The Geology of the Nipissis River and Nipisso Lake Map-Areas.

by

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INTRODUCTION

General Statement

In 1951, the Quebec Department of Mines commenced a programme of geological mapping along and adjacent to the Quebec North Shore and Labrador railroad. In 1951, P.E. Grenier, with the writer as assistant, mapped the Nipissis River area and in 1952, the writer working independently mapped the Nipisso Lake area.

Location and Access

The Nipissis River area is bounded by longitudes 65°52'W and 66°07'W and by latitudes 50°30'N and 50°45'N; the Nipisso Lake area by longitudes 65°45'W and 66°00'W and by latitudes 50°45'N and 51°00'N. The southwest corner of the Nipissis River area is twenty-four miles northeast of Seven Islands, a village on the north shore of the St. Lawrence River. The map-areas are each approximately 200 square miles.

The Quebec North Shore and Labrador railroad which will join the iron deposits of Burnt Creek with the seaport of Seven Islands provides the easiest means of access to the region. Numerous large lakes in both areas are excellent landing points for hydroplanes. Temporary landing strips have been constructed at two localities within the areas but these will not be kept in repair when construction of the railroad is completed.

In addition to these means of access, a canoe route, interrupted by two portages, one six miles long and the other half a mile, may be followed from the mouth of the Moisie River to the map-areas. In spite of a strong current, the Moisie and Nipissis Rivers are easily travelled by motor-driven canoes.

Field Work

The field mapping of the areas was done on a scale of two inches to one mile and was based on systematic traverses spaced at intervals of half a mile. Aerial photographs were used to locate and control these traverses. Preliminary base-maps were supplied by the Quebec Department of Lands and Forests and the final base-map of the Nipisso lake area was prepared from aerial photographs by Canadian Aero Service Limited.

Previous Work

In 1939, Carl Faessler, (1945) mapped an area south of the Nipissis River area and in 1940, E.W. Greig, (1945) mapped the geology of an area immediately east of that mapped by Faessler. The Iron Ore Company of Canada has done reconnaissance geological mapping and prospecting near the railroad. Acknowledgement is due this Company for permission to examine the unpublished maps and reports of this survey.

PHYSIOGRAPHY

General

The map-areas lie near the southern border of the Canadian Shield and show the characteristic rugged topography of the Laurentian plateau. As is common in other Shield areas, there is the same general accordance of summit levels that indicates the existence of a former peneplane at or near the present summit levels.

Maximum relief is about 2100 feet and the average local relief about 500 feet. The elevation (*) of the upland ranges from 1200 to 2450 feet above sea-level. The northern part of the map-region has a slightly higher elevation than the southern part.

In general, the region may be described as a rolling to rugged upland, sloping gently from north to south, that is deeply dissected by the Nipissis-Wacouno Valley and by

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(*) determined by calibrated aneroids.

its tributory valleys, the Nipisso and "upper" Nipissis. Lake Nipisso occupies a former deep valley that parallels the Nipissis-Wacouno valley.

The nature of the underlying bedrock has had a pronounced influence on the development of the topography of the region. Areas of high elevation but of low gentle relief are underlain by granitic rocks. The lower terrain is for the greatest part exceedingly irregular and the underlying rock is more mafic in composition and either strongly foliated and banded or well-jointed.

Jointing and foliation appear to be the dominant factors governing the development of the characteristic valley and ridge topography of the two map-areas.

The Nipissis-Wacouno valley, which transects both areas, lies deeply incised within the Laurentian plateau. Where the river has cut through the augen gneiss the valley is narrow with very steep walls but elsewhere it is relatively broad and the slopes are steep but not clifted. Along the southern part of the Nipissis River where it occupies the contact zone between granitic rocks and more mafic rocks, the granite forms cliffs and the mafic rocks form steep to gentle slopes.

Structural control of the valley is well illustrated below its junction with the Nipisso River. Here the river flows along the contact between the granitic rocks and the more basic paragneisses and intrusives. Above the junction the valley is incised at right angles or at a steep angle to the structure of the underlying bed-rock. Evidence of structural control of this upper portion of the valley is lacking. It is possible that the river flowing across the up-tilted peneplane surface utilized weaker zones wherever possible but that in attempting to preserve a straight course it was forced locally to cut across the structure.

The river flows and meanders upon a bed of sand and gravel. This material is the remains of a much thicker deposit whose former presence is recorded by rock-defended terraces on the valley walls. At the south end of the Nipissis River area the terraces are composed of well-sorted sand and gravel beds. When the unconsolidated deposits are traced northward, they become less well-sorted and stratified until eventually, near the north end of the Nipisso Lake area, the terraces are composed of boulders and pebbles erratically distributed in a matrix of silt and sand. This suggests that the original valley fill was deposited by glaciers and that subsequent reworking by the present stream has produced the well-sorted and stratified deposits found in the lower parts of the valley.

With the exception of the basin of the Tchinicaman and Tchinicamas Lakes which drain into the Gulf of the St. Lawrence through the Tchinicaman River, the region is part of the drainage basin of the Moisie River which empties into the Gulf of the St. Lawrence.

The whole region is exceptionally well drained, swamps are rare, although lakes are abundant. The main valleys are fed by numerous small, turbulent streams that have their origin usually in one or more lakes on the upland.

Glaciation

Both erosional and depositional features suggest the former presence of glaciers in the region. Glacial striae, crescentic gouges, grooves, polished surfaces are present on the rock exposures of the upland and on the walls of the Nipissis-Wacouno Valley.

The Nipissis River area shows intense glacial erosion but very little glacial deposition. Lake shores lack debris and the upland areas have a few glacial erratics but only thin, scattered patches of sand and gravel. The same conditions exist in the southern part of the Nipisso lake area but north of latitude 50°50' increasing amounts of glacial debris are found. The valleys contain large amounts of sand and gravel and numerous sand plains exist. Immediately east of the north end of Lake Nipisso three crescentic ridges of sand and gravel lie with their long axes approximately at right angles to the direction of glacial movement in the area. These ridges are approximately 1000 feet long, 40 feet wide, and 20 feet high. Their origin is not known but they may be recessional moraines.

A cluster of drumlinoids is found east of the junction of the Nipissis and Wacouno rivers. These drumlinoids are low, sand and gravel ridges, rising ten to twenty feet above the general surface and separated from each other by long, very straight valleys. Examination of a section of a drumlinoid where it comes into contact with the valley wall showed scattered boulders and cobbles in a silty matrix. The deposit displayed steeply inclined bedding but it could not be determined whether the dip of the bedding is an inherent characteristic of the drumlinoid or whether it was due to slumping on the valley slope. The upper portions of the drumlinoids are composed of sand and gravel with infrequent large boulders. Locally isolated patches of bedrock protrude through the drumlinoids.

In the south part of the Nipisso lake area where the Nipissis-Wacouno valley cuts through the augen gneiss, several cirque-like forms were observed on the east side of the valley. These consisted of semi-circular gouges in the cliff wall with a vertical back wall and near-vertical side walls. The average dimensions of these basins are 3200 feet wide, 1500 feet deep, and 800 feet high. One cirque was seen to consist of two basins one on top of the other with a near-horizontal surface 700 feet wide separating the two vertical walls. These basins may have been formed by small local glaciers that fed the glacier that occupied the main valley soon after the retreat of the continental ice-sheet.

The direction of movement of the ice sheet in the region was determined from glacial striae, grooves, crescentic gouges and the elongation of drumlinoids. All determinations were within ten degress of S.10°E.

Acknowledgments

The field work on which this thesis is based was carried out for the Quebec Department of Mines during the summers of 1951 and 1952. The writer is grateful to Dr. A.O. Dufresne, Deputy Minister of Mines, and to Dr. I.W. Jones, Chief of the Geological Surveys Branch, for permission to use the information collected during the field work for thesis material. The Quebec Department of Mines also very kindly supplied the writer with thin-sections, aerial photographs, base-maps, chemical analyses, and numerous other items.

The writer also gratefully acknowledges data collected during 1951 by Dr. P.E. Grenier and which were kindly put at the disposal of the writer. Dr. H.P. Eugster assisted the writer during the field season of 1952 and his help in the field and the laboratory is gratefully acknowledged.

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Plate I

Aerial Photographic Mosaic of Nipissis River Area.
Scale I inch - 3 miles approx. A - augen gneiss;
B - biotite granite; C - diorite; D - paragneisses;
E - norite.

Plate II

Aerial Photographic Mosaic of Nipisso Lake Area.
Scale 1 inch - 3 miles approx. A - biotite granite;
B - hornblende granite; C - drumlinoids; D - paragneisses;
E - anthophyllite gabbro; F - augen gneiss;
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B - Nipissis River, view southward from the Nipisso River. Railroad construction camp at mile 28. Photo - P.E.Grenier.

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A - Character of terrane underlain by norite. Photo - P.E.Grenier.

B - Character of terrane underlain by augen gneiss. Photo - P.E.Grenier.

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B - Augen Gneiss Photo - P.E.Grenier.

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A - Diorite cut by biotite granite west of Pollock Lake.

B - Hornblende paragneiss. Description P.34

GENERAL GEOLOGY

INTRODUCTION

The rocks of the two map-areas include paragneisses and acidic and basic intrusives. More than three-quarters of the rocks are of igneous origin; granitic types predominate.

In the Nipissis River area granitic rocks are found west and north of the Nipissis and Nipisso Rivers, whereas basic intrusives are found east and south of the two rivers. A narrow band of paragneisses and migmatites separates the two main rock groups. Granitic rocks occupy the southern third, except for the southeast corner, and most of the northern quarter of the Nipisso Lake area. Paragneisses and numerous basic sills underlie the intervening portion. This central part includes also a band of granitic gneiss and granulite.

The bands of paragneisses, as shown on the accompanying maps are in part composed of igneous rocks. These igneous bodies are either too small to be shown as separate units or are exposed as widely separated outcrops in localities where the structure is too little known to allow the exposures to be joined together on a map. The granite gneiss and granulite zone also contains other rock types.

The age relationships, shown in the following table of formations, are based on contact features and, where these were not available, on the comparative degree of deformation and, or recrystallization of the various rock units. Furthermore, two basic assumptions appear to be warranted from mineralogical, petrographical and structural evidence. The first is that the hypersthene-bearing rocks which include norite, gabbro, diorite, hornblendite, and pyroxenite, are derived from the same parent magma. The second assumption correlates the granitic gneiss around Hogan Lake with the main body of augen gneiss.

If the assumptions made above are correct, then the basic rocks are older than the granitic gneisses as the latter intrude the norite around Hogan Lake. Also, east of Nipisso Lake, the large inclusions of metasedimentary rocks in the augen gneiss contain several small sills of gabbro and amphibolite. Granite gneiss similar to that found in the granite gneiss and granulite zone occurs as dykes in the augen gneiss. The large gabbro dyke in the east central part of the Nipisso Lake area cuts the augen gneiss and in turn is intruded by small dykes of granite which resemble the biotite granite. The hornblende and biotite granites are the youngest major intrusions in the map-areas. Contact features show that they are younger than the augen gneiss and the gabbroic rocks. The hornblende granite is believed to be the older of the two granites as it is strongly lineated and generally gneissic, whereas the biotite granite is only locally gneissic. If the structure of the hornblende granite is protoclastic instead of cataclastic, then the relative ages of the granites are unknown.

Because the paragneisses are the oldest in the area, and because they resemble rocks that elsewhere have been assigned to the Grenville series, they are here also believed to be of Grenville age.

TABLE OF FORMATIONS

<table>
<tr><td>Cenozoic</td><td>Pleistocene
&
Recent</td><td colspan="2">Sand, gravel, till</td></tr>
<tr><td rowspan="9">PRECAMBRIAN</td><td>Keweenawan-Type</td><td colspan="2">Diabase dykes</td></tr>
<tr><td rowspan="6"></td><td rowspan="5">Post-Moisie Intrusives</td><td>Lamprophyne dykes
Pegmatite dykes</td></tr>
<tr><td>Biotite granite
Hornblende granite</td></tr>
<tr><td>Gabbro</td></tr>
<tr><td>Granite gneiss and granulite</td></tr>
<tr><td>Augen gneiss and granite gneiss</td></tr>
<tr><td>Moisie Series</td><td>Hypersthene granite and pegmatite
Hornblendite and pyroxenite
Gabbro, diorite, and amphibolite
Norite</td></tr>
<tr><td rowspan="2">Grenville-Type</td><td rowspan="2"></td><td>Migmatites</td></tr>
<tr><td>Quartzofeldspathic gneisses, schists, amphibolites, quartzites, and garnet-hypersthene gneisses.</td></tr>
</table>

GRENVILLE

Paragneisses, similar to those found in the Grenville province of the Precambrian Shield north and northwest of Montreal, outcrop in both map-areas. Wide variations in mineral composition were observed especially in the rocks of the Nipisso Lake area. Metasedimentary rocks are sparsely distributed throughout the eastern half of the Nipissis River area where they occur mainly as inclusions in the basic intrusive rocks. Good exposures are present along the east side of the Nipissis River. A band of paragneisses, averaging a mile in width, extends from the south boundary to approximately two miles below the junction of the Nipissis and Nipisso Rivers.

In the adjoining area to the north, metasedimentary rocks underlie the greater part of the area north of latitude 50°50'. The width of this belt cannot be determined as there are numerous basic and acidic rocks injected parallel to the strike of the formations.

In decreasing order of abundance the Grenville rocks consist of quartzofeldspathic gneisses, schists, quartzites, amphibolites, and hypersthene gneisses. Garnet has been seen in all types with the exception of the biotite and hornblende schists.

A strong foliation or banded structure characterizes the metasedimentary rocks of the region. The bands range from one-sixteenth of an inch to several inches in thickness and they may be traced without change in thickness or composition across tens of feet. Individual outcrops are composed usually of two or more rock-units and it is impossible to divide the Grenville on the accompanying maps into separate zones.

QUARTZOFELDSPATHIC GNEISSES

At least three-quarters of the metasedimentary rocks occurring in the region are gneisses containing abundant quartz and feldspar. The gneisses are fine-to medium-grained*, strongly crystalline, and have a light grey or green colour. Foliation is distinct, light bands alternating with dark ones, and lineation can be observed in most hand-specimens.

Key minerals, or minerals that give a gneiss its name, are - biotite, hornblende, sillimanite, graphite, muscovite, cummingtonite and epidote. Many of these minerals occur together in the same gneiss. Quartz has been strained and displays undulose extinction. Microcline is frequently present and although some was formed as a result of the original composition of the sediment, much has been introduced.

* coarse-grained - greater than 5 mm.
medium-grained - 5 to 1 mm.
fine-grained - less than 1 mm.

Biotite Gneiss - Gneisses containing biotite and hornblende in varying proportions are very abundant in the region. The basis of separation of these gneisses is as follows:

> Biotite gneiss contains biotite in excess of two-thirds of the total biotite-hornblende content.
>
> Hornblende gneiss contains hornblende in excess of two-thirds of the total biotite-hornblende content.
>
> Intermediate types are biotite-hornblende gneisses.

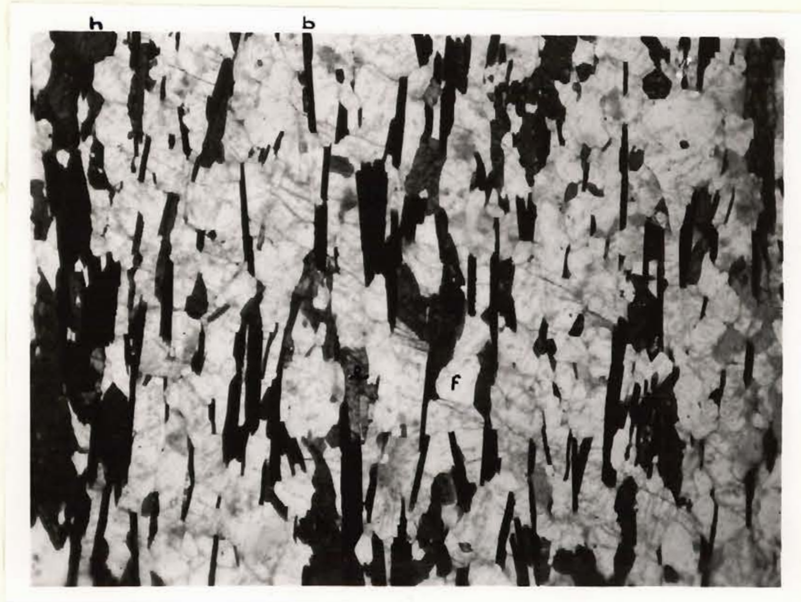
Under the microscope, the foliated character of biotite gneiss shows up as an alternation of felsic and mafic bands. The grains are equigranular, granoblastic, with sutured contacts. A preferred orientation of the quartz grains is readily seen and the biotite flakes are elongated in the same direction. Quartz is present in amounts up to sixty percent. Oligoclase-andesine makes up ten to fifty percent of the grains and shows only slight alteration to white mica. The feldspar is strongly twinned according to the albite law and rarely displays pericline and carlsbad twinning. Biotite is always pleochroic in shades of yellow and brown. Additional minerals observed in the ten thin-sections examined are hornblende, microcline, graphite, garnet, sillimanite and muscovite. Locally the biotite gneiss contains abundant pink garnets, probably almandine. One garnet specimen had a specific gravity of 3.88 and a refractive index of 1.795; these properties correspond to those of almandine. Apatite, sphene, magnetite, and zircon are accessory minerals.

Hornblende Gneiss - The colour of the hornblende gneiss depends upon the percentage of mafic minerals, outcrops with a low amphibole content are light grey, while amphibole-rich varieties are dark greenish-grey. Grain size ranges from fine to coarse, with the majority of the rocks falling in the medium-grained class.

The study of five thin-sections revealed that all have a granoblastic to nematoblastic, equigranular texture; the grain contacts show evidence of resorption. The mineral composition of the rock is variable with regards to actual minerals present as well as to the percentages of the mineral components. Maximum hornblende content, seen in thin-sections, was 55 percent. The optical properties of the hornblende are:

$Z \wedge C$ = 17°-22°; negative large ZV
X = yellow, y = light green,
Z = grass green.

Plate IX



A - Hornblende-biotite gneiss. (X 22)
b-biotite, h-hornblende, f-feldspar,
q-quartz, e-epidote.

B - Sillimanite-almandine gneiss. (X 14)
s-sillimanite, a-almandine, q-quartz,
b-biotite.

Plagioclase ranges from AN27 to AN35. It shows diffuse zoning, the borders are about five percent more sodic than the core. Alteration is very slight and where present, consists of sericite, clinozoisite, epidote, and calcite. Small amounts of biotite and epidote, and rarely garnet are occassionally seen. Accessory minerals are sphene, apatite, magnetite, zircon, and pyrite.

Biotite - Hornblende Gneiss - Twelve thin-sections of this rock-type were examined. All showed the same textural and structural properties as described for the previous two gneisses.

Biotite, hornblende, plagioclase, and quartz, in varying proportions, are the essential rock-forming minerals. Plagioclase has the composition of oligoclase-andesine with extreme values of AN15 and AN35. Two slides contained a low percentage of epidote. It occurs as anhedral to subhedral grains with a yellowish green colour, and has the properties of pistacite. Accessory minerals are sphene, apatite, magnetite, zircon, and pyrite; the first two minerals may be fairly abundant.

Sillimanite Gneiss - Sillimanite, muscovite, and graphite gneisses are found as isolated outcrops or bands in both areas. They are especially abundant along the northern border of the augen gneiss. This zone can be traced across the width of the Nipisso Lake map-area.

The sillimanite gneisses are light grey, fine-to medium-grained, and well-foliated. Sillimanite occurs in clusters of very fine needle-like grains and rarely as distinct crystals, up to half an inch in length. Locally garnetiferous gneisses are abundant. The rock contains quartz, biotite, plagioclase (AN15 to 20), microcline, muscovite, graphite, and garnet. Accessory minerals are zircon and sphene. Garnet (almandine) contains inclusions of sillimanite and was probably the last mineral to form.

Graphite Gneiss - A characteristic rusty weathered surface and finely disseminated graphite flakes facilitates identification of this rock type. Weathering destroys the adhesive bond between grains and the rock disintegrates readily from a hammer blow. The colour of fresh specimens varies from light to dark grey. Grain size is variable, although most specimens are medium-grained.

Microscopical examination reveals a granoblastic texture with the grains more or less equigranular. Biotite is pleochroic in yellow and brown. Quartz is a major component forming up to 40 percent in the thin-sections examined. Sodic andesine is present in appreciable amounts and usually shows a diffuse normal zoning. A potassic feldspar with very fine grid-twinning is also present. The feldspar is cryptoperthitic to microperthitic and is probably microcline. Locally garnet is an abundant accessory. In addition to the main minerals, zircon, pyrite, and magnetite have been observed in the thin-sections.

Although graphite locally may make up to ten percent of the minerals present, the small size of the grains, usually less than one-eighth of an inch, would appear to discourage economic exploitation of the graphite gneiss.

Muscovite Gneiss - Fine-grained muscovite gneisses are intimately associated with the sillimanite gneisses. Generally they contain a small amount of sillimanite. Essential components are quartz, muscovite, biotite, plagioclase, and microcline. The biotite has a colorless to pale brown pleochroism. Zircon and sphene are sparingly present. No evidence of replacement of one mineral by another was observed and the assemblage appears to be in equilibrium.

Cummingtonite Gneiss - A few narrow bands of cummingtonite gneiss were found interbedded with biotite gneiss.

Plate X

A - Cummingtonite gneiss. (X 16; X - nicol)
c-cummingtonite, f-feldspar, q-quartz.

B - Diopside-epidote gneiss. (X 16)
d-diopside, e-epidote, f-feldspar,
q-quartz.

The rock has a brownish-grey colour, a medium-grained size, and a rude foliation. In hand specimens, quartz, feldspar, and a yellowish-brown amphibole are easily recognized. The cummingtonite has a positive 2V=74°. $Z \wedge C$ = 20°. medium-high binefringence, and multiple twinning parallel to the "C" axis. The feldspar is calcic oligoclase. A small percentage of biotite is also present. Magnetite and zircon are accessory minerals.

<u>Diopside-epidote Gneiss</u> - One outcrop containing the mineral assemblage epidote, diopside, plagioclase, and quartz was found along the west boundary of the Nipisso Lake area, half a mile north of the augen gneiss. The rock is fine-grained, strongly foliated, and has a pitted weathered surface. The optical properties of the epidote are:

> $Z \wedge C$ = 24°, Negative 2V=74°,
> X = pale yellow, y = colorless,
> Z = pale green, and lamellar
> twinning parallel to 100.

Diopside has a pale green colour, a positive 2V=65°, and an extinction angle of 40 degrees. Plagioclase has an anorthite content of 90 percent. The composition of this feldspar was determined by comparing the refractive indices of cleavage flakes with the refractive indices of various liquids and plotting the results on curves prepared by Tsuboi (1923, p. 108). Accessory minerals are sphene and zircon.

SCHISTS

Schistose rocks in which the quartz content is less than ten percent outcrop sparingly in the region. Biotite-rich varieties predominate. The amount of plagioclase is variable but never exceeds 60 percent in the biotite schists. The schists are medium-to coarse-grained, dark coloured rocks, forming bands up to several inches thick in the surrounding paragneisses. Locally they may have a rusty coloured weathered surface.

Only one thin-section of biotite schist was examined. The rock is medium-grained, nematoblastic, and free from alteration. Biotite is the predominant mineral, with plagioclase AN25, quartz, hornblende, and sphene also present. Well-developed pleochroic haloes around zircon grains are abundant in the biotite flakes. Apatite, magnetite, and zircon are the accessory minerals.

Hornblende and hornblende-biotite schists were observed also in the field. They have the same appearance as the biotite schists except hornblende is present in amounts greater than or equal to biotite.

One thin-section of a hornblende paragneiss had five distinct bands of different mineralogical composition. The thickness and estimated mineral composition of the bands are as follows:

Thickness (Inches)		Composition
3/8	-	hornblende 90%, diopside 10%
1/8	-	hornblende 100%
1	-	hornblende 45%, plagioclase 35%, biotite 15%, sphene 5%
1/4	-	hornblende 85%, quartz 15%
1	-	hornblende 35%, plagioclase 45%, biotite 15%,microcline

The bands do not grade into each other and the mineral assemblages appear to be the result of different original chemical composition and are not due to metamorphic differentiation.

AMPHIBOLITES

Amphibolites derived from sedimentary rocks outcrop in the Nipisso Lake area. Difficulties were encountered in attempting to distinguish between the para-amphibolites (of sedimentary origin) and the ortho-amphibolites (of igneous origin). The characteristic features of the amphibolites that could be traced into gabbros were compared with those of the amphibolite bands belived to be of sedimentary origin. A list of these features was compiled and although it is realized that some characteristics have been observed in both types, nevertheless, the two amphibolites generally have distinct diagnostic properties.

Ortho-amphibolites have the following characteristics:-

1. Gneissic structure
2. Relict igneous textures
3. Grade into gabbro
4. Resists migmatization
5. Occassionally criss-crossed by hornblende veinlets
6. Contain inclusion of paragneiss
7. May pinch and swell along strike
8. Pyroxene (especially hypersthene and augite) as a relict mineral.

The characteristic features of the para-amphibolites are:-

1. Strongly foliated
2. May contain alternate paragneiss layers
3. Easily migmatized
4. Uniform width along strike
5. Quartz as an accessory mineral.

Under the microscope, the rock is composed of plagioclase AN25, green hornblende, biotite, and minor amounts of sphene, magnetite, and apatite. The foliation is clearly discernible and the grains are medium to coarse.

QUARTZITES

Many of the rocks mapped as fine-grained quartzites in the field were found, from study of thin-sections, to contain sufficient plagioclase and biotite to classify them as biotite gneisses. However, there are small patches or lenses of nearly pure quartzite in the paragneisses and in the inclusions in the norite. Several bands of quartzite outcrop on the east shore of the northwest bay of Tchinicaman Lake. One is approximately five feet wide and is composed almost entirely of quartz. Another is about three feet wide and is interbedded with graphite gneiss. A thin-section of the latter band contained about 80 percent quartz, plagioclase AN30, and a small amount of pyroxene that appears to be hypersthene. Accessory minerals are graphite, apatite, and pyrite.

East of Nipisso Lake the long folded inclusion of paragneiss that lies near the north border of the augen gneiss contains several outcrops of coarse-grained quartzite. The only other mineral observed in the rock was biotite and always in amounts less than five percent.

Garnet-Hypersthene Gneisses

Garnet hypersthene gneisses are exposed in the northwest bend of the large paragneiss inclusion that outcrops near the north border of the augen gneiss on the east side of Nipisso Lake. Similar rocks are found on the west side of Nipisso Lake three-quarters of a mile from Debor Lake.

The exposures show a strong banding in which the individual units vary from one quarter of an inch to twelve inches thick. One half of the bands is coarse-grained quartzite containing up to 15 percent red garnet. The other layers have varying amounts of quartz, hypersthene, and garnet. The bands are drag-folded and pinch and swell along the strike. The oxidation of a small amount of sulphides and the brownish-red weathering of the pyroxenes give the outcrops a deep rust colour.

Thin-sections of the pyroxene-bearing bands showed that the rock is medium-grained, granoblastic, with a few large porphyroblasts of hypersthene. The orthorhombic pyroxene has a large negative optical angle, parallel extinction on appropriate sections, polysynthetic twinning and a slight pleochroism in shades of pink and green. The dispersion is very strong with $V > R$. In hand specimens the hypersthene has a glassy yellowish-brown colour. A small percentage of a green monoclinic pyroxene is present in some slides and it may be of the diopside-hedenbergite group. Accessory minerals are apatite, magnetite, and iron sulphides. Garnet, which locally is very abundant, has an X-ray pattern similar to that of pure spessartite.

Impure Marbles

No outcrops of marble were observed in either map-area but in the southeast corner of Yodel Island

and in the bay west of the island several large angular blocks of impure marble were found along the shore. As these occurrences are nearly on strike with each other and as the rock is extremely foiable, it is believed that the boulders are erratics that have been moved only a short distance from their point of origin.

The rock is coarsely crystalline and yellowish grey or pinkish grey. Dark green diopside crystals form up to ten percent of the rock and small pale brown grains of titanite are common. Scapolite and orthoclase are also present. The scapolite is uniaxial negative and has refractive indices of $e' = 1.548$ and $w' = 1.576$.

Migmatites

Turner (1948, p.11) defines migmatites as -

> "...... composite rocks in which the effects of metamorphism have been complicated by soaking of rocks in magmatic fluids, or by the development of lenticles and sheets of liquid magma, either injected from external sources (lit-par-lit injection), or segregated as products of differential fusion of the host rock itself (anatexis)."

Within the map-region rocks are met with presenting all stages of transition from true paragneisses, through gneisses in which there has been addition of granitic material along the foliation to extreme types in which there has been complete admixture of the two rocks through assimilation of the gneiss and interchange of the material with the "magma".

Paragneisses are readily migmatized, whereas the gabbroic rocks are altered to hybrid rocks only near the granite contacts. The differences in mineralogy of the migmatites and the unaltered host-rocks show that potassium, sodium, and silicon have been introduced. It is possible that calcium, aluminum, iron, and magnesium may have been added to some of the paragneisses but available evidence indicates that the original chemical composition of the sediments can account for any anomalous concentration of these elements. Thus, in this paper, only rocks that show an introduction of potassium, sodium, and silica will be classified as migmatites.

Two bands of migmatitic rocks outcrop in the Nipissis River map-area. One, averaging 3000 feet in width and divided by the Nipisso River, strikes southwest from the northeast corner of the area, and continues to a point one mile above the junction of the Nipissis and Nipisso Rivers. From there it swings south for another mile and a half. Another zone outcrops south of Pollock Lake between the granite gneiss and gabbro. These two zones are actually complexes in which several rock types outcrop in bands too small to be mapped separately and in which migmatites are the main rock types. Migmatitic gabbros are found in the Cacaoni Lake area wherever granite is in contact with gabbro. These migmatites appear to be restricted to immediate contact zones although the complex manner in which the granite has intruded the gabbro prevents any accurate determinations of the width of the migmatite bands.

In the Nipisso Lake map-area migmatites are strongly developed in the northern part, around and between the biotite and hornblende granites. Elsewhere, in the map-area, as is similar in the area to the south, patches of migmatite are found in the paragneisses far from any known granite body.

Biotite gneiss and, to a lesser degree, hornblende gneiss appear to be the most easily migmatized paragneisses. Whether the original host-rock contained biotite as the main mafic mineral or whether the biotite has been formed by potassium metasommatism of other ferro-magnesian minerals is unknown. Several thin-sections showed biotite forming around hornblende and this suggests that some of the biotite of the migmatites was formed by alteration of hornblende.

Two main types have been observed, banded migmatites and augen migmatites. The more widespread variety consists of bands of introduced minerals along the foliation of the host rock. The development of feldspar parphyroblasts with or without the bands of granitic material serves as the basis for distinguishing the two migmatites. Migmatization of the gabbroic rocks results in an equigranular, massive rock of the same appearance as the original one but now containing quartz and microcline in addition to the original minerals.

Quartz and microcline are the introduced minerals. Plagioclase is commonly zoned; the grain borders are more sodic than the cores. Apatite and sphene are always present as accessory minerals, in addition to those usually found in the paragneiss. A few slides showed microcline replacing plagioclase. Where microcline is in contact with plagioclase, the border of the latter mineral generally contains tiny eyes or lenses of quartz; the mixture of the two minerals is hereafter referred to as granophyre.

Moisie Series

The hypersthene-bearing rocks of the Nipissis River and Nipisso Lake map-areas are grouped together to form the Moisie series. These intrusive bodies, some of batholithic dimensions, include norite, gabbro, diorite, hornblendite, pyroxenite, and a few small patches of granite. All contain hypersthene. The writer believes that these rocks are from the same parent magma whose composition closely approached that of the norite, the most abundant rock type of the series.

Wherever possible the Moisie series is outlined, on the accompanying maps, as separate rock units. Within any one unit different facies may occur but usually in bodies too small to be outlined. Thus in the main mass of norite, coarse-grained gabbroic, dioritic, and granitic facies are present but the intimate association of one type with another and the scale of the mapping does not allow these "foreign" facies to be shown on the map. Also, outcrops of fine-grained norite are included in the Pollock diorite and the Cacaoni gabbro.

Norite

Johannsen (1937, p.233) defines norites as -

> "..... plutonic rocks of hypautomorphic to xenomorphic-granular texture and the mineral combination basic plagioclase and orthorhombic pyroxene. Usually clinopyroxene is accessory so that there are all transitions through augite-norites and hypersthene-gabbros to normal gabbros."

Thin-sections of the norite from the map-areas show that the amount of hypersthene may exceed, equal or be less than the amount of augite. Thus according to the above definition, and as would be expected in such a large mass, all facies of the norite-gabbro suite are present. Furthermore, in a few places, the pyroxenes have been almost completely uralitized and the rock is composed of uralitic hornblende and plagioclase.

The characteristic feature of the norite is its fineness of grain-size, and it is upon this feature more than any other that this map-unit differs from the other gabbroic facies of the Moisie series.

Greig (1945), who mapped the area south of the Nipissis River area, called the rock pyroxene and hornblende amphibolite and suggested that it might have been dervied from sediments. However, as a result of the writer's work in the Nipissis River and Nipisso Lake areas the norite is more probably an intrusive igneous body.

Aerial photographs of the terrain underlain by norite show an extremely rugged topography controlled by strong jointing. This is especially true in the southeast corners of both areas where a distinct rectilinear drainage system reflects the pattern of the underlying joint system. The norite is cut by numerous dykes and irregular bodies of a coarse-grained augen granite believed to be associated with the granite gneiss. Outcrops invariably show numerous black dykelets of hornblende, more resistant to erosion than the host-rock, cutting the norite in a variety of directions.

In hand specimens, the norite is very fine-to fine-grained. Feldspar predominates and a mafic mineral, pyroxene or amphibole, is always present. Typically the rock is massive, with a salt and pepper appearance in which an ophitic arrangement of the minerals is often discernible. Locally, sheared varieties may be common and occassionally the rock is schistose.

Examination of ten thin-sections showed that there are two principle varieties of the norite, one a pyroxene-rich and the other an amphibole-rich facies, the former is the more abundant. Texturally, the rock is of two types, again with intermediate facies. An equigranular, granoblastic texture is common and a sub-ophitic to ophitic texture was observed in a few thin-sections. The texture is independent of the mineral constituents, as both pyroxene-and amphibole-rich types show an ophitic arrangement of the grains.

Plagioclase (AN45) forms 50 to 60 percent of the rock. Augite and hypersthene or hornblende are the other main constituents. Augite, $Z \wedge C = 45°$, positive $2V = 60°$ (approx.), is pleochroic in shades of pink and green. This pleochroism may be due to a slight titanium content. Hypersthene has -

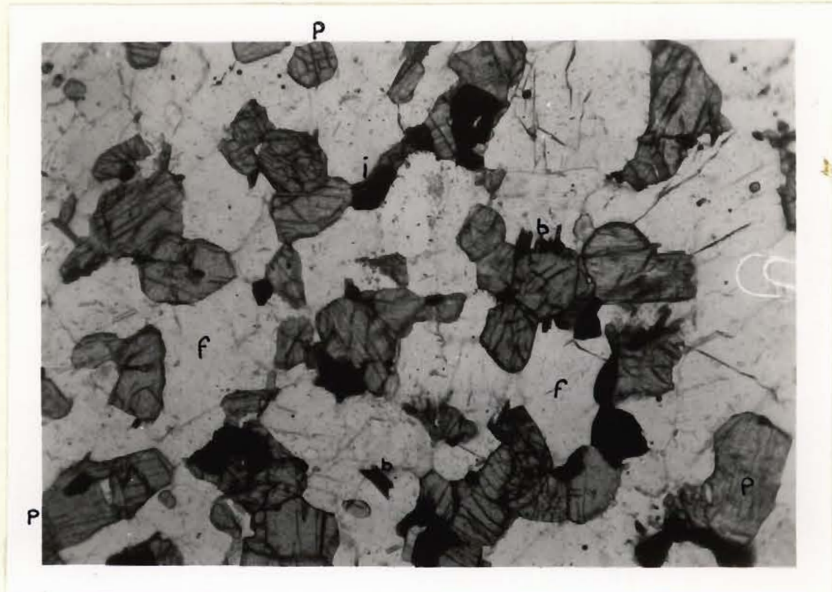
> x = pink, y = yellow; z = green
> large negative 2V, parallel extinction lammellar twinning
> parallel to the "C" axis.

Brown pleochroic biotite and ilmentite are the most abundant accessories; apatite and zircon are usually present in minor amounts. A small percentage of amphibole is formed around the pyroxene grains in most slides. One specimen taken near the contact with the granite gneiss around Hogan Lake, showed almost complete replacement of the pyroxenes by amphibole. The optical properties of the amphibole are -

> x = pale yellow; y = yellowish green;
> z = green; $Z \wedge C = 22°$; negative $2V = 85°$

The western boundary of the norite massif is for the most part concordant with the underlying paragneisses. No data are available on the other contacts. Approximate known dimensions of the body are 20 miles east-west and 23½ miles north-south. Greig (1945) reports that the

Plate XI



A - Norite. (X 16)
p-pyroxene, f-feldspar, b-biotite,
i-ilmenite.

B - Amphibolitized norite (X 84)
h-hornblende,f-feldspar,i-ilemanite

massif extends further eastward and outcrops of norite were observed northeast of the Nipisso Lake map-area. These outcrops may be part of the main massif.

Hypersthene - Gabbro

Gabbro sills, ranging from a few feet to half a mile wide, are abundant in the Nipisso Lake area. Only the larger bodies have been outlined on the accompanying map. During the field work, an attempt was made to separate the sills into hypersthene gabbro, anorthositic gabbro, and amphibolite; subsequent laboratory work proved that all the above types were present. Outlining of individual bodies could not be accomplished as metamorphism has changed the original pyroxenes into amphibole and the mineralogical composition of the gabbroic rocks was variable within any one unit. Furthermore, the structure of the area, both regional and local, could not be deciphered satisfactorily to permit correlation of the scattered outcrops.

A large mass of gabbro surrounds Cacaoni Lake and extends along the northeast boundary of the Nipissis River area into the Nipisso Lake map-area. The distribution of the gabbro is extremely irregular due to the widespread intrusion of pink biotite granite into the gabbro.

The composition of the gabbro is quite variable. Differences in composition can be attributed to variations in initial chemical composition in different parts of the magma, to hybridization by granitic solutions, and to recrystallization due to metamorphism. In general, hand specimens are green to dark green, medium-to coarse-grained, and have a granitoid or rarely ophitic texture. Occassionally the rock is strongly sheared and a gneissic or linear structure is found in place of the more common massive structure.

The unaltered facies have plagioclase as the most abundant mineral present. It occurs as lath-shaped crystals, euhedral to subhedral in crystal outline. Normal zoning is common, the core being about plagioclase AN55 and the rim plagioclase AN30. The majority of the grains are about plagioclase AN45. Hypersthene and augite occur in about equal amounts. Hypersthene has -

> weak pleochroism x = pink; y = yellow; z = green negative 2V=60°; weak dispersion V > P; lamellar twinning parallel to the "C" axis.

The monoclinic pyroxene has the following optical properties:

positive $2V=52°$; $Z \wedge C = 47°$;
$P > V$.

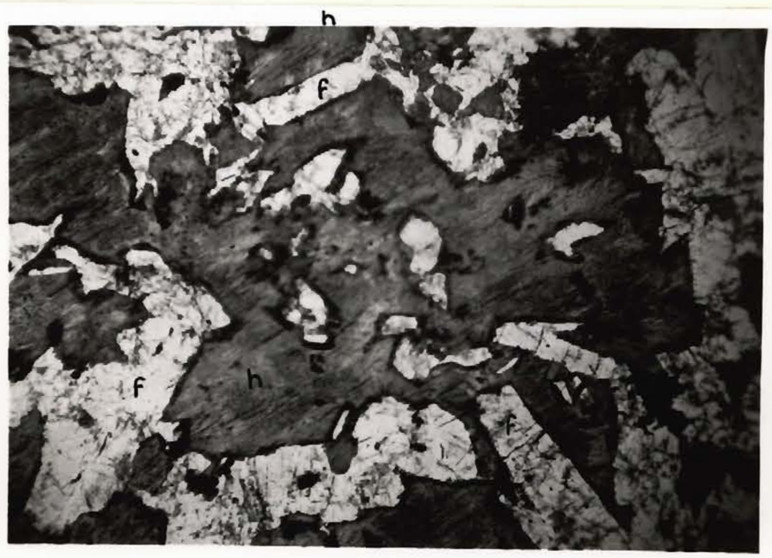
It is slightly pleochroic in shades of pink and green. Olivine was observed in one slide. It has a negative $2V = 75°$, $P > V$, parallel extinction, and good cleavage parallel to 010. Accessory minerals are magnetite and apatite.

The optical properties of the olivine and the hypersthene indicate that they contain about 40 percent of the ferrous silicate molecule. The olivine is surrounded and replaced by hypersthene.

Reheating and alteration of the gabbros by alkali-bearing bearing solutions derived from the biotite granite has affected the greater part of the Cacaoni gabbro. Texturally, the hybrid gabbros are similar to the purer members. A green hornblende, pseudomorphous after pyroxene is the predominant mafic mineral. The replacement of pyroxene by amphibole may result in a single grain of the new mineral but usually a mosaic of small hornblende crystals occupies the former position of the pyroxene. Plagioclase partially retains a lath-like appearance, however, the calcium content has decreased considerably, so that the anorthite content is now about 30 percent.

Plate XII

A - Cacaoni gabbro. (X 16)
p-pyroxene, f-feldspar



B - Cacaoni gabbro,amphibolitized. (X 16)
h-hornblende, f-feldspar

The grains show a diffused normal zoning that is accentuated by clear sodic borders surrounding a core filled with liquid inclusions. Biotite, pleochroic in shades of straw and dark brown, is fairly abundant.

Alkali metasomatism of the gabbro has introduced two new minerals, quartz and microcline-perthite. It is also responsible for the formation of biotite from amphibole or pyroxene. Alteration of the various minerals is common with plagioclase and hornblende the most susceptible. Sericite, clinozoisite, and opidote are derived from feldspar; chlorite, epidote, and magnetite from hornblende.

Among the accessories, apatite and sphene are abundant, while magnetite, granophyre, and zircon are usually present. Sphene may occur as individual grains but is usually found as a rim around magnetite.

Coarse-grained bodies of hypersthene-gabbro outcrop around Tchinicaman Lake. The majority of the contacts showed that the gabbro is younger than the norite but at several places the norite cuts across the gabbro. These relationships would indicate that the two rocks are of the same age and that the maximum development of gabbro followed that of the norite.

Thin-sections show that the gabbro is very similar to the norite and to the Cacaoni gabbro. Pyroxenes are more uralitized and there is a greater percentage of biotite. The plagioclases have a slightly lower anorthite content, AN35 to 40.

Olivine Gabbro

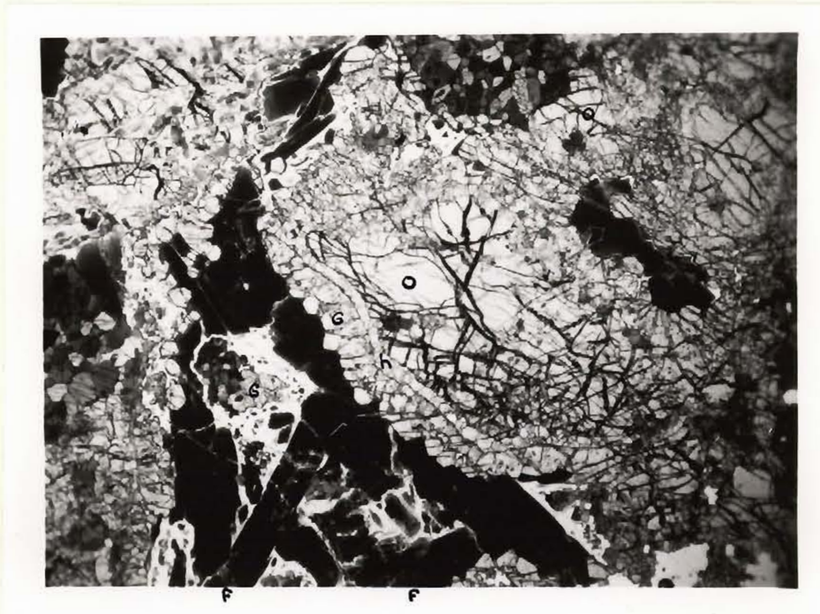
The large sill 1¼ miles south of Firth Lake, several small sills south of Albany Lake, and numerous other outcrops are composed of olivine gabbro. The rock is massive, coarse-grained, granitic to ophitic, and dark speckled gray. The pyroxenes have a bronzy lustre and the feldspars usually have a greenish-gray colour. Pale pink garnets are always present.

Only one thin-section was examined and it contained about 25 percent olivine. The olivine occurs as large grains showing the characteristic fracturing of the mineral. The optical properties are:

> colorless, high binefringence, negative 2V=85°, strong dispersion P > V, and extinction parallel to the well developed cleavage (010).

Minute non-pleochroic grains of hypersthene form rims around the olivine. A few grains of hypersthene and

Plate XIII



A - Reaction rims between olivine and feldspar. (X 16)
o-olivine, f-feldspar, h-hypersthene, g-garnet

augite are present; these contain numerous inclusions of olivine. Biotite and hornblende form clusters of interlocking grains. The hornblende has X = pale yellow, y = pale brown, z = brown; a negative large 2V; and $Z \wedge C \doteq 8°$. The composition of the plagioclase could not be determined as the grains are obscured by a bluish-green alteration product.

Garnet is the latest mineral to form. It occurs as tiny grains replacing feldspar, especially where the latter is adjacent to olivine. At the contact of olivine and plagioclase, garnet and hypersthene are formed; the garnet replaces plagioclase and the hypersthene replaces olivine.

Anorthositic Gabbro

Anorthositic gabbro was observed at the mouth of the Nipisso River and on the tip of the long point northeast of Yodel Island. The rock is composed of white plagioclase, AN47, with about 30 percent dark green hornblende. Biotite, pyroxene, and a brownish-red garnet are also present. Accessory minerals include ilmentite and pyrite. The grains are medium to coarse and have a very fresh appearance. Outcrops show a strong gneissic structure and the amphibole occurs in clots and streaks that are strongly lineated.

Diorite

The Pollock Lake body is a mica diorite. It is similar to the mica diorite reported by Greig (1945) in the Matamec Lake map-area. In hand specimens the rock is brownish-grey, coarse-grained with large flakes of biotite. It is massive and has a granitic texture. Under the microscope, the texture varies from granoblastic to granitic; the majority of the minerals have poor crystal outlines. Essential minerals are feldspar, hornblende, biotite, orthorhombic and monoclinic pyroxenes, quartz, and microcline. Magnetite and apatite are abundant accessories and zircon, sphene, pyrite, and leucoxene are also present.

This intrusive is characterized by coarse biotite flakes which may make up 20 percent of the rock. The optical properties are x = yellow, y = z = reddish brown; and a negative small 2V. Two of the five thin-sections examined contain hornblende. It is pleochroic with x = yellow, y = light green, Z = dark green and the extinction angle ($Z \wedge C$) equals 19 degrees. The orthorhombic pyroxene is slightly pleochroic; it shows parallel extinction, polysynthetic twinning, and a negative 2V=56°. The monoclinic pyroxene has a pale green colour, $Z \wedge C = 44°$, and an estimated positive 2V of 60°. The dispersion is greater for the optic axis nearly parallel to C and thus it may be called an augite.

Plagioclase forms up to 60 percent of the minerals present in the diorite. It varies from irregular near-equigranular grains to distinct lath-shaped crystals. Albite, pericline, and carlsbad twinning have been observed and one grain shows a baveno twin. It is usually zoned with a core of about AN38 and a rim of AN25. One slide contained lath-shaped crystals of plagioclase AN38 and small clear xenoblastic grains of feldspar with a composition of AN25. The larger grains are usually clouded or "dirty" due to numerous liquid inclusions and where zoning is especially noticeable, the cores are clouded and the rims clear.

Thin-sections indicate that the Pollock Lake massif may have been a hypersthene gabbro and that biotite, hornblende, quartz, and microcline are newly-formed minerals. This change in composition could be the result of autometasomatism or the result of metasomatism by granitic fluids.

Pyroxenite and Hornblendite

In the Nipissis River map-area outcrops of the ultra basic facies of the Moisie series are found in the north end of the Pollock diorite, half a mile south of the airstrip and near the west shore of the northwest bay of Tchinicaman Lake.

The small intrusive that outcrops in the northern part of the Pollock diorite is composed mainly of pale green hornblende, pseudomorphous after pyroxene, and small remnant grains of olivine, hypersthene and augite. The ultrabasic south of the airstrip has olivine (5%), hypersthene (15%), and augite (15%). Hornblende (40%) and chlorite (25%) are secondary minerals.

West of Tchinicaman Lake, the rock is medium-grained and strongly schistose. Mineral composition consists of amphibole (50%), hypersthene (35%), and equal parts of augite and magnetite. The amphibole has the following properties:

x = pale yellow, y = yellowish green,
z = pale green, α = 1.635, B = 1.645,
γ = 1.652, Negative 2V = 76, $Z \wedge C = 12°$

Hypersthene is pleochroic and has a negative 2V = 80°.
The monoclinic pyroxene has:

> positive $2V = 53°$, $Z \wedge C = 38°$, and dispersion $P > V$ more intense on the optic axis nearly parallel with "C".

These properties are similar to those of diopsidic augite. Magnetite occurs as distinct grains and as lamellae along the hornblende cleavages. The lamallae also form a right-angled grid in the hornlende grains, suggesting that the amphibole is pseudomorphous after pyroxene.

A thin-section of a similar rock contained also a small amount of plagioclase, AN35, and biotite.

Medium-grained, dark green hornblendite forms a needle-like peak about one mile north of the junction of the Nipissis and Wacouno Rivers. Two miles east of the same junction, bronzitite is found as a layer, ten feet thick, in gabbro. The rock is coarse-grained, dark brownish green, and slightly sheared.

One mile northwest of Debor Lake, a small sill of hornblendite is interlayered with the paragneisses. The optical properties of the hornblende are negative $2V = 84°$, $Z \wedge C = 20°$, and strong dispersion $P > V$. The mineral is colorless to very pale green. With the exception of a few grains of magnetite, hornblende is the only mineral present.

Hypersthene - Granite

The granitic facies of the Moisie series is found as narrow dykelets, dykes, and irregular masses cutting the norite around Tchinicaman Lake and east of the south end of Nipisso Lake. The rock is yellowish brown, coarse-grained, and frequently gneissic. Thin-sections show microcline and quartz, in addition to hypersthene, augite, biotite, and plagioclase. Pyroxenes may be fresh but usually they are uralitized or altered to brown mica. Microcline occurs as fresh anhedral grains which when closely examined reveal a sub-microscopic multiple twinning. Grains of microcline cut perpendicular to the obtuse bisectrix show the axial plane at an angle of eight degrees to the basal cleavage. The potash feldspar appears to be one of the latest minerals to form as inclusions of quartz, plagioclase, and pyroxene were observed in some grains. The anorthite content is variable, ranging from 23 to 42 percent.

Amphibolites

Ortho-amphibolites occur as sill-like bodies and only rarely as narrow dykes and dykelets. Amphibolites are wide-spread in the Nipisso Lake area and rare in the Nipissis River area. Only a few sills were recorded in the latter area but this is probably due more to inexperience in recognizing the rock-type than to an actual scarcity.

As the prefix "ortho" indicates, these rocks have been formed by the recrystallization of gabbroic or dioritic intrusives. At many places gneissic amphibolites can be traced, across the strike, through sheared gabbros, into massive gabbros that display igneous characteristics. Grain-size ranges from fine to coarse and the texture from granitic to granoblastic. Gneissic varieties predominate although massive types are occassionally found. Some outcrops contain up to 25 percent garnet which gives a reddish tinge to the usual dark green or grey colour.

Sixteen thin-sections of ortho-amphibolite were examined under the microscope. Of these, four contained relict pyroxenes and two may have been hornblende gabbros originally. The pyroxenes include the orthorhombic pyroxenes, hypersthene, and two monoclinic types, diopside and augite. Hypersthene and diopside were seen in two slides, hypersthene and augite in a third.

Hornblende which forms 40 to 70 percent of the amphibolite, has a pleochroism of yellow to grass green. Plagioclase is also very abundant and occurs as small clear xenoblastic grains and as large phenocrysts. The latter are rare and invariably show bent twin lamellae, granulation, and replacement by the smaller feldspar grains. No difference in composition of the two types could be determined. The feldspars are very fresh, only a few grains have a slight alteration to sericite, epidote, and clinozoisite. The composition of the feldspar ranges from AN30 to AN48 with the greatest number of values falling between AN32 and 38. Garnet is a common accessory. In one thin-section porphyroblasts of garnet contain inclusions of hornblende, pyroxene, biotite, plagioclase, magnetite, and apatite. The accessory minerals are magnetite and apatite and rarely sphene, zircon, and quartz.

In many places in the "Laurentian" region of eastern Canada and in the Adirondacks of northern New York State, amphibolite has been formed by the metamorphism of pre-existing diorites and gabbro. Buddington (1939, p.13) says that -

> "Such amphibolite can be proven of igneous origin only by the transitions to rock still preserving typical igneous texture."

Osborne (1936 C) claims that the amphibolites of the Shawinigan Falls area of Quebec were originally volcanic rock, either andesite or basalt. He believes that in some places original volcanic structures are still preserved in the rocks. It is quite possible that some of the narrower amphibolite bodies that have been completely recrystallized may have been originally of volcanic origin. However, there is no evidence to support this hypothesis and in fact where original structures and textures have been preserved, the rocks are undoubtedly of intrusive origin.

Hypersthene Pegmatite

The norite surrounding Tchinicaman Lake has been intruded locally by medium-grained, light brownish-grey, aplitic or pegmatitic dykes. These rocks contain quartz, feldspar, hypersthene, and garnet. As these dykes have been observed only in this one locality and as they contain hypersthene, it is believed that they are an end-product of differentiation of the norite magma.

Post-Moisie Intrusives

Augen Gneiss and Granite Gneiss

A large body of augen gneiss extends across the centre of the region covered by the two map-areas. The upper contact roughly parallels the Nipissis River as far north as its junction with the Nipisso River. From this point it strikes northeast, following the valley of the Nipisso River, to the east border of the Nipisso Lake area. The lower contact strikes east across the

Nipisso Lake area passing half a mile south of Debor Lake. On the east side of Nipisso Lake it trends northeast until it is cut off by the nornblende granite massif along the east boundary of the area. The augen gneiss extends beyond the east and west boundaries of the map-region. Locally the augen gneiss massif lacks the augen texture and the rock is a granite gneiss.

A granite gneiss body which outcrops in the south-central part of the Nipissis River area is similar to that described above, except that it lacks the augen texture. These two bodies are believed to be of the same age. Outcrops of norite immediately east of the granite gneiss body are cut by numerous dykes and small irregular bodies of coarse-grained augen gneiss. These small intrusives are probably related to a deeper under-lying mass, connected to the large body of granite gneiss.

The granite gneiss, including the augen gneiss, is usually pink but locally it may be light grey. It is fine-to coarse-grained, strongly gneissic, and has a pro-nounced sugary texture. A parallelism of the long axes of feldspar crystals and augen imparts a lineation that can be recognized in most outcrops.

The essential minerals are quartz, microcline, plagioclase, and biotite. Quartz invariably has undulose extinction and contains numerous liquid inclusions. Microcline occurs as small granoblastic grains and as porphyroblasts; it is usually perthitic and contains numerous inclusions of quartz and plagioclase. Small granulose grains of albite-oligoclase are seen in all thin-sections; these show only slight alteration to white mica. Biotite occurs in clusters of individual grains and is pleochroic from yellow to brown. Green hornblende was seen in a few thin-sections. Accessory minerals include zircon, apatite, sphene, allanite, and magnetite with rims of sphene. Garnet and hornblende are abundant in the granite gneiss along the northern and southern contacts respectively.

Microcline porphyroblasts contain numerous fragments of plagioclase, all having approximately the same crystallographic orientation in each augen. It appears as if microcline is replacing an older plagioclase augen. The neighbouring plagioclase grains contain small quartz eyes.

Both the northern and southern contacts, as well as the internal gneissic structure, of the augen gneiss massif are parallel to the foliation or schistosity of the enclosing rocks. Linear structures are also in agreement with those found in the enclosing formations. In plan, the body is "S"-shaped with a synclinal axis to the west and an anticlinal axis to the east. From the lineation of the gneiss and enclosing sedimentary gneisses, the plunge of the folds is about 30 degrees in a direction of S 5° E.

The northern or lower contact is remarkably sharp. The granite gneiss is in contact with graphite and sillimanite gneisses that are almost free from migmatization. The presence of garnet in the granite along the contact indicates that the rock may have absorbed some of the sediments. Eskola (1914) claims that the occurrence of garnet denotes an excess of aluminum in the magma, a feature not found in normal igneous rocks and that the excess aluminum is derived from assimilated sediments. The underlying metasedimentary rocks show no brecciation or deformation such as would result from the emplacement of the augen gneiss and the granite gneiss is remarkably free of inclusions.

The southern or upper contact is a broad zone in which the granite may be traced through migmatite into unaltered metasediments and basic intrusives. At several places along this contact the feldspar porphyroblasts have a rectangular outline and the rock may be described as a porphyritic granite.

On the east side of Nipisso Lake, the augen gneiss is intruded by biotite granite, hornblende granite and gabbro. It also contains two large inclusions of paragneiss. The eastern boundary of the augen gneiss is believed to be only a short distance outside the map-area and that these paragneiss inclusions may be large blocks broken off along the margin of the intrusive.

The body of granite gneiss in the south-central part of the Nipissis River area is irregular in outline but with a north-south elongation. The gneissic structure trends northeast, parallel to the structure of the enclosing rocks. Inclusions of norite are frequently found in the granite gneiss.

Granite Gneiss and Granulite

Pink granite gneiss and granulite are found in a zone, three-quarters of a mile wide, extending across the Nipisso Lake area. The southern contact of this zone lies one mile north of Debor Lake and passes through the northern part of Yodel Island. Within this zone, paragneisses and amphibolites are also present. A similar granite gneiss occurs as dykes and sills in the augen gneiss.

The granite gneiss is fine-grained, pink, and strongly gneissic. Quartz, microcline, plagioclase, biotite and hornblende are the main constituents. Zircon, apatite, sphene, and allanite are accessory minerals.

Both zircon and allanite have developed pleochroic haloes in the mica grains.

Bands of fine-grained pink granulite outcrop in the zone across the Nipisso Lake area. The granulite shows a higher grade of metamorphism than the associated granite gneiss.

The granulite is a fine-grained, pink rock with strongly-stretched quartz lenses up to one inch in length. It is composed of quartz, microcline, and plagioclase, AN16. Magnetite and zircon are accessory minerals; a small amount of muscovite occurs as an alteration product of microcline. Pink garnet crystals, up to one quarter of an inch in diameter are found in narrow layers in the granulite. The garnet has a specific gravity of 4.188 and a refractive index of 1.817; these indicate that it is probably a mixture of almandine and spessartite.

Several specimens of granite gneiss, containing biotite and lacking garnet, show stretched quartz lenses and grains. These intermediate facies of the granite gneiss - granulite suite indicate that the two end members were originally the same rock-type.

Gabbro

A large dyke cuts the augen gneiss east of Nipisso Lake. The rock is dark purplish-grey, massive, and has

has an ophitic texture. The grain size is predominantly coarse.

In thin-sections, the gabbro has an ophitic texture and does not show any evidence of deformation. The mafic mineral is a fibrous amphibole arranged in clusters that have a stubby prismatic outline. The amphibole has the properties of anthophyllite. It has no colour, positive large 2V, parallel extinction, positive elongation, and medium binefringence. Where the anthophyllite is in contact with plagioclase, it has been partially changed to green hornblende.

Plagioclase, AN40, contains minute inclusions of an unknown mineral. It is also slightly sericitized. Biotite, colourless to light brown, is present as scattered plates. Ilmenite, magnetite, and pyrite are accessory minerals.

Hornblende Granite

Two bodies of pink hornblende granite occur in the region. The larger extends from the northeast part of Nipisso Lake beyond the north boundary of the area. The other is east of Yodel Island along the east boundary and it also extends beyond the map-area.

The granite is medium-to coarse- grained, usually strongly lineated and gneissic. In a few places small lenses of dark green hornblende were observed paralleling the lineation. Essential minerals are microcline-perthite, quartz, oligoclase, hornblende, and biotite. The biotite is secondary and replaces the hornblende. Minor amounts of apatite, zircon and magnetite are present.

The east contact of the larger hornblende granite body appears to follow the trend of the overlying paragneisses. Elsewhere the contact is irregular and transgresses the foliation of the enclosing rocks. The smaller body cuts across the structure of the augen gneiss. The northwest border of this massif is a continuation of the contact between the augen gneiss and the paragneisses.

The granite is characterized by a pronounced lineation due to the alignement of hornblende prisms and the long axes of feldspar grains. In both massifs the gneissic structure is a continuation of the trend of the surrounding rocks. Similarly the lineation has the same general orientation as that seen in outcrops of other rock-types.

Biotite Granite

Four stocks of granite, in addition to numerous dykes, occur in the region. In the Nipissis River area one cuts the gabbro and paragneisses around Cacaoni Lake and another cuts the augen gneiss west of the airstrip. A small stock cuts the augen gneiss east of Yodel Island and a larger body outcrops in the northwest corner and beyond the limits of the Nipisso Lake map-area.

The biotite granite is invariably pink or red in colour and grades from fine-to coarse-grained. It is usually equigranular but locally large crystals of microcline impart a porphyritic texture to the rock. The granite has a massive structure and only locally it is gneissic.

Under the microscope the granite shows an allotriomorphic, granitoid texture. It has a high percentage of microcline and quartz. Plagioclase, AN10-15, is present in appreciable amounts and is slightly altered to sericite, epidote, and clinozoisite. Yellow to brown pleochroic biotite is the main mafic mineral and in a few slides it has been partially or completely altered to light yellowish green penninite. Hornblende, in minor amounts, was observed in only two of the six thin-sections. Accessory minerals include sphene, apatite, magnetite, granophyre, epidote, zircon and pyrite.

The granite stock on the west side of the Nipissis River is five miles long and three miles wide. If the gneissic structure of the augen gneiss along the contact of the biotite granite reflects the orientation of the contact then the north side of the stock strikes roughly east and dips about 70 degrees southward. The south border is more uniform in plan and is orientated north-east with a southward dip of about 45 degrees. Because it cuts across the structure of the enclosing granite gneiss, the attitude of the intrusive as a whole is discordant.

The contacts of the large biotite granite mass in the northwest corner of the Nipisso Lake area has been approximately located on the east and assumed on the south. The contact appears to parallel the foliation or gneissic structure of the enclosing paragneisses. As the trend of these rocks conforms with that of the paragneisses further south and east, it is assumed that this body of biotite granite is a concordant intrusive mass.

The small body of biotite granite in the Nipisso Lake area is an irregularly-shapped mass that intrudes the augen gneiss discordantly.

Pegmatite and Aplite

Pegmatite dykes and sills are very numerous in the region. They cut all the rocks except the lamprophyne and diabase dykes. Field evidence suggests that there are more than one age of dyking and that there may be as many as three ages.

Fine-to medium-grained, pink or pinkish-grey pegmatitic sills are found as layers in the paragneisses. The width of the layers varies from less than one inch to several feet. These sills do not appear to be related to any one body of granite as contact zones around the various granites show the same type of sills. They are composed essentially of quartz and microcline; apatite and sphene were also observed. The sphene is dark brown to black and probably contains a radioactive element. Haloes and radial fractures surround the grains.

Another more common type of pegmatite occurs as coarse-grained dykes. They are composed of pink potassic feldspar, plagioclase, quartz, biotite, and hornblende. The last two minerals rarely occur together in the same dyke. Nodules of magnetite grains, up to one inch in diameter, are frequently present. The minerals are usually well-formed; euhedral crystals of quartz were observed in several dykes. The dykes show sharp contacts and usually no evidence of deformation.

The age of the dykes is not definitly known but their relative undisturbed state indicates that they are very young and probably belong to a late stage of the biotite granite intrusion.

Gabbroic pegmatites, containing plagioclase and hornblende, were found in several places in the northeast part of the Nipisso Lake area. An outcrop of gabbroic pegmatite, one mile southeast of Albany Lake and half a mile east of the boundary of the area, contains large grains of pyrrhotite, pyrite, and chalcopyrite.

Fine-grained aplite dykes are common but not as abundant as the pegmatites. They are composed of quartz, microcline, plagioclase, and biotite. One dykes contains pink garnets.

Lamprophyre Dykes

Basic dykes identified in the field as lamprophyres, cut various rock-types in the region. One dyke containing plagioclase, biotite, hornblende, and quartz cuts gabbro and coarse-grained pink pegmatite. Two similar dykes were observed in the augen gneiss south of Irene Lake.

Lamprophyre dykes cutting the augen gneiss have a gneissic structure, whereas the one cutting the pegmatite has a massive structure. Most of the dykes have a gneissic structure. Although the evidence is scanty, there is some suggestion that there may be two ages of lamprophyre dykes, corresponding to the two main periods of granite intrusion.

Diabase Dykes

Diabase dykes occur in both areas and were seen cutting most of the rock types. They are closely similar to certain diabase dykes that, in other parts of the Precambrian Shield, are considered to be of Keweenawan age.

The diabase is a dense fine-grained black rock, frequently containing feldspar phenocrysts and, or, amygdules of quartz and calcite. It consists essentially of plagioclase, AN15, in a sub-microscopic ground mass of biotite, hornblende, and magnetite. Accessory minerals are calcite, apatite, and sphene.

Economic Geology

The object and duration of the writer's work did not permit of detailed prospecting in the map-areas. Deposits of sulphide minerals, ilmenite, garnet, and graphite were examined but none of these appeared very promising.

Sulphides

Two miles northeast of the junction of the Nipissis and Nipisso Rivers, a rusty weathering cliff was seen to contain scattered sulphide minerals. A sample taken from here and assayed by the Quebec Department of Mines showed 0.02 percent nickel and 0.02 percent copper.

Finely-disseminated pyrite, pyrrhotite, and some chalcopyrite were found in nearly every outcrop of the graphite gneiss that lies along the north border of the augen gneiss. A specimen from the rusty-weathering cliff, half a mile east of the airstrip assayed 0.02 percent nickel and 0.08 percent copper.

Approximately one mile southeast of Albany Lake and half a mile east of the boundary of the area coarse grains of pyrrhotite, pyrite, and chalcopyrite were found in a gabbroic pegmatite dyke. The dyke, four feet wide and exposed over 25 feet, outcrops in the bed of a stream that drains into Albany Lake. Two assays of the mineralized rock showed 1.29 and 0.17 percent copper and traces of nickel and silver.

Ilmenite

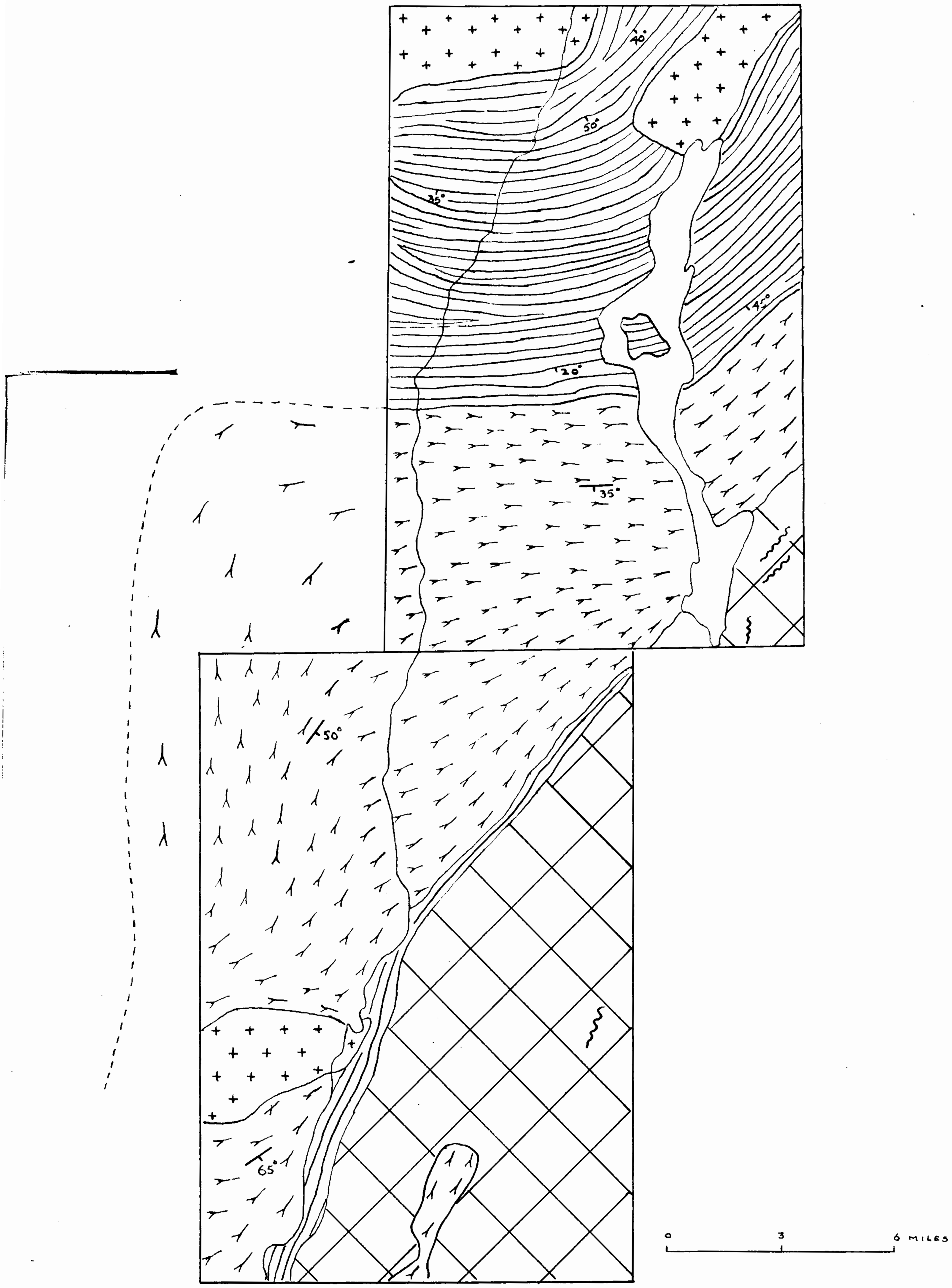
The anorthositic gabbro outcropping on the long point of Nipisso Lake, east of Yodel Island, contains minor amounts of ilmenite. A dip-needle survey of the point and adjacent mainland failed to show any indications of ilmenite concentrations.

Garnet and Graphite

The only non-metallic minerals that occur in sufficient quantities to merit discussion are garnet and graphite. However, no economic deposits of these minerals were observed. Garnets are abundant in the paragneisses and amphibolites in the bay west of Yodel Island. Gneisses containing up to ten percent graphite outcrop along the northern contact of the augen gneiss.

Sand and Gravel

Large amounts of sand and gravel from the Nipissis and Wacouna valleys were utilized in the construction of the road-bed of the Quebec North Shore and Labrador Railway.



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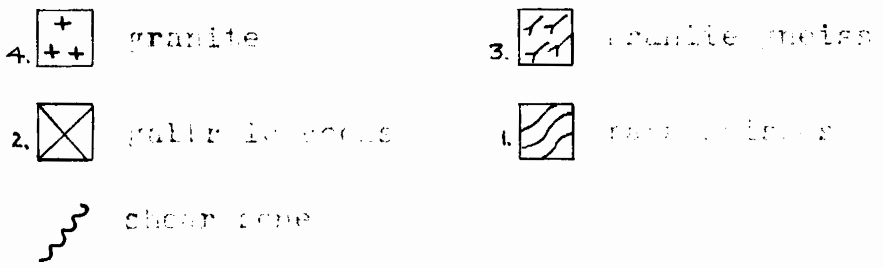

STRUCTURAL GEOLOGY

The distribution and structure of the main rock types of the map-region are illustrated on the accompanying structural map (Fig. 1). As may be seen on this map, the shape of the augen gneiss massif reflects the structural trend of the enclosing rocks. In the map-areas, the southern contact of the augen gneiss trends northeast and the northern contact mainly east. The origin of the shape of this massif is a clue to the general structure of the region and to the direction of the forces responsible for the formation of this structure.

Foliation, Schistosity, and Gneissic Structure

Strong recrystallization induced by the regional metamorphism has destroyed all primary structures of the sedimentary series. The variety of rock units in the Grenville series appears to be due to differences of chemical composition in the original sedimentary beds and as the foliation, schistosity, and gneissic structure parallel the banding produced by the various rock units, these structures may be used in the same manner as bedding to interpret the general structure of the region. Except for local variations the relict bedding dips southward and parallels the adjacent granite contact. The augen gneiss has a well-developed gneissic structure due to the alignment of feldspar grains and to the accompanying parallelism of mica flakes. The contacts of the augen gneiss control also the orientation of the gneissic structure; the gneissic structure parallels the adjacent contact. Locally near the younger granitic intrusives, especially near the biotite granite plug in the Nipissis River area, the gneissic structure of the augen gneiss conforms to the trend of the contacts of the younger granites.

In the vicinity of Irene Lake, the granite gneiss is equigranular and medium-grained and only locally retains an augen texture. The trend of the gneissic structure, in this locality, is predominantly northward but the dips vary from 35 degrees eastward to 30 degrees westward.

The small bodies of granite gneiss that intrude the augen gneiss have a gneissic structure parallel to that of the surrounding rocks. At several places dykes of the younger granite gneiss contain angular inclusions of augen gneiss that have been rotated out of the plane of former orientation. The younger granite gneiss must have been intruded later than the period of maximum

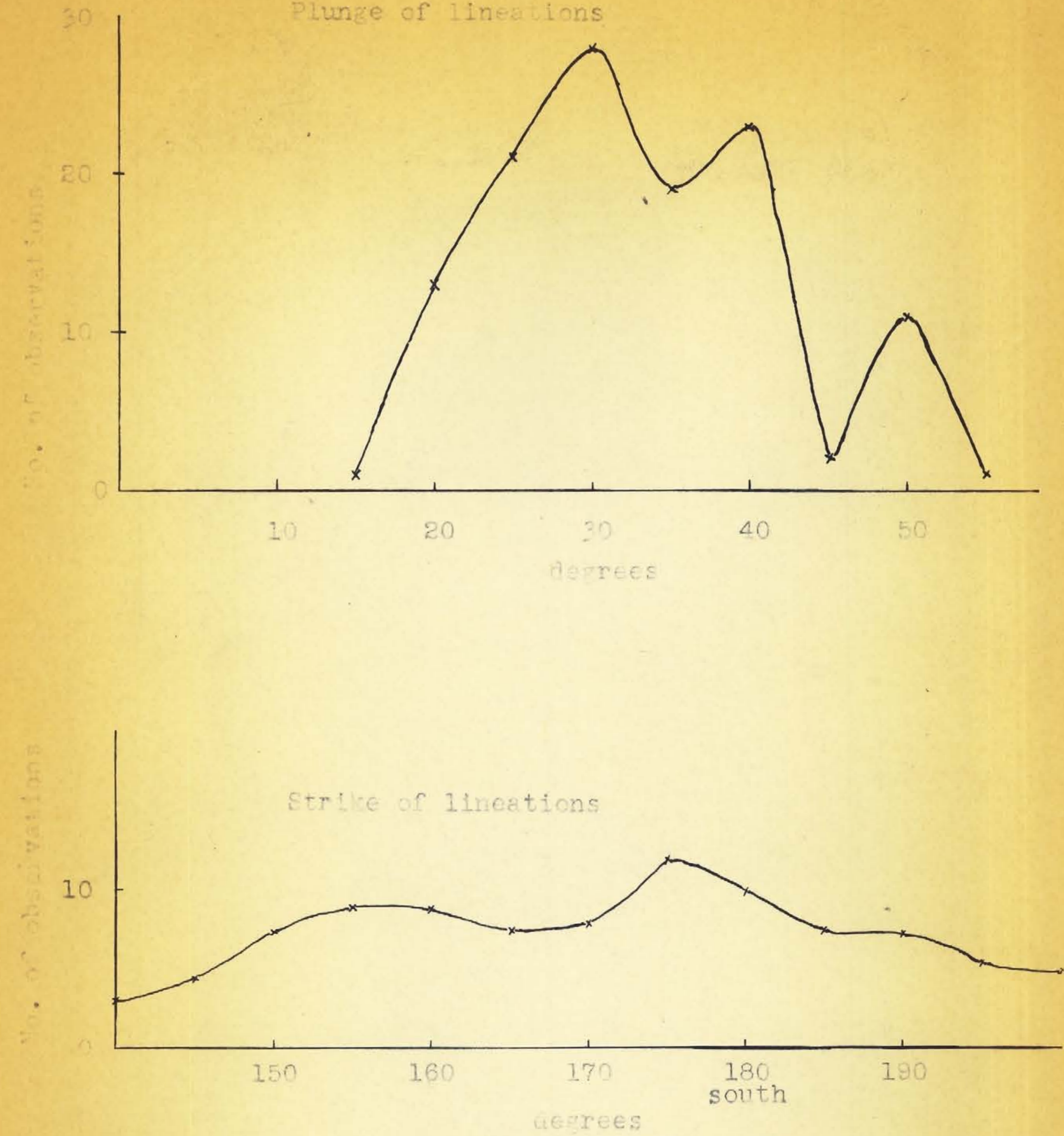

Figure 2. Frequency-distribution of plunges and strikes of lineations.

deformation and recrystallization that affected the augen gneiss and paragneisses and before the end of the regional metamorphism.

Lineation

Lineation is especially well-developed in the paragneisses and to a lesser degree in the igneous rocks. The lineation is due to the preferred orientation of prismatic or tabular minerals such as hornblende, biotite, and feldspar. The majority of the lineations strike between S.10°W. and S.30°E. and plunge between 20 and 40 degrees southward. Figure 2 shows the range in orientation of 117 measured lineations.

Folds

Northeast of Yodel Island the northeast trend of the formations is disrupted by two small open folds whose axes strike N.15°W. The warping of the lower contact of the augen gneiss imposes a fold-like pattern on this gneiss and on the underlying paragneisses. The axes of the synclinal fold, in the western part of the Nipissis River area, strikes northwest and the axis of the anticlinal fold around Nipisso Lake strikes north-northwest. These cannot be considered true or complete folds as only the lower contact and underlying rocks have been buckled, the upper contact maintains an almost uniform north-east strike.

Southeast of Yodel Island the large narrow inclusion of paragneiss and the enclosing augen gneiss have been folded. The axes of the folds, here, strike northwest.

Faults

Evidence of strong shearing is found at several places underlain entirely by gabbroic rocks. On a small island in the northeast bay of Tchinicaman Lake, the gabbro is strongly sheared and the central part of the shear zone is a mylonitic augen gneiss. The rock is composed of finely-crushed plagioclase and pyroxene, with porphyroblasts of plagioclase and garnet. Intense movements along a shear or fault zone, striking N.15°E. and dipping 70 degrees east, have produced a cataclastic texture in the gabbro. The trend of the shear zone coincides with the elongation of the northeast bay of Tchinicaman Lake.

Similar shear zones were observed in the gabbroic rocks in the southeast corner of the Nipisso Lake area. These zones, a few inches to several feet wide, are composed of rocks that show various degrees of deformation. The most intensely crushed rocks are black, flinty, structureless mylonites containing scattered porphyroblasts of plagioclase. Augen gneisses are common and are intermediate in deformational grade between the mylonites and sheared gabbros. The zones strike northeastward and dip 35 to 50 degrees east. One zone immediately east of the south end of Nipisso Lake trends N.10°E. and dips 70 degrees east.

The southern border of the hornblende granite, west of the north end of Nipisso Lake, appears to be offset along a line striking N. 15°W. Strong shearing of the granite, a physiographic lineament, and an abrupt change in strike of the contact suggest the presence of a fault. The south shore of Irene Lake may mark the location of another fault. Along the west border of the Nipissis River area and south of Irene Lake the gneissic structure strikes north and dips east. North of the south shore the strike is the same but the dip is consistently west.

Joints

All of the rocks of the map-areas are jointed. The igneous rocks, especially the more massive gabbroic types, show strong jointing. In the southeast corners of both areas, aerial photographs show a prominent ridge and valley topography that is controlled by jointing. The most conspicuous joints in the norite strike northeast and northwest; the dips are steep and may be either east or west. Shearing is conspicuous where the norite is weakly jointed, and usually trends northward. Dips to the east are more abundant and usually less steep than the western ones.

Regional Structure

In order to discuss the regional structure, it is necessary to determine the origin of the structural features described above and their relationship to the deformational forces that affected the region.

Although the augen gneiss has a phacolithic shape, it is not a true phacolith in the sense of intruding a series of folded rocks as originally used by Harker (1909 p.78). The straight upper contact indicates that the downwarping of the lower contact is a direct result of the presence of the granite gneiss. The granite gneiss was intruded as a sill-like body and attained its present shape either by gravitational settling or by flowage during metamorphism. The latter appears to be more probable.

The high grade regional metamorphism of the enclosing paragneisses indicate that the thermodynamic conditions were such that the rocks were capable of flowage under stress. Forces acting from a southeastern direction could develop a bulge in semi-plastic rocks in somewhat the same manner that blocks are torn off and pushed ahead of thrust faults. In this case, the ability of the rocks to flow would prevent fracturing and a non-disrupted bulge would form in the area of relative low pressure. The parallelism of the gneissic structure with the contacts would be developed or maintained and the lineations would be parallel to the direction of linear flow. The underlying or surrounding rocks, also in a semi-plastic state, would be wrapped around the protuberance.

The granite gneiss along the Nipisso River in the southern part of the Nipisso Lake area contains rectangular phenocrysts of feldspar in place of the more common ellipsoidal augen. Along the front of the more resistant gabbroic rocks the original porphyritic texture of the granite was preserved whereas away from this protective "shadow", the phenocrysts were squeezed into an augen shape. Toward the bulge the augens become increasingly flattened and smeared out; in the northwest corner of the Nipissis River area, the granite gneiss is equigranular and only locally an augen texture prevails. In this corner, also, the gneissic structure is considerably folded and complicated. This sequence of textural and structural changes supports the hypothesis of increased plasticity and mobility toward the bulge of the augen gneiss.

The gabbroic rocks in the eastern half of the Nipissis River area and in the southeast corner of the Nipisso Lake area responded to the regional stresses by shearing, jointing and faulting. Recrystallization and flowage are secondary to fracturing. The relative dryness of the rocks is probably the main factor that forces the rocks to fracture instead of yielding by flowage. The fault or mylonite zones, trending north-northeast to east-northeast and dipping eastwards, indicate also that the origin of the deformational forces was in the southeast.

Both the strike and plunge of the lineations show a variability that can be attributed to different local reactions of the rocks to stress and less probably to changes in direction of the stress. If the stresses came from the southeast then the lineation is in the movement plane and parallel to a.*. Lineation in a is in the principal direction of movement in the cleavage plane and in the direction of maximum deformation. E. Cloos (1946) has compiled the available data on lineation and includes in his text brief abstracts of all papers that discuss lineation, published up to 1945. Most writers interpret a lineation as bring formed by flowage or stretching in the direction of motion. E. Cloos (1943) found that the axis of maximum elongation of deformed ooids is down the dip of the cleavage and that the lineation is in a; the ooids have yielded by flowage. Washburne (1940,p.707) states -

> "The orientation of minerals along the direction of gliding is the most plastic and apparently the oldest manifestation of alpha lineation. Most or all of it was produced during crystallization and recrystallization when the planar schistosity arose ....".

The lineation of the Nipissis River and the Nipisso Lake map-areas reflects the direction of recrystallization of minerals and flowage of rock induced by stress

* Sander (1930,p.119): b is fold axis; a is perpendicular to b in the movement plane, and c is perpendicular to ab .

acting from the southeast. The development of foliation parallel to bedding and of lineation in the same plane is not clearly understood. Various factors have been emphasized as controlling the development of bedding foliation; some of these are listed below.

1. Initial anisotropism of the sediments.
2. Incipient recrystallization parallel to bedding under load or geothermal metamorphism.
3. Plastic flowage.
4. Development or rotation of slip surfaces parallel to bedding.
5. Rotation of bedding into the plane of axial cleavage.
6. Bedding acting as channels for escaping fluids.
7. Mimetic crystallization.

Any one or any combination of these factors may be the cause of foliation forming parallel to bedding. At present a lack of knowledge of the mechanical aspects of the problem and a scarcity of field and laboratory data prevent the writer from drawing any conclusions.

METAMORPHIC GEOLOGY

Present-day treatment of metamorphic petrology, and the one used by this writer, is based on the facies principle first applied by Goldschmidt (1911) and later elaborated by Eskola (1914). A mineral facies as defined by Eskola.

> " .... comprises all the rocks that have originated under temperature and pressure conditions so similar that a definite chemical composition has resulted in the same set of minerals, quite regardless of their mode of crystallization, whether from magma or aqueous solution or gas, and whether by direct crystallization from solution ----- or by gradual change of earlier minerals ...." (Barth,1952,p.330).

A mineral facies includes rocks of any chemical composition, and therefore a widely varying mineral assemblages which have reached chemical equilibrium during metamorphism under a particular set of physical conditions.

Eight metamorphic facies have been recognized by Eskola; these are shown in Table I.

Temperature Increasing →

Pressure Increasing ↓

			Sanidinite Facies
Green Schist Facies	Epidote-Amphibolite Facies	Amphibolite Facies	Pyroxene Hornfels Facies
			Granulite Facies
	Glaucophane Schist Facies		Eclogite Facies

TABLE #1 - Metamorphic Facies
(From Turner 1948, p.61, After Eskola 1939, p.344)

Minor but persistently recurring departures from the standard typical mineral assemblages, due to small differences in temperature and pressure have been used to define sub-facies.

The control of the mineralogical composition of rocks may be easily illustrated by the use of three-component triangular ACF diagrams*. Eskola bases his ACF diagrams upon the oxides Al_2O_3, CaO, $(Fe,Mg)O$. Special diagrams can be constructed to illustrate rocks with anomalous oxide percentages.

Chemical analyses show that twelve oxides are necessary for the development of minerals. Thus according to the mineralogical phase rule, twelve minerals may occur in equilibrium in a rock. Of the twelve oxides,

---

* The rules for preparation of an ACF diagram may be found in Turner (1948, p.57).

many play a limited role in the formation of minerals and can be neglected for practical purposes. In the Nipissis River and Nipisso Lake map-areas, petrographical study indicates that:

CO_2 - forms a carbonate

P_2O_5 - is used to form apatite

TiO_2 - combines with Ca and silica to form sphene; with FeO to form ilmenite; or it enters as a substitute oxide into biotite, garnet, or other minerals.

Fe_2O_3 - forms magnetite or substitutes limitedly for Al_2O_3 in some minerals.

SiO_2 - governs the degree of silication of the minerals and is always present in amounts sufficient to prevent the formation of undersaturated minerals such as spinel, corundum, etc.

Na_2O usually enters into the plagioclase but where the ratio CaO/Na_2O is very high, the Na_2O acts as an independent component and epidote may occur with plagioclase.

The amount of K_2O present in the rocks, whether it was present in the original rocks or introduced by migmatization, governs the formation of certain minerals and therefore the stable assemblages of minerals corresponding to the bulk composition of the rock. It was necessary to construct three ternary diagrams to graphically represent the effect of potassium.

If water is present in excess then hydroxyl-bearing minerals will form in the amphibolite facies. It appears that for the greater part of the paragneisses, water was present in sufficient amounts to permit the formation of amphiboles and micas. However, for a few sedimentary beds and for many igneous bodies, there was a deficiency or complete lack of water and thus for these rocks, water is an added component and a hydrous mineral phase can exist in equilibrium with a "dry" assemblage.

The remaining four oxides - Al_2O_3, FeO, MgO, CaO - are the most important oxides in the formation of the rock-forming minerals. FeO and MgO can be considered as interchangeable and thus treated as one oxide (Fe,Mg)O. However, it was found that almandine-biotite is a stable assemblage in some rocks with an excess of K_2O. The high ratio of FeO/MgO in almandine limits the extent to which biotite may replace almandine and magnesia-rich biotites can exist in equilibrium with almandine-bearing assemblages.

Application of the facies principle to the rocks of the Nipissis River and Nipisso Lake map-areas indicated that the bulk of the rocks contain mineral assemblages common to the amphibolite facies. Furthermore, the assemblages, sillimanite-almandine and hornblende-plagioclase-almandine, correspond to typical mineral groups of the sillimanite-almandine sub-facies.

Figures 3 and 4 illustrate stable mineral assemblages for rocks of the map-areas with an excess of K_2O and free of K_2O respectively. Figure 5 is an AKF diagram for rocks with excess Al_2O_3 and SiO_2, showing the effect of potassium on the stable assemblages. Rocks with no water or with a low water content are illustrated in Figure 6.

The following mineral groups corresponding to those of Figure 3, are found in stable equilbrium in the Nipissis River and Nipisso Lake areas:-

1. Sillimanite - biotite - plagioclase
2. Sillimanite - biotite - plagioclase - garnet
3. Sillimanite - biotite

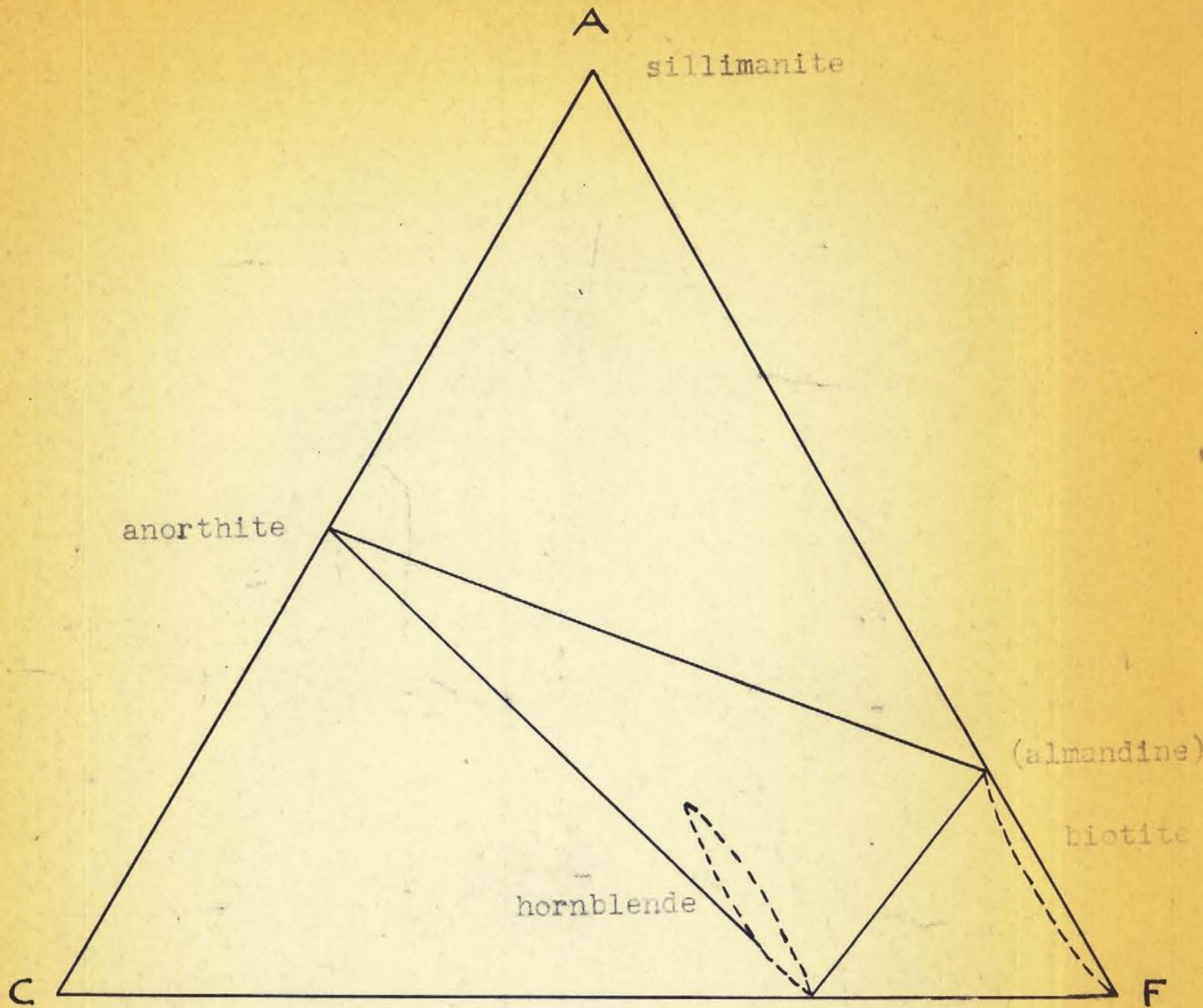

Figure 3. ACF diagram for rocks with excess K_2O.

4. Plagioclase - hornblende-biotite
5. Plagioclase - bornblende-biotite-garnet
6. Plagioclase - biotite - garnet
7. Plagioclase - biotite
8. Plagioclase - hornblende-biotite-epidote

SiO_2 and H_2O are present in excess so that quartz is a possible component of all the above assemblages and the hydroxyl-bearing ferromagnesian minerals are present. Microcline is also a possible mineral component.

Figure 4 illustrates the possible mineral assemblages present in rocks free of K_2O. This ideal condition of no K_2O in the rocks occurs frequently enough to justify the construction of a corresponding ACF diagram. However, many of the assemblages shown below may contain minor amounts of biotite as a result of a very limited amount of K_2O present in the rocks. SiO_2 occurs in sufficient amounts to form the saturated minerals but only occassionally free quartz appears. The following are stable mineral association found in the rocks of the map-region:-

9. Sillimanite-plagioclase-garnet
10. Plagioclase - hornblende - garnet
11. Plagioclase - hornblende - diopside
12. Plagioclase - diopside - epidote
13. Diopside - epidote - grossularite

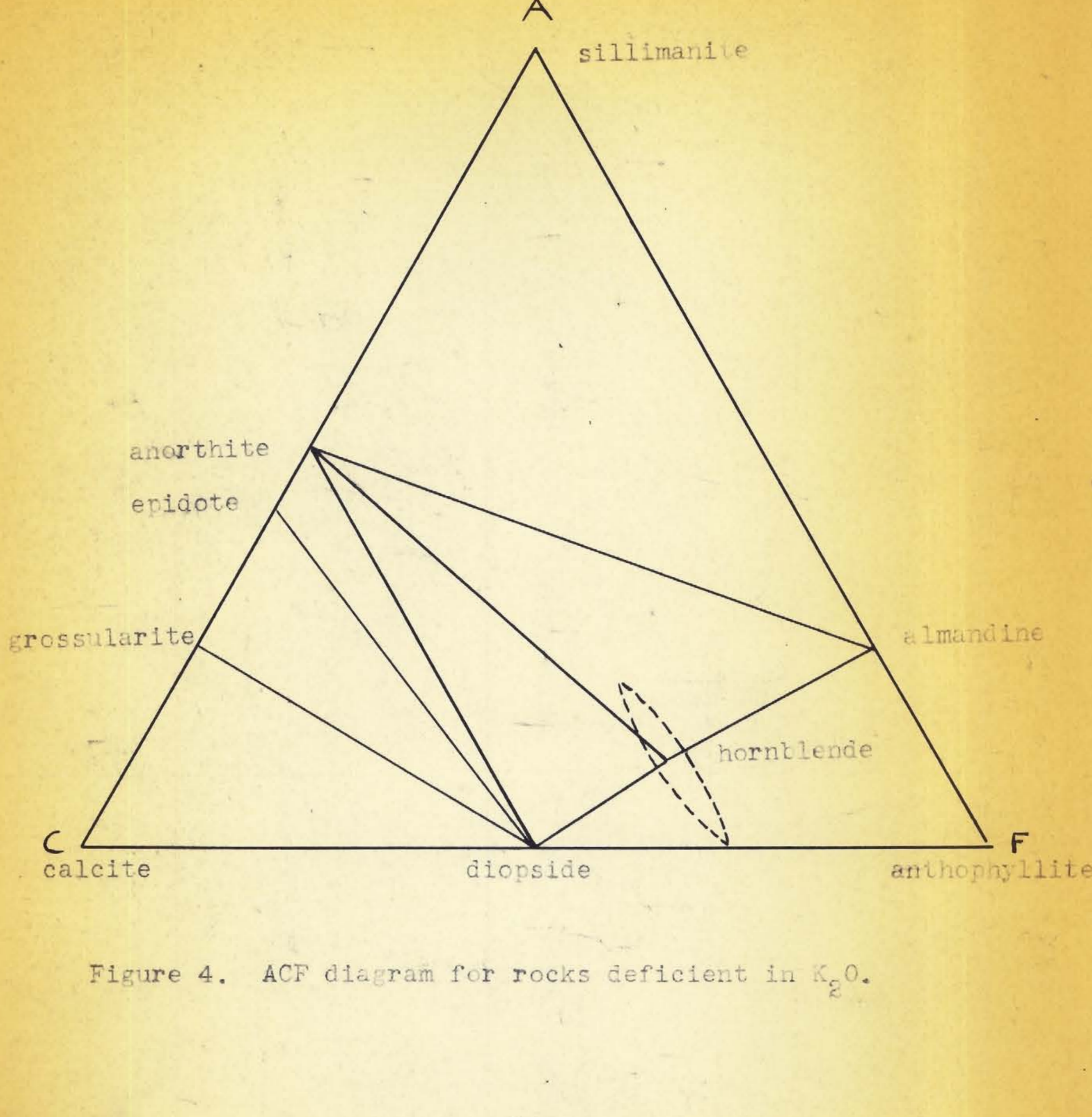

Figure 4. ACF diagram for rocks deficient in K_2O.

14. Plagioclase - hornblende
15. Hornblende - diopside
16. Diopside - epidote
17. Diopside - grossularite
18. Calcite - diopside

The presence of epidote, with or without plagioclase, as a stable mineral in some of the assemblages corresponding to Figure 4 is anomalous and requires explanation. Epidote is considered, by most petrologists, unstable in the amphibolite facies. Turner (1948, p.81) states -

> " Albite is stable over a wide range of physical conditions, but the extent to which CaAl may replace NaSi in the albite lattice is determined not only by the CaO content of the rock, but by the temperature and shearing stress at the time of metamorphism."

On page 84, Turner states -

> " In view of the restriction imposed by prevailing high shearing stress upon the lime content of the plagioclase, Na_2O, CaO, and Al203 may act as independant components and the maximum number of minerals that can exist in equilibrium in the presence of excess water is thereby raised ......".

The ability of epidote to take much ferric iron into its crystal lattice, may result in the necessity of considering ferric iron as a independent component and therefore a mineral containing this iron will be stable in some mineral assemblages of Figure 4. This may explain the association plagioclase (An90) - diopside - epidote. Similarly H_2O may act as an independent component and a hydrous calcium silicate (epidote) could exist in equilibrium with plagioclase.

Figure 5 shows the stable mineral associations for rocks with excess SiO_2 and Al_2O_3, whether deficient in K_2O or otherwise. Plagioclase, quartz, and microcline are possible members of the assemblages. Corresponding stable mineral associations in the rocks of the Nipissis River and Nipisso Lake areas are:-

19. Sillimanite - biotite - muscovite - plagioclase
20. Biotite - muscovite - plagioclase
21. Cummingtonite - biotite - plagioclase
22. Anthophyllite - plagioclase.

Barth (1952, p.343) states -

> " In rocks showing insufficient K_2O relative to Al_2O_3, for the formation of mica, one or two of the following minerals occur: andalusite, cordierite, anthophyllite (or cummingtonite). The amount of these minerals in relation to mica is determined by the amount of K_2O.....".

Barth does not explain this statement. It seems logical to suppose that in rocks containing plagioclase, hornblende would form in place of anthophyllite. In the rocks of the map-region, the association anthophyllite-plagioclase is found in a dyke; cummingtonite-plagioclase

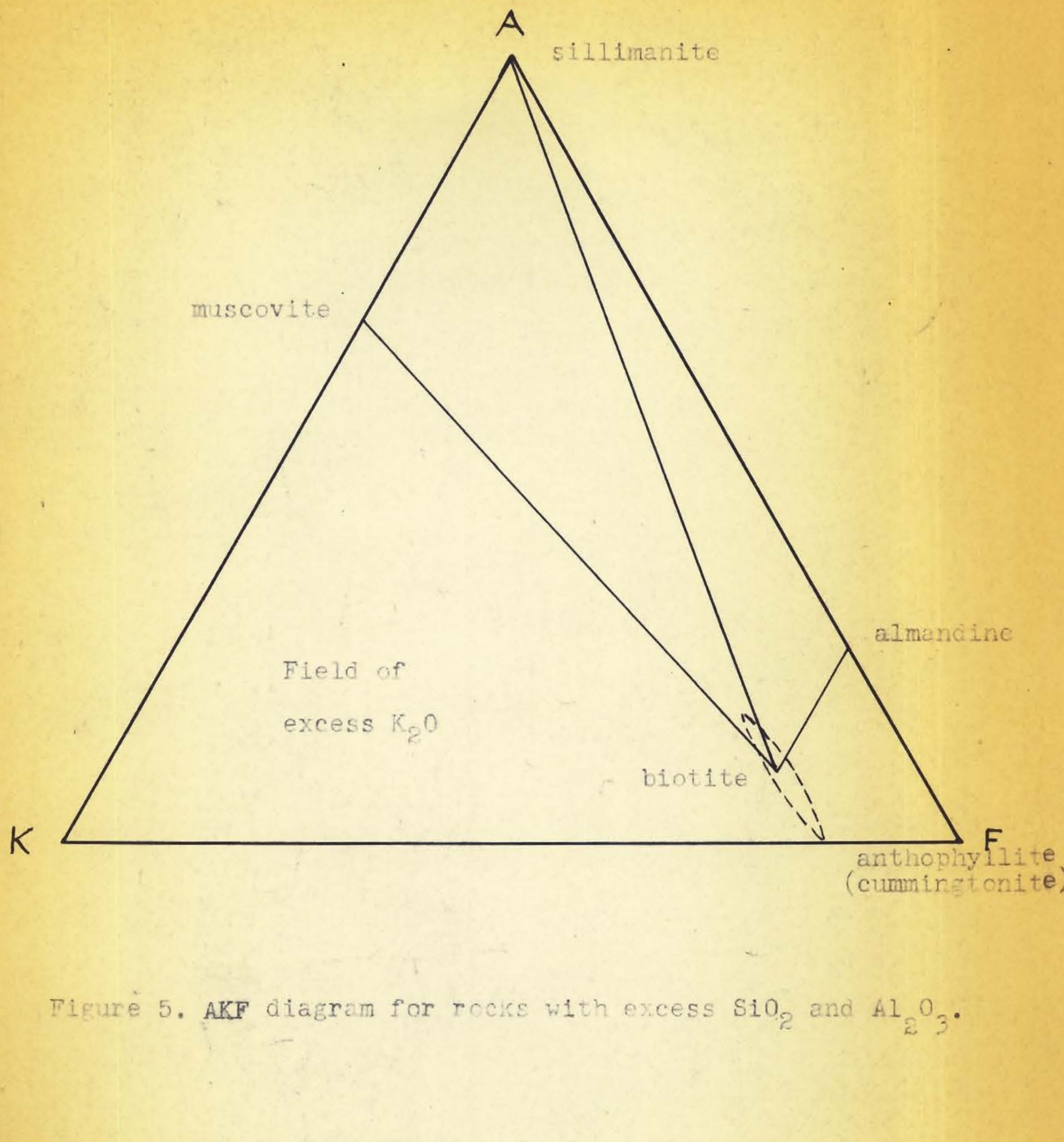

Figure 5. AKF diagram for rocks with excess SiO_2 and Al_2O_3.

quartz is found in a metasedimentary rock. In the first assemblage, anthophyllite is pseudomorphous after pyroxene and the amphibole is derived from a magnesian pyroxene without any reaction with the plagioclase. The second assemblage is due to progressive metamorphism and the formation of cummingtonite appears to be the result of the high MgO/CaO ratio of the original sediment. Yoder (1951, p.56) claims that the formation of anthophyllite does not take place in an environment of excess water. Thus a high magnesium content, a low water content or a combination of the two may be the necessary requirements for the formation of magnesian amphiboles. This condition is seldom encountered in the Nipissis River - Nipisso Lake map-region as anthophyllite and cummingtonite are rarely seen.

The effect of a deficiency of water is illustrated in Figure 6. Stable assemblages observed in the rocks of the map-region are:-

23. Hypersthene - garnet - plagioclase
24. Plagioclase - hyperthene - diopside
25. Plagioclase - hypersthene - diopside - hornblende
26. Plagioclase - garnet
27. Plagioclase - hypersthene
28. Hypersthene - diopside

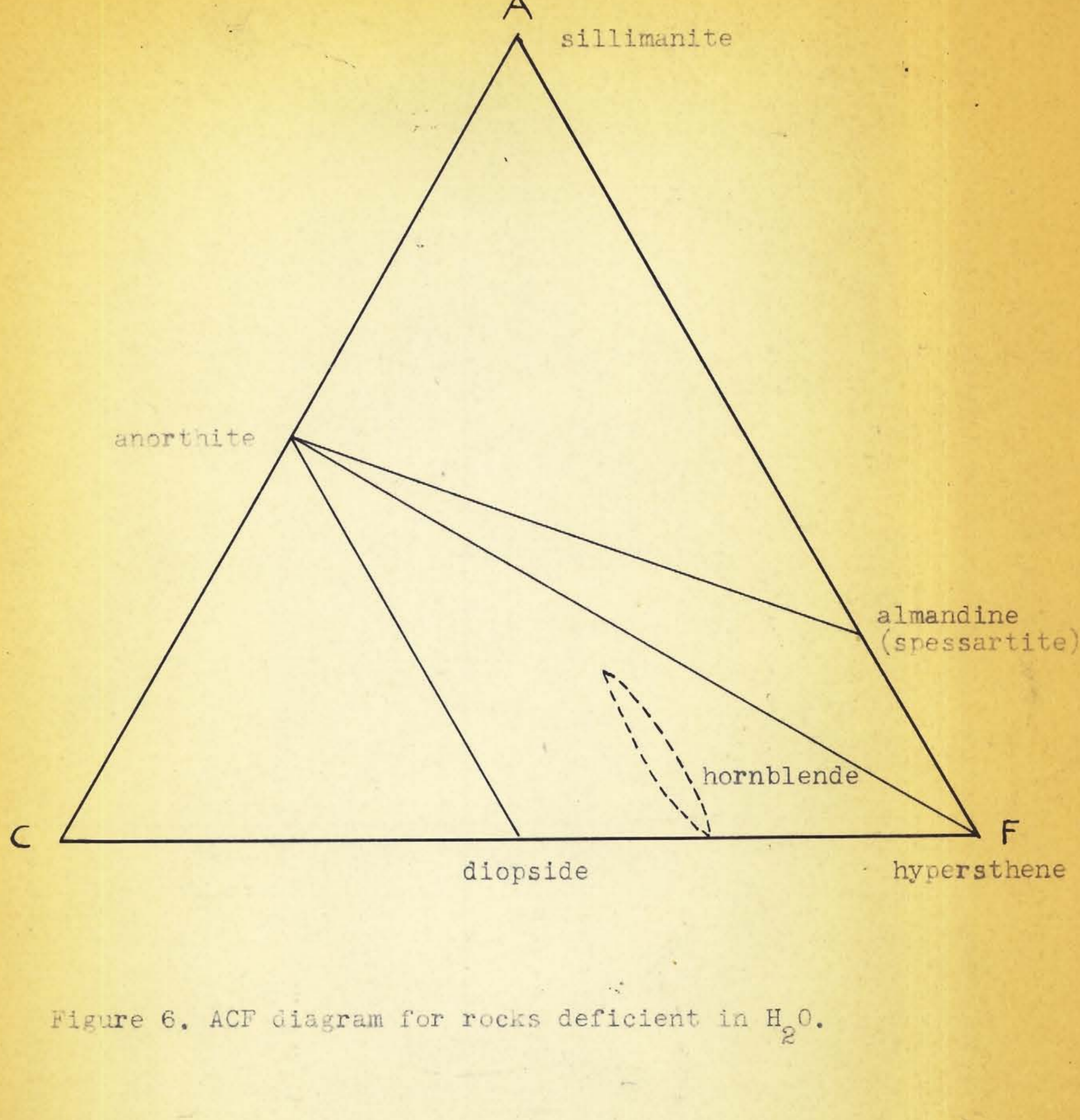

Figure 6. ACF diagram for rocks deficient in H_2O.

29. Hypersthene - garnet

30. Hornblende - hypersthene - diopside

A high content of MnO in the hypersthene gneisses allows spessartite to form in these rocks; usually almandine - pyrope is the stable garnet. As water constitutes an independent component in the system, hornblende can exist in equilibrium with hypersthene and diopside.

It is noted that the typical mineral assemblages, plagioclase - hornblende and plagioclase - biotite, are found in all parts of the map-region. The occurrence of these assemblages suggest that temperature-pressure conditions were uniform for all parts of the region and that differences of mineral associations results from different chemical compositions of the rocks. Of prime importance were the amounts of K_2O and H_2O in the rocks. The effect of shearing stress cannot be evaluated but it appears that at the great depth of burial (in the zone of flowage) the role of directional pressure, in the development of stable minerals, may be negligible.

Comparison of the ACF diagrams of Eskola, Barth, and Turner with those of this paper show that the sillimanite - almandine sub-facies of the amphibolite facies is represented by the mineral assemblages of Figures 3,4, and 5. Figure 6 corresponds to the granulite facies of these writers. These petrologists emphasize that the temperature-pressure conditions are higher in the granulite facies than in the amphibolite facies and that the former must be considered as a separate facies. This view is not shared by the writer who believes that mineral assemblagies corresponding to the granulite facies may be stable in the amphibolite grade of regional metamorphism if the rocks are deficient in H_2O.

Most writers agree that water plays a part in metamorphism but most relegate it to a secondary or subordinate role in the formation of stable minerals. Harker (1936, p.16) recognizes that the chemical action of water is essential in the formation of minerals of metamorphism but that its prime function is as a solvent. Turner * (1935) claims water must be treated as an independent component and recognizes that under similar thermodynamic conditions different sub-facies may develop according to the amount of water present. However, in a later publication (1948,p.51) he states:-

> "The appearance of orthoclase and pyroxenes in place of muscovite and hornblende respectively, is usually attributed to higher temperature of metamorphism rather than to a less aqueous environment."

---

* A view shared by Vogt (1927, p.516) and Eskola (1939, p.316).

Barth (1936, p.822) expressed a contrary view, namely that the presence of hydroxyl-bearing silicates is determined by an aqueous environment as opposed to a "dry" metamorphic environment. Recently Yoder (1951) demonstrated that some minerals are not stable in the presence of an excess of water vapour and suggested that some metamorphic facies result not from changes in temperature but from changes in the amount of water vapour.

Thus it can be seen that Vogt, Eskola, Turner, and Harker recognize that water is important in the formation of metamorphic minerals but that it is overshadowed by the effect of temperature and pressure.

The writer is of the opinion that if thermodynamic conditions are uniform throughout an area, the presence of amphiboles or pyroxenes in different rock types is determined by the amount of water present during the formation of these minerals. In most of the metasedimentary gneisses water is present in excess and hydroxyl-bearing minerals will be formed. In the gabbroic bodies, meteoric water was lacking and at the high temperatures and pressures of the amphibolite facies, the original "dry" mineral assemblages were stable. Usually narrow sills and dykes and the marginal part of the larger bodies, contain hornblende as the stable ferromagnesian in place of pyroxene. This suggests that the H_2O of the surrounding rocks was able to migrate, for short distances, into the igneous rocks.

If, locally, mineral assemblages corresponding to the granulite facies are found in areas where the regional metamorphism is of the amphibolite grade, it does not necessarily follow that the temperature-pressure conditions were different in these localities. Where these apparently "higher" grade rocks are completely surrounded by rocks of the amphibolite facies, it is more proable that temperature-pressure conditions were uniform throughout the region and that the amount of water in the rocks was variable.

The variations in the mineral assemblages can be treated solely from the viewpoint of differences in the bulk chemical composition of the rocks. These differences can be attributed to different original compositions of both the igneous and sedimentary rock groups and in part to the addition of material by migmatization. The granitic, gabbroic, and paragneissic rocks contain mineral assemblages stable under the conditions of high grade regional metamorphism. These conditions are:-

1. High temperature
2. High pressure (hydrostatic)
3. Differential water content.

The chemical analyses and the norms and modes of two rock types, one pyroxene-bearing and the other amphibole-bearing, are shown in Tables 2 and 3, respectively. The rocks are part of the norite mass that outcrops around Tchinicamas Lake. The shape of the amphibole grains, pseudomorphous after pyroxene, and the occurrence of relict pyroxenes strongly suggests that the original rock was norite and that subsequently it has been altered to amphibolite.

Comparison of the chemical analyses shows that the change from norite to amphibolite has resulted in a gain of 1.23% of CaO, 0.69% of MgO, and 1.15% of H_2O (+105°) and a loss of 3.02% of SiO_2 and 0.63% of FeO. Other differences in chemical composition are very small and will not be considered in this work. The gain and loss of MgO and FeO are so similar that perhaps it can be attributed to differences in the original composition of the two rocks rather than to an introduction and loss of MgO and FeO respectively. Thus the major changes are in the amounts of CaO, H_2O, and SiO_2.

The writer earlier postulated (pp. 104-5 of this thesis) on a theoretical basis, that the change from pyroxene to amphibole during high grade regional metamorphism is dependant mainly on the introduction of water. This concept is supported by the chemical analyses

TABLE 2

Chemical analyses of norite and amphibolitized norite.

	G-26	GH-171
SiO_2	51.32	48.30
TiO_2	1.37	1.26
Al_2O_3	15.71	16.05
Fe_2O_3	1.59	1.64
Fe O	9.78	9.15
Mn O	0.20	0.21
Mg O	6.83	7.52
CaO	8.70	9.93
Na_2O	2.80	2.68
K_2O	.80	0.80
P_2O_5	0.24	0.22
H_2O+	0.72	1.87
H_2O-	0.03	0.03
$C O_2$	0.11	0.06
S	0.08	0.08
CR_2O_3	0.03	0.04
V_2O_3	0.01	0.03
Ni O	0.01	0.01
Ba O	0.04	0.03
Sr O	0.01	0.02
Cu O	0.01	0.01
U_3O_8	0.002*	0.001*
TOTAL	100.36+	99.91+
Sp. Gr.	2.999	3.020

* Uranium oxide (U308) equivalent according to beta radiation.

\+ Less 0.03 for O = S

G - 26 - Norite from Tchinicaman Lake. Analysist M. Archambault

GH - 171 - Amphibolitized norite from one mile south of Lorna Lake. Analysist M. Archambault.

TABLE 3

Norms and modes of norite and amphibolitized norite.

NORMS

	G-26	GH-171
Quartz	.42	
Orthoclase	4.45	4.45
Albite	23.58	22.53
Anorthite	28.08	29.47
Diopside	10.42	14.56
Hypersthene	26.70	10.02
Olivine		11.32
Magnetite	2.32	2.32
Illmenite	2.58	2.43
Pyrite	0.12	0.12
Apatite	0.67	0.67
Calcite	0.20	0.10
An Content	An 55	An57

Approximate MODES

	G-26	GH-171
Plagioclase	49.4	38.2
Augite	21.1	) 2.4
Hypersthene	15.0	)
Hornblende		58.6
Biotite	12.4	
Illmenite	1.2	1.7
Apatite	0.8	+
An Content	48	46

which show an increase in the amount of H_2O in the amphibolite. The loss and gain of SiO_2 and CaO respectively in a rock is what may be expected when pyroxene is changed to amphibole, if the associated plagioclase remains unchanged and the oxides are free to migrate. However, in a system where there has been no loss or gain of material, except H_2O, the CaO of the newly-formed hornblende is supplied by the plagioclase and the excess SiO_2 produced by the change of pyroxene to amphibole is utilized by the more albitic feldspar. Thin-section study shows that the anorthite content of the plagioclases in the amphibolites of the Nipissis River and Nipisso Lake map-areas is lower than that of the plagioclases in the gabbroic rocks. This supports the theory that the change -

pyroxene + plagioclase (high An) --- amphibole + plagioclase (low An)

requires only the introduction of water. If water is absent, pyroxenes are stable in the amphibolite facies.

GENESIS OF THE ROCK TYPES

One of the main problems of the petrology of a highly metamorphosed terrain is to determine the original rock types that are now represented by schists and gneisses. Furthermore, the granitic or gabbroic rocks may also have originated in several different ways.

The presence of textural or structural features characteristic of sedimentary or igneous rocks is usually sufficient proof of the origin of the unknown rock type. Comparison of the chemical analysis of a rock with analyses of rocks of known origin may indicate whether it is of a sedimentary or igneous origin. However, similarity of chemical analyses does not conclusively prove that two rocks have a common origin. Some minerals such as sillimanite, calcite, graphite, etc., indicate an anomalous concentration of certain oxides, which may be diagnostic of a primary* rock type. Finally, field relationships of the rocks and similarity to rocks in other areas aid in determining whether a rock is of sedimentary, intrusive, or extrusive igneous origin.

The origin of rocks similar to those of the Nipissis River and Nipisso Lake areas has been discussed by many workers in the Grenville province of Canada and the United States and in other regions of high grade

* As opposed to secondary or metamorphic.

regional metamorphism. Some of the papers examined are: Adams (1896, 1909), Adams and Barlow (1910), de La Rue (1948), Buddington (1931, 1939), Claveau (1950), Faessler (1930,1931,1933), Groves (1935), Holland (1900), Osborne (1935a, 1935b, 1936a, 1936b,1936c,1938), Tilley (1921a,1921b), Wilson (1916,1920).

Paragneisses

The gneisses and schists that have been described as Grenville-type are believed to be derived by metamorphism of sedimentary rocks. The mineral assemblages found in the paragneisses have been produced from the original composition of the sediments and only locally the addition of granitic material (K, Na,Si) has affected the recrystallization. No evidence indicating the addition of the elements Ca, Mg, Fe, and Al has been found in any of the rocks although some of the narrow layers containing a very high percentage of amphibole may have been formed in this way.

Metamorphic differentiation is another process which tends to change the composition of the rock from its original composition. It involves an exchange of material from one rock type to another, with a resultant increase in the stable components in each. In the paragneisses of the map-areas, metamorphic differentiation appears to have been negligible. The occurrence of bands, one eighth of an inch thick, identical in mineral composition to bands many feet thick and the remarkable uniformity of these narrow bands over tens of feet is rarely found in rocks formed by metamorphic differentiation. Furthermore, thick bands of biotite gneiss show a fairly uniform distribution of the mineral components which would not be expected if differentiation had been active.

Original textures and structures have been completely destroyed. In many places a pseudo-bedding or stratification can be seen in the quartzite and in quartz-rich biotite gneisses. It is particularly clear where between successive quartzitic bands, there are narrow layers of dark biotite or hornblende schist, representing original shaly partings in the sandstone. All gradations between pure quartzites and biotite-rich gneisses were observed in the field. The quartzites are undoubtedly of sedimentary origin and it is logical to assume that the associated biotite gneisses represent impure sandstones. The probable sedimentary equivalent of some of the metasedimentary rocks are as follows:

biotite gneiss ----------------	sandstone
sillimanite gneiss ------------	clay
biotite schist ----------------	potassic shale
hornblende schist -------------	dolomitic shale
amphibolite -------------------	marl
diopside-epidote gneiss --------	calcareous shale
graphite gneiss ---------------	carbonaceous shale
hornblende gneiss -------------	greywacke, dolomitic shale, or tuff.

An extreme in chemical compsosition is represented by the hypersthene gneisses that are interlayered with quartzite. Banding similar to that of the other metasedimentary rocks and its considerable areal extent indicate that these gneisses are of sedimentary origin. The hypersthenic layers have a high content of Fe, Mg, and Mn. The association of silica-rich and iron-rich layers is characteristic of banded iron-formations.

In the type locality of the Grenville series, near the village of Grenville, Quebec, limestone, sillimanite-garnet gneisses, and quartzites are abundant. Minor amounts of hornblende gneiss and amphibolite are also present. These rock units are found in nearly all parts of the Grenville province, although the relative percentages of the rocks are extremely variable. The metasedimentary rocks of the Nipissis River and Nipisso Lake map-areas are similar to those in other parts of the Grenville province and can be considered as Grenville-type.

Granites

The origin of granite is a highly controversial subject and much has been written on the genesis and mechanics of formation of these granitic rocks. In this paper, the data on the mode of emplacement of the granitic rocks of the Nipissis River and Nipisso Lake areas will be examined and discussed.

Augen Gneiss

The large phacolithic-shaped body of augen gneiss has the mineral composition of a granite. Examination of numerous outcrops gave the writer the impression that the augen gneiss is uniform in composition. Appreciable variations in mineral composition were observed only near the upper and lower contacts. At a few localities in the Nipisso Lake area garnets are present in the augen gneiss, along the lower contact, indicating some assimilation of paragneissic material. This contact was examined in the Nipisso Lake area and at one place west of Irene Lake and found to be remarkably abrupt. Inclusions are rare and the adjacent sedimentary rocks are locally, slightly migmatized. Near the east border of the Nipisso Lake area, the augen gneiss contains two large inclusions of paragneiss. These inclusions may have formed by magmatic stoping or by some process of injection whereby the magma penetrates the surrounding rocks, by-passing and isolating the large blocks or inclusions.

The upper contact along the Nipisso River is marked by a complex zone of various rock types amongst which contaminated granite and migmatite predominate. Along the Nipissis River the contact is more abrupt and only locally a narrow migmatite zone is developed, Near the Nipisso River in the Nipisso Lake area, the augen gneiss contains rectangular phenocrysts of feldspar and resembles a porphyritic granite.

Available evidence indicates that the augen gneiss was injected into the country rocks as a porphyritic granite. This injection was accomplished by forcibly moving the beds aside and partially by some process akin to magmatic stoping. The temperature of the granite was not high enough to melt or assimilate the large inclusions. Volatiles, carrying alkaline elements and silica, concentrated near the upper part of the massif, and the outward migration and deposition of this material formed migmatites in the overlying rocks.

Although the granite appears to have been injected into the country rock, it does not necessarily follow that the writer postulates a magmatic source for the rock. Whether the granite is a differentiation product of a magma or a product of refusion of sedimentary rocks at depth is unknown. If the granite is palingenetic, it must have been in a molten or semi-molten state to eliminate the primary structures of the original rocks and to allow complete interchange of the oxides in order to obtain a fairly uniform composition.

Biotite and Hornblende Granite

Stocks of biotite and hornblende granite intrude the paragneisses and the augen gneiss. Contacts are sharp and transgress the trend of the enclosing rocks. The large stock of biotite granite in the Nipissis River area has pushed aside the augen gneiss and the gneissic structure of the latter rock parallels the contacts. In the Nipisso Lake area, the gneissic structure of the older granite is generally at a sharp angle to the contacts with the biotite and hornblende granites. Locally the gneissic structure is parallel to the adjacent contact.

The lineation and gneissic structure of the hornblende granite parallels that of the enclosing rocks and this indicates that intrusion of the granite took place prior to the close of the regional deformation. The biotite granite does not have a gneissic structure and presumably was intruded after the deformation.

These younger granite bodies are the products of a granitic magma that probably formed, at depth, by melting of the granite gneiss during regional metamorphism.

The association of young granite stocks with older granite gneisses has been described by Eskola (1949) and E. Cloos (1940). Eskola (P.470) attributes the formation of the younger rocks to granitization but does not discuss the source of his granitic material. Apparently he does not obtain it from the older granite as it has undergone granitization by fluids from the young granite magma.

Migmatites

In the Nipissis River and Nipisso Lake map-areas, evidence supports the presence of different ages of migmatization associated with the three main types of granite. Each granite body is surrounded by an aureole of migmatites, the widest around the biotite granite and the narrowest around most of the augen gneiss. All three zones of migmatites show similar mineral characteristics; potash feldspar, quartz, and some plagioclase have been added to the rocks. The appearance of pink feldspar in the non-granitic rocks was used, in the field, as an indicator of the presence of introduced material.

The reaction of the host-rocks to the granitization fluids depended primarily on their structure and texture and secondarily on their mineral composition. Where the country rock has a strongly developed planar structure, such as foliation, the granitic material occurs in numerous thin sheets parallel to the foliation. The sheets may be bounded by sharp contacts but usually they are zones from which there has been diffusion of material into the adjacent rock. Locally dykes or veins of granite are found. In the more massive amphibolites and gabbros the granitic material is introduced as veins and dykes cutting the host-rock in a variety of directions. Usually the host rock adjacent to these veins is coarser in grain size, indicating that it has recrystallized. In the more massive rocks, porphyroblasts of feldspar are common.

The migmatitic aureole around the upper contact of an intrusive body is wider than that around the lower. This is especially true of the augen gneiss as migmatites are strongly developed along part of the upper contact and are absent along the lower. Furthermore, inclusions of paragneiss in the lower and central part of the augen gneiss east of Nipisso Lake are only slightly migmatized.

The minerals introduced by migmatization are predominantly potash feldspar (microcline) and quartz. The introduction of potash has a very definite effect on the amphibolites and hornblende gneisses. The borders of these rock bodies and those parts that are adjacent to granitic veins or dykes contain a greater percentage of biotite than the normal rock. Hornblende reacts with potash and perhaps with sodium to form biotite.

The greatest development of migmatite is adjacent to granite contacts but locally in the belt of paragneisses, outcrops of migmatite are found far from any known granite. It was noted that pegmatitic dykes were usually abundant in the migmatite outcrop or in adjacent outcrops.

The genesis of migmatites has received widespread attention and many theories on the origin of these rocks have been advanced by different writers. The development of the various theories appears to have been influenced by the type of migmatite that was examined.

The three main theories of origin are as follows*:

1. Development by injection of magma.
2. Development by magmatic soaking.
3. Development by differential fusion (in situ).

Within the map-region migmatites derived by forceful intrusion of granitic material are of limited development. Some aplitic or pegmatitic dykes and sills as narrow as half an inch are found in the amphibolites and more rarely in the paragneisses. Migmatites formed by differential fusion may occur locally but the association of the mixed rocks with granitic bodies or pegmatitic dykes weakens any support of this theory.

Most of the migmatitic rocks of the Nipissis River and Nipisso Lake map-areas show structures and textures incompatible with forceful injection. The distribution of the granitic material indicates that there was an intimate penetration of the macro-and micro-structural openings of the invaded rock and that the transfer of material was affected in a fluid medium (water) derived mainly from the granite and partly from the country rocks. The width of the migmatite aureole would be dependent upon the amount of water given off by the granitic body and by the ease with which the solutions could penetrate and soak

* The names of the leading exponents of the various theories may be found in Turner (1948), pp. 304-311.

the host rock. The tendency for the solutions to rise or to move into zones of lower pressure accounts for the lack of migmatites along the lower contact of the augen gneiss. The paragneisses with a well-developed foliation would tend to be completely saturated, whereas the more massive amphibolites, with a much lower porosity and permeability, would tend to resist the invasion of the granitic solutions.

Turner (1948, p.311) agrees with Eskola in postulating that the active liquids are essentially magmas (silicate melts rich in water) rather than aqueous solutions. This view is not shared by the writer as silicate melts could not produce or retain the textures and structures of the migmatites in the Nipissis River and Nipisso Lake map-areas. The intimate mixture of rock types (host and guest) without destruction of any of the original structures of the paragneiss and the occurrence of isolated porphyroblasts of feldspar in the host rocks can be explained only by penetration by and deposition from a fluid of extremely low viscosity. Many writers insist that these characteristics can be explained by ionic migration of the elements throughout the host rock with or without the aid of an intergranular fluid medium. Others contend that the temperature-pressure conditions of the depths at which migmatites are formed are such that water can exist only in the gaseous state and as the solvent properties of a gas are so low, it would be impossible to obtain sufficient quantities of water to account for the amount of granitic material deposited from a gaseous solution. The validity of this statement is now questionable as Smith (1953) found that water retains its solvent properties for all temperature-pressure conditions existing below the earth's crust. Thus water has the solvent powers required to transport the large amounts of granitic material and the low viscosity to move without restriction into any available openings in the rock.

In place of a silicate melt rich in water the writer believes that migmatization is accomplished by aqueous solutions carrying potassium, sodium, and silicon.

The formation and deposition of the granitic minerals is governed by physical-chemical conditions prevailing in the solutions and in the rocks; the thickness of each deposit is depended upon the ease with which new material can be brought in. Foliation, fractures, or any other planes that have a high permeability should be the loci of deposition for the greatest amount of granitic material. In rocks near the contact, the large amounts of available material would utilize any and all such planes and also any other openings in the rocks; at greater distances from the contact only the more select planes would contain granitic minerals.

Although these planes may allow passage of the granitic solutions, it does not necessarily follow that deposition would take place along all these planes. Precipitation and deposition of granitic material from the solutions would be governed by the degree of concentration of the various elements in the fluids, by the existing temperature and pressure conditions, and by the nature of the enclosing rock. For any small locality near a granitic contact the first two factors would be uniform and the structure and concentration of the granitic deposit would depend on the porosity, permeability, and chemical composition of the enclosing rock.

In the paragneisses, where porosity and permeability are high, only the foliation planes would present a surface of nearly uniform composition as all other planes would encounter bands of variable composition. Thus, if any one type of band contained precipitating agents, then the greatest deposition of material would be adjacent to these bands. This explains why the bands of granitic material tend to follow the foliation of the rock rather than to occur as crosscutting dykes. In the amphibolites and gabbros, porosity and permeability are low and the best openings are along fractures and shear planes. Deposition of the introduced material would take place in these openings and the rock would be crisscrossed by granitic dykes.

Moisie Series

The hypersthene-bearing rocks of the Nipissis River and Nipisso Lake map-areas include norite, gabbro, diorite, and minor amounts of hornblendite, pyroxenite, and hypersthene granite. Norite and gabbro are the most abundant rock types. The compositions of these two rock types are similar but the percentages of the minerals are different. A combination of the two rocks would have a mineral composition corresponding to that of hyperite.

The textures, structures, mineral associations, and modes of occurrence of the hypersthenic rocks indicate that they are associated and have a common origin. These rocks are similar to charnockitic rocks of India, Norway, and northeastern United States. Most petrologists agree that the charnockitic suite of rocks are of igneous origin but some think that the present assemblage of minerals has been formed by crystallization from a magma and others think that they have formed by recrystallization during metamorphism. Buddington (1939,p.229) summarizes the theories of origin as follows:

> " ..They have been explained as a comagmatic series of igneous rocks with a primary gneissic and granulitic structure as a result of deformation before complete consolidation with some superimposed dynamo-metamorphism at high temperatures (Holland, 1900), as primary crystallizations from a relatively dry magma (Goldschmidt 1922, p. 9), as plutonic igneous rocks of the usual characters which have undergone slow recrystallization in the solid state on being subjected to conditions of plutonic metamorphism (Tyrell, 1926), as the product of the assimilation of argillaceous sediments (J.W. Evans), and as an abnormal igneous rock type formed by reaction of granitic or acid magma with metadolerite or metagabbro under deep-seated conditions (Lebedev, 1937)."

Barth (1952,p.233) appears to favour a metamorphic origin and refers to the mineral changes observed by Groves as partial proof of this theory; he states that there is no reason why such changes would not take place if plutonic rocks were subjected to the "dry" heat and pressure of the depths of the crust. Groves (1935) claims that the reactions in his rocks are -

biotite ---- hornblende --- augite --- hypersthene.

The writer found the reverse to be true in the rocks of the Nipissis River and Nipisso Lake map-areas. The "dry" heat invoked by Barth is misleading. The amount of water in the rocks will remain the same if there are no channels of escape; it will increase if water is introduced during metamorphism. It has been shown in the section on metamorphic geology that wherever water could be added to the gabbroic rocks, the assemblage hypersthene-augite is unstable and is replaced by hornblende.

From the evidence available, the mineral assemblages of the Moisie series are the result of magmatic differentiation of a dry hyperitic melt. Subsequent regional metamorphism has imposed the present textures and structures. Local variations in mineral composition and texture exist and in no way invalidate the above theory.

The origin of the magma is in the realm of speculation. The theory of the origin of the Moisie series is applicable whether the magma is derived from a basaltic sub-stratum or from palingenesis of pre-existing rocks.

Parts of the Grenville province, near the original area in Grenville Township, have been mapped by Wilson and Osborne. In these map-areas hypersthene-bearing rocks, similar to those of the Moisie series, are well-represented. Wilson (1924) gave the name "Buckingham series" to these rocks and considered them the oldest intrusive rocks in the area. Osborne (1936b) considers the hypersthenic rocks as part of the Morin series* and that they are younger than the Trembling Mountain gneiss. Both Osborne and Wilson base the age relationships on pyroxenic inclusions in the Trembling Mountain gneiss. Wilson correlates the inclusions with the Buckingham series and Osborne interprets the inclusions as metamorphosed sediments. Adams (1895) described pyroxene granulites and pyroxene amphibolites similar to the norite of the Nipissis River and Nipisso Lake map-areas and called them the oldest intrusive rocks of the Grenville area.

Keating (1937) mapped pyroxenic rocks similar to those of Adams, and found them to be older than the Trembling Mountain gneiss. They are cut by a gabbroic dyke that he assigns to the Morin series. He also assigns the Morin series to a later period of intrusion than the Trembling Mountain gneiss although he has no definite evidence on which to base his relationship. Keating's conclusions on the ages of the pyroxene granulites, Trembling Mountain gneiss, and Morin series appear to be based on the gabbro dyke cutting the pyroxene granulites. The mineral composition of this dyke is unknown and even if it contains hypersthene, the possibility exists that it belongs to a late phase

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* In addition to the hypersthenic rocks, the Morin series includes comagmatic granites, slightly younger than the hypersthenic rocks.

of the magma that produced the hypersthenic rocks of that area. From this consideration, the hypersthene-bearing rocks could be of the same age and older than the Trembling Mountain gneiss. Buddington (1939) finds that the anorthositic-gabbroic rocks of the Adirondacks are the earliest intrusives. The concept of a granite older than hypersthene-bearing igneous rocks of the Grenville province although widely held, has not been conclusively proven.

SUMMARY AND CONCLUSIONS

The boundary between the Nipissis River and Nipisso Lake map-areas, lies approximately 50 miles northeast of Seven Islands, a town in Quebec on the north shore of the St. Lawrence River. The Quebec North Shore and Labrador Railroad which will join the iron deposits of Burnt Creek with the seaport of Seven Islands traverses the two areas from north to south.

Physiographically the two areas are part of a plateau that has been deeply dissected by the Nipissis, Wacouno, and Nipisso Rivers and by the valley of Nipisso Lake. The upland has a rugged to rolling topography with the most rugged parts underlain by strongly-jointed norite. Small lakes are abundant. Glacial erosion during Pleistocene times has oversteepened the walls of the Nipissis-Wacouno valley and smoothed and polished the rocks of the upland. Unconsolidated sand, gravel, and till, derived from the Pleistocene glaciers is abundant in the Nipissis-Wacouno valley and in the northern part of the Nipisso Lake area.

The rocks of the Nipissis River and Nipisso Lake map-areas consist mainly of granite, basic intrusives (Moisie series), and metamorphosed sediments. Quartzo-feldspathic gneisses are the most abundant rock types of the metamorphosed sediments which also include schists, amphibolites, and quartzite. The Moisie series includes, in decreasing order of abundance, norite, gabbro, diorite, hornblendite, pyroxenite, and granite; they are characterized by the presence of the ortho-pyroxene, hypersthene. Granite gneiss, with an augen texture, is found as a phacolithic-shaped body out-cropping in both map-areas. Two younger granites, containing biotite or hornblende, occur as stock-like bodies. All of the granites have a high potassium content.

In the Nipissis River map-area the structural trend is northeast and in the Nipisso Lake map-area, the trend of the rocks is east. The dips of the foliation, schistosity, and gneissic structure is southward at an average angle of 45 degrees. The regional strike of the rocks is northeast. The easterly trend in the Nipisso Lake area reflects the outline of the lower contact of the augen gneiss. This contact is lune-shaped; west of the Nipissis River area it trends northward and from the west border of the Nipisso Lake area to Nipisso Lake, it strikes east, on the east side of the lake it swings to the northeast.

Lineation, interpreted as in "a", trends east of south and plunges at an average angle of 30 degrees southward. Several shear zones, trending northeast, were seen in areas underlain by gabbroic rocks; elsewhere the high degree of recrystallization effectively conceals any faults or shear zones that may have formed before or during the regional deformation.

All the rocks of the area, except the diabase dykes, have undergone high grade, regional metamorphism corresponding to the sillimanite-almandine sub-facies of the amphibolite facies. The roles of the various oxides in the formation of stable mineral assemblages are graphically shown in a series of ACF diagrams. The presence of pyroxene-bearing assemblages, normally unstable in the amphibolite facies, is explained as due to the lack of water in the rocks rather than to different temperature-pressure conditions.

Recalculated chemical analyses of the Grenville-type metasedimentary rocks indicate that the gneisses and schists have been derived mainly from sandstones and shales containing variable amounts of potassium, aluminum, magnesium, calcium, and iron. The intrusive igneous rocks that form the Moisie series appear to have been derived by differentiation of a "dry" hyperitic magma. The granitic rocks have the characteristics of intrusive igneous bodies. The source of the granitic material is uncertain but the biotite and hornblende granites may represent re-melted and re-injected parts of the augen gneiss.

In view of the close association of the migmatitic zones with granite bodies, the granites are thought to be the source of the granitic material in the migmatites. The development of the migmatites in the Nipissis River and Nipisso Lake map-areas is governed by the amount of granitic material and water expelled by the granites and by the porosity, permeability, and water content of the host rocks.

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ROSIWAL ANALYSES

Metasedimentary Rocks

	1.	2.	3.	4.	5.
Quartz	72.6	59.1	56.6	46.7	36.8
Plagioclase	18.8	6.2	1.9	4.4	30.8
Microline		11.6	14.5	23.2	
Biotite	6.8	14.5	13.9	13.1	
Hornblende					
Garnet				5.3	
Epidote					25.4
Sillimanite	1.4	0.5	12.9	5.9	
Diopside					6.5
Muscovite		7.9	0.1	1.5	
Sphene		+			+
Apatite	0.4				
Calcite					
Zircon		+	0.1	+	+
Pyrite					
An (Content)	23	17	14	14	90

1 - Biotite Gneiss GH-168
2 - Muscovite Gneiss E-69
3 - Sillimanite Gneiss E-68
4 - Sillimanite Gneiss H-102
5 - Diopside - Epidote Gneiss H-29

ROSIWAL ANALYSES

Metasedimentary Rocks

	6	7	8	9	10
Quartz	30	20.7	19.7	17.0	14.2
Plagioclase	35.6	29,9	50.0	56.5	50.5
Microcline		34.0	5.3		
Biotite	34.2	14.3	4.2	13.2	18.0
Hornblende			20.0	12.7	13.7
Garnet		1.3			
Epidote					3.1
Sillimanite					
Diopside					
Muscovite					
Sphene			0.1	+	+
Apatite	+	+	0.3	+	+
Calcite					+
Zircon		+			
Pyrite				+	
Magnetite			0.3		
An (Content)	45	15	27	34	34

6 - Biotite Gneiss GH-169
7 - Biotite Gneiss H-2
8 - Hornblende Gneiss H-45
9 - Hornblende Gneiss GH-162A
10 - Hornblende Gneiss G-221

ROSIWAL ANALYSES

Metasedimentary Rocks

	11	12	13	14
Quartz	11.8	3.9	3.8	
Plagioclase	52.0	36.6	37.0	47.4
Microcline				
Biotite	2.7	12.8	6.9	7.3
Hornblende	32.7	35.1	37.0*	40.8
Garnet				
Epidote				
Sillimanite				
Diopside				
Muscovite				
Sphene	+	2.3		1.6
Apatite	+	0.7		0.4
Calcite				
Zircon			+	
Pyrite		2.5		
Magnetite		5.7	+	2.5
An (Content)	27	29	28	25

11 - Hornblende Gneiss G-40
12 - Hornblende Gneiss H-50
13 - Cummingtonite Gneiss H-101
14 - Paramphibolite E-100

* Cummingtonite

ROSIWAL ANALYSES

Amphibolites

	1	2	3	4
Plagioclase	38.2	29.0	32.4	
Hornblende	58.6	59.0	65.5	59.0
Biotite		12.0	2.1	
Hypersthene)	) 2.4			34.7
Augite)				3.5
Magnetite	1.7	+	+	3.0
Apatite	+		+	
Sphene		+	+	
An Content	46	43	26	

1 - Amphibolitized Norite GH-171
2 - Amphibolitized Norite G-20
3 - Amphibolite G-173
4 - Hypersthene amphibolite GH-110

ROSIWAL ANALYSES

Norite

	G-7	G-26	GH-104	GH-70
Plagioclase	57.5	49.4	50.0	53.8
Hypersthene	16.2	15.0	15.0	17.2
Augite	21.1	21.1	16.1	
Hornblende			9.2	20.9
Biotite	1.6	12.4	6.0	
Ilmenite	1.0	1.5	3.5	1.3
Apatite	0.8	0.5	0.3	+
An Content	40	48	40	40

ROSIWAL ANALYSES

Gabbro

	1	2	3
Plagioclase	61.0	58.6	50.0
Hypersthene	8.0	13.2	17.2
Augite	10.0	13.2	20.3
Hornblende	3.5	11.2	
Olivene		2.4	
Biotite	5.5	+	9.7
Magnetite) Ilmenite)	9.3	1.3	2.0
Sphene			+
Apatite	2.0	+	+
Zircon			+
An Content	37	45	40

1 - Tchinicaman Lake Gabbro G-5
2 - Cacaoni Lake Gabbro GH-136
3 - Tchinicaman Lake Gabbro G-45

ROSIWAL ANALYSES

Granites

	1	2	3	4
Quartz	44.0	36.5	18.4	53.0
Plagioclase	18.5	28.2	36.8	16.1
Microcline	24.1	30.6	32.0	21.2
Biotite	10.8	4.4	11.8	8.0
Hornblende	1.3			0.8
Epidote			+	+
Magnetite			+	
Apatite	+	+	+	+
Sphene	+		+	+
Zircon	+	+		
An Content	18	8	13	10

1 - Augen Gneiss G-126
2 - Augen Gneiss G-143
3 - Biotite Granite GH-125
4 - Biotite Granite GH-133

RECALCULATED CHEMICAL ANALYSES*

	1	2	3	4	5
SiO_2	86.3	79.4	75.2	73.8	67.1
TiO_2	0.2	0.4			
Al_2O_3	6.7	9.5	15.0	12.6	15.5
Fe_2O_3	0.4	0.8	0.7	0.7	0.8
Fe O	1.0	2.1	2.0	2.7	2.5
Mg O	0.9	1.8	1.7	2.2	2.1
Ca O	1.5	0.9	0.7	1.4	1.8
Na_2O	1.9	1.1	0.6	1.0	3.4
K_2O	0.6	4.2	3.6	5.2	6.9
P_2O_5	0.2				
H_2O	0.3				

1 - Biotite Gneiss GH-168
2 - Muscovite Gneiss E-69
3 - Sillimanite Gneiss E-68
4 - Sillimanite Gneiss H-102
5 - Biotite Gneiss H-2

* Oxide percentages calculated from Rosiwal analyses, using the W.J. Mead mineralogical slide rule.

RECALCULATED CHEMICAL ANALYSES

	6	7	8	9	10
SiO_2	64.5	60.7	60.0	57.3	58.9
TiO_2			0.6	0.6	0.4
Al_2O_3	15.6	15.4	17.4	17.4	15.7
Fe_2O_3	1.6	2.1	1.6	2.3	2.3
FeO	2.7	4.8	3.5	4.2	4.2
MgO	2.8	4.4	3.4	4.0	4.6
CaO	5.5	5.4	6.6	7.2	7.8
Na_2O	4.7	3.3	4.9	4.6	4.8
K_2O	1.4	3.0	1.4	1.7	0.6
P_2O_5	0.1		0.1	0.1	0.3
H_2O		1.2	0.7	1.0	0.6

6 - Hornblende Gneiss H-45
7 - Biotite Gneiss GH-169
8 - Hornblende Gneiss GH-162A
9 - Hornblende Gneiss G-221
10 - Hornblende Gneiss G-40

RECALCULATED CHEMICAL ANALYSES

	11	12	13	14
SiO_2	53.4	52.2	50.5	49.8
TiO_2	1.7	1.2	2.0	3.2
Al_2O_3	15.7	15.5	14.8	14.3
Fe_2O_3	1.4	1.7	1.6	1.7
FeO	7.8	9.4	9.1	10.2
MgO	6.5	7.6	7.4	7.5
CaO	9.4	7.9	8.7	8.7
Na_2O	4.3	3.8	4.0	3.6
K_2O	0.1	0.4	1.1	0.6
H_2O	0.1	0.4	0.5	0.4

11 - Norite G-7
12 - Norite GH-70
13 - Norite G-26
14 - Norite GH-104

RECALCULATED CHEMICAL ANALYSES

	15	16	17	18
SiO_2	50.2	49.0	47.9	46.5
TiO_2	0.1	1.4	0.3	
Al_2O_3	13.8	14.7	14.6	5.7
Fe_2O_3	4.3	3.7	4.2	6.7
FeO	7.6	8.1	8.1	14.0
MgO	8.4	7.7	8.8	16.7
CaO	10.3	10.7	10.4	7.9
Na_2O	3.5	3.1	3.1	1.4
K_2O	0.8	0.6	1.5	0.5
H_2O	1.0	0.9	1.3	0.9

15 - Amphibolite G-173
16 - Amphibolitized Norite GH-171
17 - Amphibolitized Norite G-20
18 - Hypersthene Amphibolite GH-110


FIGURE 7.
X-RAY DIFFRACTION GRAPH OF
SPESSARTITE, FROM GARNET-HYPERSTHENE GNEISS
NORELCO SPECTROMETER
SLITS 1°; 0.006 mm.
CHART SPEED 1/2° / MIN.
Cu α RADIATION
λ Cu α = 1.5418 A°
2 Sin θ = nλ / d
INTENSITY OF REFLECTION
2θ
2.90
2.59
2.368
2.272
2.115
1.881
1.674
1.607
1.548
20°
30°
40°
50°
60°
0
10
20
30
40
50
60
70
80
90
100
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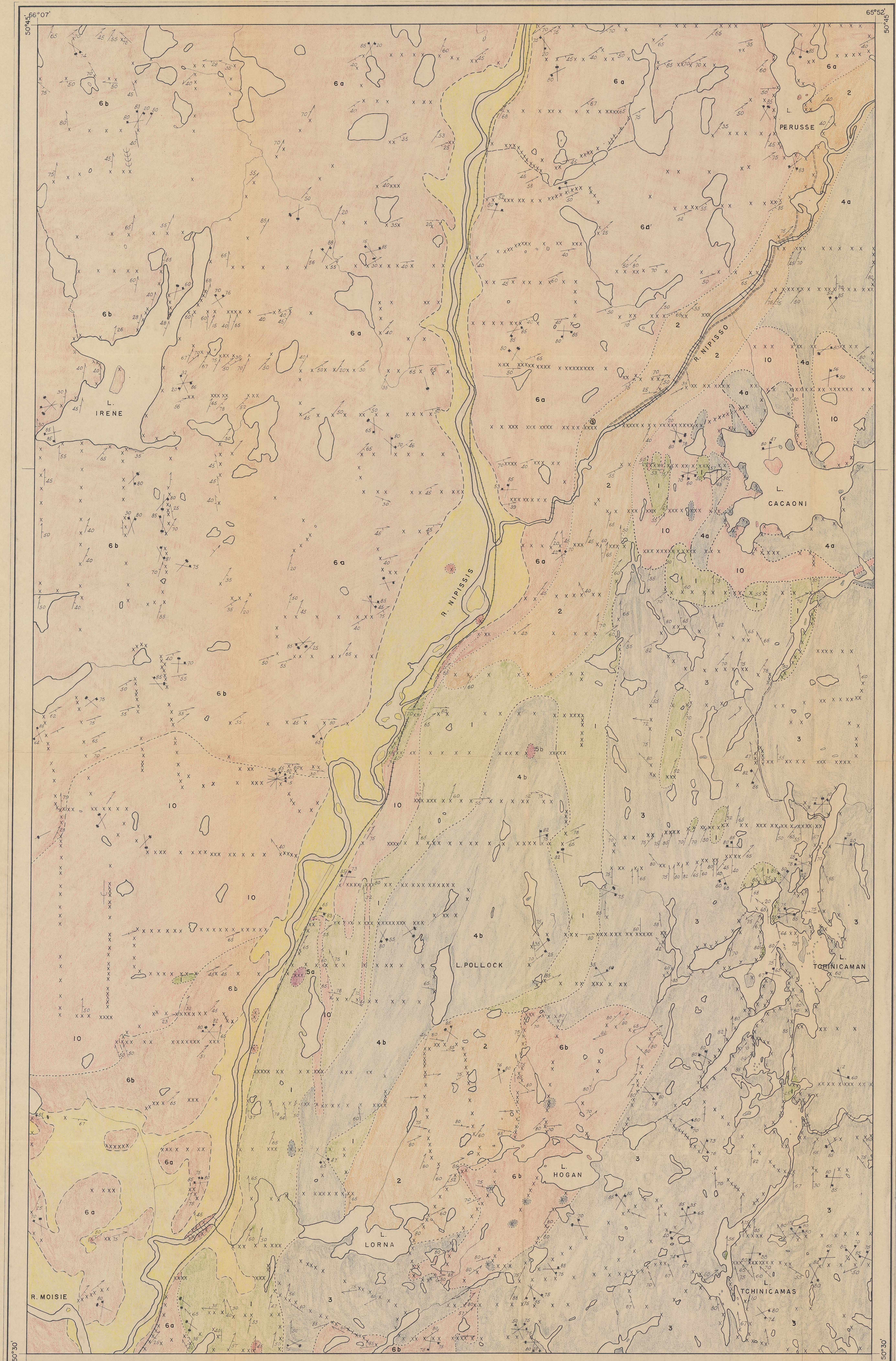
FIGURE 8.
X-RAY DIFFRACTION GRAPH OF
SILLIMANITE, FROM SILLIMANITE GNEISS
NORELCO SPECTROMETER
SLITS 1°; 0.006 mm.
CHART SPEED ½°/MIN.
λ Cu α = 1.5418 Å
2 SIN θ = nλ/α
INTENSITY OF REFLECTION
2θ
20°
30°
40°
50°
60°
4.71
3.70
3.63
2.85
2.69
2.550
2.314
2.213
1.890
1.770
1.732
1.651
1.566
0
10
20
30
40
50
60
70
80
90
100



CENOZOIC

RECENT AND PLEISTOCENE

- Sand, gravel, till

PRECAMBRIAN

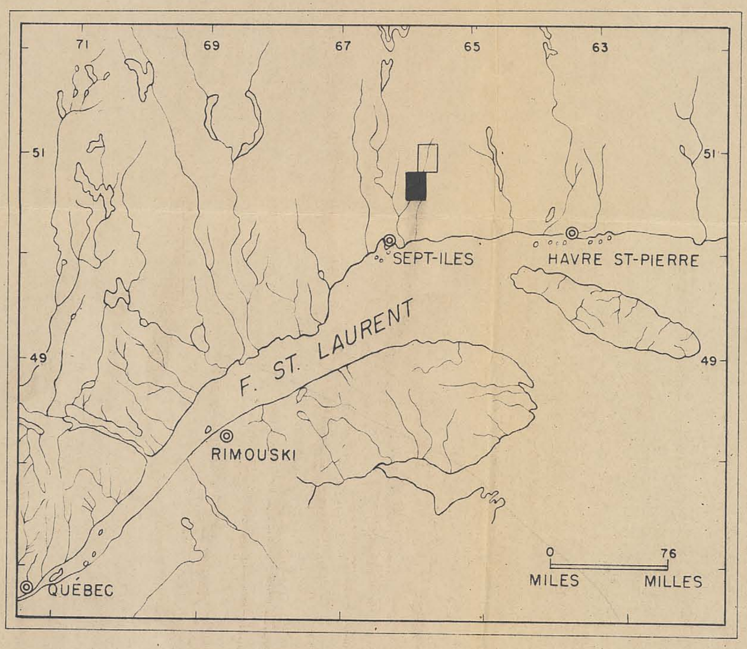
- 10 — Biotite granite
- 9 — Hornblende granite
- 8 — Anthophyllite gabbro
- 7 — Granite gneiss and granulite

(9, 8, 7: EXPOSED IN NIPISSO LAKE AREA)

- 6 — (6a) Augen gneiss, (6b) Granite gneiss
- 5 — (5a) Pyroxenite (5b) Hornblendite
- 4 — (4a) Gabbro (4b) Diorite
- 3 — Norite
- 2 — Complex of migmatite, granitic gneiss and paragneiss
- 1 — Paragneisses

- × Observed outcrop
- (a) (b) (c) Geological boundary (a) Located (b) Approximate (c) Assumed
- Strike and dip foliation, schistosity and gneissic structure
- Strike and dip of joints
- Glacial striae
- Temporary landing field
- Quebec North Shore and Labrador Railway
- Tractor road
- Portage
- Ⓢ Sulphide mineralization

0 1 2
Scale of miles

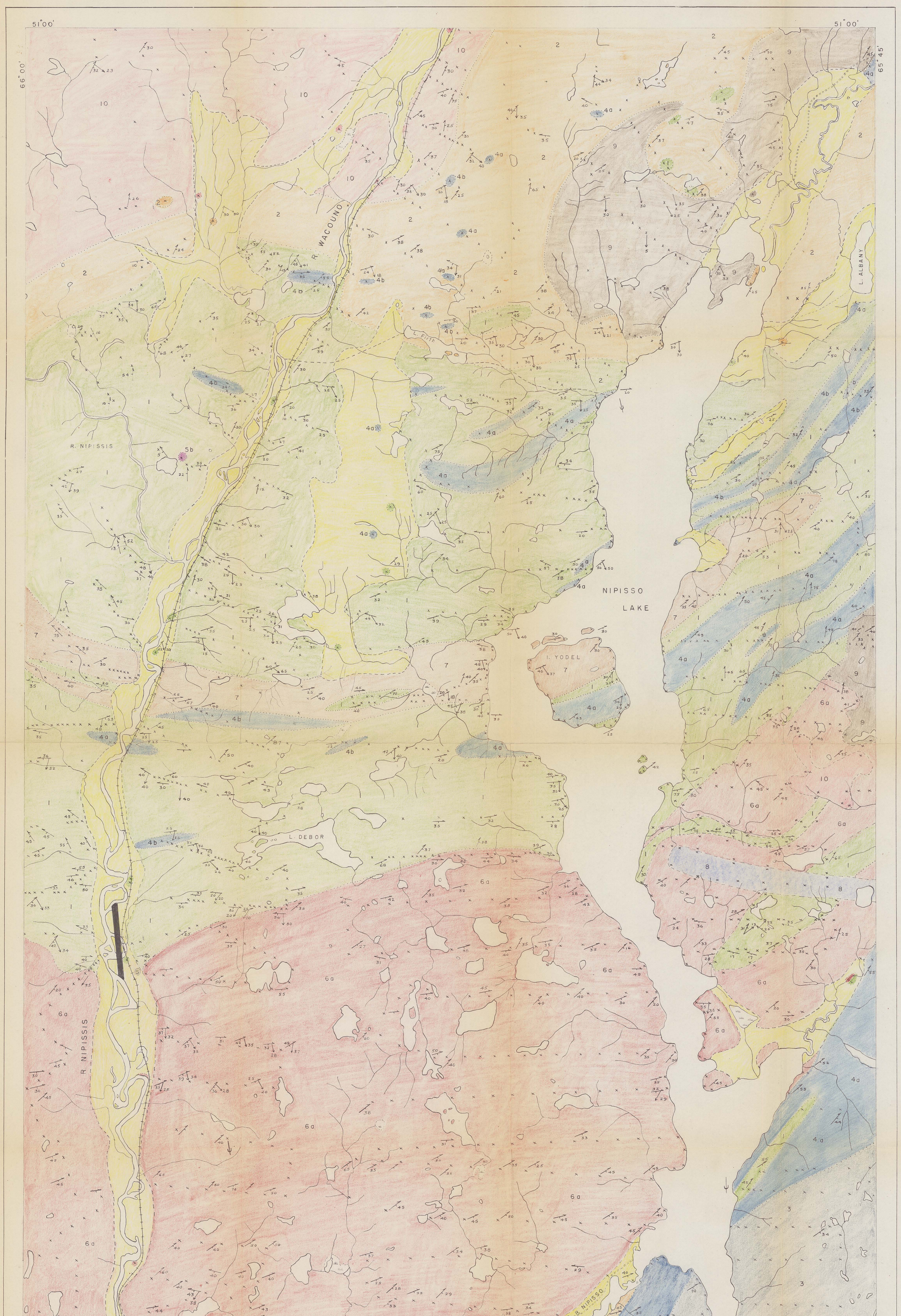


28°W

No B-571

NIPISSIS RIVER AREA

GEOLOGY: P.E. GRENIER AND H.R. HOGAN 1951



CENOZOIC

RECENT AND PLEISTOCENE

Sand, gravel, till

PRECAMBRIAN

10 Biotite granite

9 Hornblende granite

8 Anthophyllite gabbro

7 Granite gneiss and granulite

6 (6a) Augen gneiss, (6b) Granite gneiss

5 (5a) Pyroxenite (5b) Hornblendite

4 (4a) Gabbro (4b) Amphibolite

3 Norite

2 Migmatite

1 Paragneisses

× Observed outcrop

(a) (b) (c) Geological boundary (a) Located (b) Approximate (c) Assumed

Strike and dip foliation, schistosity and gneissic structure

Strike and plunge of lineation

Glacial striae

Temporary landing field

Quebec North Shore and Labrador Railway

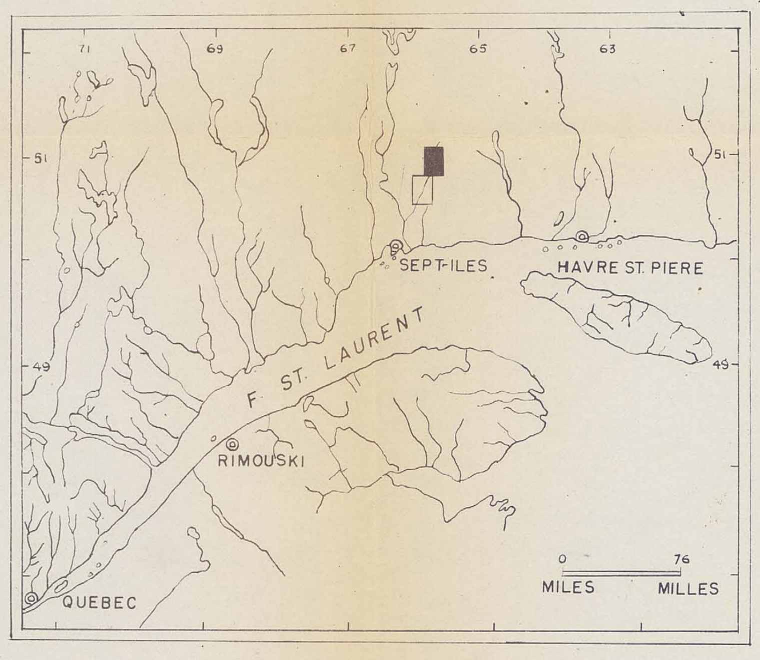
Tractor road

Portage

(s) Sulphide mineralization

0 1 2

Scale of miles



28°W

NIPISSO LAKE AREA

GEOLOGY: H.R. HOGAN 1952