1) the plagioclase porphyroblasts in the composite gneisses, (2) the quartz veinlets and blobs in the composite gneisses, (3) the altered basic dyke in the microcline-plagioclase-quartz gneiss discussed on page 55, and (4) the replacement of banding by pegmatitic material shown in Plate No. 11. Therefore it would appear highly probable that fluids were the medium through which equilibrium in plagioclase composition was established.

Garnets are widely distributed and normally represent a moderate grade of metamorphism when formed from argillaceous rocks. But it is possible that many of the original rocks were impure sandstones or greywackes, in which case, lacking sufficient alumina to form such minerals as cyanite, staurolite, and sillimanite, garnet and biotite could persist into the highest grades of regional metamorphism. (37-pp.246-7)

Hypersthene occurs with garnets in nearly all proportions and in some instances appears to have formed from them, presumably as a result of continually increasing temperature. Plate 38 shows hypersthene forming in fractured garnets; such evidence suggests that alkalies may have been added to the rocks or were supplied by the resorption of biotite. These could combine with the alumina from the garnets forming feldspars, thereby releasing iron and magnesia for the formation of hypersthene. This appears to be the most logical explanation, for hypersthene and garnets are usually considered to be compatible minerals in the granulite facies.

Hypersthene never occurs in the biotite gneisses even as an accessory, but is most common in the granulites, and in the coarse grained composite gneisses that contain "sanidine-anorthoclase". The latter mineral probably formed at temperatures of around 870°C., hence its presence is in keeping with Harkers' contention that hypersthene is a mineral belonging to the highest grades of metamorphism. (37-p.57)

The hypersthene granulites in the area have noticeable similarities to the granulite facies of Eskola, except for their lack of orthoclase. They were probably derived for the most part from sedimentary rocks, and are considered to represent "a moderately high temperature of formation", and to be the products of deep seated metamorphism. (24-p.360-3)

The coarse composite gneisses containing hypersthene, garnets, and accessory "sanidine-anorthoclase", were probably formed by both migm~~i~~atatic intrusion and replacement of layered rocks at high temperatures. The presence of solutions or gases is indicated by the occasional large porphyroblast of plagioclase, and by large patches or grains of opalescent quartz. Rocks which probably represent an early stage in this process are to be seen in Plates Nos. 10 and 11.

In general the rocks in the Canimiti River area are considered to represent a moderate to high grade of regional metamorphism, in which directional stresses at first predominated but were later succeeded by hydrostatic pressures.

Wahl's area to the south contains large masses of biotite and garnet gneiss, which have all the elements necessary for the formation of hypersthene and sanidine minerals; but from the fact that these were not formed, it is necessary to conclude that the temperatures and possibly hydrostatic pressures were lower than those in the Canimiti area.

STRUCTURAL GEOLOGY

Introduction

Metamorphism has obscured most of the distinctive features which formerly may have existed in the original rocks, and there is now a uniformity of appearance that in many places is only broken by slight variations in colour, grain size, and mineralogical composition. These differences may have been inherited from formerly contrasting rock types, but some could be the result of differences in kind and grade of metamorphism.

There appear to be transition zones, and these could be sharp contacts obliterated by diffusion at high temperatures, (69-p.137) or gradational changes in former sedimentary rocks. Such distinctive rocks as exist can only be followed, over short distances, and could not be traced through definite fold or fault structures except on a small scale.

Foliation

The term foliation is used to denote a parallelism of the platy or tabular minerals, such as the micas and feldspars, without their segregation into streaks or schlieren. Schistosity is lacking in the rocks, but nearly all have to some extent a gneissose to sub-schistose foliation, which is invariably parallel to the banding of layering.

Banding or Layering

Well defined sill or sheet-like masses of varying widths, whose compositions are in marked contrast to those of adjacent bands or the enclosing rocks are referred to as bands or layers. They may be isolated individual layers or a succession of layers constituting the greater part of some rock exposures. (See Plates No. 5,7,9, and 10) There are five distinguishable types:

(1) Alternating biotite-rich and feldspar-rich layers, usually of narrow width, which are most common in the biotite gneiss.

(2) Garnet-rich bands in garnet gneiss, some of which are mere lines of individual garnets. (See Plate No. 22)

(3) Layers arising from diverse concentrations of biotite, hornblende, pyroxene, and feldspar, and which have been modified by replacement, or injection of various amounts of igneous material, as sill-like masses between the layering. These are associated with the medium grained composite gneisses, and pass

gradationally into the coarser facies, losing at the same time their sharp clear cut boundaries, but still retaining their overall layered aspect. (See Plates Nos. 10 and 11)

(4) Lit-par-lit banding caused by numerous parallel injections of acidic igneous material, usually in biotite or garnet gneiss; (See Plates Nos. 7, 8, and 9) though it may also occur with the mafic layering described in type 3.

(5) Hypersthene rich mafic layers of medium and coarse grain which usually occur as individual bands in the more massive granulites.

Directly or indirectly most of the layering is considered to be related to primary bedding or cleavage in former sedimentary rocks, though some of the more mafic layers may represent metamorphosed basic sills. The biotite and garnet rich bands are probably the metamorphic facies of individual beds, whereas the lit-par-lit bands have been formed by the intrusion of igneous material either along bedding or cleavage planes.(1) In many places the perfection of this layering suggests that the injected rocks had been slates, (see Plate No. 5) yet the absence

(1) Refer to Page 187.

of highly aluminous minerals such as sillimanite and corderite, implies that rocks of this nature were never numerous in this area. Schistosity may have provided the channels for the intrusion of some igneous layers especially those to the south of the Ottawa River, where the multiple layering pinches and swells in a more irregular manner as compared to that found in the composite gneisses. (See Plates Nos. 7 and 10).

Read considers the foliation of granite gneisses to have been controlled by sedimentary structures, (51-p. 772-3) and not by processes of dynamic metamorphism. This is in accord with the evidence seen in the Timiskaming rocks in the adjacent areas to the north, where "schistosity is almost everywhere perfectly parallel to the bedding." (23-p.64) Therefore, the contention that much of the banding in this area is probably relict bedding, seems valid; though schistosity injected by igneous material, undoubtedly has accounted for some.

Structural Trends in the Area

The layering and foliation display an overall trend in a northeasterly direction, but this is disrupted by discordant strikes and dips which indicate the presence of large folds whose inferred axes parallel the major trend, and have axial planes that are overturned to the northwest. However marked divergences are found around Lake Tombbah, and in the locality to the southeast of the Nose Lakes, where small folds outlined by layering and others indicated by strikes and dips, have axes which plunge to the east. Other discordances are found in the north and northwest sections of the sheet; where the foliations strike to the north or northwest, and indicate the existance of folds whose axes also plunge to the east.

Folding

North of Gabbro Lake, a large overturned syncline is indicated by the attitude of the strikes and dips of the foliation and banding. It extends N 50°-60°E up to and beyond the Canimiti River, and plunges between 20° to 50° in the same direction. What appears to be a complementary anticline, occurs between the Canimiti and Chochocouane Rivers to the southeast of the syncline; it has an axis which plunges N 60°E till it crosses the Chochocouane, when it swings more towards the north.

A drag-fold crosses and recrosses the Chochocouane at the falls in the central part of the area; one limb comprises the resistant garnetiferous formation that supports the falls. The southeastern portion of the "S" is seen on the small island below the falls and along the east shore. The axes strike N 60°E and plunge at around 50° in the same direction, while the axial planes are overturned to the northwest. The orientation of this folding indicates a movement towards the south or southwest on the northwestern side of the fold with a slight downward component, relative to the southeast side. Dragfolds are usually integral parts of large folds and their attitudes indicate the attitudes and positions of such folds. Therefore in this case, the axis of a larger fold should lie to the northwest of the above drag-fold, and possibly does. Though the strikes and dips recorded give only a weak indication of its existence.

Two miles south of the drag-fold previously described, the foliation of two garnetiferous exposures suggests the presence of another but larger fold that is possibly of the same nature, and might be explained by similar differential movements.

East of the Elbow Lakes, the air photographs show a fold-shaped ridge lying to the south of and against an east striking "topographic break", which is probably a fault. The outlines of the ridge are shown on the accompanying geological map; the eastern half is composed of garnet gneisses, but through lack of exposures the composition of the western part was not determined. However it may represent a continuous formation which has been drag-folded against the inferred fault, or a drag-fold disrupted by the fault. In any case there is insufficient evidence with which to decipher its attitude or the movements responsible for its formation. The orientation of the "S" shape suggests a general movement of northwest side to the northeast with a movement in the opposite direction on the southeast side.

In the central part of Lake Tombbah along the north shore, there are several symmetrical, open, anticlines and synclines, which form a reef extending south into the lake. They are in layered granulites and measure some 30 feet from crest to crest. They plunge to the east at between 30 to 40^{o}. Some 400 yards further to the east, on the shores of the large island in that vicinity, other minor folds are inferred from the strikes and dips of the layering. These are closed folds, whose axes also plunge to the east at an undetermined angle.

Other minor folds with similar axial trends are suggested by the attitudes of the foliation and layering in the rocks to the north and south of the eastern end of Lake Tombbah. The differential movements which caused these folds probably acted at right angles to their axes, and therefore in a north-south direction.

A scarp lies to the south of the little lake in the northern part of the area, at latitude $77^{o}10'20''$ west and longitude $47^{o}02'54''$ north. In it at one place, there is a small overturned fold whose axis is horizontal and strikes N 60^{o}E. The overturning is towards the northwest and the fold appears to have formed as the result of a dragging movement along a small over-or under-thrust fault. The latter strikes N 60^{o}E and dips to the southeast at 23^{o} (See Diagram No. 1). The stresses which caused this fold (and fault) must have acted along a northwest-south-easterly direction.

Large underlying folds in the gneisses and granulites are suggested by the outlines of lakes or groups of lakes, such as Beak Lake and the Nose Lakes in the south-west corner of the sheet. These lie inside a larger fold pattern formed by the Ottawa River and Lake Dozois. (The latter is mostly outside the western boundary of the area) All have a common axial plane which starts at the junction of the Ottawa River and Dozois Lake, passing northwards through "Y" lake, and hence to the tip of Beak Lake, where it then swings more to the east and is lost. The foliation and banding have a tendency to conform to the general pattern in restricted localities, such as in the vicinity of Beak Lake where the strikes and dips are seen to curl around the tip of the lake, while minor folds are found whose axes conform to the strike of that of the large fold pattern. The presence of plated "flaser gneiss" erratics in this general locality, suggests that faulting is possibly the reason for the lack of complete accordance between the foliation in some places, and the overall fold pattern outlined by the rivers and lakes. Yet some of the discordance may be the result of plastic flowage. Wahl (71) in the area to the south, found that the annular arrangement of the lakes in the Cawatose Basin was a direct reflection of the structural trends of the underlying rocks; therefore it seems probable that the fold patterns outlined by the rivers and lakes in the present area are also reflections of the underlying rock structures.

Ptygmatic folding is undoubtedly quite prevalent in the rocks of the area though it is seldom seen, or at any rate, is difficult to prove. A good example occurs immediately to the east of the Canimiti River in the north central part of the sheet. A basic dyke or layer several inches in width, has been tightly folded and disrupted by flowage. It is in massive granulites which display no evidence of having been faulted, and there is no indication that the basic material was injected into the rocks after folding or fracturing had taken place.

Complex, tightly closed folds can be seen in the exposures along the C.I.P. & P. Company road, north and east of the Elbow Lakes, in well banded composite gneisses. Locally they have conformable axial trends, but the magnitude of the igneous injection banding, and their apparent transition into the coarse composite pseudo-igneous rocks, suggests that the end stages of folding were governed primarily, by plastic flow. Thin sections of these rocks show little evidence of strain or fracturing of their minerals.

Faulting

"Flaser gneisses" consisting chiefly of quartz and pink feldspar are frequently found in the steep west facing scarps, and occasionally in definite faulted zones. They are also seen as numerous fragments at the bases of scarps, along shores and at the outlets of many lakes. Because of their marked associations with linear elements such as valleys and their occurrence in proven faulted zones, their existence in any locality is held to be indicative of zones of differential movement and faulting.

The faulted zone on the Canimiti River near its junction with the Chochocouane, is in acidic gneisses. These in many places have good "flaser" structure and contain small fragments of basic dykes and pegmatites, as well as sparsely disseminated sulphides. The zone is exposed for roughly 15 feet along its strike, and has a minimum width of approximately 20 feet, but could be much wider. The foliation strikes N 40°E and dips to the southeast at about 60°. A left-handed strike-slip is indicated by a small pegmatite dyke which has been truncated and dragged by the movement in this zone; (See diagram No.3) if it had a counterpart it is not visible in the exposure and a strike separation of at least 15 feet would be indicated. However, it is possible that the pegmatite was injected into folded structure after the movement had occurred, in which case there would be no counterpart.

About one half mile south of here the Canimiti turns due east, and passes between two northeasterly trending ridges. Both have approximately the same height and width, steep west facing scarps and gentle back-slopes. They are so disposed that the one to the north of the river is 300 to 400 feet to the west of the line of strike of the one to the south. The positions of these ridges as seen in the air photographs, suggest that they formerly constituted a single ridge which was cut in two by a northeast or east striking fault. This would explain the gap through which the Canimiti River now flows, as well as its easterly course in that locality. The suggestion is strengthened by the fact that the previously described fault zone is only a short distance to the north and has a left-handed strike separation, similar to that implied by the positions of the ridges.

A few miles northeast of Gabbro Lake, a fault cuts garnet gneisses and has a strike of N 65°E, and dips 70° to the southeast. It is noteworthy for its parallelism to the axial plane of the suggested large fold which it transects, and it is in a logical position to have provided stress relief when folding could no longer do so. (18) The direction and movement on the fault plane could not be definitely determined, but the attitudes of the foliation and injection banding on either side of the fault, and of the "flaser" gneisses, indicate that there was probably more than one movement. (See diagram No. 4) On the south side there are sparsely banded and moderately garnetiferous gneisses, these strike S 85°E and dip to the south at 67°. On the north side the gneisses are highly garnetiferous and much injected by acidic igneous material. This banding as opposed to that on the south side, strikes N 15°E and dips to the east at between 30 to 40°. A pink pegmatite was intruded along the fault and has been so strongly sheared by movement, that it is now a highly plated "flaser" gneiss consisting of alternating layers of quartz and feldspar, and occasional fine films of sericite. It has a few tiny drag-folds that appear to plunge steeply to the east and which by their attitudes, indicate a movement of northwest side to the northeast. On the other hand there is the suggestion of a slight dragging of the well banded garnet gneiss against the fault which indicates a relative movement in the opposite direction to that evidenced by the drag-folds. The direction of the movement along this fault is not clearly indicated, but definite proof of faulting is shown by the contrasting rock types on either side of the "flaser" gneiss. There is no indication that the grey acidic injection bands in the garnet gneiss are related to the intrusion of the pink pegmatite "flaser" gneiss in the fault, and evidence has been found elsewhere in the area to show that they are older than the pink pegmatites. (See under "Early Pegmatites.")

The position of this fault and of the "flaser" gneiss is of exceeding interest. It is on the shore of a little lake, at the mouth of a small creek; the latter follows the base of a northwest facing scarp and the fault has a similar strike. It is only exposed over a length of about 10 feet before it disappears under swampy overburden, but its course is marked for another 10 to 20 feet by the presence of "flaser" gneiss erratics. From this example and that of the fault zone on the Canimiti River, it can be concluded that "flaser" gneisses are associated with faults, and that those valleys in the area containing abundant "flaser" gneiss erratics, are probably underlain by faults or fault zones.

Lowther (42-p.51) has shown that some of the ridges in the Villebon-Denain area to the north transect the bedding of the Timiskaming sedimentary rocks, and must be bounded by faults.

Some two miles north from the junction of the Canimiti and Chochocouane Rivers, there is a sub-schistose hypersthene-augite-hornblende rock in the bed of a small creek. Mica along certain preferred planes gives the rock a sub-schistose appearance, and suggests that shearing has occurred along this zone. The zone as exposed, is at least 20 to 25 feet wide and may be much wider, the foliation strikes west and dips north at between 50 and 60°, but it is possible that the zone itself may strike more to the south and conform to the general trend of the creek in whose bed it is exposed.

The quartz diorite stock in the northwest corner of the sheet has a steep scarp along its western margin;

in the air photographs this stands out as a strong, straight, north-trending cliff for a distance of from two to three miles, and is undoubtedly the result of faulting. The face of the scarp consists of layers of granulite and red to pink quartz diorite. These strike N 10°E parallel to the trend of the scarp, and dip to the east at from 60° to 80°. In some places slickensided flutings are seen whose axes have steep plunges in the general direction of N 70°E. They are probably mullion structures, though this could not be verified, since they were too high up on the scarp face to be closely inspected.

At the eastern end of the Elbow Lakes, a strong "topographic break" is seen in the air photographs. It has an easterly strike and probably represents a fault, though conclusive proof is lacking. It is, however, parallel to the fault north of Gabbro Lake.

Three quarters of a mile north of the Kanimiti Geodetic Station in the west central part of the area, there is a small lake in which a zone of "flaser" gneisses can be seen on a small island at its northern end. Though it was not possible to reach the island, the strongly plated aspect of the gneisses stands out, and a general trend was noted towards the northeast, while the dip appeared to be almost vertical. The southeastern shore is bordered by a steep ridge, and there are fragments of "flaser" gneiss lying along the shore at its base. In view of such evidence the lake is considered to occupy a fault zone, and has been shown as such on the accompanying geological map.

Three and a half miles north of Murdock's camps, in the central part of the sheet, there is a north-striking fault that dips steeply to the east, and is evidenced by a zone of "flaser" gneisses. These intersect northwest-striking garnet gneisses at an acute angle, and are interlayered with moderate amounts of the same rock over an exposed width of from 10 to 15 feet. No evidence as to the direction and amount of movement in this zone was seen. Its proximity to the straight north trending channel of the Chochocouane in that locality, suggests that the latter's channel has been influenced by similar faulting.

A very small exposure of "flaser" gneiss occurs to the east of the quartz diorite stock in the northwest corner of the area, at the mouth of the small creek which joins the two small lakes seen in that locality. The exposure is on the southwest bank of the creek, and the "flaser" gneiss strikes N 35°W and dips to the northeast at from 50 to 60°. The rocks west of the "flaser" zone are garnet gneisses but to the east are layered granulites. The creek is parallel to and in part in the "shear", since "flaser" gneiss erratics are also in evidence on its northeastern banks. No direct evidence was found to indicate the direction and extent of movement in this zone.

"Flaser" gneiss erratics are found along the southeast shore of "Y" Lake, in the southwest corner of the map, and for this reason an assumed fault is shown on the accompanying geological map, striking parallel to the northeast arm of the lake.

The relatively straight easterly-trending channel of the Ottawa River, may occupy a fault, for during the excavation for the new highway bridge, the abutment section on the north side showed quartz diorite, whereas that on the south displayed highly biotitic, and well foliated biotite gneisses, the foliation of which is parallel to the course of the river and dips at around 50° to the south.

The Chochocouane River in this vicinity has a pronounced north-striking channel, and the rocks of the quartz diorite stock on its east bank which were exposed during the building of the new road, showed much contortion, so it may be that another fault exists below its channel.

Thrust Faulting

A small overturned fold occurs in the northwest part of the area at lat. 77°10'20" west and long. 47°02'54" north. It has formed in layered garnet gneisses as a result of an over or underthrusting action along a plated fault plane. This strikes N 60°E and dips to the southeast at 23°. (See Diagram No. 1)

A similar structure lies about one and a half miles east of Murdock's Camps in the southern part of the sheet. This fault strikes N 55°E and dips 50° to the southeast; folding of the layered gneisses against the footwall, and bent tension fractures on the hanging wall provide ample proof that the movement was of an over or underthrusting nature. (See Diagram No. 2) The axis of the drag-fold is nearly parallel to the fault strike, with a plunge of only a few degrees to the northeast.

The stresses responsible for the movements on both of these faults must have acted toward or from a northwest direction.

If these faults are considered in conjunction with the consistent east to southeasterly dips of the banding and foliation, as well as with the inferred folds which are overturned towards the northwest; thrust faulting on a considerable scale is suggested.

<u>Age of Faults</u>

The fault north of Gabbro Lake cuts the grey pegmatite <u>lit-par-lit</u> sills which intrude the garnet gneiss, and is in turn intruded by pink pegmatite. (Now "flaser" gneiss) Its position indicates that it formed after folding could no longer provide stress relief. (18) It is thus post grey pegmatite, and pre-pink pegmatite.

The "flaser" zone on the Canimiti River contains fragments of early basic dykes and movement along it appears to have folded and cut a pink pegmatite; however, this pegmatite could have been injected into folded structure, after faulting and deformation along the zone had taken place. It can therefore be either pre or post-pink pegmatite.

In conclusion it seems probable that differential movements between beds in folds provided the first fault zones, but with the attainment of close tight folds the easterly striking faults occurred and gave further stress relief, some of these were post grey pegmatite and pre-pink pegmatite, but others were probably post pink pegmatite. Repeated movements have undoubtedly occurred down through geological time along the "flaser" zones which are thought to exist beneath the floors of many of the linear valleys. (72-p.39), (22-p.51)

Joints

The joints in the area have vertical dips and persistent strikes between S 30°E and S 60°E. They are clearly younger than all the igneous rocks.

Lineations

Preferred orientations are shown by pencil-like masses of quartz in some "flaser" gneisses and quartz porphyries; the hornblende crystals in restricted parts of the hornblende syenite stock and granulites; basic inclusions in the quartz diorite orthogneiss of Lake Tombbah; the axes of minor folds and flexures in the layered gneisses and granulites; and by the axes of trough-like crenulations with at times slickensided and apparently faulted surfaces.

Long slender masses of quartz which have a common orientation are found in some "flaser" gneisses enclosed in a fine to medium grained platy groundmass of quartz and feldspar. Unfortunately they were seen in only one exposure. This occurs to the east of the quartz diorite stock in the northwest corner of the sheet, and is indicated by the fault shown there on the accompanying map. The long axes of these quartz masses plunge N 55°E at between 40° to 55° and conform to the dip of the foliation in the gneisses. No evidence was available by which the movement along this fault zone could be determined, so their relationship to the stresses responsible for the faulting, are not definitely known. However, the fault scarp which borders the western margin of the quartz diorite stock, has flutings whose axes plunge N 70°E, at 60° to 80°. The movement must have been parallel to the flutings, and since the quartz masses of the "flaser" zone to the east are oriented roughly parallel to the flutings, it seems reasonable to conclude that the same stresses were responsible for the formation of both. A short distance south of this locality, an exposure of granulite has hornblende crystals with preferred orientations. These plunge N 50°E at around 50°, which is slightly steeper than the dip of the enclosing layers.

In the case of the quartz masses, there is some reason to assume that their orientation was connected with forces acting along a northeast-southwesterly direction. The long axis, presumably the crystallographic axis, is parallel to the direction of these assumed movements and therefore lies along the <u>a</u> fabric axis direction, in the <u>ab</u> plane, which is probably represented by the plating of the "flaser" gneiss. A similar relationship is visualized for the hornblende crystals, but the processes causing the orientation in both cases were probably different. The lineation of the quartz crystals has probably arisen as a result of movements at the time of the intrusion and consolidation of the pink pegmatites: (paratectonic) though postcrystallization gliding and orientation along the lines visualized by Sander, (58-pp.173-202) and Schmidt, (90-pp.176-69) or fracturing and orientation as shown in the experiments of Griggs and Bell, (79-pp,1723-96) might possibly have been effective in causing such structure. A thin section of a "flaser" gneiss from Lake Tombbah showed only long fingers of quartz interlayered with smaller and more granular crystals of quartz and feldspar. This could be taken to indicate mylonitization and solution of quartz which was then deposited along certain preferred channels, such as might be provided by shear planes, or the introduction of late residual siliceous solutions concomittent with the shearing of the earlier consolidated material. The hornblende on the other hand, is not associated with a recognizable "flaser" zone, but its orientation was probably accomplished at the same time, under the same stress conditions, as a result of recrystallization during metamorphism.

Pencil-like quartz crystals up to 5 mm. in length are seen in the quartz porphyry dyke on the highway, a few thousand feet north of the old Ottawa River bridge. These plunge to the east at 40°, and since the rock shows no signs of postcrystalline deformation, may be either the result of primary igneous lineation or of differential stresses applied during consolidation. The fact that the dyke cuts the foliation and banding of the enclosing gneisses, shows that the dyke, and therefore the lineation of the quartz, occurred later, or at the close of the major period of deformation.

The hornblende gabbro or amphibolite along the north shore of Gabbro Lake has in places adjacent to the lake, hornblende crystals with common orientations. These plunge to the east at 10 to 25°, almost parallel to the strike of the layering of the enclosing gneisses, and to the long axis of the lake. Such features suggest that the lake, the lineations, and the foliations, have been aligned by faulting or differential movements, along an easterly-striking zone underlying the lake. There is no evidence to show the possible nature of the movement in such a zone. If it be assumed that the hornblende crystals are orientated parallel to the <u>b</u> fabric axis, the movement would be in the nature of an over-or underthrust along a north-south direction. On the other hand, an orientation parallel to <u>a</u> is just as possible, and would imply a strike slip movement in an east-west direction.

The quartz diorite to granitic intrusives which border the western group of the Nose Lakes, have a few isolated sections in which preferred orientations are shown by quartz and hornblende crystals. However, there is no consistent trend, and no explanation can be offered other than that they are primary orientations, consequent on currents present in the intrusives just before consolidation.

Trough-like flutings or grooves, seldom measuring over an inch from side to side, constitute the most numerous lineations. They plunge with the dip of the layering and at the same angle, or in the plane of the layering and obliquely to the dip. They are usually restricted to the more layered rocks but also occur in poorly banded granulites. In a few instances they have slightly chloritic surfaces, suggesting that they have been formed in a manner similar to that of mullion structure, and are therefore related to differential movements. In this case, their strike is undoubtedly parallel to the direction of movement, the a fabric direction. The normal flutings bear no resemblance to drag-folds, inasmuch as they are more like a series of symmetrical wrinkles with no evidence to show that they owe their origin to differential movement between layers or beds. In some instances they are seen on the limbs of small folds which can be measured in tens of feet. The fold is a mass of small flutings or crenulations the axes and axial planes of which are only sub-parallel to that of the larger fold, and both the fold and crenulations are of the open type. In cross section they are identical in scale proportions. The only explanation is that the rock layers were so nearly equal in composition or plasticity as a result of prevailing high temperatures and/or the presence of solutions, that there was little difference in strength between layers. This could presumably account for "S" shaped drag-folds not being formed: since they are usually the product of differential movements between layers of different strengths and plasticities.

Two lineations shown on the map about a mile north of Beak Lake represent flutings with chloritic surfaces, and are almost diametrically opposed in direction of plunge. Their attitudes are probably related to fault movements since the rocks are much contorted in this locality; as such they would be aligned in the direction of the a fabric axis. The chloritic surfaces of these troughs must of necessity be interpreted as indicating their formation at or after the close of the main period of orogeny and metamorphism, otherwise the chlorite would not have been preserved.

No plausible explanation can be offered for those flutings which contain no chlorite and strike obliquely to the dip of the layering, unless they represent mullion structures formed at temperatures too high to permit the development of chlorite.

In general, it must be considered that many of the flutings have been formed by the same stresses which caused the major folds in the area, and as such lie parallel to the b fabric direction of stress. This contention is strengthened by the attitudes of the flutings to the assumed folds in the area north and northeast of Gabbro Lake. Here they strike and plunge to the east with the axes of the suggested folds, or in a few cases, those in the axial regions of the folds, strike parallel to the axial plane, that is to the northeast. South of the Ottawa River, the flutings (See Plate No. 8) also display a marked easterly strike and plunge.

The hornblende syenite stock in the southeastern part of the sheet, was seen to have aligned hornblende crystals in only a few exposures. Those observed, plunge N 60°-80°E at 20° to 30°. Wahl found a similar lineation in the southern two thirds of this stock which extends into his area, and assumed that it was a primary structure, indicating that the syenite had been intruded from the direction of plunge of the lineation.[1] The lineations in the gneisses on either side of this stock, are almost at right angles to those of the hornblende crystals in the stock itself, suggesting that the syenite is a postkinematic intrusive. This interpretation is supported by the fact that the syenitic pegmatites cut the layering of the gneisses in many localities.

Minor folds in the layered gneisses along the north shore of Lake Tombbah have axes which plunge to the east at 30° to 45°; while two miles northeast of the lake, there are small folds whose axes strike and plunge to the northeast at 35°. Such folds must have been formed by stresses acting toward or from southerly and south-easterly directions.

Basic inclusions showing all degrees of digestion are seen in the quartz diorite orthogneiss, on the small island in the eastern part of Lake Tombbah; (See Plate No. 6) the more digested inclusions have ellipsoidal shapes and common orientations of their longer axes, which plunge to the east at from 30° to 40°. This attitude is conformable to that of the folds which occur further to the west along the north shore of the lake, and indicates that the quartz diorite orthogneiss was a parakinematic intrusive, and therefore older than the hornblende syenites.

(1) Wahl unpublished Thesis, McGill University, 1947.

The lineations shown by the axes of major and minor folds, most flutings, inclusions, and in a few cases of hornblende and quartz crystals, have either easterly or northeasterly strikes and plunges. There is little doubt but that they lie approximately parallel to the b fabric axis, and therefore at right angles to the direction of maximum stress responsible for the deformation of the rocks in the area. In the southern part of the area the eastern trend appears to be dominant, suggesting that the stress was from the south or the north, but in the central and northern portions the trends are mixed, and no explanation can be offered other than that the stresses being applied must have acted along a more northwesterly direction. This is confirmed to some extent by the two small thrust faults previously described, and shown in diagrams 1 and 2. The drag-fold on the Chochocouane in the central part of the sheet, indicates a movement of northwest side to the southwest or possibly south, and its attitude which is nearer to that of the northeasterly trending lineations, suggests that the latter, which are mostly represented by flutings, have their axes approximately parallel to those of unrecognized drag-folds. In this case a regional stress acting toward or from a southerly to southwesterly direction would be compatible with most structures save the small thrust faults. Yet the pronounced easterly dips of the rocks are not satisfied by this explanation, unless it is assumed that to begin with, differential movements occurred at first in a northeast-southwest to north-south direction, and that later an application of stress along a more southeast-northwesterly direction caused the structures to be overturned.

If the mullion structure in the fault in the northwest corner of the sheet, and the quartz crystals in the "flaser" gneiss in the same locality, are really alligned parallel to the a fabric axis, then they were probably formed by stress adjustments at the close of or after the period of major deformation; for it was then that the pink pegmatite "flaser" gneisses were intruded. These stresses must have acted along a northeast-southwesterly direction. It was probably during this late stage that the hornblende syenites and associated rocks were emplaced.

Structural Relationship to the Surrounding Areas

Wahl's area to the south has a concentric arrangement of its lineations that plunges inward towards a central point or axis. This occurs in the southern and eastern parts, and gives topographical expression by the annular trend of the lakes in the Cawatose Basin. Moving northwards the lineations become aligned with the easterly and then the northeasterly trends of those in the present area. Northward in Lowther's area lineations have not been recorded, but the strikes of the foliations are to the northeast, with dips to the southeast as in the Canimiti area. These continue north to the Timiskaming-Gneiss contact zone, but north of here the structural trends change, and strike to the east or lose their continuity. The contact zone extends to the northeast and the gneisses along and to the south of it, have foliations which parallel its trend and generally dip to the southeast. In Haig township, lineations have been recorded which are roughly in accord with those of the Canimiti area. (48) (49) Southwestwards along the contact, the Timiskaming sediments loop to the north and continue on to the west. But a strong lineament represented by Grand Lake Victoria, continues the trend to the southwest. (See Regional Map).

The structural similarity between the regions to the north and those in the Canimiti area, indicates that the rocks were undoubtedly deformed by the same stresses. These must have acted either toward or from a northwesterly to northerly direction, but most probably at right angles to the Timiskaming-gneiss contact, and suspected fault zone. (50)

THE MODE OF EMPLACEMENT OF THE IGNEOUS ROCKS AND THEIR ASSOCIATED PHENOMENA

Lit-par-lit Sills and Migmatites

The most striking feature about the area is the great amount of granitic material seen in the rocks as narrow, closely spaced sills. These parallel the foliation of the enclosing gneisses and their numbers vary from exposure to exposure; some rocks are so saturated, that they are a mass of green biotite and garnet rich layers, regularly interspersed between others of grey granitic material. The latter show little evidence of having thrust aside the host rocks, though they occasionally form long narrow lenses with feeble signs of marginal contortion. Chilled contacts are generally lacking, in fact the margins are in many places difficult to delimit, and blend imperceptibly into the host rocks. The sills may contain lenses of garnet or biotite, still perfectly aligned with the general foliation, or have coarse feldspars growing out into the darker layers, intersecting them in the manner of re-entrants formed by replacement rather than deformation. Dykes are rarely seen, but one occurs at mileage

58 on the highway where it acts as a "feeder" to the sills in the garnet gneiss. The rarity of granitic dykes as opposed to sills is taken as an indication that the rocks at the time of intrusion were probably in a semi-plastic condition.

The amount of injected and/or replaced material is so great in rocks such as the coarse composite gneisses (migmatites), that the layered appearance has been lost; not by fracturing and the formation of stockwork, as in brittle rocks, but by the merging of sills, apparently as a result of fluids "seeping through" the separating layers of gneiss, and causing the removal of material by solution. Relics of these digested layers are seen as faint "shadow" lenses or bands of garnet and biotite, which through their lack of distortion indicate an absence of stress during intrusion and replacement. Many of the potash-rich sills have "sanidine-anorthoclase" and myrmekite in or near their margins; the former is taken to indicate high temperature conditions, while the latter, Sederholm considers, are secondary products formed in the presence of abundant solvents at high temperatures. (60-p.70,95) The composite gneisses have occasional large porphyroblasts of plagioclase, which are considered to be products of replacement common to migmatized and granitized rocks.

(19-p.118) (57-pp.389-447) (55-p.221). There are also irregular patches of pink to opalescent quartz, which were without doubt deposited by solutions.

The observation of a "feeder" dyke to the granitoid sills in one place, and of a few sills with chilled margins, along with the intrusive nature of the quartz diorite stock near the Ottawa River, makes it apparent that some of the granitic material is of intrusive origin. On the other hand the abundance of quartz in the sills, the large euhedral feldspar crystals which appear to have grown out into the enclosing gneisses, and the restriction of myrmekitic structures to those rocks in immediate contact with the sills, indicate that the intrusive material was rich in volatiles and/or water, which must have penetrated the intruded rocks causing replacement in places and probably brought about some recrystallization.

The coarse composite gneisses are believed to represent an extreme process, in which the intrusive material was abundant and exceedingly rich in fluids. The large euhedral feldspars and blobs of opalescent quartz indicate that volatiles and/or water must have permeated the invaded rocks causing extensive recrystallization, and replacement of material.

The abundance of acidic material as sills gives the impression that there is a large magma underlying the area from which it must have been derived. This is strengthened by the occurrence of the small quartz diorite stock near the Ottawa River and of another at the eastern end of Lake Tombbah.

However it is possible that some of the granitic material has developed locally from the rocks themselves; by a process of metamorphic differentiation whereby "solution, recrystallization and mechanical deformation act to variable degrees as selective agents" in the development of laminated structure. (69-p.147) Perhaps the rocks represent a deep zone such as described by Eskola, from which granitic juices were squeezed out to provide granitic material for batholiths at higher levels. (28-p.455)

The Ottawa River Quartz Diorite Stock

The north abutment excavation for the new highway bridge over the Ottawa River, showed well foliated and injected biotite gneiss at the top of the section. This frays out downwards into massive white quartz diorite, which can be seen under the microscope to contain quartz and plagioclase, with only accessory biotite. The long shoots of biotite gneiss are contorted yet descend nearly vertically into the quartz diorite. They lack the appearance of having been thrust aside to make room for the advance of the intrusive. The frayed ends of the biotite gneiss thin out into tiny schlieren of biotite, which can frequently be traced for some distance into the quartz diorite before they die out. In this locality numerous exposures were found of what seem to be contorted and contaminated quartz diorite orthogneiss, but because of the evidence seen in the bridge abutment section, they were all mapped as quartz diorite.

There is therefore, in this vicinity, a small granitic stock which was so fluid, either by virtue of heat and/or abundant volatiles, that it was able to intrude quietly, by digesting the rocks in its path. This implies that the intrusive was being generated locally by heat supplied from an unknown source. The great number of sills which were sent out ahead, and their lack of chilled contacts in most places, indicate that the intruded rocks must have been pre-heated by emanations coming from the intrusive. The sills were probably in a fluid state, rich in mineralizers, and could have acted as a heating system. Grout indicates such a belief in the following quotation:

> "The lit-par-lit injections probably constitute an "advance guard" of the magma. More dilute

> and aqueous or at least somewhat different from the main magma. They may possibly be gasious and watery separates from the magma." (34-p.414)

If the intrusive was generated in place by the fusion of pre-existing rocks such as represented by the biotite and garnet gneisses, it would be expected to have potash either in the form of biotite or orthoclase, but neither occur. The acidic pegmatoid sills in the vicinity of the Ottawa River stock approximate closely its composition, and have only plagioclase, quartz, and antiperthite, with accessory biotite, yet in other localities they contain orthoclase, more antiperthite, and microperthite. Whether the sills are in reality differentiates of the quartz diorites cannot be definitely shown, but judging by their numbers, high quartz content, and narrow widths, they must have been rich in fluids, and not viscous melts, otherwise it is difficult to see how they could have invaded their host rocks without showing disruptive effects and predominantly chilled contacts.

The fusion of biotite rich rocks could have provided water, forming at the top of the intrusive a silicate melt rich in water or a watery separate rich in silicates and alkalies. These could have advanced ahead of the intrusive along bedding or schistosity planes and upon reaching cooler zones deposited the potash as orthoclase. In a similar manner the magnesia and iron from the biotite may have travelled outwards as "fronts" (55-p.236) in the pore spaces of the rocks or in the sill solutions, becoming fixed upon reaching rocks with an excess of alumina, and forming garnets. In this respect it is to be noted that the garnetiferous rocks, have for the most part, been more intensely injected by acidic material than the others. In some instances garnets are seen to be larger and more numerous in the country rocks adjacent to the acidic sills, and to become smaller and less numerous away from them.

In opposition to the foregoing hypothesis, it was found that the sills in the highly garnetiferous rocks have notable amounts of potash feldspar, whereas those in rocks with few garnets but much biotite, have only plagioclase and antiperthite. The inference, is that the potash for the feldspars in the sills may have been made available during the transformation of biotite into garnets, while little or no potash was to be had in the low garnetiferous or biotite gneisses, since the biotite was still stable. This statement is in general tantamount to saying that some of the material in the sills was derived by the solution and recrystallization of the original sediments in place.

It seems reasonable to assume that both processes have been operative in rocks such as occur in this area. Local generation of igneous material undoubtedly took place in the case of the quartz diorite stocks, and these in their turn, must have distributed by permeation and injection, fluids and magmatic material, which assisted in the metamorphism of other rocks.

Gradational Contact of the Lac des Montagnes Pegmatites

A short distance to the east of Lac des Montagnes, there are small irregularly shaped pegmatitic to granitic masses intruding the gneisses. One contact zone of particular interest shows a complete and gradual gradation from biotite gneiss, through biotite granite, into a white, non-biotitic, coarse grained pegmatite. This transition zone is only 5 to 8 feet wide, yet it shows clearly that the pegmatite has reacted with the biotite gneiss, and digested some of it. Thin sections show the pegmatitic and pegmatoid masses from this locality have much microperthite and microcline. These minerals may have been formed with potash obtained by the "assimilation" of biotite. The absence of mafic minerals in the pegmatite shows that magnesia and iron must have been removed, and in view of the rocks involved, fluids must have played a prominent part in their removal.

Lake Tombbah Quartz Diorite Orthogneiss

The quartz diorite orthogneiss which constitutes some of the islands in the eastern part of Lake Tombbah contains inclusions of basic fragments in all stages of digestion. (See Plate No. 6) These show a richness in hornblende which is foreign to the host rock in which biotite is the only mafic mineral. Sederholm (61-p.138) refers to the occurrence of similar phenomena and accounts for it in the following words:

> "The basic rocks dissolved in the granite seem to disappear as if by magic, perhaps escaping together with the volatile or fluid constituents. Only in rare cases phenomena are observed that seem to give an indication of what has happened. So the "basic halos" around fragments in the Obbnas granite tell of a diffusion extending to a certain limit."

In Plate No. 6, the angular and undigested inclusion seen in the background consists of hornblende and pyroxene, whereas the nearly digested patch in the left foreground contains only hornblende and biotite. Other examples in various stages of digestion leave little doubt but that there must have been a reaction between the inclusions and the intrusive, along the lines visualized by Bowen:

> "Let us take for example, a magma saturated with biotite, say a granitic magma. This magma is effectively supersaturated with olivine, pyroxene and hornblende and cannot dissolve them in spite of the marked contrast of composition, which is often supposed to be an aid to the solution of inclusions. But the magma can and will react with these minerals and convert them into biotite, usually by steps. ---The inclusions may thus become completely incorporated though not in any sense disolved." (13-pp.197-198)

It is obvious that the quartz diorite has altered the inclusions by converting the pyraboles into biotite. The composition and appearance of this intrusive is similar to that of the Ottawa River quartz diorite as seen in those exposures representing the transition zone between the intrusive proper and the biotite gneisses. Therefore at depth this intrusive may also be devoid of biotite, and as suggested in the former case, the potash, iron and magnesia may have been removed by fluid phases or advanced through the pores of the intruded rocks in the " a tache d'huile" manner of Termier. (65-p.585) In this respect it is interesting to note that the feldspars in the gneisses and granulites are with only few exceptions plagioclase An_{28-35}, and those in the quartz diorites are plagioclase An_{28-32}. This suggests that the intrusives had succeeded in establishing an equilibrium with the paragneisses, and argues for the former presence in these rocks of some fluid or gaseous medium connected with the magma, through which equilibrium was established.

The Hornblende Syenites and Associated Intrusives.

The pink to red quartz diorite in the northwest corner of the sheet has injected the gneisses along its eastern margin in a lit-par-lit fashion, while elsewhere in that locality there are suggestions that material probably associated with it, has "soaked" the pre-existing rocks causing the formation of hybrid or composite gneisses, such as are seen to the south of Composite Lake. The reddish colour of the quartz diorites is more pronounced in those areas adjacent to rusty-weathering granulites, suggesting that their colour is probably in part, consequent on the assimilation of such rocks, in which there was much iron.

The hornblende syenites, quartz syenites, and granodiorites which constitute the two large intrusives in the southeastern part of the area, appear to have been injected conformably into the surrounding gneisses and granulites. However their contact areas are poorly exposed. In the few places seen, syenitic material appears to have penetrated the granulites both as sills, and as "granitizing" solutions, establishing an irregular transition zone of varying width which probably seldom exceeds one hundred feet. A typical exposure of the transition zone rocks can be seen on the large island at the western end of Lake Tombbah. It is a granulite, but on a fresh surface the feldspars are pink rather than white or grey, and there is only a weak foliation. If the rock were coarser grained it could be mistaken for a mafic syenite.

Pegmatites are quite numerous in and around these intrusives, especially to the north of Lake Tombbah. In some instances irregular small patches and pipe-like masses of medium to coarse grained quartz syenite material, occur in the more hornblendic facies. They appear to grade into the latter, and undoubtedly represent late fluid-rich segregations, and probably are the roots of syenitic pegmatites which were removed by erosion.

In general it appears that the syenites and their associated intrusives have injected the gneisses and granulites in a conformable manner; and that they had fluid phases in varying amounts which penetrated the injected rocks, forming transition zones by replacement or/and injection of material. However these effects were much more restricted, than those which accompanied the early grey quartz diorite.

Granitization

The composite, hypersthene garnet gneisses in the north of the area, are in some cases so well banded by layers of light and dark minerals, such as seen in Plate No. 10, that there is little doubt as to their sedimentary origin. In some exposures these grade imperceptibly into medium and coarse grained granitic rocks (See Plate No. 34) which may contain both hypersthene and garnets, but in all other respects they appear to be igneous rocks. Lit-par-lit injections are numerous, yet on approaching the granoblastic and coarser facies, the banding fades and may even disappear, and the rocks become massive. Opalescent quartz may be present in irregular patches or crystals of all sizes, or as small veins, in addition to porphyroblasts of plagioclase. Such minerals in metamorphic rocks indicate that fluids must have aided in their alteration. (33-pp.109-111) The foliation in the vicinity of these composite rocks points to the possibility of their having a cupola or ellipsoidal dome-like shape so common to many intrusives. There may be an intrusive immediately beneath these zones, yet the banding of these rocks and others, is probably as much the result of replacement as of intrusion. This is clearly demonstrated by the evidence seen in Plate No. 11. These processes have so altered the pre-existing rocks that they are granitic in appearance. The banding in most places shows no evidence of having been deformed by the forcible injection of viscous igneous material; thus they are undoubtedly rocks which for the most part have been made over in place by solutions or gases. In this respect, they conform to Read's definition of granitization, whereby "solid rocks are converted to rocks of granitic character without passing through a magmatic stage". (53-p.47)

The process of palingenesis as described by Sederholm is ~~exa~~mplified in the rocks of the area, and appears to differ little from the present conceptions of granitization, if his "ichor" is taken to mean fluids or gases capable of carrying silicates; (61-pp.129-135) while the process of migmatization appears to be granitization which has not been carried to completion.

The broad transition zones between the intrusives of the area and the invaded gneisses, as well as the ubiquity of acidic lit-par-lit sills, fit into Termier's conception of an area in which the intrusives have been generated in place at great depths. (66-p.590-3) The most conclusive evidence for this is seen in the mode of emplacement of the "early quartz diorite" stocks, which apparently advanced by digesting the rocks in their paths.

In general it must be concluded that the rocks of the area have been granitized to varying degrees; probably at a time when they lay at some depth in the earth's crust, and that the process appears to have been more intense in the northern parts where most of the composite gneisses occur.

RELATIONSHIPS OF THE ROCKS TO THE TIMISKAMING AND GRENVILLE

The gneisses in the northern part of the area are within seven miles of the Porcupine-Malartic belt of Keewatin-Timiskaming sedimentary and volcanic rocks; while to the south, Grenville type limestones and quartzites lie less than six miles away, in the northeastern part of Wahl's area. (71-p.6) Therefore the Canimiti River rocks occupy as it were, the transition zone between the recognized Grenville and Timiskaming rocks. But because of their complex metamorphic nature they have been usually classified with the Grenville. The justification for this action will be considered in the light of what has already been shown and deduced by other geologists, who have worked in both the Grenville and Timiskaming provinces, and in the light of the new evidence presented in this thesis.

Cooke (23-p.66) considers that the large bodies of Timiskaming sediments lying to the north of the Caniμiti area, derived their material from a northerly direction, and were laid down in a shallow sea or lake; which however as deposition continued must have expanded, and deepened its basin, possibly to such an extent that it finally merged with the sea. In any case extensive off shore deposits must have been laid down, though now only near shore sediments such as greywackes are found. Bain (7) concurs with this idea, but goes further, and suggests that the off shore deposits are in reality those which are now referred to as Grenville. A glance at the accompanying Regional Map shows that these suggestions have some merit. In the first place the Grenville rocks are limestones, quartzites, and aluminous metasediments; mostly derivatives of mature weathering. These lie to the south of the immaturely weathered Timiskaming sediments, forming as it were, a normal sedimentary sequence from north to south; just as it should be if all the rocks were derived from the north. Secondly, Bancroft's traverse along the C.N.R. Northern Transcontinental Line, between Hervy Junction and Doucet, shows that limestones are last recorded about 100 miles east of Doucet, and as the Timiskaming-Gneiss contact zone is approached, sillimanite gneisses become less numerous. (8-pp.128-68) This again suggests a gradation northwards into less aluminous and less calcic sedimentary rocks. Lastly the rocks in the Canimiti River area, which occupy the "no man's land" between the recognizable Grenville and Timiskaming rock types, have alumina to lime and alkali ratios varying from 1.89 to 2.20. These are far too high for igneous rocks, (Dalys' anorthosite 1.65) but definitely compatible to those of shales and greywackes. (See Table 2) In addition banding such as is shown in Plates Nos. 5 and 10, is characteristic of the latter rocks. If all these features are considered in respect to the proximity of the large body of Timiskaming greywackes to the north, and to Lowther's statement that "there is a gradation eastwards from normal Temiscamian greywackes to a coarse grained garnetiferous gneiss"; (42-p.49) then it must be concluded that the gneisses and granulites are most probably in part metamorphic facies of Timiskaming sedimentary and volcanic rocks. Such being the case, the relatively rapid rise in grade of metamorphism which occurs in the short distance across the Timiskaming-Gneiss contact zone, must indicate that these contrasting rock types have been brought into contact by faulting, as previously suggested by Norman. (50)

The Timiskaming-Gneiss contact can be seen on the accompanying regional map to extend northeastwards as far as Lake Mistassini, in which locality Norman has found Huronian type sediments to be separated from the gneisses to the southeast by a northeasterly-trending fault. By virtue of the fact that the sediments have been preserved, and from other data, he is of the opinion that the gneisses have been elevated relative to the sediments and probably thrust over them. This is the only area in which the faulted nature of the Timiskaming-Gneiss contact has actually been proved.

Northwest of the Canimiti Area the southwesterly extension of the fault zone is probably represented by the long axis of Grand Lake Victoria. A projection of this line still further to the southwest, would join the contact zone between the Huronian rocks and gneisses, which Collins defined as extending from the north shore of Georgian Bay just east of Panache, northeastwards to the south end of Lake Timiskaming. (76-p.102-3) These rocks, as elsewhere, have sharply contrasting grades of metamorphism, which suggest that the contact is a faulted zone.

To-date there is little agreement among geologists as to the position of the Grenville. Miller and Knight consider that the Grenville rocks in southeastern Ontario lie above the Keewatin, and unconformably below sedimentary rocks which they believe are of Timiskaming age. (47) Wilson does not agree with this interpretation, for he thinks that the so called Keewatin volcanics in the Hastings area, are conformable with the Hastings sediments, (conglomerates) which unconformably overlie the Grenville rocks. (73), (88) There are many areas in which it is doubtful whether a distinction can be made between the Keewatin and the Timiskaming, on the basis of a predominance of either volcanic or sedimentary rocks, separated by a persistent unconformity. In the Malartic area to the north, Ambrose and Gunning found that sedimentary and volcanic rocks were everywhere intercalated, and that such unconformities as were found, were only of local extent and not restricted to any particular horizon. (36-p.5) (23-p.53)

Adams has described granulites from the type Grenville area 200 miles to the southeast, which are in many respects similar to those found in the Canimiti area. (1-p.80j) Perhaps they also are metamorphic facies of the Timiskaming sediments, deposited in the initial Timiskaming geosyncline, which may possibly have started in the region of the St. Lawrence River. This basin, fed by large rivers, could have expanded rapidly to the north, northwest, northeast, and southwest, until its progress was checked in the regions now occupied by the Keewatin-Timiskaming rocks, of the Porcupine-Malartic belt. Then later, faulting along the present Timiskaming-Gneiss contact elevated the Grenville or eastern side relative to that on the west. Subsequently, erosion could then have removed great thicknesses of rock from the elevated portions to the east. A large basin such as visualized above, with access to the sea, would have been suitable for the deposition of limestones, while local fluctuations in depth, with occasional periods of emergence, could have provided conditions for the reworking of the arkosic sands into beds of pure quartz sand, and shales. Such a history might explain the seeming lack of conglomerates amongst the "Grenville" rocks.

The comparitively high grade of metamorphism displayed by the Grenville gneisses as opposed to that of the Keewatin-Timiskaming rocks to the north, suggests that the Grenville province as a whole has been elevated and erroded to some depth.

Gowganda conglomerates lie unconformably on the gneiss complex along the eastern shore of Lake Timiskaming. (39-p.21) (See Regional Map). In the

Larder Lake area Wilson found that the Pontiac (Timiskaming) schists are injected by granitic material of the gneiss complex (called Laurentian), and that these in turn are overlain unconformably by Cobalt (Huronian) conglomerates. (87-p.31) All these Huronian sediments are flat lying and relatively undeformed, indicating that the stresses which deformed the gneisses were pre-Cobalt. Yet in other regions rocks of both the Cobalt and Bruce series lie unconformably on the gneisses, and are much folded; while south of the Huronian - Gneiss contact, Huronian remnants have been intruded by the Killarney granites and assimilated by them. (84-pp.753-70) (76-pp.103-28)

The fact that the Chibougamau (Huronian?) sediments have been truncated by faulting along the Timiskaming-Gneiss contact, argues that the stresses responsible for the structural trend in the "Grenville" gneisses, were still active in Huronian times in northeastern Quebec, and that as in the Georgian Bay area, folded Huronian rocks may have overlain the gneiss complex to the south, prior to their being removed by erosion. However, this argument achieves very little, for Killarney intrusives invading the region, could have converted the basal formations of the Huronian rocks into gneisses and schists, indistinguishable from the pre-Huronian complex. Yet if the geology in the Larder Lake and Timiskaming areas has been interpreted correctly, the Grenville complex must be post-Timiskaming and pre-Cobalt.

Gill (77-p.29) (78-p.61-69) has discussed the age relationships between the various precambrian systems of the "Canadian Shield". He concludes that the dominant trend in each geological province is the result of a major geological cycle, composed of more than one geosyncline, and that the attitudes of the provinces to one another in some cases is indicative of their relative ages. Thus for example the Keewatin-Timiskaming rocks of the Porcupine-Malartic belt and the other rocks of the Superior province, have an overall structural trend to the east which appears to have been cut off by the predominant northeasterly trend of the Grenville province, along a line extending from the north shore of Lake Huron to Lake Mistassini. The implication is that the structural trend of the Grenville was accomplished by an orogeny which was younger than that responsible for the deformation of the "Superior" rocks. Hence the rocks of the Grenville province must belong to a younger geological cycle.

Wilson has compared the lead uranium and thorium ratios made by Ellsworth of the Geological Survey of Canada, with more recent age determinations done with the mass-spectograph, on the isotopic composition of the lead isolated from radioactive minerals. He found that they gave comparable figures, which in turn check with the newer spectographic strontium to rubidium ratios. (86-p.543) The ages given by these methods for the various "Grenville" rocks from different localities range from 760 to 1150 million years, whereas the early Precambrian rocks of Manitoba range from 1760 to 2200 million.

The wide age range of the Grenville province suggests that it is composed of rocks belonging to more than one geosynclinal cycle. By comparision the late Precambrian to Carboniferous rocks of the Appalachins have age ranges of from 580 to 200 million years. Based on these figures the Grenville rocks must have been formed during the Proterozoic, prior to and possibly contemporaneously with the lower and middle Huronian series. This is in agreement with the age of the Grenville province as suggested by its overall structural relationship to the Superior province, and is also in accord with the evidence seen in the Larder Lake and Timiskaming areas.

Finally a Proterozoic age is suggested for the Grenville by the maturely weathered nature of its sedimentary rocks, which consisted of aluminous shales, clean sandstones, and limestones. Rocks not known to occur in any quantity prior to the Proterozoic. (77)

The foregoing evidence indicating that the rocks of the Grenville province are post-Timiskaming and pre-Cobalt, finds no contradiction in the Canimiti area. The rocks are probably metamorphosed Timiskaming type sediments with possibly some intercalated volcanics, which were involved in an orogeny younger than that which affected the recognisable Timiskaming rocks of the Porcupine-Malartic belt to the north. Hence if successive orogenies and geosynclines are related, the rocks in the area must have been or are overlain by younger rocks, not now recognisable, or since removed by erosion. The high grade of metamorphism suggests that the rocks were formerly at some depth. But as a result of faulting along the Timiskaming-Grenville contact, the Grenville side was elevated and deeply eroded. The decrease in metamorphic grade from the Canimiti area southwards into the Cawatose area, implies that such uplift must have been greater in the Canimiti area adjacent to the fault zone; in which case younger sedimentary rocks might be expected to have survived erosion more readily in the Cawatose area. Bearing this in mind the occurrence of one exposure of Grenville type limestone and quartzite in the Cawatose area may be significant. They could be the representatives of rocks which may formerly have overlain the Canimiti area. On the other hand an undiscovered contact between the Grenville and Keewatin-Timiskaming rocks may be present in the Canimiti or Cawatose areas.

It might be argued that the high grade of metamorphism in the present area is the result of abundant igneous intrusion in and along the faulted Timiskaming-Grenville contact, at the time of or after faulting took place, and that the rocks were never depressed to great depths. If such were the case, the general lack of chilled contacts between the acidic igneous rocks and the intruded rocks, the absence of acidic dykes as opposed to numerous sills, the migmatites, and the presence of ptygmatic folds, must all be explained. Since they are features generally regarded as the products of deep seated metamorphism.

The consistent south to southeasterly dips and the two small thrust faults previously described, lend support to Norman's theory that the movement along the Timiskaming-Grenville fault zone was in the nature of a thrust acting toward or from a northwesterly direction. Such a movement, it is to be expected, would have elevated rocks from deep zones, and these would logically be concentrated in the vicinity of the fault and become more prominent as erosion progressed. Thrust faulting is therefore not incompatable with the increased grade of metamorphism found in the Canimiti area as opposed to that prevailing in the Cawatose sheet to the south. However, normal block faulting of the Grenville rocks and tilting could just as easily have produced a similar result, though no evidence was seen to support such a hypothesis.

If the granulites and gneisses are of Timiskaming age, then the "greenstones" which are believed to be paragneisses must be Timiskaming rocks which were preserved by faulting, or post-Timiskaming rocks resting unconformably on the gneisses, and possibly Huronian. In the latter event the syenites would be of Huronian age or younger (Killarney?) since a syenitic pegmatite is known to intrude "greenstone", but in the former instance they would probably be Algoman, as has been suggested by their similarity in structural trend to rocks of like composition intruding the Timiskaming series to the north.

As for the early grey granitic stocks and sills, the oldest acidic intrusives in the area, since they intrude the granulites and gneisses they must be post-Timiskaming, if the latter rocks are accepted as being of Timiskaming age. While unconformities elsewhere in the region indicate that they are in all probability pre-Cobalt. (39-p.21) Cook describes similar rocks as intrusive into the southern border of the Timiskaming greywackes to the north, and granites that are in some places transitional into syenite. (23-pp.134-8) This relationship may well exist between the granitic rocks and the syenites in this area, since nowhere have these rocks been seen in contact, though there is a tendency for certain younger granitic intrusives to show enrichment in potash and soda, as well as more sharply defined contacts. This suggests that the syenites are younger differentiates from the same magma that gave rise to the granites and quartz diorites. Thus if the syenites are Algoman, the granitic rocks are probably earlier intrusives of the same or a preceding period. Bell (89-p.73) in his report on the "Assup River Area" discusses the relationships between the Keewatin-Timiskaming rocks and the Grenville gneisses, and his remarks are worth noting at this point:

> "Near the margins of the Keewatin belt, however, the strike of the schists parallels their contact with the granite gneiss. Thus within half a mile of the gneiss on the south, the normal east-west strike of the schists changes abruptly to a northeast direction to parallel the line of contact between the greenstone and gneiss and also the banding in the latter. This direction of folding appears to have been superimposed on the earlier east-west folding, which in places has been dragged sharply into the northeast direction. The granite injections to which the gneiss owes its origin followed the development of this northeasterly foliation in the schist.

> ------both directions of folding are found in the sedimentary rocks in this area and for some distance to the west. That part of them which has been infolded with the greenstones strikes north of west, while the southern extremities of these folds and the main body of the sedimentary rocks on the south have been folded along easterly or northeasterly axes, that is roughly parallel to the margin of the southern granite batholith. From this it seems apparent that there have been two periods of folding, one in which the lavas and sedimentary rocks were folded together in a general direction 10° to 30° north of west, and a second disturbance which affected the rocks in the vicinity of the granite intrusions, and which was connected with, and for the most part preceded the general period of these intrusions. However, the granites, and consequently the deformations that accompanied their intrusion, may differ somewhat in age."

Bells' statement would seem to indicate that the granitic intrusions in the gneisses, belong in part to an orogeny younger than that which folded the Keewatin-Timiskaming rocks. Therefore to suggest that the granitic rocks in the Canimiti and surrounding areas are of Algoman age is an unjustified assumption. Though it is conceivable that Algoman intrusives resting at great depths, could be partly remobilized by the effects of a later orogeny, or plastically deformed and made to conform with new trends. The safest conclusion seems to be that the granitic rocks in this part of the Grenville province may be in part Algoman, but that all were intruded in post-Timiskaming times prior to the deposition of the Cobalt series, and some must be younger than the Grenville type sedimentary rocks.

The contact between the Superior and Grenville provinces is probably a fault zone or zones to which the faults and suspected faults in the Canimiti area are related. No exact age can be given. There is evidence only in the Chibougamau area to indicate that there was movement after and possibly prior to the formation of the Chibougamau sediments. (Cobalt?) (45-pp.51-57) While the rugged linear topography in the Canimiti area and region is taken as proof that the associated faults were active in more recent times. This is substantiated by the investigations of Cooke, (21) (22) and Wilson (72).

Yet in view of the radioactive age determinations previously quoted, and the evidence provided by unconformities, the inferred faulting between the Timiskaming and Grenville rocks probably first occurred during an orogeny which deformed the Grenville type sedimentary rocks, prior to the deposition of the Cobalt series, and after the folding of the Keewatin-Timiskaming rocks.

ECONOMIC GEOLOGY

Mineral Occurrences

No economic deposits are known to occur in the area, There are quartz veins which are seldom of any size, and carry only traces of gold. Disseminations of sulphide were found in some granulites, basic lenses, and in one "flaser" zone, however assays show that they contain only traces of gold,silver, lead and nickel.

A small pegmatitic quartz vein adjacent to the metadiabase dyke at the "narrows", on the mainland north of Soulier Island, contains some pyrite but gave only traces of gold upon being assayed.

A white quartz vein some 3 to 4 feet wide and of unknown extent was uncovered during the construction of the new section of the highway several hundred feet northwest of the new bridge over the Chochocouane River. It is barren, save for large books of dark biotite that occur along its contacts with the enclosing gneisses. The strike is N 50°E and the dip is vertical, and it appears to conform to the strike of the gneisses in that locality.

On the C.I.P. & P. Company road 1500 feet east of the Freville-Champrodon township boundary, there is a fine-grained, greenish acidic band of rock 2 to 4 feet wide, in coarse composite gneisses. This contains disseminated sulphides, mostly fine grained pyrrhotite with a little chalcopyrite and graphite, and a representative specimen when assayed gave only traces of nickel silver and lead. The zone strikes to the northeast, but its extent is not known since it disappears under glacial till, nor could the dip be determined. Some 3500 feet east of here along the road, there is a small rusty lens-shaped zone in composite gneisses which carries graphite. It is less than 2 feet long and only 2 inches wide, and presumably contained sulphides prior to being leached by surface waters. On the same road, but about three-quarters of a mile west of the Canimiti River, the composite gneisses contain narrow mauve to opalescent quartz stringers; these occasionally carry sulphides, but were not assayed.

Fine grained sparse disseminations of sulphide are found in the granulites and gneisses; in such instances the rocks have a fresh sugary appearance, and resemble fine-grained granites, suggesting that they have probably been formed by some process of metasomatism.

Small basic lenses only a few feet in dimensions, seen in the composite gneisses, may contain sufficient pyrrhotite to deflect a compass.

The fault zone which traverses the Canimiti River, contains in its "flaser" gneisses sparse disseminations of sulphide; but there are included fragments of basic material which have much greater concentrations, (2-3%)

and are strongly magnetic, indicating that the sulphide is probably pyrrhotite, or that there is magnetite present. An assay of this basic material gave traces of nickel and silver, but no platinum.

The pegmatites in the area carry no minerals of economic importance. Though magnetite was seen in an alkaline variety associated with the syenitic intrusive at the western end of Lake Tombbah.

Origin And Age Of The Mineralization

The quartz veins in the composite gneisses, and those associated with pegmatites, must have been formed by hydrothermal processes associated with the granitic intrusives, most probably the syenites and associated rocks, since they are the youngest and most differentiated.

The sulphide disseminations in the gneisses and in the fault zone on the Canimiti River were probably formed at the same time, as a result of injection and/or replacement of the enclosing rocks by pneumatolytic or hydrothermal processes along zones of differential movement or faulting, and as such must have developed after the major part of the folding was completed.

Economic Possibilities

The occurrence of such deposits as Sherritt Gordon, (75) Calumet Island, (83) and Tetreault,(82) in areas of complex Grenville type rocks, emphasizes the need for caution before condemning the mine-making potentialities of similar areas.

There are fundamental differences between the Canimiti and the areas in which these mines occur. The Canimiti area has no recognisable sedimentary rocks but only their inferred metamorphic facies; whereas the Sherritt Gordon ore body lies along the margin of a quartzite; the Tetreault ore is associated with limestones and their alteration products; and the Calumet deposit is in a region underlain by much limestone, hornblende, gneisses etc. It would appear that relatively cool and permeable or brittle rocks are needed to localize mineral bearing solutions, causing them to deposit their loads by cooling and/or replacement. Perhaps the most significant feature of the Canimiti rocks is their general lack of alteration minerals such as epidote, zoisite, apatite, amphiboles, chlorite, and sericite, in which there is an (OH) or (F Cl) radical. This is in marked contrast to the other areas, where such minerals in addition to carbonates are common, both in the rocks and with the ores. From this it is inferred that the rocks in the area were formerly very hot, and probably at such great depths in the crust that mineralizing fluids were unable to precipitate their contents until the rocks had cooled; by which time most of the fluids had been forced or drained off into higher, cooler, and since eroded crustal rocks.

In view of the conditions which are thought to have prevailed, it is considered that mineral deposits of value are not likely to occur in this or any similar area, unless it can be shown that there are underlying intrusives which post-date the periods of intense metamorphism, and that there are favourable host rocks such as limestones present.

Despite the pessimism with which the area is regarded there are certain possibilities that should not be overlooked.

The pegmatites seen are small and carry no minerals likely to be of economic importance. However, magnetite was found in a syenitic variety associated with the Lake Tombbah syenitic intrusive, hence the latter might contain or have marginal deposits of this mineral.

Some of the valleys in the northwest corner of the area could be underlain by "greenstones" preserved by faulting; and it is not inconceivable that they and some of the faults might have concentrations of economic minerals. However, because the valleys contain lakes or are filled with moraine, investigation of such places could only be carried out by geophysical methods and diamond drilling.

If there are sulphide deposits in the area, they probably contain nickel as suggested by the assays and the presence of pyrrhotite. In this respect the fault zone on the Canimiti River is deserving of attention, and should be searched for large included masses of basic material in which sulphides may have been concentrated, or for similar concentrations at places where the fault zone transects basic dykes or sills.

Insofar as the quartz veins in the area are concerned, they show no promise of carrying more than traces of gold, but all veins should be sampled, especially those that are associated with the finer grained biotite gneisses in the northeastern part of the area.

CONCLUSIONS

The area is underlain by hypersthene garnet and biotite granulites and gneisses, rocks believed to have been chiefly sediments, most probably Keewatin-Timiskaming greywackes, with some tuffs, slates, and possibly volcanics. These as a result of folding, accompanied by faulting and two periods of igneous intrusion, were highly metamorphosed. (In part, "granitized") Original structures were mostly obliterated, but bedding and schistosity are thought to be represented in some rocks by layering which parallels the foliation, and probably provided the channels for lit-par-lit injection. Locally temperatures and concentrations of igneous material and fluids were very great. The rocks were replaced or assimilated, in places becoming coarse grained and granitic in appearance.

During this process reactions between the pervading solutions or gases and the intruded rocks, resulted in the formation of a potash-soda feldspar of variable composition, termed in this thesis "sanidine-anorthoclase".

The evidence indicates that vermicular and myrmekitic intergrowths of quartz and feldspar were formed at high temperatures, as a result of interaction between injected igneous materials or fluids and garnetiferous paragneisses.

Ultrabasic and basic hypersthene rich sills were probably the earliest intrusives: these were followed by the "early" grey quartz diorites, granites, and associated pegmatitic sills and lit-par-lit injections. None of the latter are very large, yet they are widespread, suggesting that a magma of their bulk composition may underlie the area. The high quartz content of some and the general absence of chilled contacts, indicates that they were intruded into rocks already heated to high temperatures. On the other hand, some "sills" may have been formed by selective refusion of the original rocks. Nothing is known about their ages, except that they are pre-hornblende syenite, and intrude gneisses believed to be metamorphosed Timiskaming rocks.

Hypersthene gabbro, red quartz diorite, hornblende syenite, granodiorite, quartz syenite, and their associated pegmatites, are the youngest intrusives. They are considered to be post-Timiskaming since they intrude the gneisses and because some stocks have trends similar to those in the areas to the north, which intrude rocks of Timiskaming age.

"Greenstones" found outside the northwest boundary of the area are only of moderate metamorphic grade; and their high alumina ratio suggests that they are of sedimentary origin. They resemble the Keewatin-Timiskaming rocks in the areas to the north, and could be infolded or faulted remnants of these rocks. They are lying either unconformably on or in fault contact with the gneisses, hence the possibility of their being younger than the Timiskaming, possibly Huronian, or Grenville, must not be discounted. In the former case the syenites would probably be Killarney; in the latter instance they would belong to a post-Algoman pre-Killarney period of intrusion.

The deformation of the rocks in the area and region was accomplished by forces acting toward or from a north or northwesterly direction. The rocks were folded and overturned to the northwest; minor thrust faults indicate that there was some over-or underthrusting toward or from the same direction. At first during folding, differential movements between beds afforded stress relief, but when the folding became tight and could no longer supply relief, faulting occurred repeatedly, and was accompanied by the intrusion of the pink pegmatites. It was about this time, or possibly at the close of the period of maximum folding that the syenites and associated rocks were intruded.

Because of the high temperatures prevailing in the rocks at the close of folding, plated "flaser" gneisses were formed along zones of differential movement and faulting, instead of schists or fracture zones.

Faulting along the Timiskaming-Gneiss contact probably occurred during the period of maximum folding, resulting in the elevation of the southeastern side relative to that on the northwest. Erosion then unroofed the elevated rocks, but probably never succeeded in wearing them down to base-level because of repeated movements along the old faulted zones. The high grade of metamorphism seen in the Canimiti rocks suggests that the amount of material removed must have been considerable. While the decrease in metamorphic grade towards the south suggests that the rocks adjacent to the Timiskaming-Gneiss contact were raised higher than those to the south.

No typical Grenville rocks were seen in the area, though they could be present, or may have overlain the area and been removed by erosion.

The coincidence between topographical and geological trends indicates that in many places the topography is a direct reflection of the underlying rock structures, only slightly modified by Pleistocene glaciation.

A review of the literature on Precambrian correlation finds some agreement as to the position of the

Grenville rocks. Radioactive determinations and geological structures infer that they were deposited and associated with an orogeny later than that which affected the Timiskaming rocks, and probably prior to the deposition of the Cobalt sediments. If such is the case, some of the intrusives in the area could be younger than Algoman. There is little reason to suspect the presence of Killarney intrusives, though there were probably some structural adjustments in the region during this period.

No mineralization or "showings" of any importance are known to occur in the area. The lack of alteration minerals and recognizable volcanic or sedimentary rocks is taken to indicate that the rocks, during the end stages of metamorphism, were very dry and devoid of fluids. In view of this, it is thought unlikely that mineral deposits of importance will be found in the area.

RECOMMENDATIONS

Further investigation of the "greenstones" in the locality outside the northwestern boundary, might disclose more of these rocks, and provide additional evidence as to their origin and age.

Chemical analyses of the more and less altered greywackes, and volcanic rocks from the Keewatin-Timiskaming belt to the north, would be invaluable in comparing and assessing the effects of igneous and metamorphic action upon the rocks in this and the surrounding areas.

A detailed study of the apparent gradational zones between the hypersthene and garnet bearing gneisses and granulites, might show whether these rocks are different facies of the same rock, or were different rocks.

The collection and analysis of garnets from every part of the area, might provide further clues as to the original compositions of the rocks.

Any further mapping in the adjacent areas, should entail one summer in which a reconnaissance survey would be made, to be followed by a more detailed examination during the succeeding summer.

Plate No. 1. Profile of an elongated ridge. The steep slope of the ridge faces west. Highway 58, mileage 52.

Plate No. 2. A typical lake of the area. Note the steep rock scarp which constitutes the southeast shore of the lake. Highway 58, mileage 55.5.

Plate No. 3. Looking northeast up the valley of the Chochocouane River. Note the rough accordance of the horizon. Taken from the hill west of Paree's Camp.

Plate No. 4. Looking southwest towards the valley of the Canimiti River. Taken from the north-south ridge at long. 77°05'00" W, Lat. 47°40'33" N. in Champrodon township.

Plate No. 5. Exposure of green garnet gneiss with some injection banding. Layered appearance is very suggestive of impure arenaceous or slaty rocks. Abandoned part of Highway 58, north of the Ottawa River.

Plate No. 6. Quartz diorite orthogneiss with inclusions of basic rock. Note the almost digested inclusion in the foreground. Small island in the eastern part of Lake Tombbah.

Plate No. 7. Biotite gneiss with lit-par-lit injections of quartz diorite pegmatoid and pegmatitic material. Abandoned part of the highway south of the Ottawa River.

Plate No. 8. Sheet-like layers of quartz diorite pegmatoid sills in biotite gneiss. Hammer handle lies in the direction of the lineation. Abandoned part of highway south of the Ottawa River.

Plate No. 9. Garnetiferous migmatitic injection banding. Small island at the western end of Lake Tombbah.

Plate No. 10. Layered composite gneisses. C.I.P. & P. Company road east of Composite Lake.

Plate No. 11. Close view of banding shown in Plate No. 10. Cross-cutting dykelet demonstrates igneous injection. Whereas the large sill it joins, has eaten into the undistorted dark layer seen a little to the right of centre. This is undoubtedly the result of replacement.

Plate No. 12. Banded mafic composite gneiss. The hammer is against a mafic layer but on the right hand side, the rock has broken along a lighter coloured layer. Composite Lake.

Plate No. 13. Massive hornblende gabbro or amphibolite? Highway 58, mileage 53.5.

Plate No. 14. Brecciated hypersthene layers or lenses, intruded by syenitic material presumably from adjacent syenitic pegmatite. Highway 58, mileage 53.5.

Plate No. 15. Porphyroblastic hypersthene-augite-hornblende rock. Large crystal has been outlined with chalk. Weathered knob lies on top of the specimen. Specimen is from the Canimiti River section.

Plate No. 16. Sub-schistose hypersthene-augite-hornblende rock. Micaceous surface is deceptive and is only a thin coat covering pyroxene. Canimiti River (shear?).

Plate No. 17. Medium grained hypersthene-augite-hornblende specimen from band in the Nose Lakes section. Hornblende and augite usually predominate over hypersthene in the bands from this locality.

Plate No. 18. Hypersthene-bearing granulites. Note massive appearance. The hypersthene content is low in the specimen on the left, but is higher in the others.

Plate No. 19. Mafic hypersthene-bearing inclusions which occur in granulites. Note the ellipsoidal shape of that on the right. This is mineralized and deflects a compass needle. The specimen on the left contains no sulphides and is rounder.

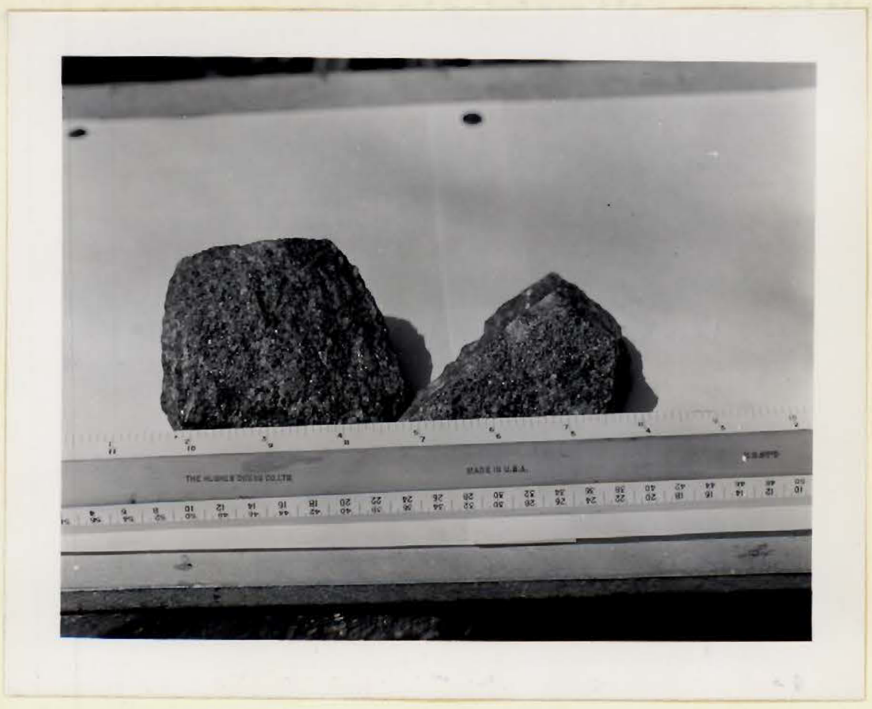


Plate No. 20. Garnet gneiss; the specimen on the left has 40% of garnet, that on the right is the normal variety with only 10-15%.

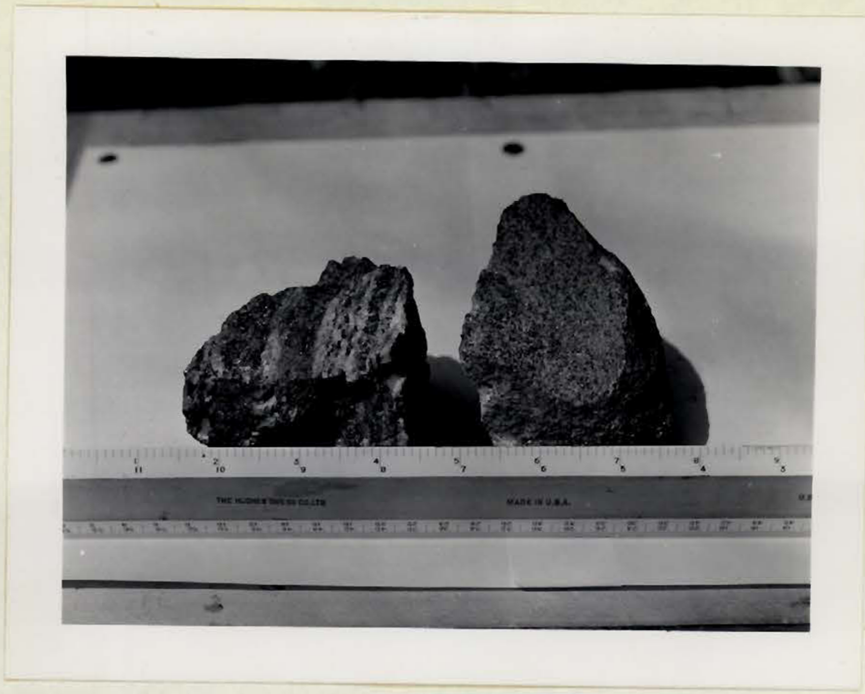


Plate No. 21. Garnet gneiss. Note the dark bands of coarse red garnets in the left hand specimen, and the massive nature of the other. The red garnets in the former specimen are believed to have a spessarite-almandite composition.

Plate No. 22. Highly garnetiferous light grey to green gneisses. Note the fine garnet banding in the right hand specimen. That on the left is soaked with quartz diorite pegmatoid material, and contains microperthite and "sanidine-anorthoclase".

Plate No. 23. Biotite gneiss from Lac des Montagnes.

Plate No. 24. "Granitized" looking biotite garnet gneiss showing depth of weathering.

Plate No. 25. Quartz diorite orthogneiss taken from exposure shown in Plate No. 6.

Plate No. 26. Quartz diorite with moderate content of biotite. Taken from the contact zone between massive white quartz diorite and biotite gneiss. North abutment section of the new highway bridge over the Ottawa River.

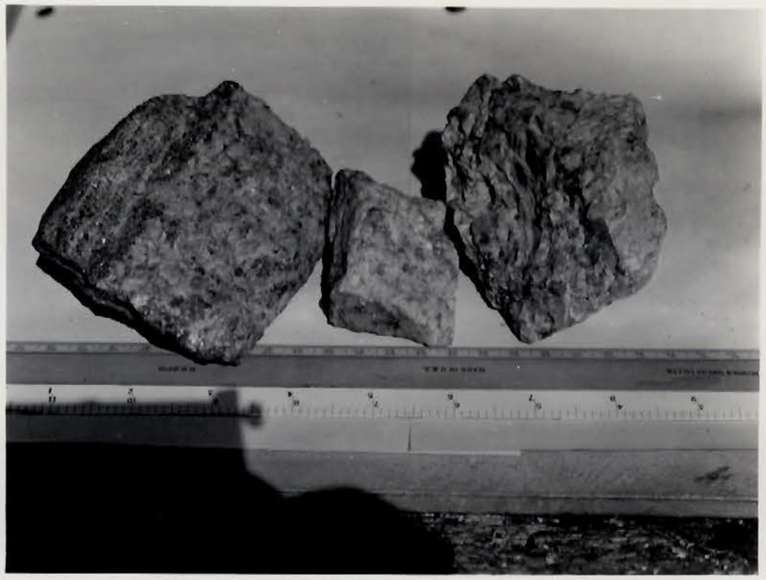


Plate No. 27. The two specimens on the left are from glassy quartz diorite pegmatoid sills. That on the right is from a coarse grained oligoclase pegmatite which cuts them.

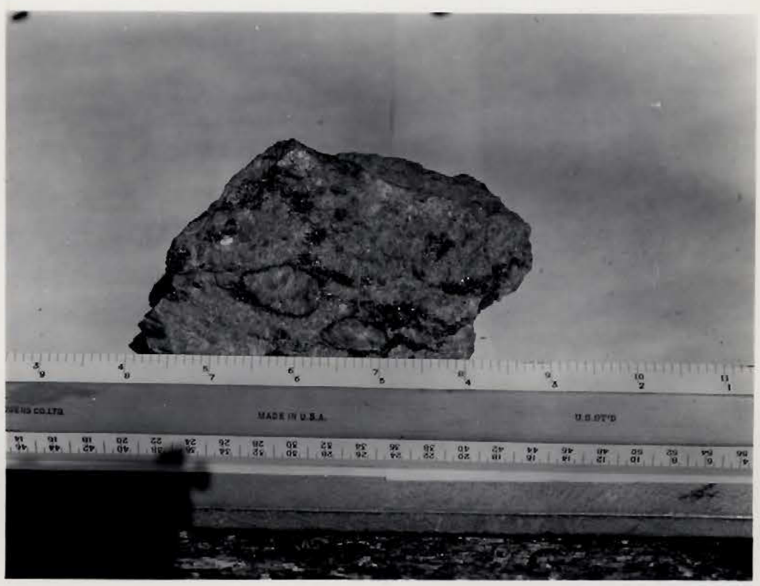


Plate No. 28. Pink pegmatite "augen gneiss". The "eyes" have been outlined with chalk.

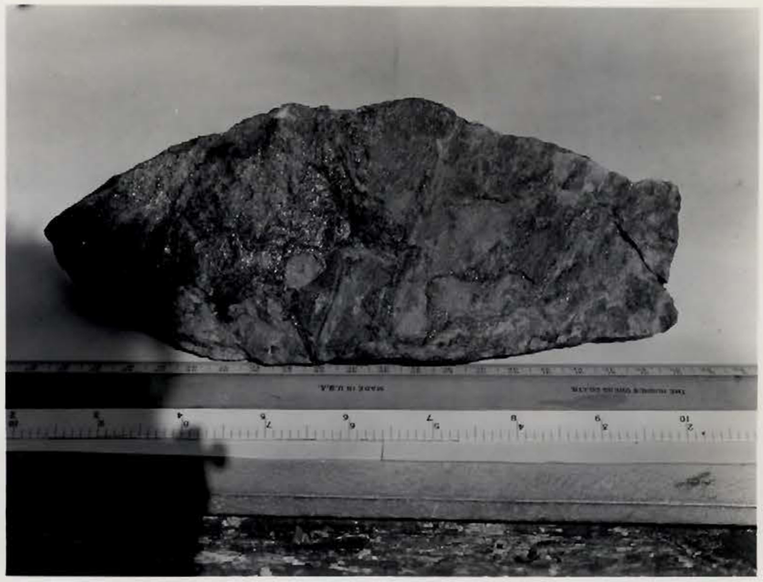


Plate No. 29. "Flaser" gneiss. Contains sheared pink pegmatitic material contaminated by mafic minerals. Note pseudo-slickensides. From fault area northeast of Gabbro Lake.

Plate No. 30. Slightly sheared micaceous and chloritic "greenstone" from the exposure on the south boundary of Freville township.

Plate No. 31. Hornblende syenite.

Plate No. 32. Coarse dirty brown hypersthene-bearing pegmatite that intrudes the "greenstone" rocks exposed on the south boundary of Freville township. (See Plate No. 30)

Plate No. 33. Alkaline pegmatite, contains only microperthite which is partly albitized. Highway 58, mileage 53.5.

Plate No. 34. Coarse grained composite gneiss from the northern part of the area. Contains feldspars, quartz, 5-10% of hypersthene, 2-5% of garnet and small amounts of "sanidine-anorthoclase". (See Plate No. 53)

Plate No. 35. Hypersthene granulite. Note sub-parallel orientation of the hypersthene and biotite (dark), in a less orientated groundmass of quartz and feldspar. Nicols uncrossed, X 20.

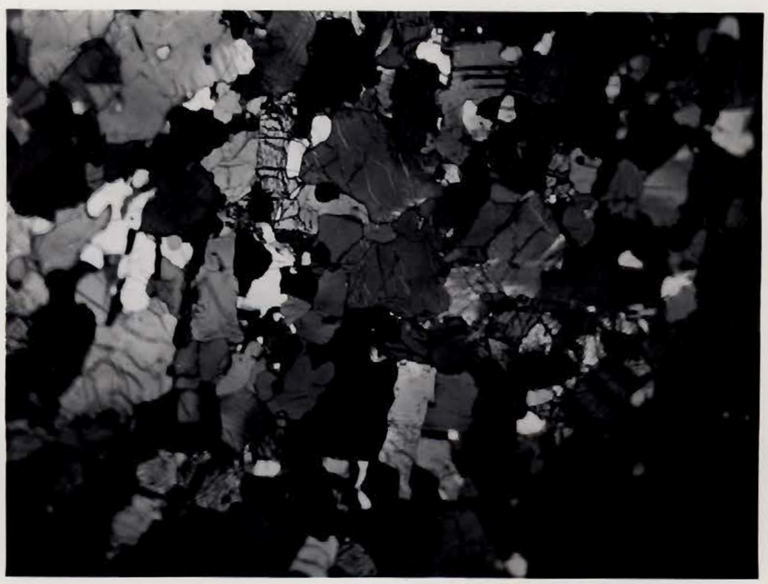


Plate No. 36. Same section as No. 35, but with crossed nicols. Note absence of twinning in feldspars, and slightly directional, but allotrimorphic texture. Nicols crossed, X 20.

Plate No. 37. Garnet gneiss with weak preferred orientation, showing some fracturing of the larger feldspar crystals. The smaller crystals may be of cataclastic origin. Nicols crossed, X 20.

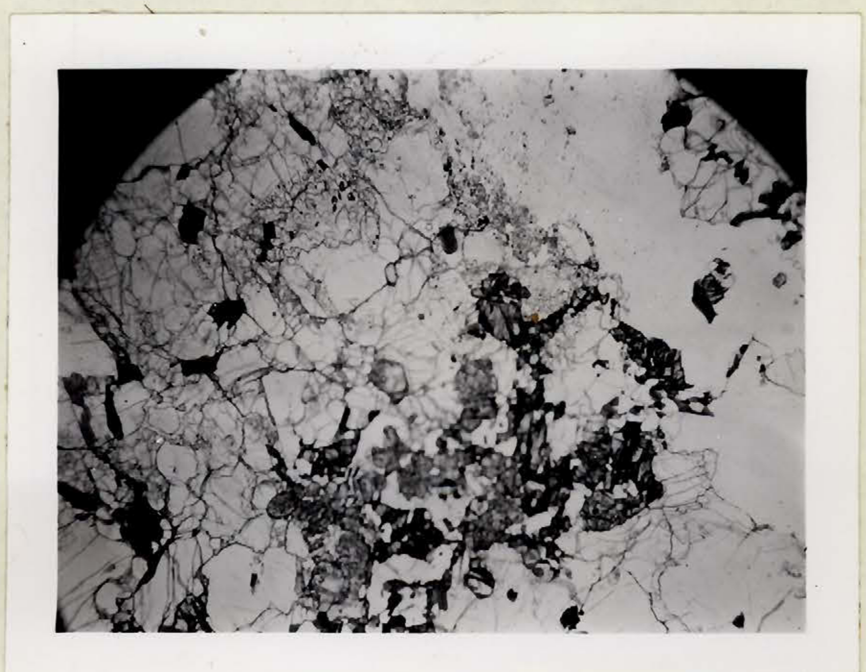


Plate No. 38. Granulite containing both hypersthene (dark outlines) and garnet intimately intermixed. Large crystal of garnet in the upper right hand corner contains hypersthene which seems to be forming along fractures in the garnet. Nicols uncrossed, X 20.

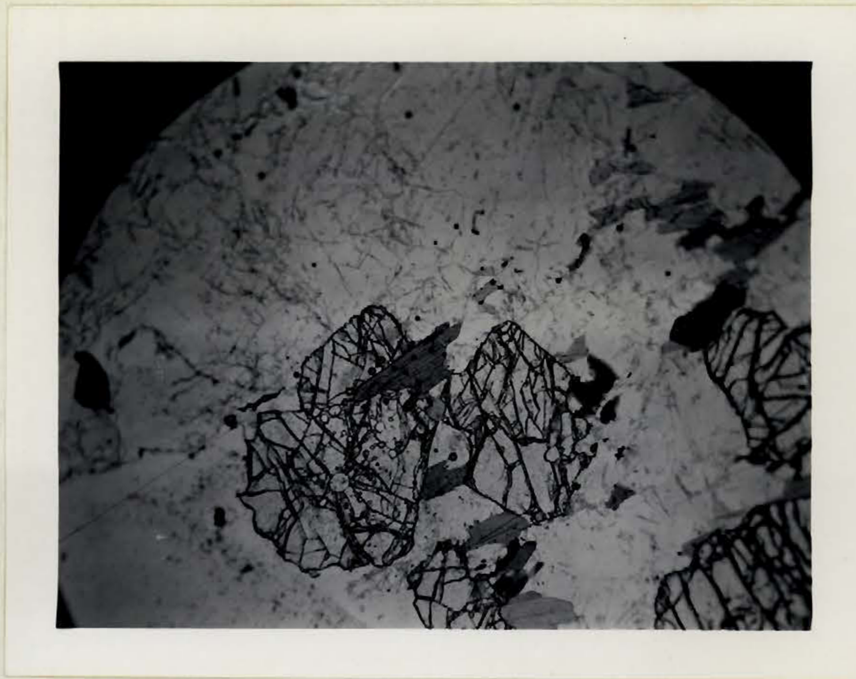


Plate No. 39. Garnet gneiss, showing penetration of garnet by biotite. Note the numerous small rounded inclusions of quartz and feldspar. Nicols uncrossed, X 20.

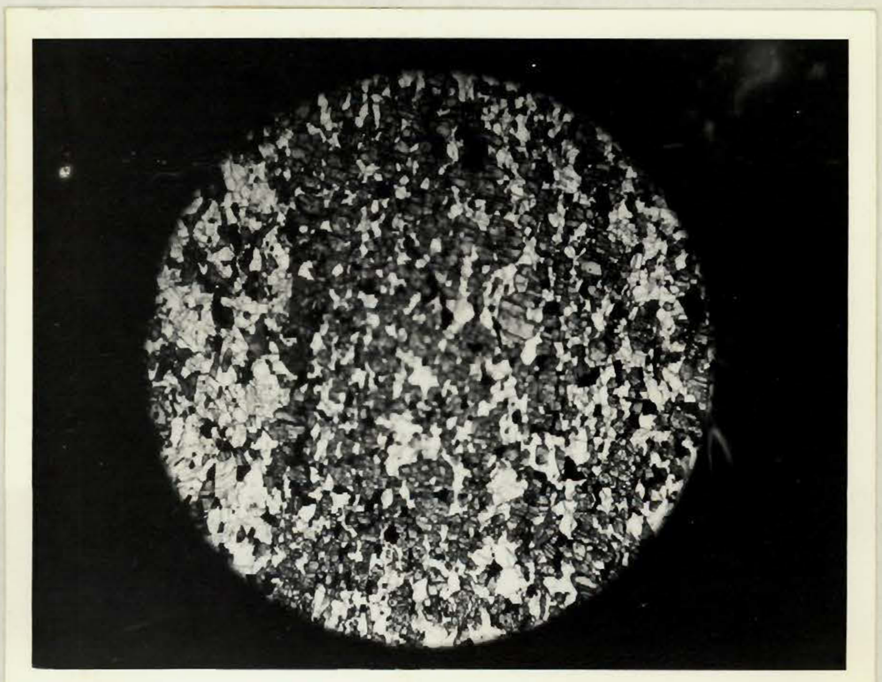


Plate No. 40. Garnet gneiss occurring as an included band in the hypersthene gabbro. Note the directive texture. Contains 20% of garnet, 25% of hypersthene, augite, and hornblende combined, plagioclase 35%, iron oxides 15%, quartz 5%. Nicols uncrossed, X 36.

Plate No. 41. Typical fine to medium grained biotite gneiss from south of the Ottawa River. Note clarity of feldspars and general lack of twinning. Biotite constitutes only 10-15% of the section. Nicols uncrossed, X 20.

Plate No. 42. Biotite gneiss from Lac des Montagnes. Note the slight reaction rims around the biotite in the centre of the section, and the bent albite twinning. This section shows weak albitization. Nicols uncrossed, X 20.

Plate No. 43. Biotite gneiss from north of Lac Dozois. Nicols uncrossed, X 20.

Plate No. 44. Biotite gneiss same as for Plate No. 43, but nicols crossed. Note rounded and embayed anhedra of quartz. (light). X 20.

Plate No. 45. Antiperthitic plagioclase An_{32} from quartz diorite pegmatoid sill, near mileage 58 on the highway. The small patches are potash feldspar. Some are bounded in part by twinning planes, others follow fractures. The larger patches are quartz. Note the patch indicated by the arrow; this if inspected with a hand lens, shows tiny microperthitic lamallae which are probably albite. Nicols crossed, X 20.

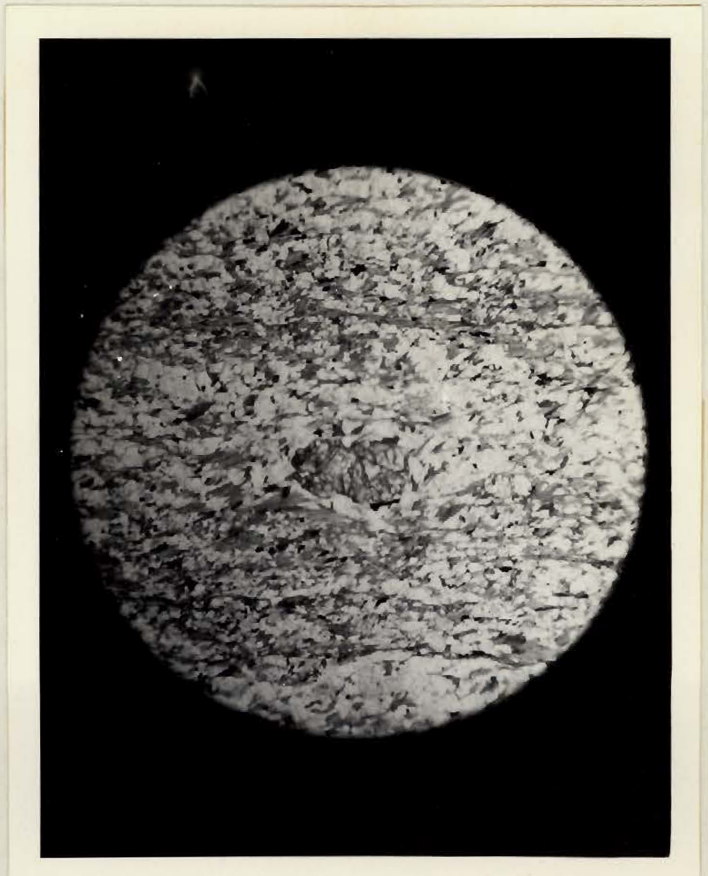


Plate No. 46. "Greenstone", showing an occasional garnet porphyroblast, and good directive texture outlined by biotite and minor amounts of chlorite. Nicols uncrossed, X 20.

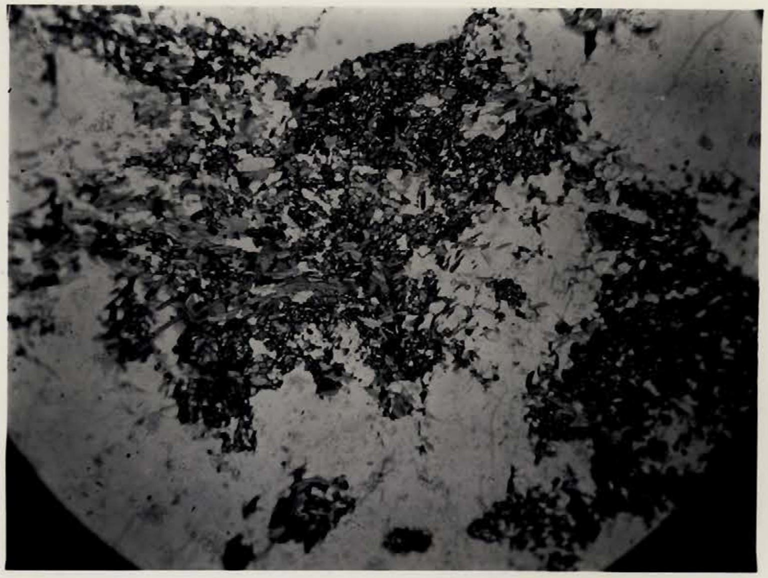


Plate No. 47. Composite gneiss, dark variety with fine grained mafic clusters of hypersthene, biotite, garnet, augite, hornblende, quartz and feldspar, in a coarser matrix of plagioclase and quartz. Nicols uncrossed, X 20.

Plate No. 48. Medium grained granoblastic matrix surrounding clusters shown in Plate No. 47. Note abundant twinning which is normally scarce in the rocks of the area. Nicols crossed, X 20.

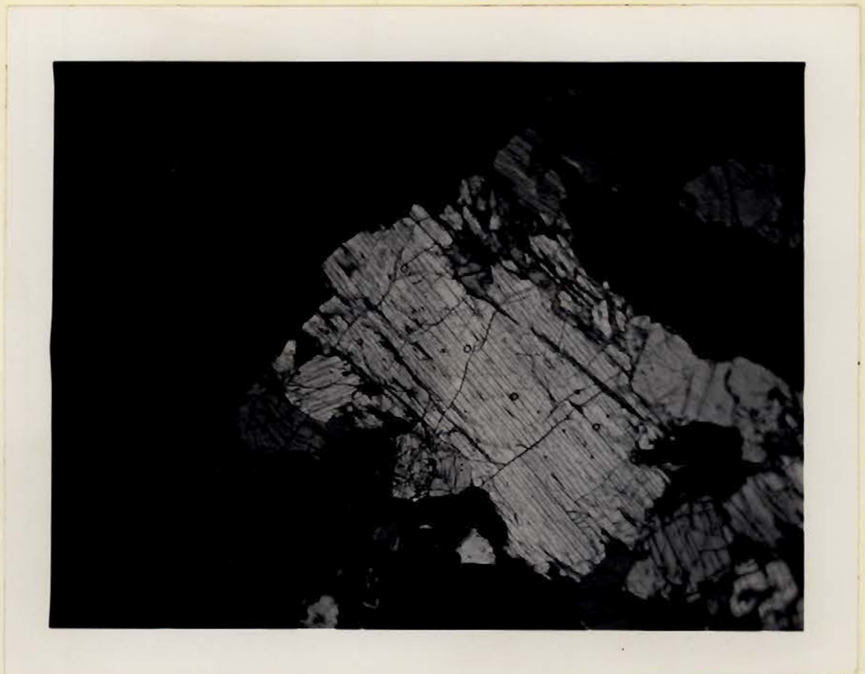


Plate No. 49. Large crystal of hypersthene in coarse grained porphyroblastic hypersthene-augite-hornblende rock. (See Plate No. 15) Showing good 010 cleavage. Nicols crossed, X 20.

Plate No. 50. Microperthite in hornblende syenite. Note albite filling fractures and apparently starting to replace the margins of the large crystal. The small fresh crystal of microcline is partly surrounded by a resorbed pyroxene that could be either hypersthene or aegirine-augite.

Plate No. 51. Showing microperthite with good rods of albite. A small crystal showing an indistinct vermicular texture may be seen between the two large crystals. Hornblende syenite. Nicols crossed, X 32.

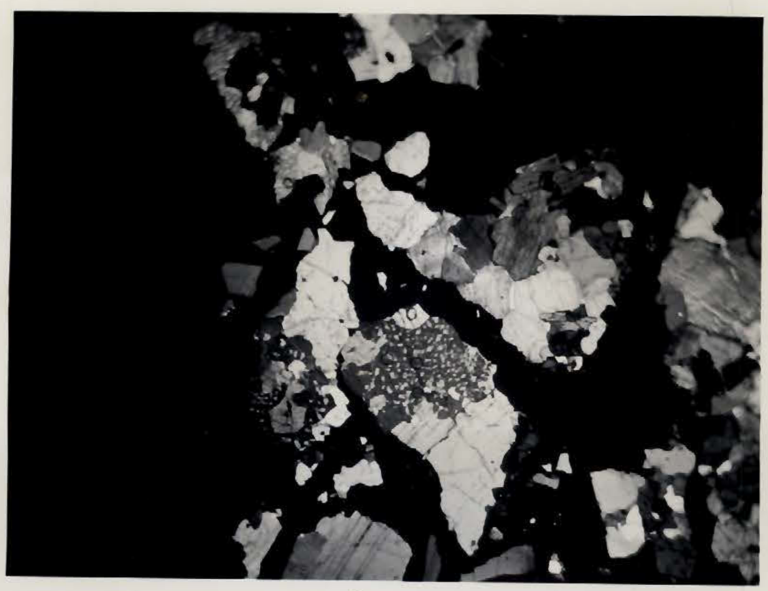


Plate No. 52. Anorthoclase (dark) replacing plagioclase. Hornblende syenite. Nicols crossed, X 20.

Plate No. 53. Composite gneiss containing "sanidine-anorthoclase", (dark) which fills half of the field, and contains numerous small inclusions that are only faintly visible. These are plagioclase, having a composition of An_{30-34}. Nicols crossed, X 16.

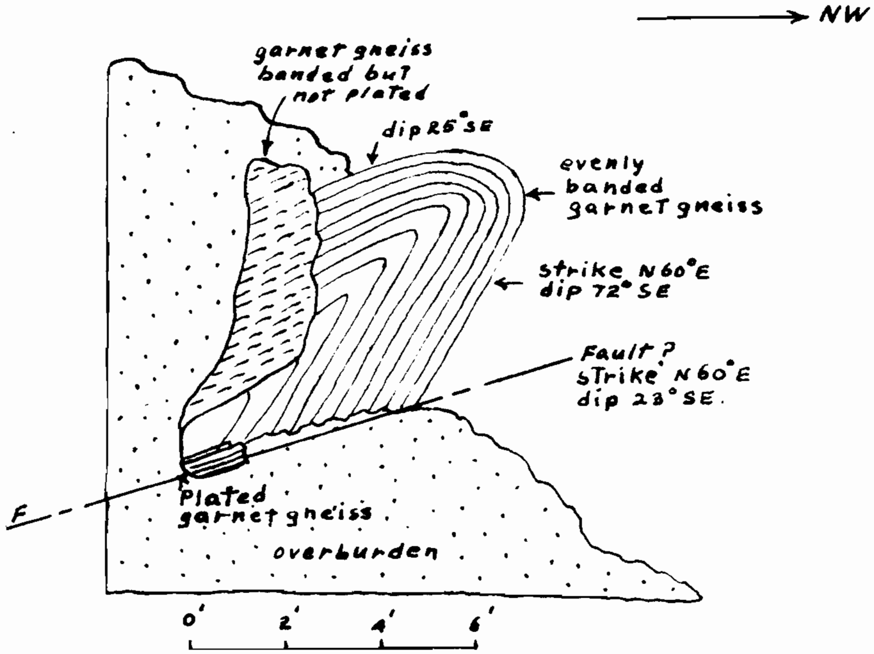


DIAGRAM NO. 1. Small overturned fold formed against thrust fault. Found in northwest facing scarp south of Elbow Lake.

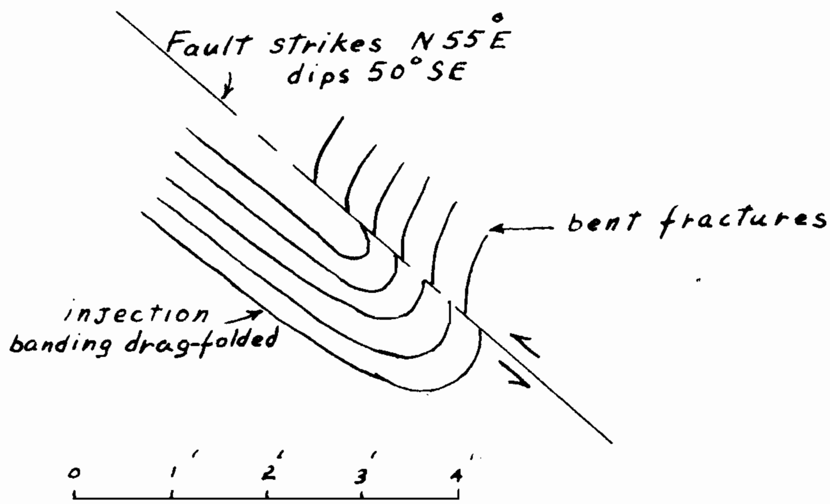


DIAGRAM NO. 2. Faulted and dragfolded structure exposed on a vertical scarp one and a half miles east of Murdock's Camps. The section shown is parallel to the dip of the fault.

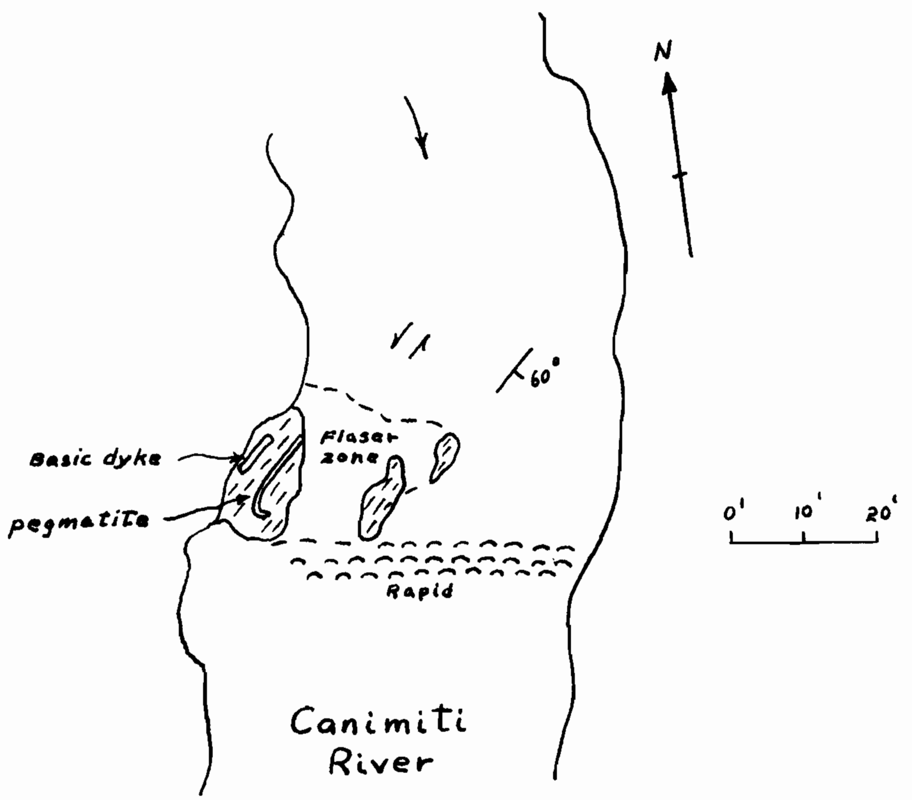


DIAGRAM NO. 3. "Flaser" gneiss fault zone on the Canimiti River.

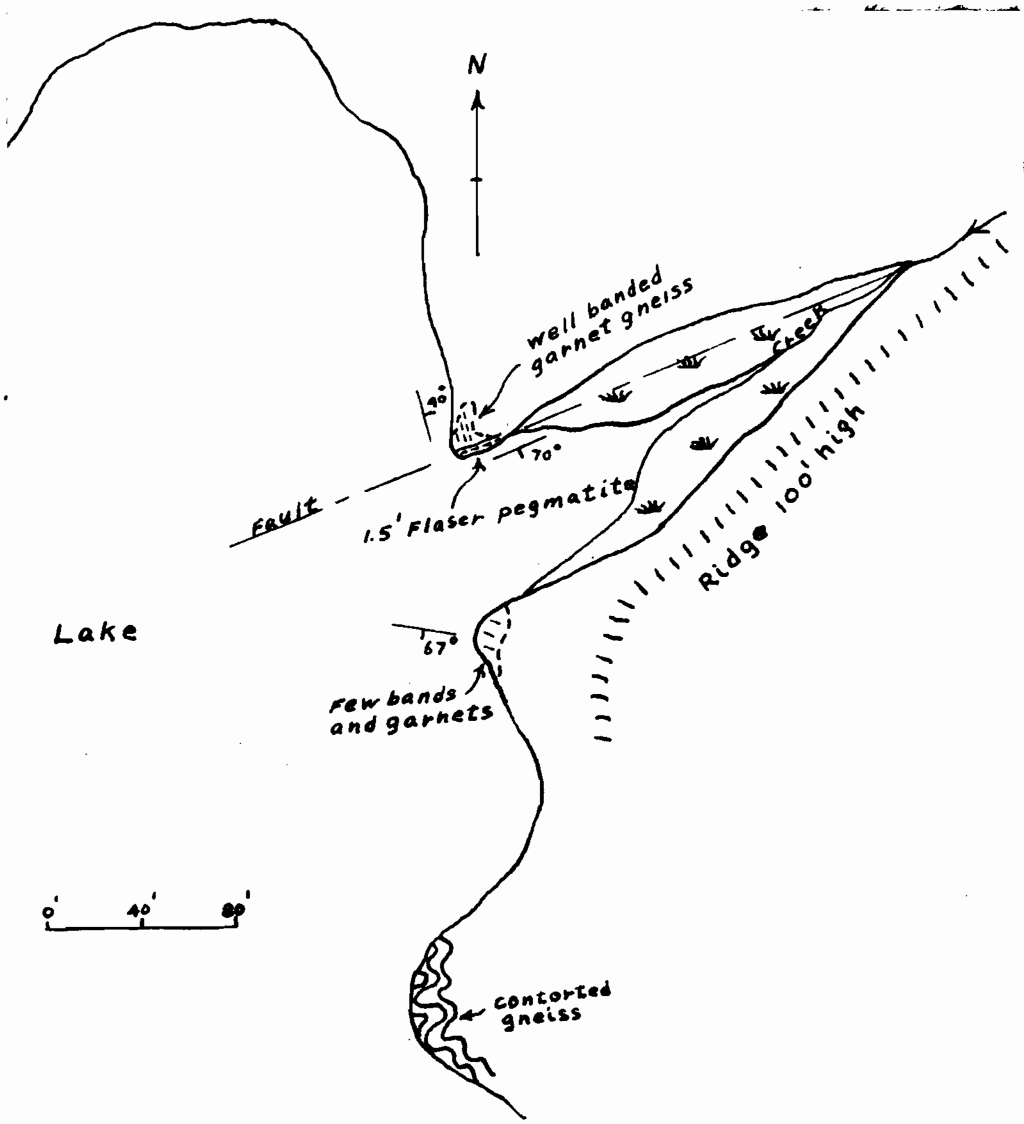
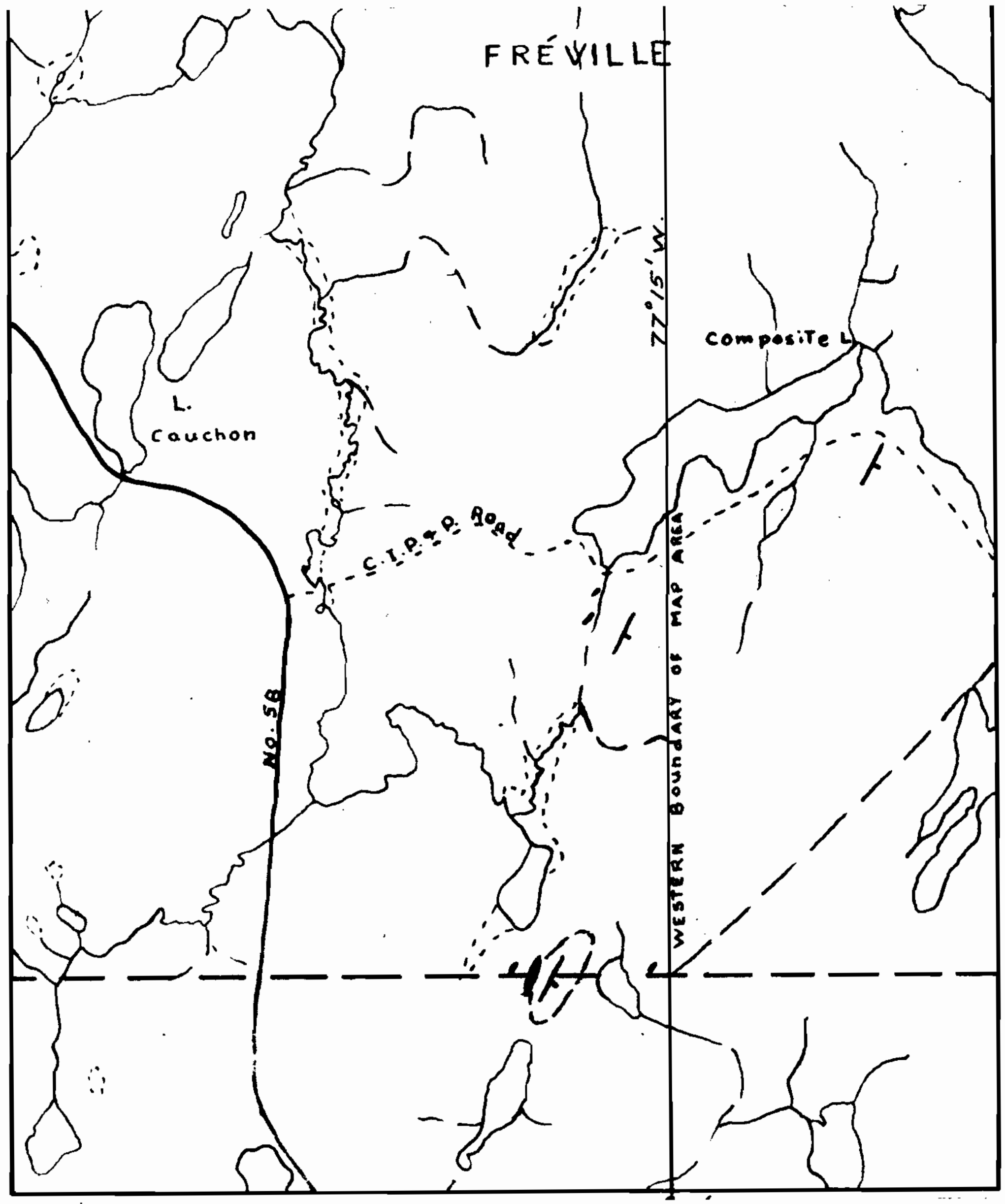


DIAGRAM NO. 4. "Flaser" pegmatite in the fault zone northeast of Gabbro Lake.



SUPPLEMENTARY MAP SHOWING THE POSITION OF "GREENSTONE"

EXPOSURES IN THE AREA OUTSIDE THE MAP SHEET

Scale: 2 inches = 1 mile

LEGEND

"Greenstone"   Composite gneiss

Strike and Dip of Foliation

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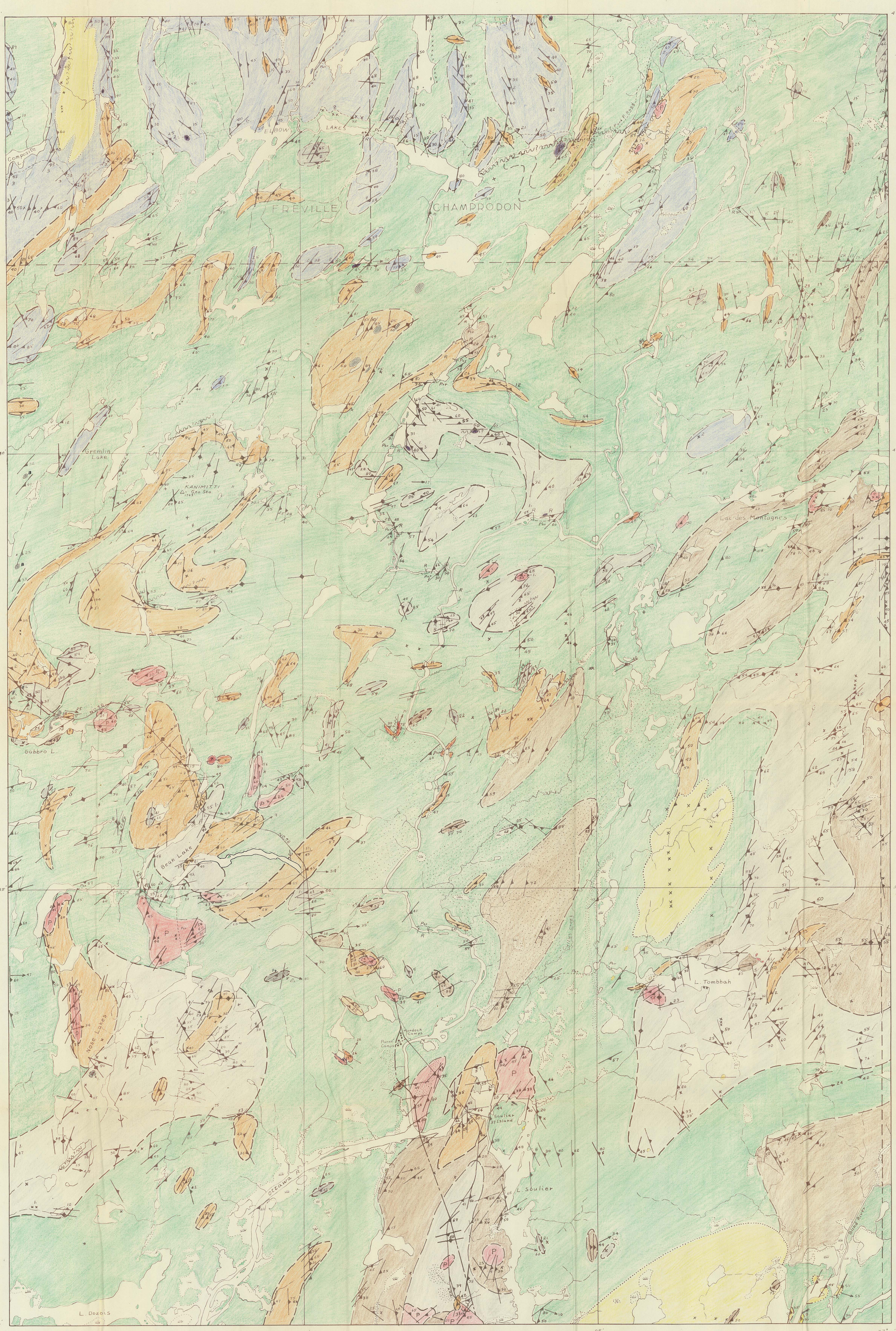


LEGEND

PLEISTOCENE

SAND AND GRAVEL.

PRECAMBRIAN
POST
TIMISKAMING ?

INTRUSIVES

BASIC DYKES.

QUARTZ DIORITE, I. HORNBLENDE SYENITE TO QUARTZ SYENITE, AND ASSOC PINK TO REDDISH BROWN PIGMATITES IN PLACES BEARING HYPERSTHENE AND OR HORNBLENDE.

HYPERSTHENE GABBRO, I, HORNBLENDE GABBRO (AMPHIBOLITE ?)

INTRUSIVE CONTACT

"GREENSTONE" (SEE SUPPLEMENTARY MAP)

– FAULT CONTACT ? UNCONFORMITY ? –

INTRUSIVES (SEQUENCE OF INTRUSION NOT KNOWN.)

QUARTZ DIORITE TO GRANITE DYKES AND PEGMATITES INJECTED IN LARGE NUMBERS INTO GNEISSES AND GRANULITES, P.I CONTAIN "SANIDINE-ANORTHOCLASE" MINERALS, PINK PEGMATITE "AUGEN" AND "FLASER" GNEISSES.

QUARTZ DIORITE ORTHOGNEISS, I, QUARTZ DIORITE, BOTH TYPES MAY CONTAIN MUCH BIOTITE, AND INCLUSIONS OF PYROXENE-HORNBLENDE COMPOSITION.

COMPOSITE GNEISSES, MEDIUM GRAINED, BANDED WITH BOTH HYPERSTHENE AND GARNETS. I, CONTAINS CHIEFLY HYPERSTHENE, 2, IGNEOUS TEXTURED RELATIVELY MASSIVE MEDIUM TO COARSE GRAINED, GRADE INTO FOLIATED AND BANDED HYPERSTHENE AND GARNET BEARING GNEISSES.
3, MEDIUM GRAINED MUCH MAFIC BANDING.

PARAGNEISS ?

BIOTITE-QUARTZ-PLAGIOCLASE GNEISS, WITH MUCH ACIDIC MATERIAL AS LENSES, AND LIT-PAR-LIT INJECTIONS.

GARNET-QUARTZ-BIOTITE-PLAGIOCLASE GNEISS.

HYPERSTHENE-BIOTITE-QUARTZ-PLAGIOCLASE. GNEISSES AND GRANULITES LOCALLY WITH MAFIC INCLUSIONS OR BANDS I. WITH GARNETS.

HYPERSTHENE-AUGITE-HORNBLENDE ROCKS, IN SMALL BANDS OR LENSES.

UNDIFFERENTIATED GNEISSES AND GRANULITES.

SYMBOLS

STRIKE AND DIP OF FOLIATION AND BANDING, OR LAYERING A, VERTICAL B, INCLINED.

DIRECTION AND DIP OF PETROFABRIC AXIS.

INTRUSIVE BOUNDARY ASSUMED.

METAMORPHIC ROCK BOUNDARY ASSUMED.

SMALL EXPOSURE.

GLACIAL STRIAE.

FAULT, FAULT ASSUMED.

MUSKEG OR SWAMP.

BUILDINGS

SURVEYED LINE

HIGHWAY NO 58

HIGHWAY UNDER CONSTRUCTION

BUSH ROAD

GEODETIC SURVEY STATION AND ELEVATION

PORTAGE

RAPID

FALLS

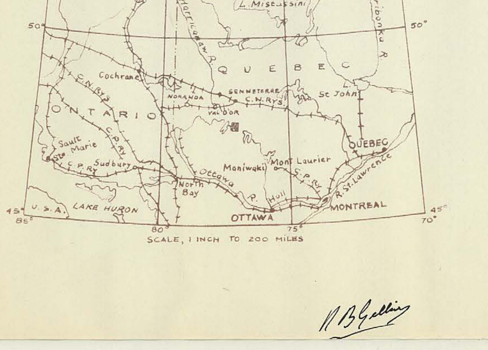
CANIMITI RIVER AREA

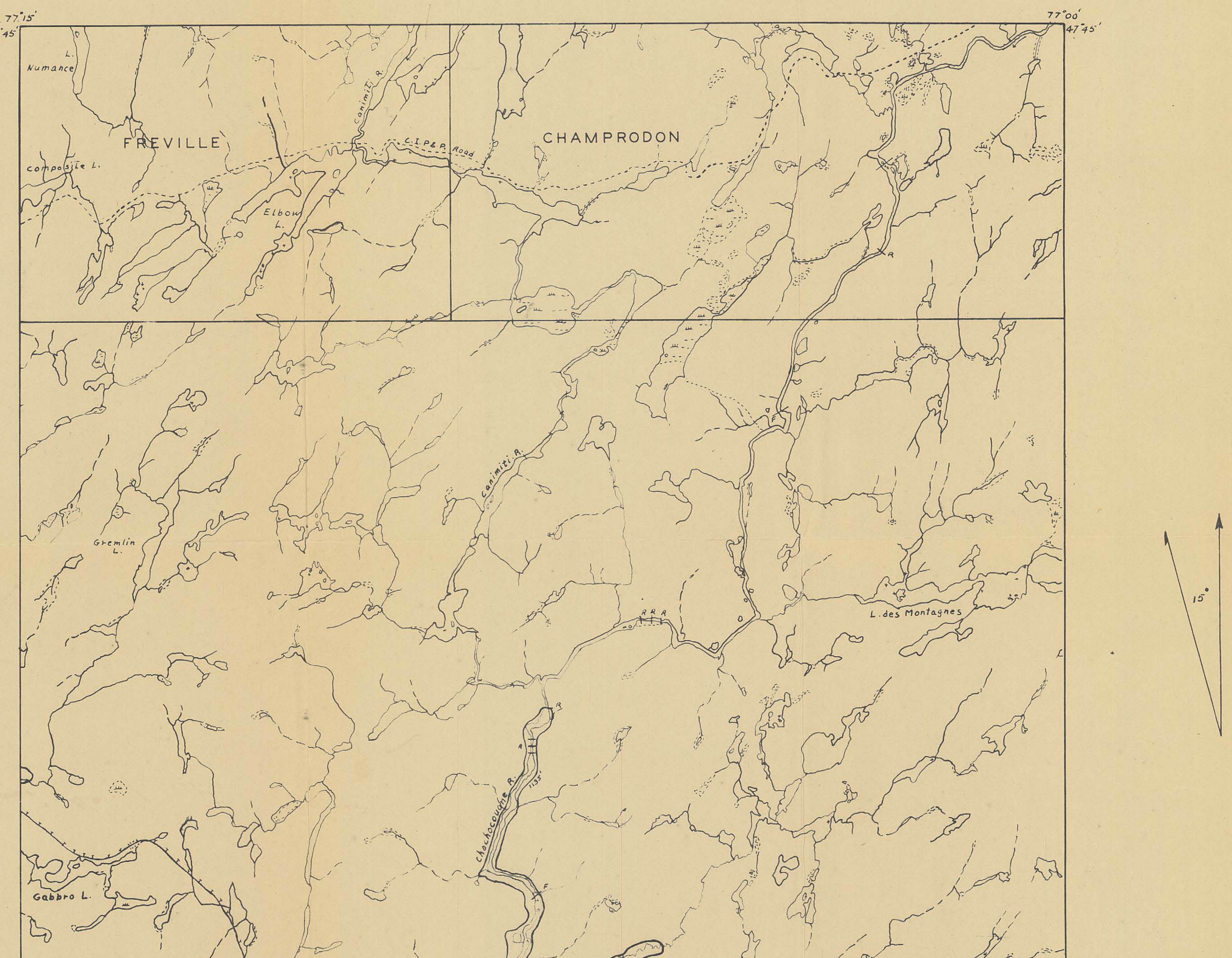
PONTIAC COUNTY

SCALE: 2 INCHES TO 1 MILE.

Miles

1 0 1 2 3





REPRODUCED FROM MAP OF QUEBEC
STREAMS COMMISSION 1947

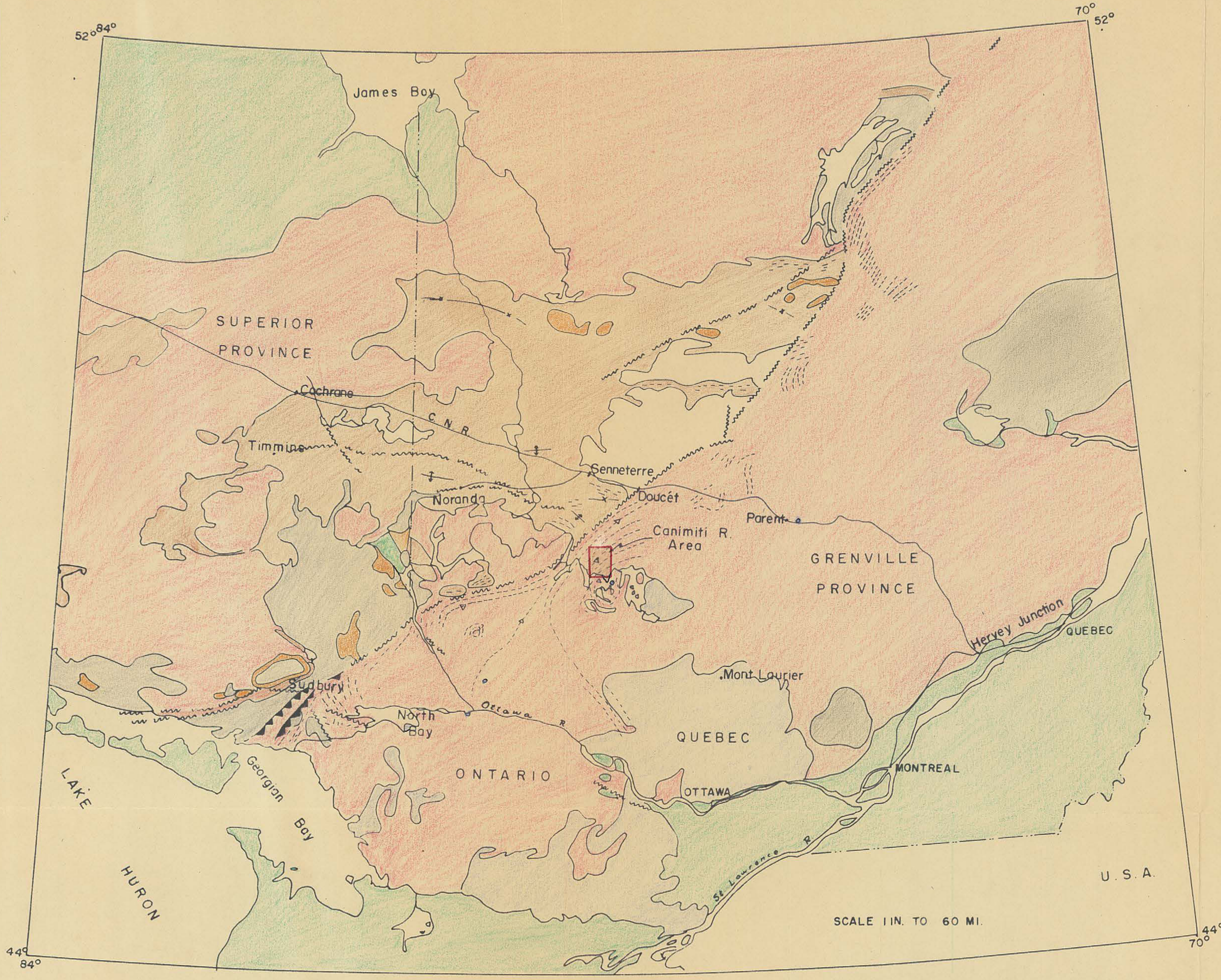
CANIMITI RIVER

PONTIAC COUNTY
QUEBEC

MAP SHOWING AREA TO BE FLOODED BY DOZOIS DAM 1135' CONTOUR

SCALE 1 INCH TO 1 MILE

1 ½ 0 1 2



REGIONAL MAP

SHOWING GENERAL GEOLOGY AND STRUCTURE

LEGEND

- Palaeozoic and younger sedimentary rocks
- Huronian - Keweenawan rocks
- Grenville type schists, gneisses etc., limestones prominent
- Complex gneiss, and schists undifferentiated
- Keewatin - Timiskaming sedimentary and volcanic rocks

INTRUSIVES

- Gabbro, diabase, norite, peridotite
- Anorthosite , gabbro

Symbols

- Thrust fault showing direction of dip
- " " inferred
- Fault
- " inferred
- Trend (or strike) of foliation or bedding
- Direction of dip " " " "
- Anticlinal axis
- Synclinal "

Base Map and General Geology after Geological Survey of Canada, Map 820A. Structure in part after Geological Association of Canada, Tectonic Map of Canada, 1950