GEOLOGY IN THE VICINITY OF THE GRENVILLE FRONT, MOUNT WRIGHT DISTRICT, QUEBEC.

by

Peter J. Clarke

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ABSTRACT

The Labrador Trough (an iron-rich belt of Proterozoic rocks) passes into the Grenville Orogenic Province near Mount Wright, Quebec. The Proterozoic metasedimentary sequence includes gneisses, schists, quartzite, marble, and iron formation, and overlies Archean rocks of the pyroxene granulite facies. The Proterozoic sediments follow sedimentary facies zones which reflect the shape and depth of their depositional basin. Gabbro sills intrude the Proterozoic rocks. This thesis describes the geology of the region with special reference to the effects of the Grenville Orogeny on the Archean basement and Labrador Trough rocks.

The Grenville metamorphism ranges from greenschist to middle almandine amphibolite facies in the area studied. The Grenville T.P. conditions resulted in progressive metamorphism of the Proterozoic rocks but in the déstruction of the originally higher grade assemblages in the granulite and gabbro.

A cursory study is made of the plagioclase, biotite, hornblende, garnet, and pyroxenes of the various rock units. The compositions of orthopyroxene and clinopyroxene coexisting in iron formation, and of calcite coexisting with dolomite in the marble are studied in more detail.

The Proterozoic rocks are deformed by two, approximately perpendicular, fold systems. At least one additional older system deforms the Archean rocks. The structural geology of the region is discussed, and stereonet diagrams are presented to illustrate the geometry of the structures formed by the complex folding. The structural pattern governing the occurrence of the iron deposits is described, and an application of this pattern in prospecting for new deposits is suggested.

TABLE OF CONTENTS

Page

CHAPTER I

INTRODUCTION 1
Acknowledgements 3
Previous Work 3
Geological Setting 4
Labrador Trough 4
Grenville Province 5

CHAPTER II

GENERAL GEOLOGY 7

CHAPTER III

ARCHEAN ROCKS 13
Introduction 13
Archean Rocks North of the Grenville Front 16
Granulite 16
Archean Intrusions 19
Altered Archean Gneiss 21
Archean Rocks South of the Grenville Front 22
Alteration and Chemical Composition of the Granulite 25

CHAPTER IV

PROTEROZOIC GNEISSES AND SCHISTS 31
Introduction 31
Quartzofeldspathic Rocks 32
Albite-Epidote-Chlorite Schist and Grit 32
Poorly Segregated Gneisses 34
Well Segregated Gneisses 37
Chemically Distinctive Rocks 45
Rusty-Weathering Graphitic Schist 45
Quartz-Mica-Kyanite Schist 46
Hornblende-Pyroxene-Garnet Rock 47
Potassic Gneisses 50
Comparison of the Compositions of Gneisses and Schists 52

Page

CHAPTER V

IRON FORMATION SERIES 57
Introduction 57
Quartzite 59
Marble 61
Iron Formation 63
Oxide facies 65
Silicate-carbonate facies 67
Olivine-pyroxene-carbonate facies 73
Origin and metamorphism of the iron formation 75

CHAPTER VI

PROTEROZOIC IGNEOUS ROCKS 82
Introduction 82
Rocks of the Basic Suite 82
Gabbro 82
Corona development 86
Metagabbro Amphibolite 87
Intermediate Rocks 89
Ultrabasic Rocks 89
Acidic Orthogneiss 90
Granitic Rocks 93
Quartz Monzonite 93
Granite East of the Moisie River 94

CHAPTER VII

MINERALOGY 96
Introduction 96
Procedure 96
Minerals of the Common Rocks 97
Plagioclase - General Features 97
Plagioclase in this study 99
Biotite - General Features 101
Hornblende - General Features 102
Biotite and hornblende in this study 104
Garnet - General Features 106
Garnet in this study 108
Pyroxenes - General Features 111
Pyroxenes in this study 113
Minerals of the Iron Formation and Marble 116
Pyroxenes 116
Cummingtonite 118
Pyroxene Geothermometry 120
Carbonates 125

Page

CHAPTER VIII

STRUCTURAL GEOLOGY 128
Introduction 128
Structural Features 128
Folding and Minor Features 128
Fabric diagrams 133
History of folding 144
Faults 145
Archean-Proterozoic Contact and the Grenville Front 147

CHAPTER IX

ECONOMIC GEOLOGY 149
Iron Deposits 149
Sulfide Deposits 153
Bloom Lake Deposit 153
Pegma Lake Deposit 154
Minor Sulfide Deposits 155
Non Metalic Minerals 155

CHAPTER X

SUMMARY AND CONCLUSIONS 157

APPENDIX

TABLES OF ROCK COMPOSITIONS 162

REFERENCES CITED 189

TABLES

Table

1 Chemical Analyses of Gneisses 28

2 Average Composition Range of Poorly Segregated Gneiss 37

3 Average Composition Range of Well Segregated Gneiss 41

4 Approximate Values of K_2O/Na_2O, MgO/CaO, and Al_2O_3 of Gneisses 44

Table		Page
5	Mineral Assemblages in Metamorphosed Iron Formation	79
6	Mineral Composition of Hornblende-Garnet Rock and Amphibolite	88
7	Composition of Coexisting Pyroxenes and Amphiboles in Iron Formation	122a
8	Lattice Spacings, Magnesium Contents and Equilibrium Temperatures of Calcites from the Marble	126
9	Metal Content of Bloom Lake Sulfide Samples	154
10	Average Composition of Gneisses and Schists	164
11	Average Composition of Iron Formation Series Rocks	166
12	Average Composition of Igneous Rocks	168
13	Mineral Composition of Archean Granulite, Normanville Area ..	169
14	Mineral Composition of Archean Intrusions, Normanville Area .	170
15	Mineral Composition of Gneisses, Normanville Area	171
16	Mineral Composition of Distinctive Schists, Normanville Area.	172
17	Mineral Composition of Quartzite and Marble, Normanville Area	173
18	Mineral Composition of Iron Formation, Normanville Area	174
19	Mineral Composition of Igneous Rocks, Normanville Area	176
20	Mineral Composition of Granulite and Altered Granulite, Gras-Felix Area	177
21	Mineral Composition of Well Segregated Gneiss, Gras-Felix Area	178
22	Mineral Composition of Poorly Segregated Gneiss, Gras-Felix Area	180
23	Mineral Composition of Distinctive Rocks Above Iron Formation Series, Gras-Felix Area	181
24	Mineral Composition of Metasomatized Gneiss East of Moisie River, Gras-Felix Area	183

Table		Page
25	Mineral Composition of Iron Formation Series Rocks, Gras-Felix Area	184
26	Mineral Composition of Acid Igneous Rocks, Gras-Felix Area	186
27	Mineral Composition of Intermediate and Basic Igneous Rocks, Gras-Felix Area	187

MAPS AND ILLUSTRATIONS

MAPS

THE NORMANVILLE AREA - Scale 1 mile - 1 inch ..... (In pocket)

THE GRAS LAKE-FELIX LAKE AREA - Scale 1 mile - 1 inch ..... (In pocket)

FIGURES

Figure		
1	Index Map	2
2	Sketch-map of the Geology Near Mount Wright	8
3	Schematic Cross Section of Part of the Mount Wright Region	9
4	Mineral Reactions from Repeated Metamorphism of the Archean Granulite	27
5	Oxide Ratios of Analysed Gneisses	30
6	Compositions of Gneisses	54
7	Sedimentary Facies of Rocks Underlying the Iron Formation	58
8	Sedimentary Facies of the Iron Formation	64
9	Mineral Assemblages in Metamorphosed Iron Formation and Gneiss	80

Figure		Page
10	Plagioclase Compositions of Common Rock Types	100
11	Variation of Refractive Index of Hornblende and Biotite with Rock Type	105
12	Variation of Cell Edge and Refractive Index of Garnet with Rock Type	109
13	Variation of a_o/n of Garnet with Rock Type	110
14	Nomenclature of Pyroxenes in the System $CaMgSi_2O_6$ - $CaFeSi_2O_6$ - $Mg_2Si_2O_6$ - $Fe_2Si_2O_6$	112
15a	Refractive Indices on Cleavage Flakes of some Amphiboles and Pyroxenes	114
b	Variation of Refractive Indices of Amphiboles and Pyroxenes with Rock Type	115
16	Compositions of Coexisting Pyroxenes from Iron Formation	117
17	Fe/Mg Distribution Between Coexisting Orthopyroxene and Cummingtonite	119
18	K_D Values of Pyroxenes from the Mount Wright-Mount Reed Iron Formation	123
19	Relationship Between Calcium Solubility Gaps and K_D Values of Coexisting Pyroxenes	124
20	Structural Features in the Area Near Mount Wright	129
21	Stereonet Plots of Structural Elements of Superposed Folds ..	137
22	Stereonet Plots of Structural Elements of the Normanville, Gras Lake, and Felix Lake Areas	140
23	Structural Control of Iron Deposits in Cross-folded Areas Near Mount Wright	152
24	Key to Abbreviations in Rock Composition Tables	163

PLATES

Plate		Page
I-A	Outcrop of Archean granulite, north of the Grenville Front.	17
B	Photomicrograph of granulite, north of the Grenville Front.	17
II-A	Outcrop of contorted Archean granulite, south of the Grenville Front	23
B	Hypersthene in Archean granulite, partly replaced by secondary biotite and garnet	23
C	Clusters of secondary biotite and garnet formed by complete replacement of hypersthene in altered granulite	23
III	Photomicrograph of albite-epidote grit	33
IV	Porphyroblastic biotite schist, Normanville Area	36
V-A	Outcrop of poorly segregated gneiss, Felix Lake Area	39
B	Photomicrograph of poorly segregated gneiss	39
VI-A	Outcrop of well segregated gneiss, Gras Lake Area	40
B	Photomicrograph of well segregated gneiss	40
VII-A	Photomicrograph of mica-kyanite schist	48
B	Photomicrograph of hornblende-garnet rock	48
VIII	Outcrop of black-weathering marble, Gras Lake Area	62
IX	Segregation pod of quartz surrounded by coarse residual hematite, Normanville Area	66
X-A	Interlayered quartz and silicate-carbonate bands in iron formation, Normanville Area	69
B	Alternating bands of pyroxene and quartz in silicate-carbonate iron formation near Gras Lake	69
XI-A	Photomicrograph of quartz-cummingtonite iron formation, Normanville Area	71
B	Photomicrograph of quartz-pyroxene iron formation, Gras Lake Area	71
XII	Hobdadite, a variety of silicate-carbonate iron formation, Gras Lake Area	75
XIII-A	Photomicrograph of corona in gabbro from the Normanville Area	84
B	Photomicrograph of corona in gabbro from the Felix Lake Area	84

Plate		Page
XIV	- Photomicrograph of acidic orthogneiss associated with the gabbro of the Felix Lake Area	92
XV-A	- Chevron folds in the cummingtonite schist of the Normanville Area	134
B	- Sigmoidal folding in the well segregated gneiss of the Gras Lake Area	134
C	- Isoclinal folding in the Archean granulite of the Normanville Area	134
XVI-A	- Small cross folds in quartz specularite iron formation, Normanville Area	135
B	- Small cross folds in well segregated gneiss, Gras Lake Area	135

CHAPTER I

INTRODUCTION

This thesis is a study of petrological and structural changes in some Labrador Trough sediments, and in the underlying Archean rocks, as they pass into the area affected by the Grenville Orogeny. The study was made in the Mount Wright region of Quebec where the Labrador Trough, the Superior Structural Province and the Grenville Structural Province come into contact with each other.

The location and geological setting of the area studied is shown in Figure 1. It includes three map sheets; a single northern sheet (Normanville Area), and two adjoining sheets in the south (Gras Lake-Felix Lake Area). The area between the two parts has been mapped by Murphy (1959, 1960).

The Normanville Area is bounded by latitude 52°45'N and 53°00'N, longitude 63°30'W on the west, and slightly overlaps the Quebec-Labrador border on the east. The Gras Lake-Felix Lake Area is mainly bounded by longitudes 66°30'W and 67°30'W, and latitudes 52°15'N and 52°30'N, but was extended slightly south of Gras Lake, and north of Felix Lake to include known occurrences of iron formation that would not otherwise have been mapped. In all, the area covers about 1000 square miles.

The mapping, on which the thesis is based, was done for the Quebec Department of Mines as part of their program of providing geological information on areas of current economic interest. The field work was done in the summers of 1959, 1960, and 1961. Pace and compass traverses were run at

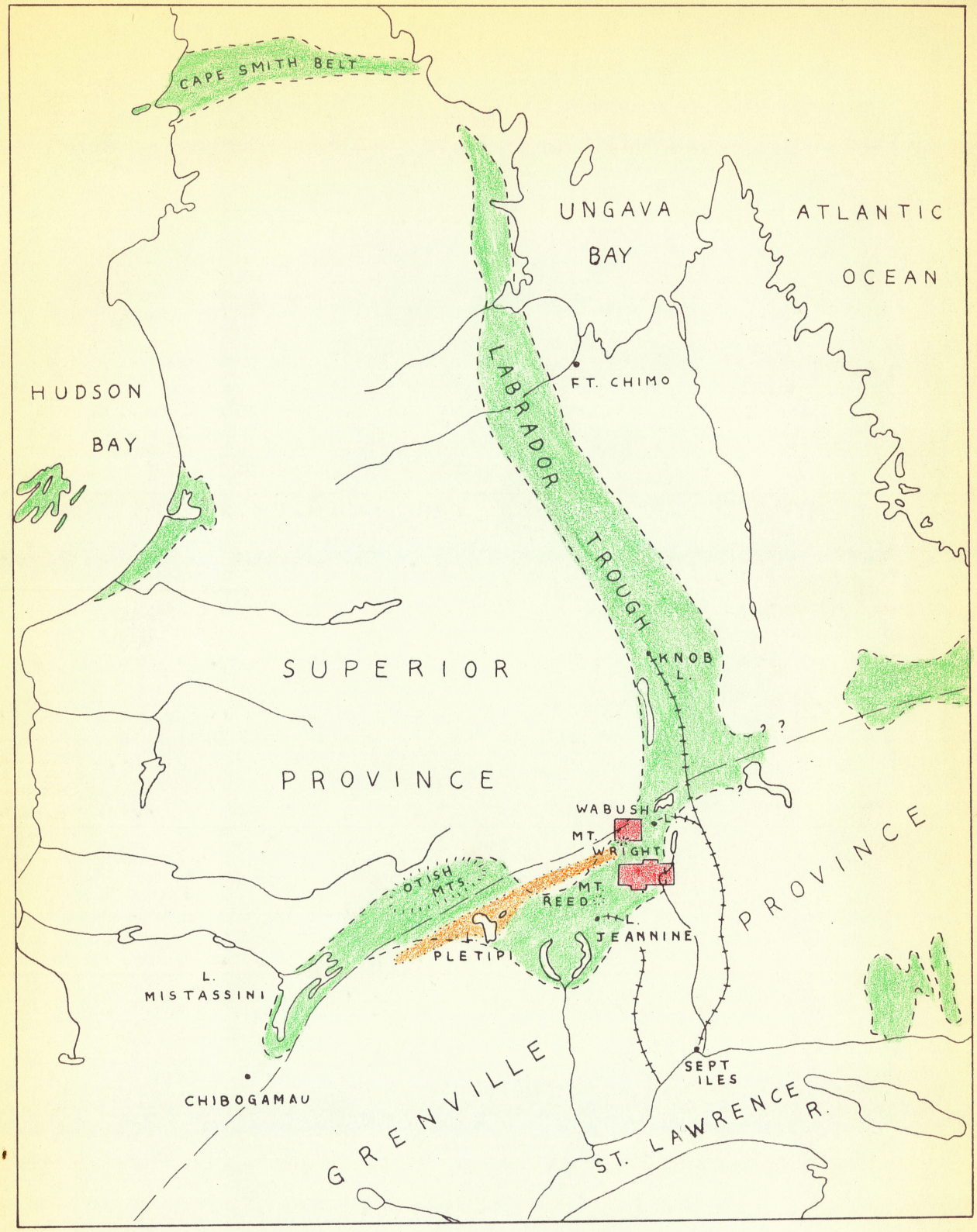

FIGURE I

INDEX MAP

LEGEND

PROTEROZOIC ROCKS

GRENVILLE FRONT

AREAS MAPPED

NEGATIVE GRAVITY ANOMALY

MILES 0 100 200

SCALE

½ mile intervals, using ½ mile : 1 inch aerial photos as ground control. Field data were plotted on ½ mile : 1 inch base maps, and geological maps were published on a 1 mile scale (Clarke 1960, 1961, 1963).

Acknowledgements

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Previous Work

Publications on the area include a 4 mile : 1 inch geological map by Duffel and Roach (1959), and studies of the mineralogy of the iron formation by Mueller (1960) and Krank (1961). Theses, involving detailed study of parts of the area, have been written by Gross (1955), Gleeson (1956), Krank (1959), Spatt (1959), and Jackson (1962).

Reports of assessment work including diamond drill logs, and geological and geophysical maps of many of the iron deposits were also available to the author. These reports and theses provided details that the author could not have collected in his own work.

The geology of nearby areas have been described by Gill et al. (1937), Phillips (1958, 1959), MacKean (1959), Murphy (1959, 1960), Gastil and Knowles

(1960), Klein (1960), and Sinclair (1960, 1961).

Geological Setting

In the Mount Wright-Mount Reed region, Proterozoic sediments of the Labrador Trough, and the basement rocks on which they lie, pass into the Grenville Structural Province and are involved in its metamorphism. The sediments, although metamorphosed, retain many of their original characteristics. They resemble the less-altered trough rocks in composition and stratigraphic sequence, and show sedimentary facies changes, grading southeastward from shelf deposits to rocks deposited in a quieter offshore environment. In their present metamorphosed form, they are gneisses, schists, and recrystallized quartzite, marble, and iron formation.

Part of the northern area lies beyond the Grenville Front, and here the rocks are Archean hypersthene granulite, and a few small outliers of unmetamorphosed Proterozoic grit and iron formation. The Grenville Front in the present area is a metamorphic gradient which raises the rocks from the middle greenschist to the middle almandine amphibolite facies in a distance of approximately 12 miles. It is accompanied by a strong negative gravity anomaly, indicating a much deeper disturbance than would be suspected from the surface geology.

At this point, it is well to review the important features of the Labrador Trough and Grenville Province, so that the present area can be seen in relation to the regional geology. Much of the material in this review comes from Harrison (1952), Murphy (1961), and Gross (1961).

Labrador Trough

The Labrador Trough is a folded belt of Proterozoic rocks extending

south from the northwestern corner of Ungava Bay to slightly north of Wabush Lake, a distance of some 600 miles. The rocks are folded and thrust towards the west, gently on the western side, but with increasing intensity to the east. Near Wabush Lake the belt swings southwest to Lake Mistassini, 300 miles away. For the first half of this distance the sediments were involved in the Grenville Orogeny, and are highly metamorphosed and deformed. Farther southwest they lie beyond the Grenville Front and are flat-lying and unmetamorphosed. Iron formation occurs throughout most of the Proterozoic belt. The sedimentary series, in which the iron formation occurs, is best developed in the western part of the belt; in the central and eastern parts, it is less abundant, and interlayered with basic sills and volcanic rocks.

The western border of the trough is marked by an unconformity between Archean gneisses and granitic rocks, and the Proterozoic sediments of the trough. The eastern border is difficult to define as the sediments are sheared and metamorphosed to resemble the older rocks beneath them.

In most places, the Proterozoic rock succession consists of grey to greenish black slate (Attikamagen), overlain by orthoquartzite, arkosic quartzite, conglomerate and grit (Wishart). This in turn is succeeded by red to grey black slate and iron formation, (Ruth and Sokoman) and by black slate and grey to greenish argillite (Menihek). Dolomite (Denault) occurs beneath the quartzite in the Knob Lake and Mistassini Areas and above the iron formation near Ungava Bay. Formation names given here are from the Knob Lake Area, and do not apply to formations throughout the trough.

Grenville Province

The term "Grenville" was first used as a series name by Sir William

Logan to apply to a sequence of crystalline limestone and gneiss that occurs in Grenville Township, Province of Quebec. Since its initial use by Logan, the name has been used to denote tectonics, lithology, location and time. Hewitt (1957) has summarized the ways in which he believes the term "Grenville" should be used. He writes:

> "The "Grenville province" is defined geographically as the area lying southeast of the "Grenville front", it is a structural and tectonic unit, and is coincident with the "Grenville orogenic belt". The Grenville province, as constituted at present is that area of the Canadian Precambrian Shield which was directly involved in the mountain building of the Grenville orogenic cycle which apparently culminated with the intrusion of granites and pegmatites and a period of deep-zone regional metamorphism, about one thousand million years ago. The Grenville province cannot be defined as that area in which the Grenville series occurs, because it has become apparent that the term "Grenville" really has no defined stratigraphic value; the Grenville is not a time stratigraphic unit but rather a poorly defined lithologic assemblage."

The nature of the northwest limit of the trough referred to as the Grenville Front, is not everywhere the same. In places it appears to be a southeasterly dipping thrust fault, but elsewhere, it is a metamorphic zone of variable width. Essentially unmetamorphosed rocks of the Labrador Trough have been traced as far south as Sawbill Lake. There is no exposure immediately south of the lake, and where they outcrop again, a few miles away, they have become metamorphosed (Gross, 1961). The metamorphic gradient also crosses the Normanville Area, where it can be traced with intermittent outcrop from the middle greenschist to the middle almandine amphibolite facies.

Age determinations, based on the potassium/argon content of micas, indicate metamorphic ages of about 2400 to 2500 million years for the Archean Basement rocks, 1550 million years for the main part of the Labrador Trough, and 900 to 1100 million years for the rocks involved in the Grenville Orogeny (Leech et al., 1963).

CHAPTER II

GENERAL GEOLOGY

All the bedrock is Precambrian in age. It can be divided into the following groups;

1) Archean granulites and the rocks that intrude them.

2) Mainly Proterozoic gneisses, schists, and migmatite.

3) The Iron Formation Series composed of Marble, Quartzite, and Iron Formation, and equivalent to the Dolomite, Chert, and Iron Formation of the Labrador Trough.

4) Igneous rocks intrusive into the above groups.

The locations of the main rock groups are shown in Figure 2. Because the stratigraphic succession and metamorphic grade change within the area, relationships between the various rock types are best represented by a schematic cross-section, such as Figure 3.

The Archean rocks underlie most of the area northwest of the Grenville Front. They consist of hypersthene-and augite-bearing granulites, granitic rocks injected into the granulites, and migmatite formed by the mixing of granulite and injected material.

Granulite also occurs along an east-west belt in the southern half of the Gras Lake-Felix Lake Area. The Grenville metamorphism has altered the southern granulite, but has not completely destroyed its hypersthene or granulitic appearance. In strongly altered samples the hypersthene is replaced by clusters of fine-grained red-brown biotite, quartz, and garnet, that give the rock a characteristic speckled texture.

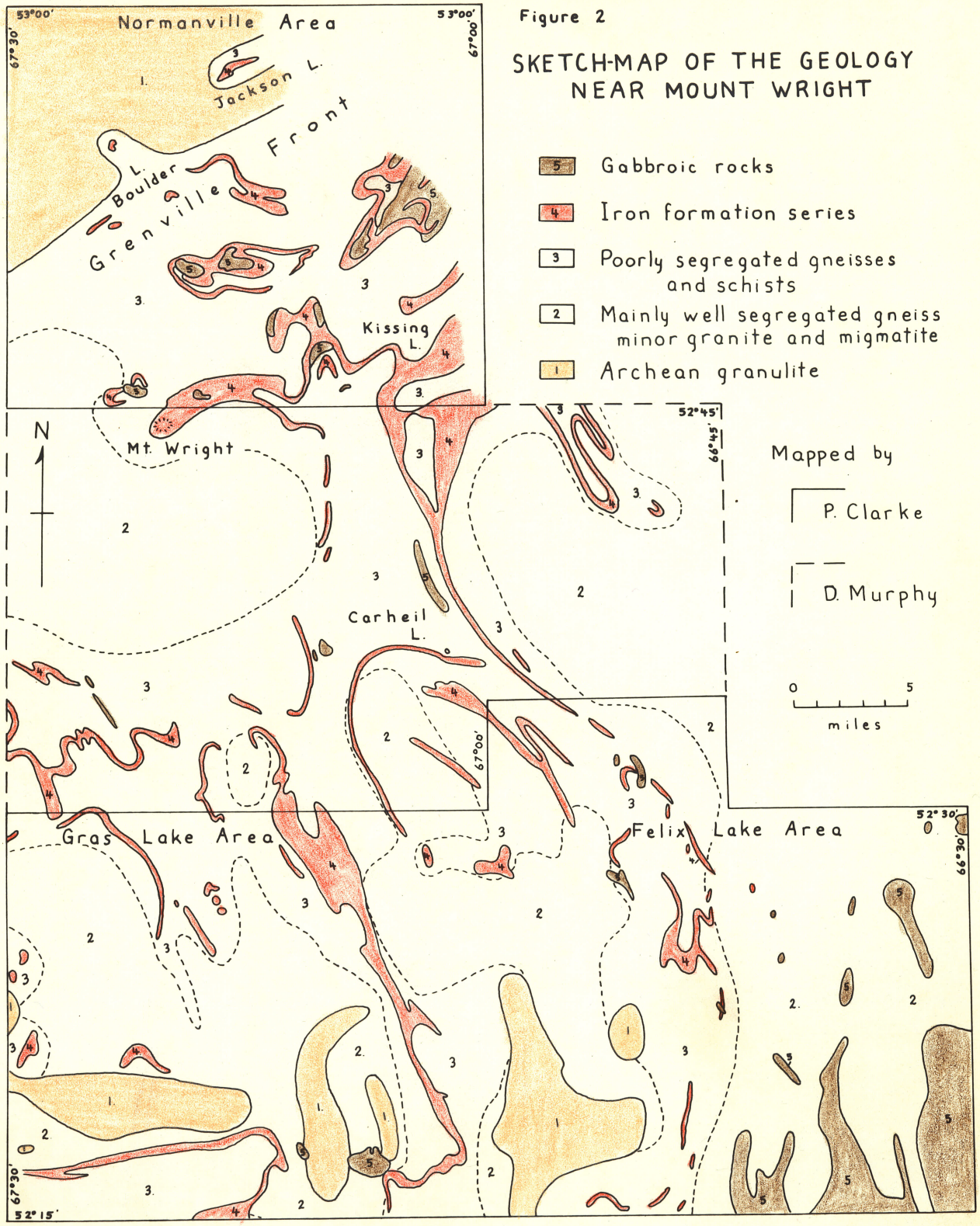


Figure 2

SKETCH-MAP OF THE GEOLOGY NEAR MOUNT WRIGHT

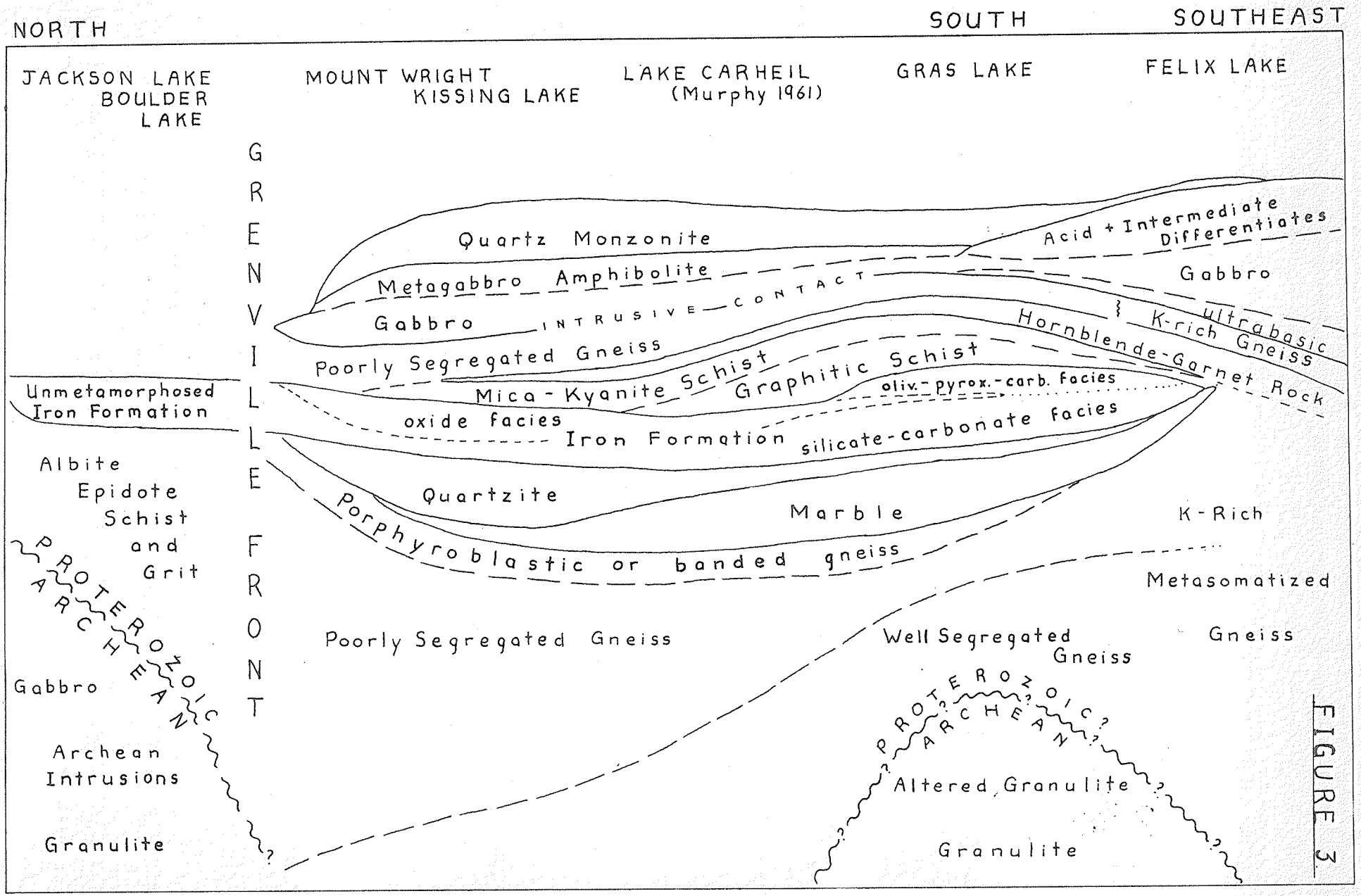


FIGURE 3

Schematic Cross Section of Part of the Mount Wright Region.

Proterozoic rocks include lower gneisses, the Iron Formation Series, upper gneisses and schists, and the granite and gabbro which intrude them. The lower gneisses can be classified on the basis of metamorphic segregation of their mafic and felsic constituents. In gneisses with a "well segregated" texture the mafic and felsic minerals are partly separated into speckles, lenses or bands. The biotite is more tabular than flaky, and is not oriented in a single plane, so fissility is poor. Both biotite-rich and hornblende-rich types are common.

In the poorly segregated gneiss there is little separation of the mafic and felsic minerals. The mica is flaky, and the rock has good fissility. Much of the gneiss directly under the Iron Formation Series contains felsic bands or porphyroblasts in an otherwise unsegregated groundmass. The felsic segregations are separated from the rest of the rock by a mafic selvage.

The degree of segregation of a gneiss reflects the amount of metamorphic remobilization it has undergone. The poorly segregated gneisses are Proterozoic paragneisses and are apparently conformable with the overlying Iron Formation Series. The well segregated gneisses were probably derived from similar sediments, but may also contain some completely recrystallized Archean rocks. The well segregated gneisses are most common in the Gras Lake Area, and western part of the Felix Lake Area. Most of the Proterozoic gneiss in the Normanville Area is poorly segregated.

North of the Grenville Front the Archean basement is overlain by a grit or schist, containing fragments of quartz and feldspar in a matrix of epidote, chlorite, and fine-grained secondary quartz and albite.

A thin layer of slightly metamorphosed iron formation overlies the basal grit. The Proterozoic sequence is much thinner here than farther south.

The Iron Formation Series is composed of marble, quartzite, and iron formation. It is thickest in the southern part of the Normanville Area, thinning gradually southeastward, and pinching out over the Archean rocks to the northwest. Near Mount Wright the iron formation is mainly of the oxide facies and is associated with quartzite. These formations thin to the southeast, or pass into marble and the silicate-carbonate facies or pyroxene-chlorite-carbonate facies of iron formation. In the southern part of the area the whole Iron Formation Series is only about 10 feet thick.

North of the Grenville Front the iron formation is thin and only slightly metamorphosed. It is composed mainly of quartz, magnetite, siderite, and some stilpnomelane. Fibrous grunerite and poikilitic garnet first appear near Boulder Lake. The silicate-carbonate facies in the southern part of the area is composed of quartz, hypersthene, diopside-hedenbergite, magnetite, and dolomite.

In the Gras Lake Area the Iron Formation Series is overlain by a rusty-weathering graphitic gneiss. The rusty-weathering gneiss extends north to the southern border of the Normanville Area, where it changes to common unsegregated gneiss. Other distinctive rocks above the iron formation are a quartz-mica-kyanite schist, and a pyroxene-hornblende-garnet rock. These rocks are interlayered with poorly segregated gneiss. They are best exposed in the central part of the Gras Lake-Felix Lake Area.

Gabbro sills intrude the gneisses and Iron Formation Series throughout the area. The gabbros are common in the Normanville Area, and

abundant near Felix Lake, where they are accompanied by ultrabasic, acidic and intermediate differentiates. The gneisses near Felix Lake are microcline-rich and were apparently baked and metasomatized by fluids emanating from the gabbros. Some of the gabbro in the northern and western parts of the area is recrystallized to amphibolite. Near Felix Lake, the altered gabbro is more highly metamorphosed and contains pyroxene in place of amphibole. Quartz monzonite and some pegmatite intrude the lower gneisses and Iron Formation Series. These granitic intrusives are probably the product of remelting and injection of gneissic material during the Grenville Orogeny. No Proterozoic intrusions were recognized north of the Grenville Front.

CHAPTER III

ARCHEAN ROCKS

Introduction

The oldest rocks of the area are Archean pyroxene granulites and the acidic rocks intruding them. They underlie the Proterozoic sediments at the base of the Labrador Trough between Mount Wright and Wabush Lake (Eade et al., 1960; Fahrig, 1960). They occur north of the Grenville Front in the Normanville Area, and south of the front in the southwestern part of the Gras Lake-Felix Lake Area.

Radioactive dating of these granulites shows metamorphic ages between 2365 and 2500 million years and similar to the ages throughout the rest of the Superior Province (Leech et al., 1963).

The granulites in the Normanville Area were not greatly affected by the Grenville Orogeny. However, in the Gras Lake-Felix Lake Area, they were remetamorphosed and most of their hypersthene is replaced by biotite, quartz, and garnet.

The petrology of granulites and rocks of the charnockitic suite has been summarized by Eskola 1952, and Subramaniam 1959. The rocks have similar textures and mineralogy wherever they occur, and are generally believed to have formed under conditions of extreme temperature and pressure. Their minerals are typically high temperature forms with more substitution and exsolution than minerals in the amphibolite facies. They may be strained due to rearrangement on cooling. The following properties characterize the minerals of the granulite facies (Eskola, 1952; Subramaniam, 1959);

Quartz_ In hand speciman the quartz has a blueish opalescent lustre.

In thin section it shows wavy extinction due to the welding of many small segments into larger composite grains. Subramaniam (1959, p. 334) suggests that the blue iridescence is caused by the dispersion of light by the boundaries of the rewelded grains.

Plagioclase Tan or blueish grey in hand speciman, the plagioclase forms unzoned grains with few twins. An_{30} is the most common composition in acid and intermediate granulites. Finely intergrown antiperthite and mesoperthite (equal parts potassium feldspar and plagioclase feldspar) indicate a high temperature of crystallization (Michot, 1951). The dark colour is probably caused by the reduced state of fine iron dust in the feldspar, and can be lightened by soaking the rock in warm hydrochloric acid.

Potassium feldspar The potassium feldspar appears to have been originally untwinned orthoclase. Microcline twinning develops through the stages; 1) undulatory extinction, 2) fine twins in the strained parts of grains, and 3) well formed cross hatched twins. Hair perthite and the development of microcline twins from strain shadows are characteristic of the granulite facies.

Garnet Pyrope-rich almandine, with lower Fe/Mg ratios than garnets in amphibolite facies rocks of the same composition. Garnet forms in alumina-rich granulites or from the reconstitution of orthypyroxene.

Orthopyroxene Commonly hypersthene, it may contain more alumina than is normal if the rock is alumina-rich. The occurrence of pyroxene in rocks of acidic or intermediate composition is characteristic of the granulite facies.

Clinopyroxene Diopsidic augite.

Hornblende Brown in thin section and strongly pleochroic, it is richer in titania, ferric iron, and the alkalies than hornblende of the amphibolite facies.

Biotite Biotite may be either primary or secondary associated with the alteration of orthopyroxene or garnet.

Others Minor amounts of sillimanite, cordierite, or graphite may occur in some sedimentary granulites, and apatite, iron oxides, and pyrrhotite are common in charnockites.

Subramaniam (1959) reexamined the charnockites of the type area near Madras, and redefined charnockite as:

> "a hypersthene quartz feldspar rock, with or without garnet, and characterized by greenish blue feldspar and greyish blue quartz, the dominant feldspar being microperthite."

According to Subramaniam acidic charnockitic rocks can be classified in the following types;

1) True charnockite (hypersthene granite or birkremite).
2) Enderbite (hypersthene quartz diorite).
3) Hypersthene "quartz syenite".
4) Alaskite (a quartz feldspar rock devoid of mafic minerals but grading into charnockite).

The Archean granulites of the Mount Wright Area show most of the features of granulites noted by Eskola (1952) and Subramaniam (1959). They are essentially composed of hypersthene, blue quartz, and dark coloured feldspar, arranged in a layered granoblastic texture. They include rocks of intermediate and basic composition which are thought to have formed from older sedimentary and volcanic rocks, respectively (Roach and Duffel 196?). Granitic rocks form generally conformable bodies in the granulite. They are referred to here as Archean intrusions.

The granulites north of the Grenville Front were not affected by the Grenville Orogeny, whereas, the granulites in the Gras Lake-Felix Lake Area were partly recrystallized to minerals of the almandine amphibolite facies.

Archean Rocks North of the Grenville Front

Granulite

The granulite north of the Grenville Front is a brown to greenish brown rock with a medium grained granoblastic texture. Mineral layering is common, but the rock lacks fissility and forms smooth, rounded outcrops. All outcrops contain some granitic material, which may form thin layers on foliation planes (Plate XV-C, p. 134) or completely surround blocks of the granulite (Plate I-A). Where the injected material comprises more than half the rock mass the rock is classified as an Archean migmatite.

Two types of granulite are recognized; intermediate granulite, composed essentially of hypersthene, quartz and oligoclase, and basic granulite, composed essentially of hypersthene, augite and andesine. Both types have granoblastic textures and contain hypersthene, blueish quartz, and tan feldspar. In addition to these minerals biotite and some garnet occur in the intermediate granulite, and hornblende and augite occur in the basic granulite. Accessories are opaque oxides, apatite, zircon and rutile. The primary minerals are partly altered to sericite, green uralitic amphibole and talc (Plate I-B).

Table 13 in the Appendix gives mineral compositions of six thin sections of the intermediate granulite. Typical sections have compositions in the range; 34% to 55% plagioclase (An_{25-32}), 0% to 12% microcline, 18%

PLATE I

A - Rounded inclusions of metasedimentary material in Archean granulite Normanville Area.

B - Photomicrograph of granulite north of the Grenville Front. Minerals are hypersthene, biotite, plagioclase and quartz. Plane polarized light, magnification 300x.

to 24% quartz, 7% to 13% biotite, 1% to 11% hypersthene 0% to 8% garnet, and traces of opaque oxide, apatite, and zircon. Alteration of the primary minerals forms 4% to 8% uralitic amphibole and traces of epidote, chlorite and sericite.

Mineral composition of thin sections of the basic granulite is shown in Table 13 in the Appendix. Typical samples are composed of 29% to 41% plagioclase (An_{30-40}), 6% to 12% biotite, 5% to 12% hornblende, 0% to 12% hypersthene, 19% to 31% clinopyroxene, 4% to 8% opaque oxide, and traces of apatite. Rare samples contain as much as 20% quartz. Alteration of the primary minerals may produce as much as 5% of any of the secondary minerals uralite, anthophyllite, epidote or talc. The basic granulite differs from the intermediate type in containing primary hornblende and clinopyroxene, a more calcic plagioclase, and in lacking much quartz or microcline.

The minerals of both rock types show most of the features of the granulite facies listed earlier. Their quartz is blue and their feldspars tan to grey in colour. Most samples contain hypersthene. In thin section the quartz grains are seen to be made up of many small welded segments of slightly different orientations. The plagioclase is unzoned. Some grains contain both albite and pericline twins. The twins are narrow, and commonly pinch out within the grain. Microcline is very finely perthitic, generally untwinned, and shows undulatory extinction. The hypersthene is pleochroic from pink to green, and has an $Fe^{+2}/(Fe^{+2} + Mg^{+2})$ ratio of about 0.55. The clinopyroxene is light green augite. Primary hornblende is greenish brown, and secondary uralite blueish green. Biotite forms irregular or tabular grains, with light brown to dark reddish brown pleochroism, and

a refractive index (n_Y) of about 1.653. The garnet forms large pinkish brown grains. One sample had the cell edge (11.517 Å) and the refractive index (1.793), of a pyrope-rich almandine.

Secondary alteration products have formed on some of the primary minerals but were never found to replace them completely nor to change the granulitic texture of the rocks north of the Grenville Front. The main effects of retrograde metamorphism are the breakdown of the hypersthene and plagioclase. The hypersthene is cut by veinlets of fine-grained colourless anthophyllite, and is rimmed by green uralite where it touches plagioclase. Tablets of colourless clinozoisite and flecks of sericite cloud the plagioclase. Microcline is unaffected by the alteration. In strongly altered specimens, biotite is bleached, and contains sagenitic rutile. Fine-grained mixtures of secondary biotite and quartz replace the hypersthene in these samples. Secondary garnet was not recognized in the granulite north of the Grenville Front.

Archean Intrusions

The Archean granulite is cut by stocks, dykes and sills of a medium- to coarse-grained leucocratic igneous rock. The intrusive rock is best exposed half a mile north of Jackson Lake and in the hills west of Cherny Lake. Gill et al. (1937) describe a large batholith of the rock about 15 miles northeast of the Normanville Area.

Blue quartz, pink microcline, and greenish plagioclase make up more than 90% of the rock, the rest being biotite and secondary epidote and sericite. In coarse grained samples the feldspar cleavage is visibly warped.

Composition estimates of eight thin sections are given in Table 14 in the Appendix. A typical rock of this type contains about 45% plagioclase, 10% to 15% microcline perthite, 10% to 25% quartz, 5% to 10% biotite, and traces of muscovite, epidote, magnetite, apatite, sphene, and leucoxene. A pink pegmatitic or aplitic phase contains 50% to 60% microcline perthite, 10% to 20% plagioclase, 20% to 30% quartz, and generally less than 5% mafic minerals.

Thin sections show large quartz grains composed of many small welded segments. The microcline has shadowy extinction or is very finely twinned. Flame or hair perthite forms about one-third of its volume, and clear albite rims the microcline where it is in contact with plagioclase. Most of the plagioclase is altered to sericite or clinozoisite. Plagioclase compositions range from An_2 to An_{35}, but are generally less calcic than An_{20}. Biotite occurs in both primary and secondary forms. Most of the primary biotite is reddish brown, and some is frayed and altered at its edges. Fine-grained euhedral epidote, olive green biotite, chlorite, quartz, and sphene fill fractures and pockets between the coarser grains.

Charnockites and granulite facies rocks all show mineralogical features developed in response to high temperatures of formation, or from internal strain caused by cooling from these temperatures. Fine perthitic intergrowths, shadowy extinction, and warped cleavages result when orthoclase inverts to microcline. Blue iridescent quartz grains, made up of many subparallel segments, may also result from internal strain. The primary minerals are commonly altered to lower temperature secondary minerals on cooling. The Archean intrusions of the Normanville Area have all these features in common with other high temperature intrusive rocks.

Altered Archean Gneiss

Some of the Archean rocks near the northern border of the Normanville Area are too altered to be grouped with the other basement rocks. They contain variable proportions of mafic and felsic constituents, depending on the composition of the parent rock, but all types are characterized by altered plagioclase, fine green mafic alteration products, and blue quartz.

The mineral compositions of six thin sections of the altered gneiss are shown in Table 14 in the Appendix. A typical sample contains 44% to 52% plagioclase (An_{25-30}), 7% to 21% quartz, 6% to 10% olive biotite, 5% to 15% epidote, 0% to 5% hornblende, 0% to 15% augite, 0% to 5% opaque oxide, and small amounts of apatite, zircon and rutile. Alteration products such as epidote, uralite, sericite, anthophyllite, chlorite and sphene or leucoxene generally form 20% to 25% of the rock.

Primary constituents resemble those of the Archean granulite or intrusive rocks. The quartz is blue, the microcline is perthitic and rimmed with albite. Plagioclase is clouded with fine clinozoisite and sericite. Hornblende is brown. The biotite is olive brown and full of fine sagenitic rutile. It is the fine-grained alteration minerals that give the rock its distinctive appearance. The augite is everywhere rimmed with anthophyllite and uralite. Fine-grained biotite, epidote, quartz, and carbonate form in pockets between the coarse crystals, or in places surround them.

Why this part of the Archean gneiss should be more altered than others is not certain. It occurs farther from the Grenville Front than the less altered granulites. However, it occurs close to outliers of slightly

metamorphosed Proterozoic epidote schist and grit, with which it bears a strong mineralogical resemblance. The altered gneiss may have been weathered, or may have adsorbed water during the pre-Proterozoic erosion. If so, it represents a regolith between the Archean and Proterozoic rocks.

Archean Rocks South of the Grenville Front

The Archean granulite also occurs within the Grenville Structural Province. Here it is located along an east-west trending zone, stretching from near the Moisie River to the area's western border at about latitude 52°20'N. Good exposures are found in the hills southwest of Bergeron Lake and west of Leduc Lake.

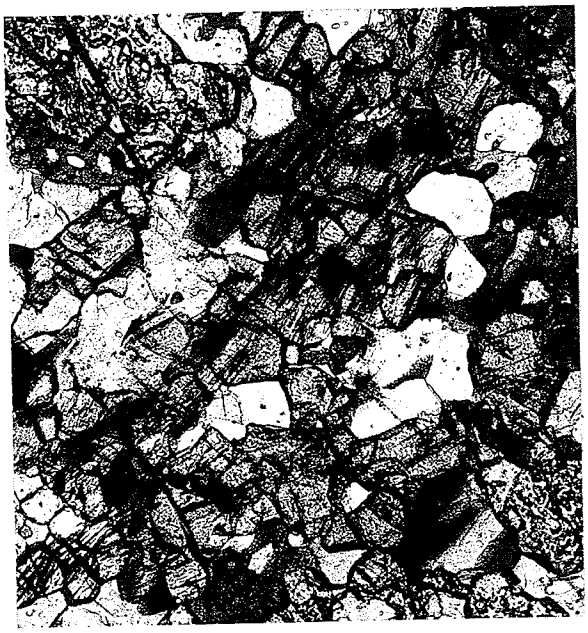
As in the area north of the Grenville Front, intermediate, basic and acidic granulites were derived, respectively, from sedimentary, volcanic and intrusive material. However, in this part of the area no attempt was made to separate the groups.

The granulites resemble the northern ones in many ways. They are light brown rusty-weathering rocks with a compact granulitic texture. Fissility is poor and the rock tends to weather into smooth rounded outcrops. Thin granitic layers are injected along foliation planes at intervals of several inches to a foot. Injected material makes up about 15% of most outcrops, and in places completely encloses blocks of the granulite. Garnet may form at the edges of granitic layers. The granulite is more contorted here than it is north of the Grenville Front. Plate II-A shows the appearance of a typical outcrop of granulite in the Gras Lake-Felix Lake Area.

Hand specimens of the granulite contain the same blueish grey quartz, tan feldspar, and granulitic texture that characterize the less

PLATE II

A - Outcrop of contorted Archean granulite occurring south of the Grenville Front.



-B-

-C-

B - Hypersthene in Archean granulite, partly replaced by secondary biotite and garnet. Parallel light, magnification 180x.

C - Clusters of secondary biotite and garnet formed by complete replacement of hypersthene in altered Archean granulite, south of the Grenville Front. Parallel light, magnification 300x.

altered type. Here, however, the Grenville metamorphism has converted most of the hypersthene to fine-grained biotite, quartz, and garnet. Complete replacement of the pyroxene leaves a rusty-weathering gneiss, in which fine-grained clusters of biotite, quartz and garnet remain in place of destroyed pyroxene. Except for its texture, the altered granulite resembles some of the unsegregated Proterozoic gneisses, and continued recrystallization might make the two indistinguishable.

In thin section the rock has a disordered texture. Rearrangement is incomplete and in addition to the fine-grained minerals replacing hypersthene, feldspar and garnet contain many inclusions of quartz and biotite. The fine-grained aggregates of biotite and quartz are generally rimmed with garnet, and in some samples, contain remnants of strongly pleochroic hypersthene. The microtexture of an altered granulite is shown in Plate II-B, and Plate II-C shows clusters of secondary biotite and garnet formed by replacement of hypersthene.

Visual estimates of the mineral composition of eighteen granulite thin sections are given in Table 20 in the Appendix. The average altered granulite contains 40% to 55% plagioclase (An_{28}), 0% to 8% microcline, 9% to 23% quartz, 6% to 24% biotite, 2% to 10% garnet, 0% to 3% hypersthene, perhaps some clinopyroxene and epidote, and traces of apatite, magnetite, pyrite, zircon, and sphene. The mineral composition of the group is more variable than that of most other rock types because it includes both intermediate and basic granulites, which are affected by varying degrees of alteration.

The feldspar is commonly strained; twins pinch out or may end abruptly against a fracture, and bent twins are common. Single plagioclase

grains contain both albite and pericline twins. The microcline shows either even or shadowy extinction. Perthitic intergrowths are rare, and relatively coarse grained. Biotite occurs both as coarse primary grains, and with garnet and quartz in fine-grained clusters replacing the pyroxenes. Both types of biotite are pleochroic from light yellow brown to red brown, and their intermediate refractive indices (n_Y) vary from 1.643 to 1.655. Some biotite is altered to chlorite with intergrown rutile, or bleached green near felsic bands. The hypersthene is pleochroic from pink to green, or may be stained rusty brown. Refractive indices of four hypersthenes indicate the composition range $Fe^{+2}/(Fe^{+2} + Mg) = 0.35$ to 0.42. The refractive indices (n_1 and n_2), measured on cleavage flakes of one clinopyroxene are 1.692, and 1.710. Almost all the garnet is secondary. The refractive indices of five garnets range from 1.783 to 1.790, and their cell edges range from 11.566 Å to 11.590 Å. They are almandines with more grossularite and less pyrope than the primary garnets in the fresh granulite.

Alteration and Chemical Composition of the Granulite

The grade of Grenville metamorphism increases from very weak in the northern part of the Normanville Area to the almandine amphibolite facies farther south. The Archean rocks of the Normanville Area lie beyond the main influence of the Grenville metamorphism. Their secondary minerals are all very fine grained and have grown on the granulite facies minerals without appreciably altering the composition or texture of the rock.

The granulites of the Gras Lake-Felix Lake Area lie well into the Grenville Province, and underwent strong repeated metamorphism during the

Grenville Orogeny. Their texture and mineral composition now differ from those of the Normanville granulites in having;

1) More complete destruction of the hypersthene.

2) Development of garnet, biotite, and quartz, rather than uralite and quartz from the breakdown of pyroxene.

3) Recrystallization rather than saussuritization of the plagioclase.

The reactions controlling these changes are shown in Figure 4. In the Gras Lake-Felix Lake Area the secondary minerals belong to the amphibolite facies; in the Normanville Area they belong to the greenschist facies of metamorphism.

A suite of metasedimentary granulite, altered granulite, and gneiss specimens was analyzed chemically to determine whether there is any chemical difference between the granulite and gneiss, and to determine what chemical changes accompany the alteration of the granulite. The analyses were made by H. Boileau of the Quebec Department of Mines. Their results, and pertinent analyses for comparison are given in Table 1.

Sediments differ in composition from their source rocks because of the selective weathering and deposition of the eroded material. The more thorough the weathering and sorting, the greater the difference will be. The main chemical changes that may accompany sedimentation are (Bastin, 1913; Pettijohn, 1949);

1) Removal of Na in solution.

2) Oxidation of Fe^{+2} and Mn^{+2}.

3) Enrichment of Al_2O_3 in clays.

4) Selective adsorption of K over Na, and Mg over Ca in clays.

These changes result in increases in the ratios, K_2O/Na_2O, Fe_2O_3/FeO,

FIGURE 4

MINERAL REACTIONS FROM REPEATED METAMORPHISM OF THE ARCHEAN GRANULITE

PRIMARY ARCHEAN MINERALS	SECONDARY MINERALS DEVELOPED BY GRENVILLE METAMORPHISM	
Granulite Facies	Amphibolite Facies (Gras Lake-Felix Lake)	Greenschist Facies (Normanville)
Hypersthene	(1)	Hypersthene + Quartz + Water → Anthophyllite
	(2)	Hypersthene + Anorthite + Water → Uralite + Quartz
	(3)	Hypersthene + Microcline + Water → Biotite + Quartz
	(3) Hypersthene + Microcline + Water → Biotite + Quartz	
	(4) Hypersthene + Anorthite → Garnet + Quartz	
Clinopyroxene	(5)	Diopside + Water + CO_2 → Tremolite + Calcite + Quartz
	(6) Diopside + Hypersthene + Microcline + Water + CO_2 → Biotite + Calcite + Quartz	
Plagioclase	(7)	Anorthite + Microcline + Water → Epidote + Sericite + Quartz (Also see No. 2)
	Recrystallized Plagioclase (Also see No. 4)	

(1) $7(Mg,Fe)SiO_3 + SiO_2 + H_2O \rightleftharpoons (Mg,Fe)_7Si_8O_{22}(OH)_2$

(2) $3(Mg,Fe)SiO_3 + 2CaAl_2Si_2O_8 + H_2O \rightleftharpoons Ca_2(Mg,Fe)_3Al_2Si_6Al_2O_{22}(OH)_2 + SiO_2$

(3) $3(Mg,Fe)SiO_3 + KAlSi_3O_8 + H_2O \rightleftharpoons K(Mg,Fe)_3AlSi_3O_{10}(OH)_2 + 3SiO_2$

(4) $2(Mg,Fe)SiO_3 + CaAl_2Si_2O_8 \rightleftharpoons Ca(Mg,Fe)Al_2Si_3O_{12} + SiO_2$

(5) $5Ca(Mg,Fe)Si_2O_6 + H_2O + CO_2 \rightleftharpoons Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2 + CaCO_3 + 2SiO_2$

(6) $Ca(Mg,Fe)Si_2O_6 + 2(Mg,Fe)SiO_3 + KAlSi_3O_8 + H_2O + CO_2 \rightleftharpoons K(Mg,Fe)_3AlSi_3O_{10}(OH)_2 + CaCO_3 + 4SiO_2$

(7) $4CaAl_2Si_2O_8 + KAlSi_3O_8 + H_2O \rightleftharpoons 2Ca_2Al_3Si_3O_{12}{\cdot}OH + KAl_3Si_3{\cdot}OH + 2SiO_2$

CHEMICAL ANALYSES OF GNEISSES

Sample No. Rock type	C-25-108-59 Fresh Granulite	C-20-101-61 Altered Granulite	C-31-160-61 Altered Granulite	D-17-61-61 Speckled Gneiss (Alt. Granulite)	D-11-42-61 Well Segregated Lower Gneiss	C-30-193-60 Poorly Segregated Lower Gneiss	Fresh Granulite Composite Spec. Roach & Duffel, G.S.C. Lab # A-749	Av. of 3 banded Lower Gneiss Murphy,(1961),p.57	Av. of 2 upper Schists Murphy,(1961),p.129	Av. Diorite by Daly Barth, p.69	Av. Granodiorite by Daly Barth, p.69	Av. of 11 Greywacke Pettijohn, p.250	Av. of 3 Subgreywacke Pettijohn, p.256	Av. Shale Clarke F.W. (1924) (p. 34)
SiO_2	65.85	59.60	56.75	60.80	60.63	62.70	62.8	65.10	56.69	56.77	65.01	64.2	77.8	58.10
Al_2O_3	15.06	16.95	16.82	16.26	16.22	16.07	16.1	15.27	17.16	16.68	15.94	14.1	9.5	15.40
Fe_2O_3	1.07	1.05	2.38	0.57	0.99	1.05	1.0	-	-	3.16	1.74	1.0	0.9	4.02
FeO	4.38	6.02	6.00	6.28	5.70	4.84	5.22	-	-	4.40	2.65	4.2	2.6	2.45
CaO	3.38	3.24	2.59	3.30	3.13	2.90	3.7	3.42	1.10	6.74	4.42	3.5	1.2	3.11
MgO	2.46	4.30	4.35	3.83	3.76	3.28	3.5	3.71	3.44	4.17	1.91	2.9	1.6	2.44
Na_2O	3.59	4.05	2.79	3.39	3.13	3.43	3.5	3.95	2.59	3.39	3.70	3.4	2.0	1.30
K_2O	2.19	2.53	5.19	2.82	3.25	2.82	1.9	1.82	3.80	2.12	2.75	2.0	1.5	3.24
H_2O+	0.94	0.72	1.27	1.17	1.43	1.40	0.76	-	-	(1.36)	(1.04)	2.1	1.6	3.7(2)
H_2O-	0.05	0.03	0.11	0.06	0.09	0.08	-	-	-			0.1	0.1	0.7(2)
TiO_2	0.52	0.74	0.87	0.65	0.70	0.65	0.6	-	-	0.84	0.57	0.5	0.6	0.65
P_2O_5	0.13	0.13	0.19	0.19	0.13	0.17	0.1	-	-	0.25	0.20	0.1	0.2	0.17
MnO	0.08	0.09	0.11	0.11	0.12	0.08	0.1	-	-	0.13	0.07	0.1	0.2	-
CO_2	0.05	0.09	0.04	0.07	0.25	0.08	-	-	-	-	-	0.6	0.5	2.63
S	0.02	0.10	0.18	0.15	0.11	0.09	-	-	-	-	-	-	0.1	-
Li_2O	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-	-
V_2O_3	0.03	0.06	0.06	0.05	0.06	0.06	-	-	-	-	-	-	-	-
BaO	0.13	0.11	0.11	0.13	0.11	0.09	-	-	-	-	-	-	-	-
SrO	0.12	0.09	0.07	0.07	0.08	0.08	-	-	-	-	-	-	-	-
Cr_2O_3	0.02	0.03	0.04	0.03	0.03	0.03	-	-	-	-	-	-	-	-
ZrO	-	0.03	0.03	0.03	0.03	0.03	-	-	-	-	-	-	-	-
TOTAL	100.07	99.96	99.96	99.96	99.95	99.93	99.3	92.27	84.78	99.99	100.00	99.8	100.4	98.51
MgO/CaO	0.73	1.33	1.68	1.16	1.20	1.13	0.95	0.79	3.13	0.62	0.43	0.83	1.33	0.78
K_2O/Na_2O	0.61	0.62	1.86	0.83	1.04	0.82	0.54	0.46	1.47	0.63	0.74	0.59	0.75	2.49
Fe_2O_3/FeO	0.24	0.17	0.40	0.09	0.17	0.22	0.19	-	-	0.72	0.66	0.24	0.35	1.64
Excess(1) Al_2O_3	2.52	3.89	3.66	3.45	3.58	4.56	3.3	2.66	8.57	-2.32	0.65	1.7	3.6	4.64

(1) Al_2O_3 in excess of that combined in normative feldspar.

(2) Av. shale Clarke p. 30. Value on p. 34 is 5.0% (total H_2O).

P. Clarke & Murphy analyses done by H. Boileau,

Roach & Duffel analyses done by K. Hoops.

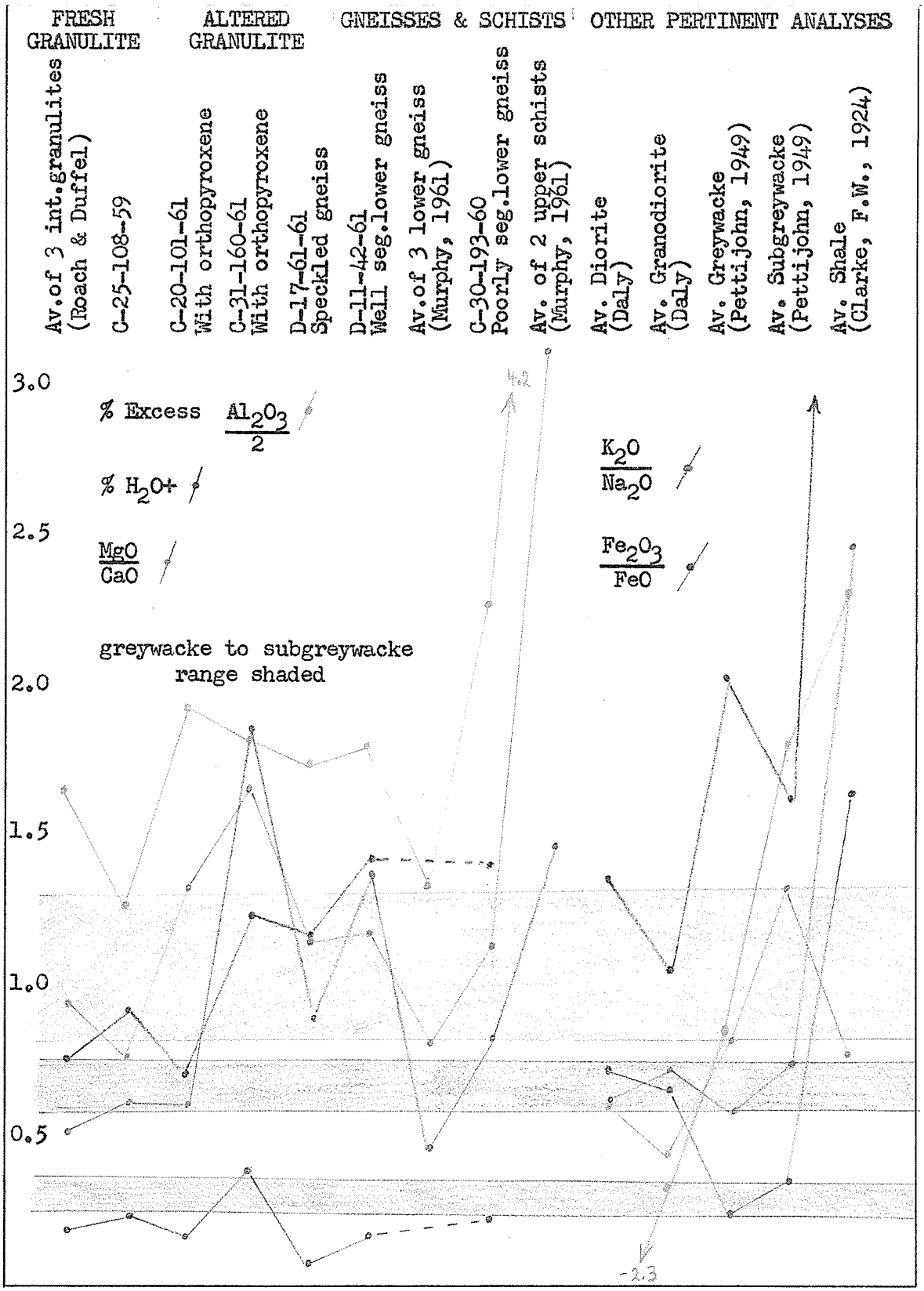
MgO/CaO, and in the Al_2O_3 contents of sediments as their detrital portion is weathered into clay. Comparison to these values with the values of average sediments gives a measure of the proportion of clay in a sedimentary rock, and a clue to the origin of an isochemically metamorphosed paragneiss.

The important oxide ratios, and the water and aluminum oxide contents of the analysed samples are plotted in Figure 5. The main change accompanying the repeated metamorphism of the granulite is the addition of water. In the last recognizable stage of alteration, the granulite still contains less water than the Proterozoic gneiss. The incoming water was probably accompanied by potassium, as the granulite with the most water (C-31-160-61), also contains more K_2O than the others. The other chemical data are inconclusive. Granulite and both well segregated and poorly segregated lower gneisses have compositions similar to greywacke or subgreywacke. The upper schists analysed for Murphy have the composition of shale.

The granulite and gneiss have similar compositions and it is possible that the well segregated gneiss represents completely recrystallized granulite. However, the belt of Archean granulite runs east-west beside a parallel synclinal structure. Folds in the surrounding gneiss bend around, and are generally overturned towards the granulite. It appears that the granulite follows a major anticlinal axis rather than a zone of weaker than average retrograde metamorphism.

OXIDE RATIOS OF ANALYSED GNEISSES

Figure 5



CHAPTER IV

PROTEROZOIC GNEISSES AND SCHISTS

Introduction

Gneisses are the most common of the local rock types, underlying more than three quarters of the area. Their compositions and textures depend on the nature of the original sedimentary material, and the degree of metamorphism or metasomatism it has undergone.

Although they occur at different places in the stratigraphic sequence, the different types of paragneiss are discussed together so as to be more easily compared. The gneisses may be classified on the basis of; 1) degree of segregation of their mafic and felsic constituents, 2) stratigraphic position relative to the Iron Formation Series, and 3) mineral composition. Two main groups of gneissic rocks are recognized, the common quartzofeldspathic to slightly pelitic rocks, and the less common chemically distinctive rocks that generally overlie the Iron Formation Series. The quartzofeldspathic group is divided on the basis of metamorphic grade and mineral segregation.

Well segregated gneisses occur below the Iron Formation Series in the more highly metamorphosed parts of the area. They may be either biotite, or hornblende-rich. Poorly segregated gneisses occur either above or below the Iron Formation Series. They have undergone less reorganization than the well segregated gneiss, and generally occur above it, or in less metamorphosed parts of the area. In the Gras Lake-Felix Lake Area the gneisses lying above and below the iron formation differ

slightly in mineralogy. In the Normanville Area they are the same. North of the Grenville Front the quartzofeldspathic sedimentary rocks occur as only slightly metamorphosed schist and clastic grit.

The chemically distinctive rocks include; rusty-weathering graphitic schist, quartz-mica-kyanite schist, a rock composed essentially of hornblende and garnet, and a very potassic gneiss. The first three types generally overlie the silicate-carbonate iron formation, and apparently formed from graphitic or aluminous sediments. The potassic gneiss is associated with the gabbros of the Felix Lake Area, and is thought to result from potassium metasomatism of the common gneiss.

Like all artificial classifications, this one is sometimes difficult to apply. The degree of segregation is variable, and the position of the gneiss relative to the Iron Formation Series is not everywhere apparent. However, the geology is represented more truthfully by dividing the gneisses this way, than it could be if the groups were combined.

Quartzofeldspathic Rocks

Albite-Epidote-Chlorite Schist and Grit

Outliers of slightly metamorphosed Proterozoic iron formation and grit overlie the granulite near Boulder and Jackson lakes. South of Boulder Lake the grit grades into a linear textured schist.

The grit contains clastic fragments of blueish quartz, altered plagioclase, and biotite, from the underlying Archean rocks, held in a matrix of fine-grained epidote, biotite, quartz, and albite. The schist contains the same minerals as the matrix of the grit. Its epidote and

biotite are elongated and oriented to give the rock a strong lineation. In some samples spindle shaped clots of quartz and feldspar accentuate the linear appearance of the rock.

Thin sections of the rock contain 1 to 3 mm. fragments of strained quartz, altered feldspar, and brown sagenitic biotite. Surrounding the fragments is a fine-grained matrix of epidote, green biotite, chlorite, albite and quartz (Plate III). Pockets of fine quartz and albite formed in strain shadows beside large fragments. The quartz in the matrix differs from that of the fragments in being clear and extinguishing evenly. In some samples the albite is myrmekitic. Composition estimates of four thin sections are given in Table 16 in the Appendix.

PLATE III

Photomicrograph of albite-epidote-chlorite grit, showing a fragment of quartz surrounded by a fine-grained matrix of epidote, chlorite, and some clear secondary quartz.

The composition is variable, but most rocks of this type contain about 10% altered feldspar, 15% strained quartz, and 0% to 5% biotite in

coarse grained fragments, in a matrix containing an additional 10% to 15% quartz, 15% to 35% albite, 10% to 20% biotite, 0% to 15% chlorite, and 5% to 20% epidote. Traces of allanite, zircon, and magnetite occur in most specimens, and calcite occurs in one.

The occurrence in the matrix of stable epidote, albite, and biotite places the rock in the quartz-albite-epidote-biotite subfacies of the greenschist facies of metamorphism (Fyfe et al., 1958, p. 223). This is the lowest grade of metamorphism recognized in the area.

The clastic texture and low metamorphic grade of the grit and associated iron formation contrast sharply with the highly metamorphosed granulites below them. The unconformity between the granulite and grit was not seen, but is indicated by the fragments of granulite in the grit, and the abrupt change in metamorphic grade.

The rock is similar to the schistose grit described by Gill et al. (1937) in the area northwest of Wabush Lake. Traced southward across the Grenville Front the linear textured schist grades into poorly segregated gneiss. Clastic fragments were not recognized in this gneiss, which occurs farther from the basement and probably formed from finer grained sediment.

Poorly Segregated Gneisses

South of the Grenville Front the albite-epidote schist grades into poorly segregated quartz-oligoclase-biotite gneiss. Most of the Proterozoic gneiss in the Normanville Area is of this type. In the Gras Lake-Felix Lake Area the poorly segregated gneiss generally occurs close to the Iron Formation Series, and is less common than the deeper, well

segregated gneiss. Poorly segregated gneisses occur both above and below the Iron Formation Series.

In the Normanville Area the upper and lower gneisses are indistinguishable, but in the Gras Lake-Felix Lake Area, the upper gneisses contain less plagioclase and biotite, and more hornblende and garnet than the lower. The gneisses of the Normanville Area contain nearly 10% of both muscovite and microcline, minerals that are rare in the southern gneisses.

The gneisses are grey, fine- to medium-grained and generally unbanded. They have a well developed bedding fissility, on which they erode into step-like outcrops. They may contain porphyroblasts and lenses, or rarely bands of quartz and feldspar, separated from the rest of the rock by a mica selvage. Layers especially rich in felsic segregations are indicated on the geological maps.

In the Normanville Area the porphyroblastic bands contain more mica and less feldspar than the common unsegregated gneiss. Compositions of five thin sections of this rock are given in Table 16, in the Appendix. Clots of coarse grained quartz and microcline are surrounded by equally coarse muscovite and shiny black biotite. The micas are crenulated, and clots of quartz may be stretched into thin contorted lenses. In places the felsic clots are so abundant that the rock resembles a metamorphosed conglomerate (Plate IV), but their minerals are fresh and more likely to have formed by metamorphic segregation.

In the Gras Lake-Felix Lake Area the porphyroblastic gneiss grades into the unsegregated gneiss, and the two are described together.

PLATE IV

Porphyroblastic biotite schist, Normanville Area.

The unsegregated gneiss has a medium- to coarse-grained granoblastic texture. Its minerals are generally free of inclusions or alteration. Plagioclase is fresh and evenly twinned, microcline shows coarse grid twinning. Biotite is subhedral, brown to olive brown in the lower gneiss, and reddish brown in the upper gneiss. Most of the hornblende has extinction angles, Z^c, of 24° to 30°, and the pleochroic formula X = yellow brown, Y = green, Z = blueish green. Refractive indices of biotite, hornblende, and garnet are higher in the upper than in the lower gneiss. Both hornblende and garnet are embayed by anhedral quartz and feldspar. Euhedral epidote with allanite cores generally forms beside the biotite.

Mineral composition of thin sections of unsegregated gneiss are given in Tables 15 and 22 in the Appendix. The common composition range of the gneiss in different parts of the area is shown in Table 2. The

range includes one mean deviation on either side of the average composition.

TABLE 2

AVERAGE COMPOSITION RANGE OF POORLY SEGREGATED GNEISSES

	Upper Gneiss Normanville	Lower Gneiss Normanville	Upper Gneiss Gras-Felix	Lower Gneiss Gras-Felix
Plagioclase	22-48 An.10-35	22-46 An.10-33	37-59 An.23-34	48-58 An.25-31
K-feldspar	5-13	1-23	-	0-3
Quartz	21-31	20-34	11-35	16-26
Biotite	15	9-21	9-23	13-23
Muscovite	4-10	3-13	-	-
Hornblende	-	-	3-11	0-4
Garnet	-	-	2-6	-
Epidote	0-2	1-5	tr	tr
Others	1-7carb.,ap.	ap.,zr.	ap.	ap.,py.,zr.

The differences in mineralogy between gneisses in different parts of the area reflect differences in chemical composition. The principal chemical differences are more K_2O and Al_2O_3 in the northern than in the southern gneisses, and more Al_2O_3 and a higher Fe/Mg ratio in the upper gneiss than in the lower gneiss in the southern part of the area.

Well Segregated Gneisses

Deeper in the section, the gneiss is more strongly segregated. Layers and lenses of quartz and feldspar alternate with more mafic portions,

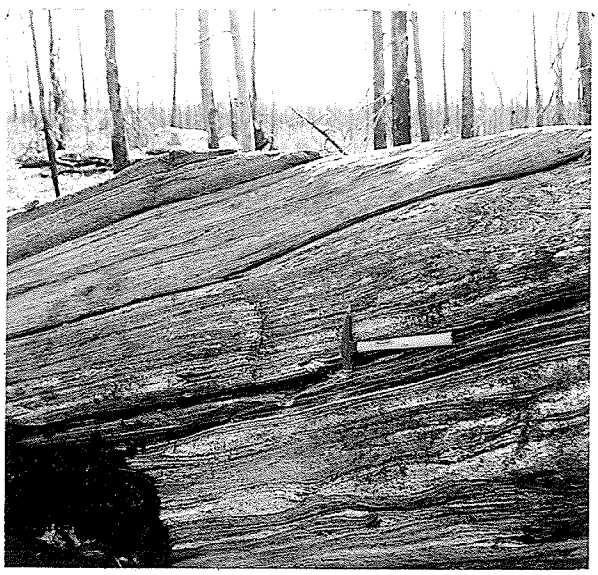
and the foliation is more contorted. Gneisses with well segregated textures underlie most of the Gras Lake-Felix Lake Area, but only occur in the southwestern corner of the Normanville Area.

The felsic layers are generally conformable to, and contain the same minerals as, the rest of the rock. All gradations exist between small felsic lenses and thick layers, such as seen in Plate VI-A, and the layers are thought to have formed within the rock rather than by injection from some outside source. Partial remelting may have helped the migration of the felsic constituents.

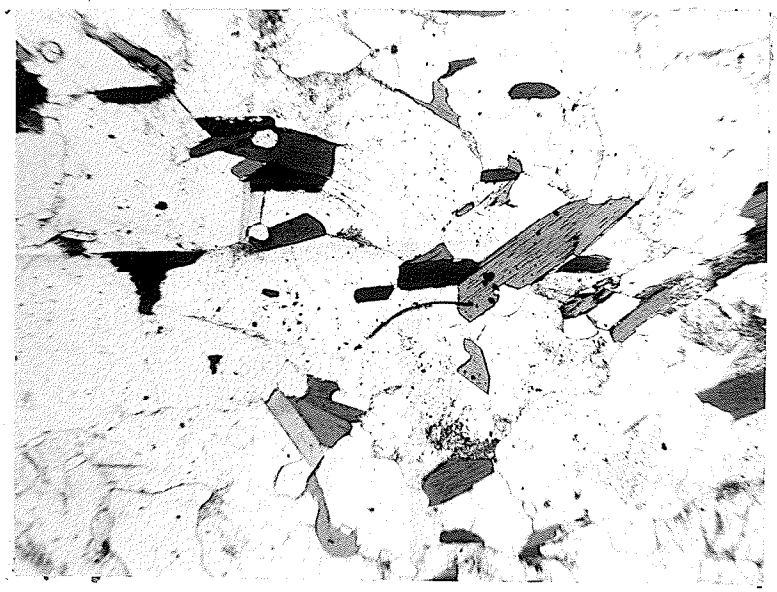
Biotite is the main mafic mineral, but some of the gneiss contains as much hornblende as biotite. In the Gras Lake Area the hornblende-rich gneiss occurs as bands, about one-half mile wide, in the biotite-rich type. The textures of the well segregated and the poorly segregated gneisses can be compared in Plates V and VI.

The most common type of gneiss contains 1/4 to 1/2 inch bands of quartz and white plagioclase alternating with mafic-rich bands. The mafic bands contain 2 mm. flakes of shiny black biotite in the ratio of 1 part biotite to 2 parts of quartz and feldspar. Mineral segregation may take the form of mafic speckles, or contorted felsic lenses instead of felsic bands. Some outcrops contain calcic-mafic layers composed essentially of hornblende, plagioclase, and diopside. These layers are from 6 inches to 2 feet thick and may be broken into boudins. They probably represent calcic interlayers in the quartzofeldspathic sediments that formed the gneiss. Local shearing and alteration are common in the lower gneiss. Where the rock is sheared, the feldspar is stained pink, and the biotite is altered to chlorite.

PLATE V

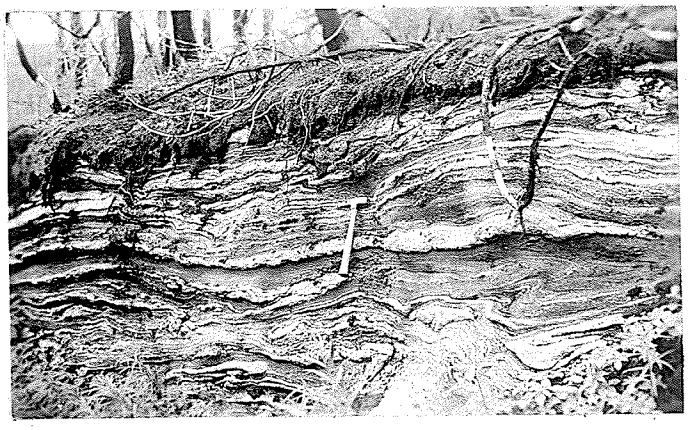


A - Outcrop of gneiss with poorly segregated texture, from the northern part of the Felix Lake Area.

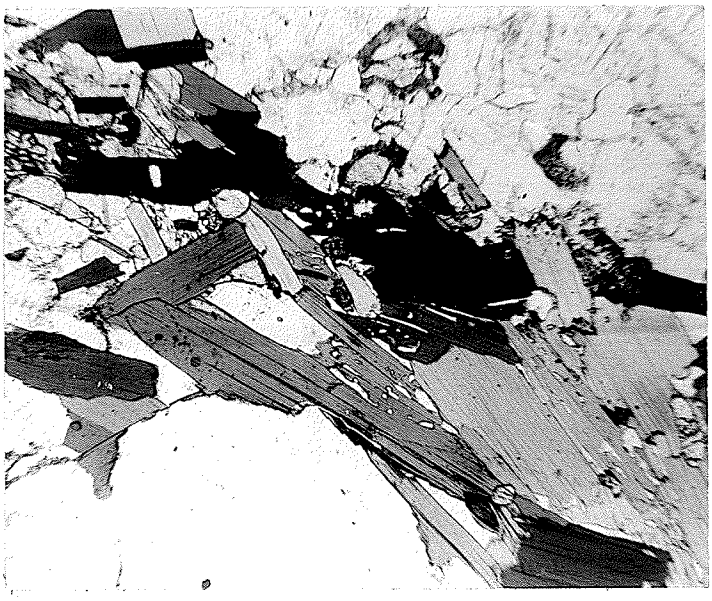


B - Photomicrograph of poorly segregated biotite gneiss; parallel light, magnification 300x.

PLATE VI



A - Outcrop of well segregated gneiss, Gras Lake Area.



B - Layer of biotite and epidote surrounded by plagioclase and quartz in well segregated gneiss. Plane polarized light, magnification 300x.

Mineral compositions of fifteen thin sections of biotite-rich, and ten thin sections of hornblende-rich gneiss from the Gras Lake-Felix Lake Area are given in Table 21 in the Appendix. Table 15 gives the compositions of 3 sections of gneiss from the Normanville Area. Only samples that were representative of the whole rock were studied. These compositions are summarized in Table 3.

TABLE 3

AVERAGE COMPOSITION RANGE OF WELL SEGREGATED GNEISS

	Normanville Gneiss (3)	Gras Lake-Felix Lake Biotite Gneiss (15)	Gras Lake-Felix Lake Hornblende Gneiss (10)
Plagioclase	33-35 An_{15-25}	40-57 An_{23-32}	44-60 An_{22-31}
Potassium-feldspar	0-5	0-13	variable
Quartz	15-45	17-28	11-27
Biotite	8-16	17-23 Bio. & Chl.	6-14
Muscovite	0-2	trace	-
Hornblende	1-12	-	6-14
Garnet	-	0-2	trace
Epidote	4-9	0-2	0-1
Others	opaque zircon sphene	apatite pyrite carbonate zircon	apatite zircon sphene

In the well segregated biotite gneiss, plagioclase generally contains regular albite twins and may be slightly antiperthitic. Quartz shows undulose extinction and planes of tiny inclusions cross many grains. Sub-

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hedral flakes of brown or olive biotite are inclined about 15° to the foliation. Common accessories are epidote, apatite, zircon, and pyrite. About half the samples showed the effects of shear and alteration. In these samples plagioclase is sericitized and partially replaced by microcline. The biotite is ragged and altered to chlorite, and hornblende may be altered to chlorite and sphene. Some sections contain garnet which is partly replaced by biotite and feldspar.

The hornblende-rich gneiss resembles the biotite-rich type in most respects. All gradations exist between a banded hornblende gneiss, and a gneissic-textured granodioritic rock, in which the mafic minerals form 2 mm. to 4 mm. specks rather than bands. Most quartz has undulose extinction. It occurs in 1/2 to 1 mm. lenses made up of several smaller grains. Plagioclase may be partly altered to sericite or microcline. Microcline twins are well developed. The microcline is either absent or occurs in large amounts. Its irregular distribution, formation by replacement of plagioclase, and association with other alteration products suggest that it is not an original constituent of the rock. Most of the biotite is brown. Hornblende has an extinction angle (Z^c) of 20° to 24°, and the pleochroic formula, X = yellow green, Y = green, Z = dark green or blueish green. It may be poikilitic and in some sections is partly replaced by biotite and epidote or sphene. Sphene and euhedral epidote generally accompany the mafic minerals. Some of the epidote has grown around cores of allanite.

Both the biotite-rich and hornblende-rich gneiss are characterized by the organization of their mafic and felsic constituents into separate bands, lenses, or speckles. Strained quartz and altered biotite

and plagioclase are more common here than in the less segregated gneiss. There has been some replacement of plagioclase by microcline, garnet by biotite and feldspar, and hornblende by biotite and epidote. Apparently this gneiss formed under conditions of greater mobility and stress than the other Proterozoic rocks. It most likely represents the lower-most Proterozoic, mixed perhaps with some completely recrystallized Archean gneisses.

Both the well segregated and the poorly segregated gneisses contain oligoclase feldspar. Kyanite is found in some of the upper schists associated with the unsegregated gneiss. These rocks belong to the intermediate, kyanite-muscovite-quartz, subfacies of the almandine amphibolite facies of metamorphism (Fyfe et al., 1958). The well segregated gneiss belongs to this or perhaps to the higher sillimanite-almandine subfacies. No sillimanite was, however, recognized in the area.

Chemical compositions of isochemically metamorphosed gneisses can indicate the type of sediment from which they formed. The breakdown of clastic material to form clay tends to increase the alumina content, and the ratios MgO/CaO, K_2O/Na_2O, and Fe_2O_3/FeO of the sedimentary material during its transportation and deposition. In general, the higher these values, the more thoroughly weathered and shalier is the sediment containing them.

The average mineral compositions of the common gneisses are recast into their approximate chemical characteristics in Table 4 as described in Wahlstrom (1957, p. 238). The values are only approximate as they are calculated from average compositions, and without exact knowledge of the compositions of minerals capable of atomic substitution. For this reason Fe_2O_3/FeO is not given, and the values of MgO/CaO are suspect.

However, because they are based on average compositions, these figures may be closer to relative compositions of their respective groups than those based on chemical analyses of single rock samples.

TABLE 4

APPROXIMATE VALUES OF K_2O/Na_2O, MgO/CaO AND Al_2O_3 OF GNEISSES

	K_2O/Na_2O	MgO/CaO	Al_2O_3 excess (1)
Upper Poorly Segregated Gneiss Normanville Area -	1.4	2.1	6.2
Lower Poorly Segregated Gneiss Normanville Area -	1.6	2.1	6.3
(2)* Average of 2 Upper Schists Carheil Area (Murphy, 1961) -	1.47	3.13	8.57
(2)* Average of 3 Lower Gneiss Carheil Area (Murphy, 1961) -	0.46	0.79	2.66
Rusty-Weathering Upper Schist Gras-Felix Area -	0.7	2.0	5.3
Upper Poorly Segregated Gneiss Gras-Felix Area -	0.4	1.6	5.1
Lower Poorly Segregated Gneiss Gras-Felix Area -	0.5	1.7	3.9
* C-30-193-60, Poorly Seg. Lower Gneiss Gras-Felix Area -	0.28	1.13	4.56
Well Segregated Biotite Gneiss Gras-Felix Area -	0.7	1.7	3.7
Well Segregated Hornblende Gneiss Gras-Felix Area -	0.4	1.0	3.3
* D-11-42-61, Well Seg. Lower Gneiss Gras-Felix Area -	1.04	1.20	3.58
* Average Shale (Clarke, 1924)	2.49	0.78	4.64
* Average Subgreywacke (Pettijohn, 1949)	0.75	1.33	3.6
* Average Greywacke (Pettijohn, 1949)	0.59	0.83	1.7

(1) Per cent Al_2O_3 above that combined in feldspar.
(2) The Carheil Lake Area lies between the Normanville and Gras-Felix areas.
* Based on chemical analysis.

The gneisses in the Normanville Area, and the upper gneisses in the Gras Lake-Felix Lake Area, generally have higher K_2O/Na_2O, MgO/CaO, and Al_2O_3, than the lower gneisses in the areas to the south. This suggests that the rocks in the Normanville Area, and those overlying the Iron Formation Series were originally shales, whereas, the lower rocks in the southern part of the area were probably greywacke or subgreywacke.

Chemically Distinctive Rocks

Several mineralogically distinctive rocks are interlayered with the common Proterozoic gneisses. Some of these layers are continuous over large areas, and because they are easy to recognize, make useful marker horizons. They occur above the Iron Formation Series, and are more common in the southern, than in the northern area. Three main types are recognized; rusty-weathering graphitic schist, quartz-mica-kyanite schist, and hornblende-pyroxene-garnet rock. Some rocks are gradational between the main types; the graphitic schist and hornblende-garnet rock may contain some kyanite, and there are rusty layers and graphite in the mica-kyanite schist.

The gneisses east of the Moisie River are very hard and microcline-rich. They appear to be feldspathized and hardened by metasomatism associated with the gabbro, that is, common in that part of the area. Because of their high microcline content, they are referred to as potassic gneisses.

Rusty-Weathering Graphitic Schist

The graphitic schist is a medium grained, poorly segregated

rock, distinguished mainly by its rusty-weathering and the presence of graphite, pyrite, garnet, and in places kyanite along with the usual quartz, feldspar, and biotite. It is most abundant in the western half of the Gras Lake-Felix Lake Area, occurring above the iron formation in the valley of the Pekans River, and between the Little Manicougan River and Hope Lake. A thin band also occurs west of Pegma Lake.

Mineral compositions of eight thin sections of the rock are given in Table 23 in the Appendix. Most samples have compositions in the following range; 39% to 52% plagioclase (An_{23-28}), 0% to 10% microcline, 15% to 29% quartz, 15% to 22% biotite, 3% to 9% garnet, 1% to 3% graphite, and minor amounts of muscovite, epidote, apatite, and zircon.

In thin section biotite is pleochroic from colourless to red brown, and is interleaved with graphite. Quartz is generally unstrained. Garnet is filled with inclusions of biotite and feldspar. The plagioclase is generally perthitic, especially near the edges of felsic clots. This schist is always associated with the silicate-carbonate facies of iron formation, and was probably derived from a foul-water shale.

Quartz-Mica-Kyanite Schist

In the eastern part of the Gras Lake-Felix Lake Area the graphitic schist grades into a quartz-rich mica-kyanite schist. The best exposures of this schist are found in the band trending southward from Lac Gentilhomme. It is a tough rock which forms rounded outcrops and caps the highest hills of the area. Quartz is the major felsic mineral. Coarse grained muscovite occurs with the biotite, and pink garnets are present in most samples. Some varieties are graphitic and rusty weathering.

Feldspar is notably rare. Deep blue laths of kyanite stand in relief on weathered surfaces. The kyanite, which may reach an inch in length, is generally concentrated with layers and pods of glassy quartz.

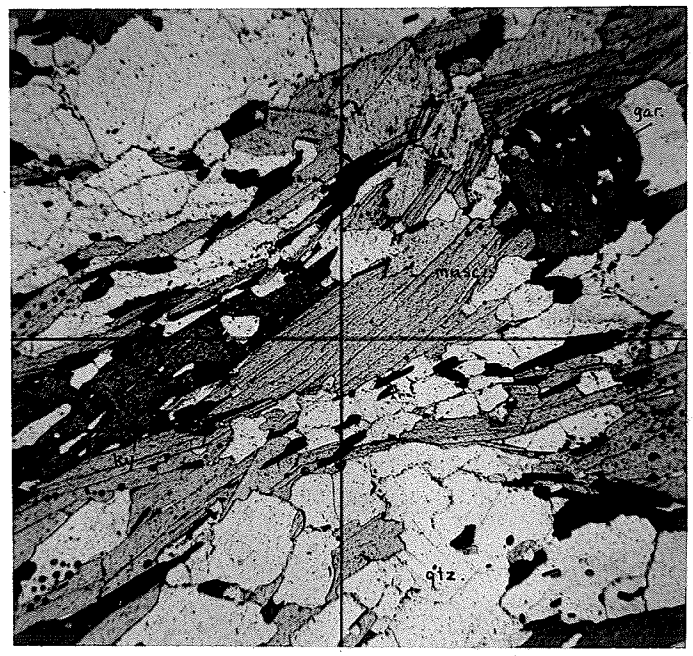
Composition estimates from four thin sections from the Gras Lake-Felix Lake Area are given in Table 23. Typical specimens contain 0% to 15% plagioclase, 48% to 55% quartz, 10% to 22% biotite, 2% to 20% muscovite, 2% to 6% garnet, and minor apatite and zircon. A thin section from the Normanville Area (Table 16) contains less quartz and more feldspar than this. Good foliation results from the alignment of mica and, kyanite, and elongate lenses of quartz. The micas are bent around porphyroblasts of garnet, or clots of kyanite and quartz (Plate VII-A). Many of the minerals in this rock resemble those of the rusty-weathering graphitic schist. Biotite is reddish brown, and is commonly intergrown with muscovite or graphite. Plagioclase is fresh and quartz is very clear and unstrained. The garnet is poikilitic.

The mica-kyanite schist is the metamorphosed equivalent of an aluminous shale. It is probably no coincidence that alumina-rich beds closely overlie the alumina-poor iron formation. This sort of distribution would result from a period of chemical weathering with transport and deposition of the iron in solution, followed by slight uplift and erosion of the clayey residue.

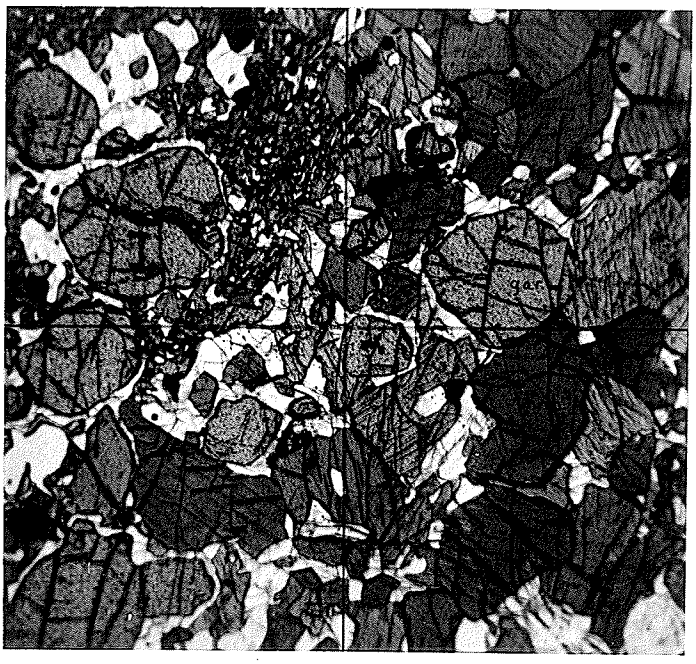
Hornblende-Pyroxene-Garnet Rock

The mica-kyanite schist is commonly overlain by a mafic hornblende-pyroxene-garnet rock. The best exposures of this rock are found in the hills west of the Moisie and Gentilhomme rivers. It is a massive

PLATE VII



A - Photomicrograph of mica-kyanite schist. Plane polarized light, magnification 180x.



B - Photomicrograph of hornblende-garnet rock. Plagioclase surrounds garnet grains, and is intergrown with clinopyroxene. Plane polarized light, magnification 180x.

black rock composed essentially of 2 to 4 mm. grains of garnet and hornblende, plus some plagioclase and pyroxene. The garnet is evenly distributed through the rock, and is commonly coated with a thin crust of plagioclase. Plagioclase may also be concentrated in thin lenses and bands, giving the rock a weak foliation.

In thin section, the biotite is red or brown. Hornblende is pleochroic from yellow green (X), to deep blueish green (Z), or in places brown, and has an extinction angle (Z^c) of 24° to 29°. It is generally anhedral and embayed by feldspar, but may also form euhedral grains in pyroxene. Most of the pyroxene is colourless to light green diopside or augite. Some is finely intergrown with plagioclase. Extinction angles ranging from 35° to 65° were recorded for the samples studied. In most of the samples, part of the pyroxene is replaced by light green actinolite, with Z^c about 18°. This actinolite grades outward into the usual green hornblende. Garnet is pink, and commonly poikilitic. Some of the plagioclase is zoned with cores of An_{32} grading into borders of An_{23}. Microtexture of the hornblende garnet rock is shown in Plate VII-B.

Compositions of eight thin sections of hornblende-pyroxene garnet rock are given in Table 23 of the Appendix. One of these samples is partly altered to epidote, scapolite, and carbonate. A typical composition of the unaltered sections is 3% to 30% plagioclase, 0% to 10% quartz, 0% to 7% biotite, 19% to 57% hornblende, 12% to 26% garnet, 4% to 24% clinopyroxene, and minor amounts of opaque oxide, carbonate, apatite, zircon, and sphene.

A thin band of hornblende-garnet rock overlies the Iron Formation Series in the Normanville Area. Its composition is similar to the one in the Gras Lake-Felix Lake Area, but it contains more quartz and

biotite and no clinopyroxene (Table 16).

The hornblende-garnet rock is probably a basic metasedimentary rock or possibly the metamorphosed equivalent of basic lavas related to the Shabogamo gabbro.

A band of basic gneiss occurs in the potassic gneisses near the eastern edge of the Felix Lake sheet. Mineral compositions of four thin sections of this rock are given in Table 24 in the Appendix. Typical specimens of this rock contain 30% to 42% plagioclase, 3% to 7% red biotite, 7% to 24% hornblende, 0% to 42% clinopyroxene, 14% to 23% garnet, several per cent opaque oxide, and traces of apatite and sphene. Most samples are rich in pyroxene or amphibole, but not both. The pyroxene is light green, with Z^c of 50%, and is partly replaced by green or brown hornblende. Garnet may be replaced by biotite and feldspar, and both garnet and hornblende are poikilitic. It is not known whether this rock and the one that occurs above the iron formation are related.

Potassic Gneisses

Almost all the gneisses east of the Moisie River are microcline-rich. These gneisses are generally finer grained and tougher than gneisses in other parts of the area. They may or may not show mineral segregation, and in either case tend to break on joints rather than foliation planes. Because of the strong jointing, outcrops may form steep cliffs or scattered frost heaved blocks. Weathered surfaces are commonly stained pink.

The gneisses may be banded, but more commonly the foliation shows as thin lenses of pink microcline and grey quartz in a finer grained mixed groundmass. Large grains of microcline show visibly warped cleavage.

The mafic minerals form 1 x 3 mm. lenses lying parallel to the foliation. Many samples contain small grains of black allanite surrounded by rusty alteration halos.

Thin sections show lenses of quartz and oriented grains of biotite and hornblende evenly distributed or forming layers in a matrix of 0.5 to 1.5 mm. feldspar grains. Both common mafic minerals have high refractive indices and high absorption; biotite is pleochroic from straw yellow to black and has n_Y = 1.65 to 1.67, hornblende is pleochroic from yellow (X), to blue green (Y) to very dark green or brown (Z) and has n_2 = 1.696 to 1.714. The index n_2 is the greater of the two indices measured on cleavage fragments (Parker, 1961). Plagioclase is more sodic than in other gneisses. Microcline has shadowy twins, rather than the even grid pattern found in the other gneisses. Albite rims coat microcline-plagioclase contacts. Light green aegirine-augite with 2V = 70° occurs in some samples. Garnet is rare and partly replaced by a mixture of feldspar and biotite.

Mineral compositions of twelve thin sections of the potassic gneiss are given in Table 24 in the Appendix. Gneisses of this type contain 40% to 50% plagioclase (An_{15-25}), 15% to 30% microcline, 11% to 25% quartz, 1% to 8% biotite, 1% to 12% hornblende, 0% to 1% aegirine-augite, about 1% opaque oxide, and traces of apatite, allanite, garnet, zircon, and sphene.

The most characteristic features of this gneiss, apart from its high microcline content, are the strong pleochroism and high refractive indices of its biotite and hornblende, the tendency for quartz to form long thin lenses parallel to the foliation, and the abnormally high content

of the accessories ilmenite, sphene, allanite, and zircon. These features seem to have been imposed on different types of gneiss by metasomatism associated with the intrusion of the gabbro east of the Moisie River. The association of gabbro and potassic gneiss also occurs in other parts of the area where basic sills have altered the surrounding gneisses. Two of the thin sections listed in Table 24 come from this sort of alteration zone.

Some of the potassic gneiss near the Moisie River contains graphite, and was probably derived from the upper graphitic schist, but most of the gneiss resembles the lower well segregated gneiss. However, because of its metasomatism, and the lack of marker beds, correlation of the potassic gneiss with any other gneiss must be very tentative.

The mineralogy of the gneiss indicates a high temperature of metamorphism. The microcline has warped cleavage and shadowy extinction, suggesting that it has reverted from orthoclase. Albite has migrated from within the microcline to its borders. Clinopyroxene and brown hornblende are common.

Facies boundaries are poorly defined for quartzofeldspathic rocks in this T.P. range, and metamorphic grades are understood most easily by comparing different rocks in the area. The potassic gneiss is metamorphosed more strongly than the common well segregated gneiss, but less than the hypersthene granulite. It probably belongs to the sillimanite almandine amphibolite or hornblende granulite subfacies as defined by Fyfe et al. (1958).

Comparison of the Compositions of the Gneisses and Schists

The mineralogical compositions of the different types of gneiss

may be compared by plotting their main mineral constituents on triangular diagrams, such as Figure 6. The first triangle here refers to the whole rock, the second to its feldspar, and the third to its mafic minerals.

The total compositions of two of the younger rocks stand apart from the others. They are the mafic-rich hornblende-garnet rock, and the feldspar-poor mica-kyanite schist. The other rocks fall in a group, and there is generally more variation within a single rock type than between the different types. The albite-epidote schist is the most variable in composition as it includes coarse unsorted grit and fine-grained schist. The potassic gneiss is the most feldspathic of the gneisses because of the metasomatic microcline it contains.

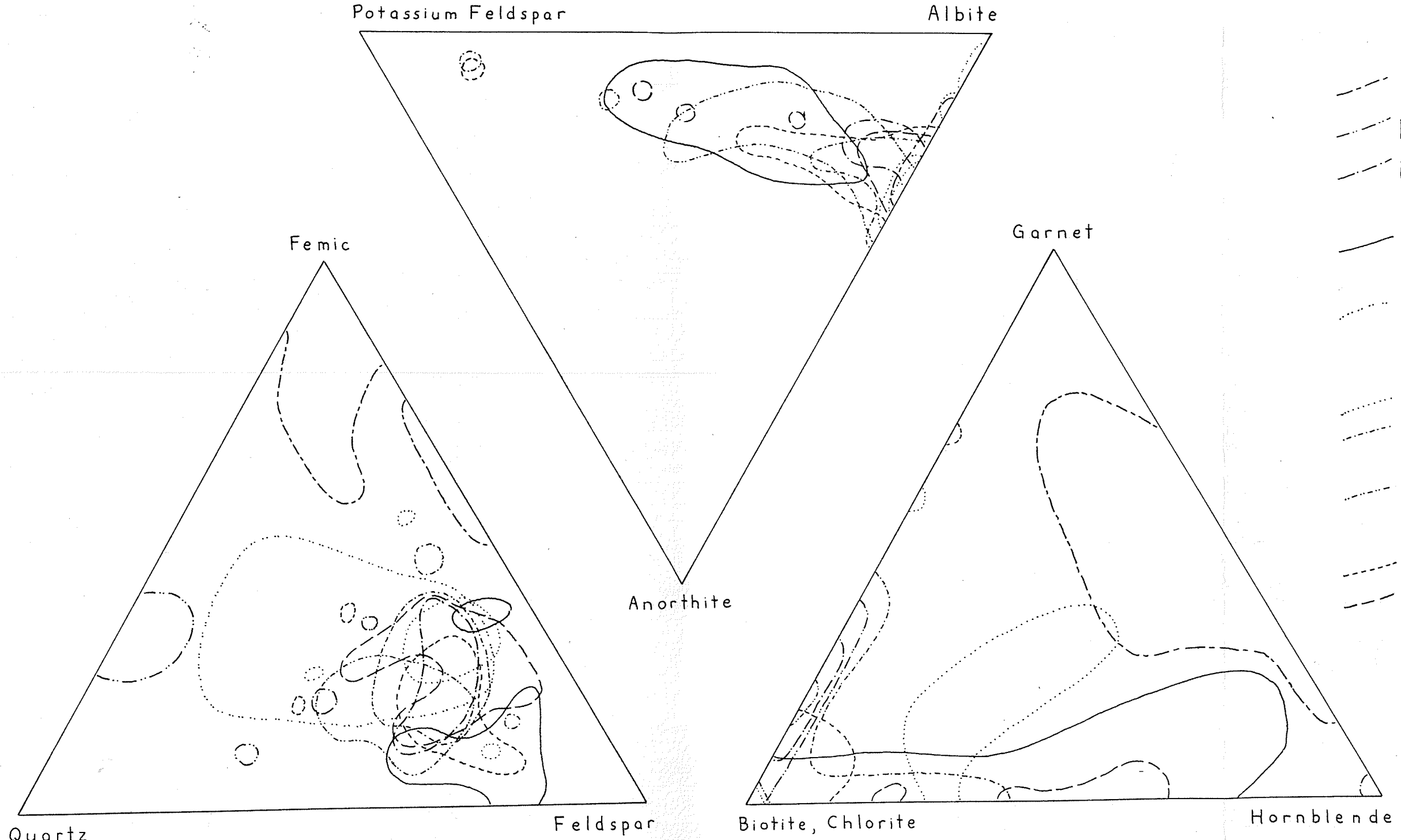
Most of the gneisses contain plagioclase in the range An_{20} to An_{32}. The unsegregated Normanville Area gneisses are slightly more calcic than average, and the hornblende-garnet rock is more sodic. The epidote-chlorite schist contains both clastic oligoclase and metamorphic albite. Compositions plotted here are the mid-points of the composition range of zoned crystals. True averages would contain several per cent more anorthite.

Rocks containing the most microcline are the unsegregated gneiss of the Normanville Area, and the lower gneiss and potassic gneiss of the Gras Lake-Felix Lake Area. The microcline is fresh and evenly distributed in the Normanville Area gneiss, and is apparently a primary constituent. In the Gras Lake-Felix Lake Area the microcline is associated with alteration or metasomatism.

It is in mafic mineral content that the gneisses vary most. Most types contain biotite, with smaller amounts of either garnet or horn-

Figure 6

COMPOSITIONS OF GNEISSES



LEGEND

- Hornblende-Garnet Rock
- Mica-Kyanite Schist
- Upper Graphitic Gneiss
- Potassic Gneiss
  - Gras-Felix Area only
- Albite-Epidote Schist
  - Normanville Area only

Poorly Segregated Gneiss

- Gras-Felix Area
  - upper
  - lower
- Normanville Area
  - upper and lower

Well Segregated Gneiss

- Biotite-rich
- Hornblende-rich

blende. The poorly segregated gneiss of the Normanville Area, the upper graphitic gneiss and the mica-kyanite schist contain biotite, some garnet, and no hornblende. Only biotite and chlorite are stable in the albite-epidote schist. In the Gras Lake-Felix Lake Area the lower poorly segregated gneiss contains biotite, and either garnet or hornblende, while the upper gneiss contains roughly equal parts biotite and hornblende with a lesser amount of garnet. The well segregated gneiss contains little garnet, and either all biotite, or equal parts of biotite and hornblende. The potassic gneiss contains mainly biotite and hornblende, with some garnet in its hornblende-rich varieties. The hornblende-garnet rock contains about equal amounts of hornblende and garnet, and smaller amounts of biotite. Some clinopyroxene occurs in this and the potassic gneiss.

The minerals of the various types of gneisses differ in composition as well as in type and amount. Cell edges of garnet, and some optical properties of plagioclase and of the mafic minerals were determined and are discussed in detail in a later chapter. The following discussion should be read with reference to Figures 11, 12, 13 (pp. 105, 109, 110), respectively.

Biotite and hornblende with the lowest refractive indices (Figure 11, p. 105) occur in the lower gneisses. They show greater variation in the well segregated than in the poorly segregated gneiss. The minerals of the upper gneiss have intermediate indices, and those of the potassic gneiss intermediate or high indices. The hornblende-garnet rock contains hornblende with low, and biotite with intermediate, indices. As used here "low", "intermediate" and "high" mean n_2 of hornblende below 1.690, between 1.690 and 1.705, and above 1.705; and n_Y of biotite below

1.640, between 1.640 and 1.660, and above 1.660.

The increase in refractive index is accompanied by a colour change from olive brown, through red brown, to dark reddish brown in biotite, and a similar darkening of the hornblende. The minerals with higher refractive index and darker colour contain more iron and less magnesium than the others. Replacement of silica by titanium and aluminum will also raise the refractive index.

Refractive indices of garnets from the lower gneisses and potassic gneiss fall in the range 1.785 to 1.796 (Figure 12, p. 109). In the hornblende-garnet rock they are as low as 1.775, and in the upper gneiss as high as 1.803. Cell edges range from 11.53 Å in the upper gneiss, to 11.64 Å in the potassic gneiss and hornblende-garnet rock. The refractive index is affected by many variables, but depends chiefly on the Fe/Mg content of the garnet. According to Sturt (1962), the function cell edge/refractive index is a measure of the calcium content in garnet. Values of this function (Figure 13, p. 110) range from 6.40 to 6.54, indicating CaO contents between 4% and 12%. The least calcic garnets come from the upper gneiss and well segregated gneiss, the most calcic from the hornblende-garnet rock. All the garnets are almandine, and the most calcic contains about 20% grossularite, and smaller amounts of the other garnet molecules.

CHAPTER V

IRON FORMATION SERIES

Introduction

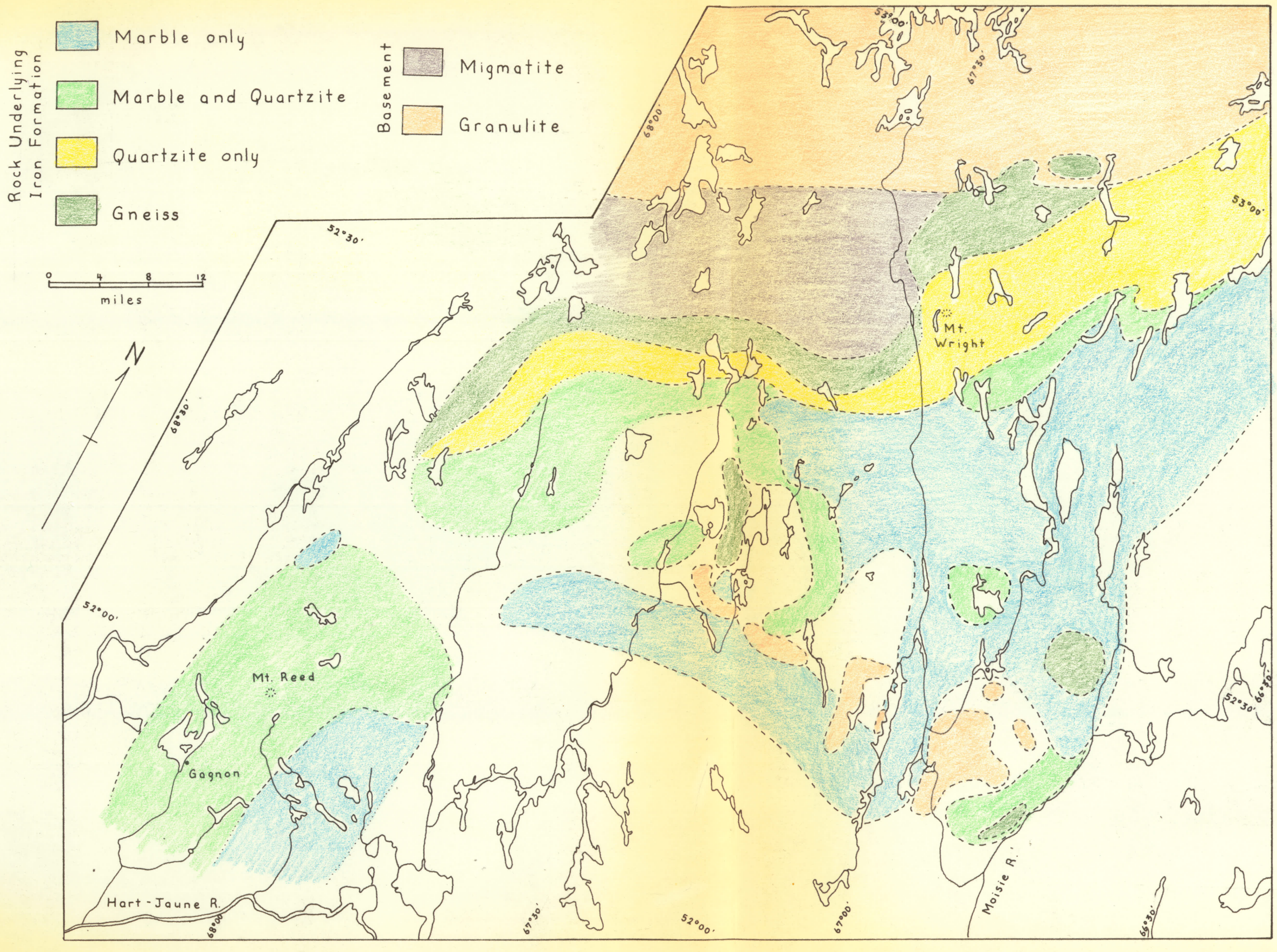
The term Iron Formation Series refers to a series of chemical sedimentary rocks including marble and quartzite, as well as, iron formation. These rocks lie conformably on the poorly segregated gneiss and are conformably overlain by the upper gneisses. Two main facies types of iron formation exist, silicate-carbonate facies and oxide facies. In general the marble and quartzite underlie the iron formation, the marble associated with the silicate-carbonate, and the quartzite with the oxide facies.

Sedimentary facies changes in this area were first described by Gastil and Knowles (1960). They pointed out lateral gradation between members of the Iron Formation Series in the area between Mount Wright and Wabush Lake similar to those described by James (1954) in the Lake Superior region.

Facies maps for the iron formation and associated metasediments, compiled by the author from Quebec geological reports on the Mount Wright-Mount Reed region, are shown in Figures 7 and 8. The type of sediment deposited depends on the material reaching the place of deposition, and on the agitation or oxidation potential of the water in that particular place.

The sedimentary rocks underlying the iron formation were deposited in three main facies zones (Figure 7). Near the northwestern edge of deposition, ie. near the shore, the iron formation is underlain by pelitic

Figure 7 SEDIMENTARY FACIES OF ROCKS UNDERLYING THE IRON FORMATION



schists, then quartzite followed by marble underlie the iron formation in zones successively farther to the southeast. The gradation from schist to marble takes place in about 15 miles. Parallel changes occur in the accompanying gneiss which appears to have formed from argillaceous sediment in the Normanville Area, and quartzofeldspathic greywacke or subgreywacke farther south.

The iron formation shows a similar facies pattern (Figure 8, p. 64). The oxide facies was deposited in a zone close to shore, and the silicate-carbonate facies under quieter, more reducing conditions to the southeast. Pyrite or graphite occur in iron formation in the extreme southeastern part of the area. There are some irregularities in the main pattern, probably caused by local deeps or shoals in the Proterozoic sea.

The mineralogy of the iron formation also depends on its metamorphic grade. The main effect of metamorphism on the oxide facies is to increase grain size, but in the silicate-carbonate facies it produces changes in mineralogy. A tongue of silicate-carbonate iron formation extends across the Grenville Front in the Normanville Area, and has been metamorphosed from low greenschist facies in the north, to middle almandine amphibolite facies in the south.

Quartzite

The quartzite is a medium grained, light grey to milky white rock, showing relic bedding as faint colour bands or a strong joint set. Some types are micaceous and schistose, or coarsely crystalline resembling vein quartz. The quartzite is thickest near Mount Wright and thins rapidly to the north, and more gradually to the south. Gross (1955) estimates

the Mount Wright quartzite at between 300 and 400 feet in thickness; in the Gras Lake-Felix Lake Area thicknesses range from 10 to 50 feet. It has an abrupt, apparently conformable contact with the marble, and is gradational with the iron formation.

Compositions of thin sections are given in Tables 17 and 25 in the Appendix. Typical sections contain between 95% and 100% quartz with minor amounts of hematite, cummingtonite, carbonate, mica, tourmaline, zircon, and rutile. Graphite and pyrite occur in the quartzite in the southeastern part of the area. The foliation shows as rude bands of coarse (2-3 mm.) grains with sutured borders and undulatory extinction, interlayered with finer (0.5 mm.) grains with a mosaic texture. The accessory minerals occur between the quartz grains or included in them, and elongate or foliate minerals lie parallel to the foliation. Any originally clastic quartz grains have been destroyed by metamorphism.

A disagreement exists as to whether the quartzite represents a recrystallized pure quartz sand (Gross, 1955), or a recrystallized chert (Murphy, 1961). Gross's interpretation of a clastic origin is based on the occurrence of rounded zircon grains in the quartzite. Murphy thinks its carbon content and its similarity to quartz layers in the iron formation indicate development from chert.

In the unmetamorphosed part of the Labrador Trough, the Sokoman Iron Formation is underlain by both chert (Fleming Formation) and quartz sandstone (Wishart Formation). The same situation likely exists where the rocks are metamorphosed, in which case the quartzite would originally have contained both cherty and sandy components. However, in the opinion of the author, the gradation between quartzite and iron formation, and the

apparent development of the quartzite some distance off shore, suggest that it is mostly a recrystallized chert.

Marble

Marble underlies the silicate-carbonate iron formation in the southern part of the area. It first appears in the southeast corner of the Normanville Area, and thickens southward. Good exposures may be seen in the valleys of the Pekans and Gentilhomme rivers, and between Hope Lake and the Little Manicougan River.

In outcrop the marble is a coarse grained, equigranular, thickly bedded rock, white on fresh surfaces, and weathering black or in iron-rich varieties, cocoa-brown. Quartz-rich beds are interlayered with carbonate (Plate VIII), and reaction between the two has produced tremolite and diopside. On exposed surfaces the quartz and calcsilicates stand in relief above the more soluble carbonate. Most of the carbonate is dolomite. Several per cent calcite may occur as fine intergranular blebs, or as coatings on the silicates. The main silicates are quartz, tremolite, diopside and phlogopite. Green diopside and actinolite form in iron-rich marbles. Most outcrops contain between 10% and 30% silicates. They occur as discrete grains or in layers several inches thick along bedding planes or later fractures. Amphiboles and pyroxenes commonly grow with their long axes aligned parallel to the regional lineation.

Dolomite, the only essential mineral, occurs as equidimensional grains, 2 to 3 mm. in size. Calcite is fine grained; either interstitial to the dolomite, or surrounding and replacing the calcsilicates. This secondary calcite may have formed when growing silicates extracted more

magnesium than calcium from the dolomite. Tremolite occurs as euhedral grains in the carbonate, or as a replacement of the diopside. The diopside is colourless and has an extinction angle of 40° to 45°, and 2V of about 65°. Tremolite is also colourless, and has an extinction angle of 17° to 20°, and 2V of about 80°. Some of the tremolite is twinned. Quartz occurs as large grains with sutured borders and undulose extinction, and as small polygons interstitial to the carbonate. The fine-grained quartz is secondary, and may have formed when the pyroxene was converted to tremolite. One section contains intergrown talc and antigorite apparently replacing olivine.

PLATE VIII

Outcrop of black-weathering marble in the Gras Lake Area. Beds of relatively pure dolomite are interlayered with thinner quartz and calcsilicate bands.

The marble is apparently a metamorphosed dolomite, originally deposited in relatively quiet water some distance from the Proterozoic

shore. Nearer shore quartzite was deposited. The facies change from quartzite to marble can be seen in a few hundred feet in a thin bed between Moiré and Kissing lakes in the Normanville Area. At Don's Pond and Midway Lake, the quartzite overlies the marble.

Metamorphic reaction between interbedded chert and dolomite produced tremolite and diopside or rarely olivine. Retrograde metamorphism caused the replacement of some diopside by tremolite, and the destruction of the olivine. The assemblage quartz-carbonate-diopside indicates almandine amphibolite grade metamorphism. The olivine-bearing sample comes from a fault zone beside the Moisie River, and indicates higher metamorphism in that part of the area.

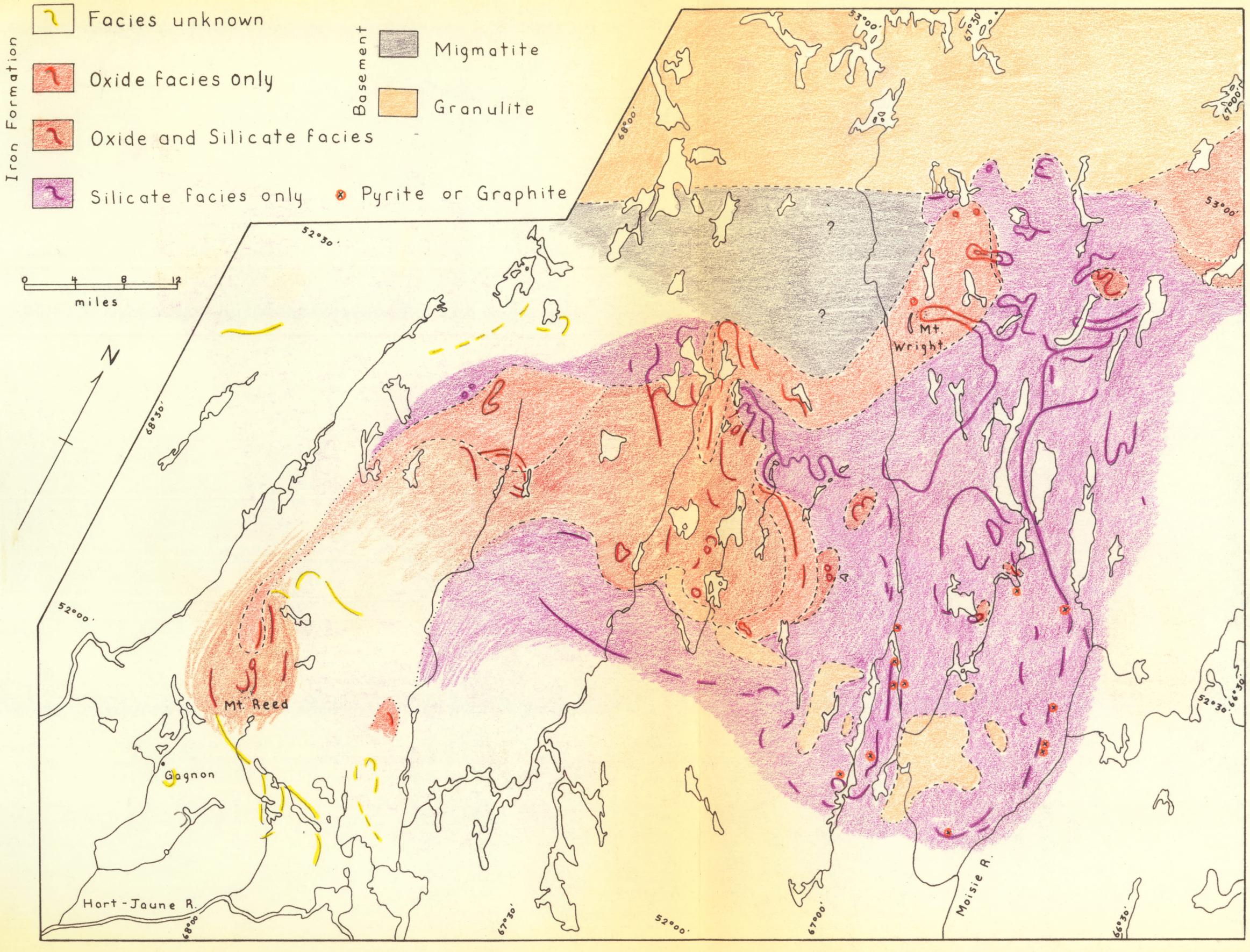
Iron Formation

Iron formation overlies the quartzite and marble, and is generally found in synclines surrounded by older gneiss. It is thickest near Mount Wright, pinching out over the Archean rocks to the north, and thinning to the south. Thicknesses reach 500 feet at Wabush Lake (Gastil and Knowles, 1960), 300 feet at Mount Wright, and range from 10 to 150 feet in the Gras Lake Area.

The economically valuable oxide facies of the iron formation was deposited near shore, and passes into silicate-carbonate facies to the southeast (Figure 8). Gastil and Knowles (1960) describe an iron carbonate facies occurring still farther off shore. No true carbonate facies was recognized in the present area, but in the southwestern part of the Gras Lake-Felix Lake Area there is an olivine-pyroxene-carbonate band that may be its metamorphic equivalent.

Figure 8

SEDIMENTARY FACIES OF IRON FORMATION



The sedimentary facies map (Figure 8) is simplified to show only the main oxide and silicate-carbonate groups. The oxide facies may be either hematite- or magnetite-rich, and the silicate-carbonate facies includes the olivine-pyroxene-carbonate band. The sulfide facies was not recognized, but in the southern part of the area minor amounts of graphite and pyrite occur in the silicate-carbonate facies. The transition of a single layer of iron formation from hematite oxide through magnetite oxide to silicate-carbonate facies can be seen in the Bloom Lake syncline.

In the central part of the Normanville Area two iron formation layers are separated by gneiss. Near Boulder Lake the lower layer is silicate-carbonate, and the upper layer quartz hematite iron formation. Elsewhere, where more than one facies occurs, the oxide facies overlies the silicate-carbonate facies and these may be overlain in turn by the olivine-pyroxene-carbonate facies.

Oxide facies

The oxide facies is the most economically important variety of iron formation. It resists erosion, and its tendency to form hills results in the exposure of most of the large deposits. The best deposits occur in the hills near Hesse, Mogridge, Bloom, Boulder, Daigle, and Fire lakes. The iron formation is thicker, and forms larger deposits, in the Normanville Area, than in the Gras Lake-Felix Lake Area.

The iron may occur either as blue grey specular hematite or magnetite, depending on the oxidation state of the original sediment. The quartz-magnetite iron formation is rarer than the quartz-hematite, and is gradational between the quartz-hematite and the silicate-carbonate iron formation.

Most outcrops are composed of mixed quartz and iron oxide interlayered with grey glassy quartz. Thin layers or streaks of green actinolite form beside the hematite bands, and cummingtonite or hypersthene accompany the magnetite. The iron formation contains between 10% and 45% iron oxides, and generally averages about 30%. Quartz or hematite may migrate and become enriched in pods or lenses. South of Mogridge Lake 6-inch vugs in the iron formation are lined with coarsely crystalline striated hematite and quartz. On Hesse Hill a large lens of milky quartz is surrounded by an 18-inch rim of residual hematite (Plate IX). A similar,

PLATE IX

Segregation pod of quartz surrounded by coarse grained residual hematite, Hesse Hill, Normanville Area.

but larger, zone of iron enrichment formed beside a granite sill intruding the iron formation south of Halfmile Lake.

Thin sections of the oxide iron formation show layers of mixed

quartz and coarse grained (0.2-2 mm.) hematite or magnetite, alternating with thicker quartz layers. The quartz has slightly undulose extinction and a mosaic texture. Grains in the pure quartz layers may be slightly elongated parallel to the foliation, and are coarser than grains in the mixed layers. Hematite forms coarse tabular grains parallel to the foliation or finer grains included in the quartz. Magnetite occurs as equant, anhedral grains commonly rimmed and veined by late hematite. Minor amounts of muscovite, dolomite, actinolite, tourmaline and zircon occur in the hematite-rich iron formation, and cummingtonite and hypersthene occur in magnetite-rich samples. Yoder (1956-57) shows that iron silicates are unstable in rocks containing hematite, as the two react to form magnetite, quartz, and water. If layered rocks contain both silicates and hematite, it is because oxygen did not migrate between the layers.

Compositions of thin and polished sections of oxide iron formation are listed in Tables 18 and 25 in the Appendix. Average samples contain 60% to 82% quartz, 5% to 25% hematite, 1% to 22% magnetite, plus 5% to 10% actinolite, cummingtonite, or hypersthene in some samples, and traces of mica, tourmaline, and zircon. These are volume percentages. Weight percentages of iron oxides are higher and of quartz are lower in proportion to the specific gravities of the minerals. Individual rocks are rich in either hematite or magnetite, and the iron silicates are found in the magnetite-rich rocks.

Silicate-carbonate facies

Rocks of the silicate-carbonate facies are composed of quartz, iron-rich amphiboles and pyroxenes, magnetite, and some carbonate. Thicknesses range from 40 to 400 feet, the thickest being near the Pekans River

in the Gras Lake Area. Most of the available iron is combined in silicates, and the facies does not generally contain enough magnetite to be of economic importance. Most varieties of the rock form hills with good outcrop. Outcrops of silicate-carbonate iron formation are shown in Plate X.

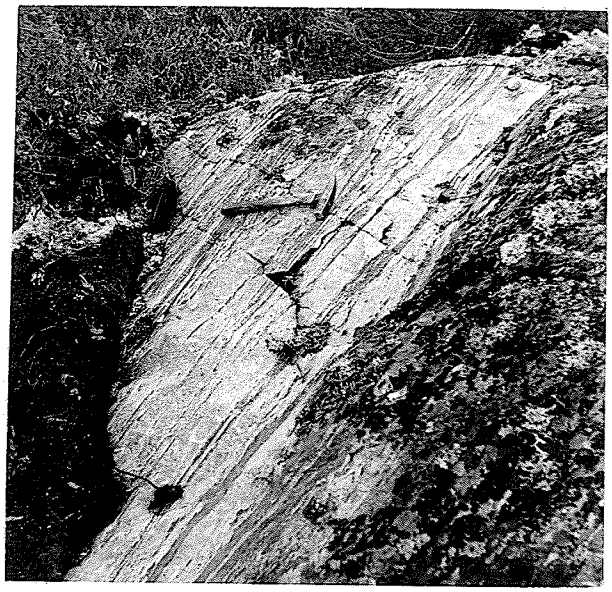
Mineralogy and texture of the silicate-carbonate facies depend mainly on its grade of metamorphism. The rocks are similar throughout the Gras Lake-Felix Lake Area and in the southern part of the Normanville Area, but become finer grained and more schistose as the Grenville Front is approached. North of the Front, they are only slightly metamorphosed and consist of quartz, siderite, and magnetite.

In the southern part of the area, rocks of the silicate-carbonate facies are composed essentially of quartz, brown and green pyroxene (hypersthene and diopside-hedenbergite), cummingtonite, carbonate and magnetite plus minor amounts of garnet and graphite. The quartz and iron silicates form alternating layers or irregular masses. Magnetite occurs in both the quartz and iron silicate portions. In some places ferrodolomite forms rusty-weathering bands or lenses. Carbonate layers generally lack quartz.

Compositions are extremely variable, and a thin section may not be representative of the outcrop from which it came. Field notes give the following composition range; 10% to 30% orthopyroxene, 0% to 40% clinopyroxene, 25% to 70% quartz, 10% to 30% cummingtonite, 5% to 10% magnetite, 0% to 10% carbonate, and as much as 3% garnet and graphite. These are common compositions, but any mineral may be lacking in an individual sample. Table 25 in the Appendix gives estimated mineral compositions of twenty four thin sections of silicate-carbonate iron formation. The range of composition is large, and few sections have a composition close to the

PLATE X

A - Interlayered quartz and silicate-carbonate bands in silicate-carbonate iron formation south of Kissing Lake, Normanville Area.



B - Alternating bands of pyroxene and quartz in silicate-carbonate iron formation near Gras Lake.

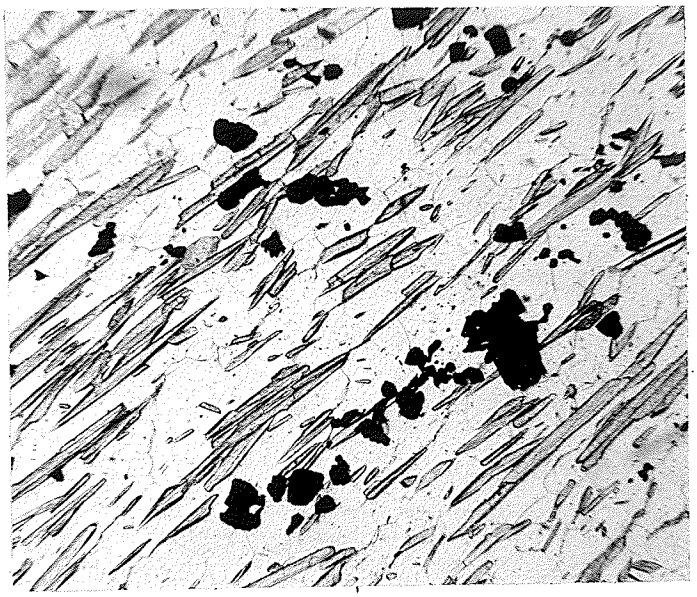
average.

The most common variety of the rock contains layers of coarse grained (1.5 mm.) quartz with minor pyroxene and magnetite, alternating with fine-grained (0.5 mm.) quartz and about 35% to 50% pyroxene with or without magnetite (Plate XI-B). The quartz layers are made up of a mosaic of equidimensional grains with sutured borders, and generally even extinction. The orthopyroxene is brownish pink, optically negative, and not strongly pleochroic; it ranges in composition from ferrohypersthene to eulite, and commonly forms large (2-4 mm.) poikilitic grains. The clinopyroxene has a strong basal parting; it is green, optically positive, and has an extinction angle (Z^c) of 42° to 55°. Most of the clinopyroxene is ferrosalite but some is salite. Cummingtonite replaces the hypersthene, but may also occur as discrete grains in the silicate layers; it is colourless to light brown, commonly twinned, and has an extinction angle of 12° to 23°. The carbonate is generally altered to limonite.

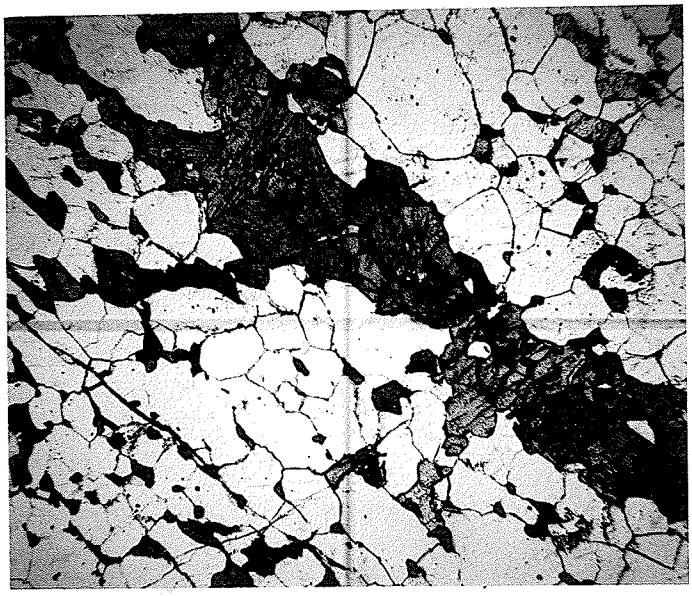
Metamorphism near Greenwater and Bloom lakes was less intense than in the southern parts of the area. Here the iron formation is a quartz-cummingtonite schist in which honey coloured needles of twinned cummingtonite are dispersed through a fine mosaic of quartz (Plate XI-A).

The quartz-cummingtonite schist is speckled with magnetite octahedra and large limonite blotches. The limonite is probably an alteration product of siderite. The rock deforms by tight chevron folding with the cummingtonite needles oriented perpendicular to the fold axes. Compositions of four sections of cummingtonite schist are given in Table 18 in the Appendix. The compositions vary within the limits 40% to 60% quartz, 8% to 40% magnetite, 10% to 30% cummingtonite, and actinolite in calcic

PLATE XI



A - Needles of cummingtonite in quartz-cummingtonite-magnetite schist near Greenwater Lake, Normanville Area. Plane polarized light, magnification 300x.



B - Layers of quartz and hypersthene in silicate-carbonate iron formation of the Gras Lake Area. Plane polarized light magnification 180x.

layers.

Farther north near Boulder and Jackson lakes the metamorphism becomes very weak and the iron formation retains most of its sedimentary features. Here it is a fine-grained, grey, massive to thin bedded rock composed essentially of quartz, magnetite, and siderite, with lesser amounts of stilpnomelane, fine cummingtonite, and garnet. The quartz forms a mosaic of clear, unstrained grains, 0.1 to 0.3 mm. in diameter and shows bedding by slight changes in grain size. Magnetite and siderite both occur as distinct grains or as clusters of grains elongated parallel to the bedding. The siderite is partly altered to limonite. It is distinguished from dolomite by its alteration, darker colour and higher refractive index (n_E = 1.635, n_O = 1.87).

Compositions of thin sections from the Jackson Lake and Boulder Lake deposits are given in Table 18 in the Appendix. At Jackson Lake the iron formation is composed of quartz, magnetite, and siderite, and minor cummingtonite and stilpnomelane. In weathered samples some of the siderite is altered to limonite. An average rock of this group contains 56% to 67% quartz, 13% to 27% magnetite, 10% siderite, and 3% to 9% limonite.

Near Boulder Lake the siderite has disappeared, there is less quartz, and cummingtonite is a major constituent. Large porphyroblasts of pink garnet have formed in some samples. The garnet replaces cummingtonite and incorporates magnetite layers without disturbing them. A rim of stilpnomelane occurs between the cummingtonite and garnet. The garnet of one sample has n = 1.818, and a_o = 11.62 Å. Cummingtonite in the same sample had refractive indices n_1 and n_2 of 1.676 and 1.696. These properties indicate a $Fe^{+2}/(Fe^{+2} + Mg)$ ratio of 0.72 in the cummingtonite, and

suggest that the garnet is andraditic almandine. The stilpnomelane forms small flakes with parallel extinction. They are length slow, pleochroic from yellow (X) to green (Z), and optically negative with a very small 2V.

The average composition of the thin sections studied is 15% to 55% quartz, 9% to 50% cummingtonite, 6% to 36% magnetite, 1% to 6% stilpnomelane and 0% to 6% limonite. Large garnets occur in some samples. To the south the schist passes into the quartz-cummingtonite schist described earlier.

Olivine-pyroxene-carbonate facies

The upper member of iron formation in the Gras Lake Area lacks quartz and is characterized by large grains of pyroxene and olivine set in a groundmass of carbonate, chlorite and amphibole. This type of iron formation is well exposed at the top of Lamêlée and Hobdad hills, and near the southwestern corner of the Gras Lake Area. Outcrops are coarse grained, dark green to black, and rusty-weathering. Some varieties are tough and resist weathering, whereas, others weather easily, leaving the pyroxenes projecting from the softer carbonate and chlorite. South of the Little Manicougan River the rock is cut by thin stringers near which the pyroxene is altered to hornblende and garnet. In shears the rock is altered to soft chlorite schist.

Table 25 gives the mineral composition of three thin sections of the rock, and one comparable section from an olivine carbonate pod in the common silicate-carbonate iron formation. The rock is distinguished by the presence of olivine or its alteration products, and the absence of quartz. The average composition of unaltered thin sections falls in the range; 17% to 43% orthopyroxene, 10% to 44% dolomite, 7% to 15% olivine,

10% to 14% magnetite, as much as 5% cummingtonite, and traces to a few per cent of biotite, garnet, and spinel. The mafic minerals may alter to hornblende, chlorite or serpentine.

Orthopyroxene and cummingtonite contain less iron than in the common silicate-carbonate iron formation. The orthopyroxene is bronzite, and is commonly full of schiller magnetite. Olivine forms round grains which may be colourless or reddish brown; it is optically negative, with a 2V of approximately 70°. The brown colour seems to be a stain or alteration, and does not affect the optical properties of the mineral. Olivine (hortonalite) from a carbonate pod in the common silicate-carbonate iron formation has a Fe/(Fe + Mg) ratio of 0.75. Chlorite, dolomite, and in one section hornblende form the groundmass surrounding clots of olivine and orthopyroxene. Garnet and green spinel are accessories.

Lamêlée and Hobdad hills are capped by a striking variety of this rock made up of 3-inch rosettes of grey orthopyroxene set in a groundmass of green chlorite and buff carbonate (Plate XII). Some of the chlorite flakes have been bent by the growing orthopyroxene, with which they are apparently in equilibrium. Shears in the rock are filled with fibrous brown cummingtonite and brittle green mica. This rock has been thoroughly described by Krank (1959) who named it hobdadite.

PLATE XII

Hobdadite, a variety of silicate-carbonate iron formation, in which nodules of bronzite grow in a matrix of chlorite and iron-rich carbonate. This outcrop is on the top of Lamêlée Hill.

Origin and metamorphism of the iron formation

Much has been written about the origin of Precambrian iron formations. It is beyond the scope of this thesis to add anything to the discussion so it will be kept as brief as possible. Those interested in theories of deposition of iron formation are referred to the works of Evoy (1955), Hough (1958), and Bérard (1959) where they are reviewed in more detail.

Most authors agree that iron formations are chemical sediments deposited in bodies of standing water. There is less agreement on whether the iron comes from weathering of an old landmass or from contemporaneous vulcanism, or on whether it is deposited in fresh or salt water.

Iron sedimentation was put on a quantitative basis when Krumbein

and Garrels (1952) outlined the fields of stability of iron oxides, carbonates, and sulfides in terms of the oxidation potential and pH of the water in which they are deposited. James (1954) described the gradation from oxide facies to carbonate, silicate, and sulfide facies in Lake Superior iron formations. This is the best known geological example of the control of facies by oxygen supply.

In the Mount Wright Area the sedimentary textures and most of the original minerals of the iron formation were destroyed by metamorphism. In places of strong deformation even the sequence of deposition is uncertain. Although sedimentary detail has been lost, sedimentary facies can still be recognized and have been shown in Figure 8. The main facies zones run parallel to the Archean-Proterozoic contact; oxide facies occurs closest to the contact, and silicate-carbonate facies farther to the southeast. A sulfide facies was not recognized but pyrite and graphite occur in the southeastern parts of the silicate-carbonate facies. Local differences of environment resulted in the deposition of a tongue of the oxide facies as far south as Fire Lake, and the deposition of a tongue of the silicate-carbonate facies as far north as Jackson Lake.

Conditions of sedimentation changed rapidly near the Proterozoic shore. Near its northwestern limit, the iron formation is thin and discontinuous, and near Boulder Lake it occurs as two bands separated by gneiss. The two bands thicken and run together in the centre of the Bloom Lake syncline. The iron formation reaches its maximum development in the southern part of the Normanville Area, and thins again gradually southeastward.

The iron was most probably derived from weathering of the Archean

continental rocks in the northwest, transported in solution, and deposited as banded chert and hematite, or as quartz, siderite and magnetite, depending on the local oxidation potential. The iron amphiboles and pyroxenes formed by metamorphic reaction between quartz and iron carbonate, or by dehydration of hydrous iron silicates such as greenalite (Deer et al., 1962, v. 2, p. 245):

$$7\ FeCO_3 + 8\ SiO_2 + H_2O \longrightarrow Fe_7Si_8O_{22}(OH)_2 + 7\ CO_2$$

Siderite + Quartz + Water ⟶ Grunerite + Carbon Dioxide

or

$$7\ Fe_3Si_2O_5(OH)_4 + 10\ SiO_2 \longrightarrow 3\ Fe_7Si_8O_{22}(OH)_2 + 11\ H_2O$$

Greenalite + Quartz ⟶ Grunerite + Water

With higher grade metamorphism hypersthene formed instead of grunerite (cummingtonite), and if siderite was present in excess of quartz, olivine was produced.

Detailed studies of the iron formation have been made at Bloom Lake (Mueller, 1960, 1961) and at Fire Lake and Mount Reed (Krank, 1961). Their main concern is the mineralogy of the iron formation, in particular the compositions of coexisting silicates. The present thesis is based on larger scale mapping, and is more suited to show regional changes in the iron formation and other rock units.

The iron formation changes in both sedimentary and metamorphic facies within the area. Minerals of the oxide facies are stable through all grades of metamorphism, becoming coarser grained as the grade increases. These changes are important economically as the coarser the ore the easier it is to concentrate.

Minerals of the silicate-carbonate facies have smaller stability fields, and a number of isograds are marked by changing assemblages. Yoder (1956-1957) and James (1955) have studied the mineral assemblages developed in iron formation in response to metamorphism. They approached the problem differently; Yoder studied the chemical systems $FeO-SiO_2-H_2O$ and $FeO-Al_2O_3-SiO_2-H_2O$, while James described natural assemblages observed in the field. According to Yoder unmetamorphosed rocks in the system $FeO-SiO_2-H_2O$ are composed essentially of greenalite and quartz. Increasing metamorphism produces new minerals in the sequence greenalite - minnesotaite - grunerite - fayalite (or hypersthene if the rock contains an excess of quartz). If alumina is present the sequence is chamoisite - stilpnomelane - chloritoid - biotite - almandine, and if there is an excess of alumina, additional isograds are marked by staurolite, kyanite, and cordierite. In the present area the iron silicates seem to have formed by reaction of siderite and quartz, so Yoder's carbonate-free assemblages do not strictly apply. James' natural assemblages are closer to the ones found here. Table 5, condensed from James (1955, p. 1475), shows mineral assemblages developed by increasing metamorphism of non clastic iron formation composed originally of quartz and iron carbonate and/or iron silicates. In the Normanville Area low grade assemblages change to high grade ones in a distance of about 12 miles.

TABLE 5

MINERAL ASSEMBLAGES IN METAMORPHOSED IRON FORMATION

Low Grade (1)	Intermediate (2)	High Grade (3)
Carbonate	Grunerite	Grunerite
Quartz	Quartz	Quartz
Stilpnomelane	Magnetite	Magnetite
Minnesotaite	Carbonate	Pyroxene
Magnetite	Garnet (clastic only?)	

(1) Chlorite and biotite zone.
(2) Garnet and staurolite zone.
(3) Sillimanite zone (inferred).

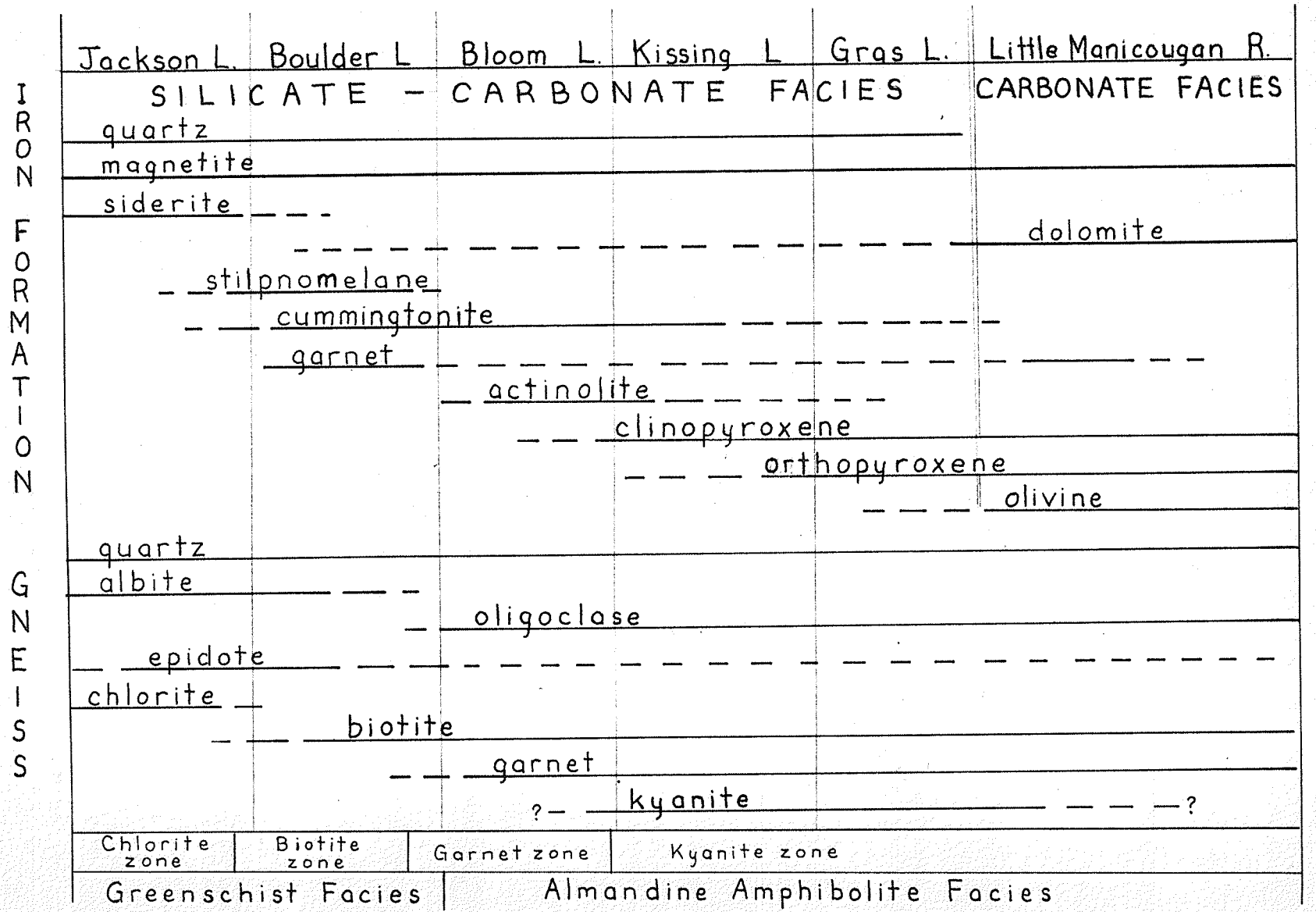
The minerals present in a succession of iron formation deposits crossing the Grenville Front in the Normanville Area are shown in Figure 9. They are similar to those of James, but differ in some details; minnesotaite was not recognized here; clinopyroxene appears before orthopyroxene, and both are stable in the kyanite zone; olivine is present in carbonate pods within the kyanite zone.

The mineralogy of the gneisses associated with the iron formation is also shown in Figure 9, and metamorphic facies and subfacies boundaries are placed in relation to the mineralogy of the gneisses and iron formation. Chlorite changes to biotite between Jackson and Boulder lakes, and kyanite was first observed near Kissing Lake. Sillimanite and staurolite were not found in the area, so the facies boundaries marked by these minerals cannot be shown. The common gneiss is quartzofeldspathic in composition, and does not contain the sensitive aluminum silicates.

The importance of the bulk composition of a rock in determining the stability fields of its constituent minerals has been suspected for some time. Sietsarri (1954), (quoted from Reynolds and Fredrickson, 1962),

Figure 9

MINERAL ASSEMBLAGES IN METAMORPHOSED IRON FORMATION AND GNEISS



questions the validity of the mineral facies concept when applied to rocks of different composition:

> "--- one may actually wonder whether the present classification of the metamorphic facies with their critical mineral assemblages is not unconditionally valid; and whether the bulk composition might be a more important factor in controlling mineral associations of the metamorphic rocks than is assumed."

The early development of orthopyroxene in iron formation is an excellent example of the telescoping of isograds by rock composition. Orthopyroxene, clinopyroxene, and olivine, are stable in iron formation interbedded with common quartz-feldspar-biotite-(garnet-kyanite) gneisses. In pelitic rocks pyroxenes do not occur at lower than the pyroxene granulite facies; in iron formation they are stable in intermediate almandine amphibolite facies.

CHAPTER VI

PROTEROZOIC IGNEOUS ROCKS

Introduction

The Proterozoic rocks of the area are intruded by two main groups of igneous rocks, granitic rocks, and a basic suite composed mainly of gabbro but including ultrabasic, intermediate, and acidic differentiates. The granitic rocks are found in areas of moderately high metamorphism and generally occur as conformable bodies in the lower gneiss. The gabbro forms sills in competent rocks of the Iron Formation Series and in the gneiss east of the Moisie River. Much of the gabbro has been altered to amphibolite or to a feldspar-garnet-pyroxene gneiss. The intrusion of both the granitic and gabbroic rocks is thought to have accompanied the Grenville Orogeny.

Rocks of the Basic Suite

Gabbro

Thick gabbro sills intrude the Proterozoic rocks of the area, and stand as hills above the less durable gneiss. The gabbro has been named "Shabogamo" after the lake near which it is extensively exposed, Fahrig (1960).

The gabbro shows marked variation in texture and mineral composition. It was originally ophitic, and in the Normanville Area the ophitic texture is still easy to recognize. Alteration, probably accompanying the

Grenville metamorphism, has produced coronas of fine-grained secondary minerals surrounding the primary mafic minerals, and in most of the southern area has destroyed the original ophitic texture.

In the Normanville Area euhedral laths of labradorite penetrate augite, hypersthene, and olivine. The augite is clouded with magnetite dust and the hypersthene contains schiller magnetite. The primary mafic minerals are rimmed with successive coronas of fine alteration products. Colourless fibers of orthopyroxene radiate outward from corroded olivine cores. These are surrounded by green uralite, and in some samples by an outer rim of garnet. Magnetite, albite, and quartz are interstitial to the early crystallizing grains.

A typical composition for this type of gabbro is; 50% to 65% plagioclase (An_{55-75}), 7% to 10% olivine, 5% to 7% augite, 5% to 7% opaque oxide, 5% hypersthene, 3% to 5% biotite, and a few per cent antigorite, iddingsite, and apatite. The coronas add about 5% of both secondary orthopyroxene and uralite, and traces of garnet.

Few gabbro bodies in the Gras Lake-Felix Lake Area have retained their ophitic texture. Those that have, contain 1/4 inch laths of light green altered plagioclase surrounded by black mafic minerals. Rims of fine-grained red garnet have grown between the mafic minerals and the feldspar. Coronas from the Normanville and Felix Lake areas are compared in Plate XIII.

The coronas are more strongly developed in the southern area. The inner layer of fibrous orthopyroxene is the same, but in the southern area the second layer contains green clinopyroxene as well as uralite, and the outer garnet layer is always present. Where the recrystallization is

PLATE XIII

A - Photomicrograph of corona in gabbro from the Normanville Area. Olivine and plagioclase react to form a double halo of bronzite surrounded by uralite. Plane polarized light, magnification 300x.

B - Photomicrograph of corona in gabbro from the Felix Lake Area. Olivine-plagioclase reaction produces a triple halo of fibrous bronzite, surrounded by clinopyroxene which grades outward into garnet. Plagioclase is recrystallized, and clinopyroxene is full of magnetite dust. Plane polarized light, magnification 150x.

advanced, the garnet rims of adjacent coronas may merge to form networks or paths through a matrix of pyroxene and feldspar. Further recrystallization is accompanied by the development of a crude gneissosity parallel to the foliation of the surrounding gneiss.

The recrystallized gabbro in the southern area is composed of anhedral plagioclase and euhedral garnet inclosing streaks of clinopyroxene, biotite, hornblende, and magnetite. Some samples contain large green porphyroblasts of aegirine-augite. Table 27 in the Appendix gives the composition of thirteen thin sections of gabbro from the Gras Lake-Felix Lake Area. Samples in which an ophitic texture can still be recognized are marked with an asterisk. Average rocks from this group contain 38% to 50% plagioclase, 5% to 17% clinopyroxene, 9% to 17% garnet, 3% to 19% hornblende, 2% to 10% biotite, 0% to 10% orthopyroxene, as much as 8% olivine or iddingsite, 0% to 4% magnetite, and small amounts of apatite, spinel, and pyrrhotite. The composition range is large as the percentages include primary and secondary forms of plagioclase, amphibole and pyroxene, and are averaged from rocks in different stages of alteration.

Biotite in the gabbro is red brown, and has an intermediate refractive index, n_Y, between 1.645 and 1.670. Primary hornblende is pleochroic from yellow brown to dark brown, and secondary varieties are green. Green hornblende replaces augite, and biotite replaces orthopyroxene. The primary clinopyroxene is augite with an extinction angle of about 50°, and is full of dusty magnetite inclusions. In the altered gabbros near Felix Lake bottle-green aegirine-augite with an extinction angle of about 65° is more common. Some samples contain both clinopyroxenes. The garnet occurs as small euhedral grains with a refractive index

between 1.777 and 1.783, and a cell edge between 11.556 and 11.575 Å.

Incompletely altered gabbros contain two generations of plagioclase. The primary laths are strongly altered. They contain many tiny tablets of clinozoisite, and any twinning has been destroyed. The fine alteration products probably give the plagioclase its green colour. Clusters of small polyhedra of secondary plagioclase occur between the larger grains. These are twinned, and less calcic (An_{20-40}) than the primary plagioclase.

Corona development

Corona development in Norwegian hypersthene gabbros is discussed by Reynolds and Fredrickson (1962). They find that olivine in contact with plagioclase is invariably surrounded by an inner layer of fibrous bronzite, and an outer layer of simplicitic blue green hornblende and spinel. Magnetite has only the outer hornblende spinel corona. A third layer of garnet is present in rare highly altered samples.

Coronas are thought to have developed when aequeous silica-bearing solutions caused the olivine-bronzite transformation, which in turn liberated sufficient iron and magnesium to form hornblende and spinel from the feldspar. Spinel formed where the plagioclase contained more alumina than could be incorporated in the hornblende. Silica and spinel are incompatible, and if silica is not removed quickly enough by the olivine-bronzite reaction, the extra alumina forms garnet rather than spinel. Reynolds and Fredrickson conclude that since coronites have not reached equilibrium, their mineral assemblages depend on the amount and rate of addition of water and silica as much as on the temperature and pressure at which the reaction took place, and the usual concept of

mineral facies cannot be applied to explain their mineralogy.

Coronites of the Normanville Area are similar to the Norwegian ones. Olivine is surrounded by an inner rim of orthopyroxene, and an outer rim of green hornblende, but rarely spinel. The reaction rims do not contain clinopyroxene nor much garnet. Complete recrystallization of the gabbro yields amphibolite. In the Felix Lake Area, the gabbro was more thoroughly recrystallized under a higher grade of metamorphism. Secondary clinopyroxene and garnet are common, and complete recrystallization yields a pyroxene-garnet-feldspar gneiss. One can conclude that in the present area, the mineralogy of both coronitic and completely recrystallized gabbro is strongly influenced by the degree of metamorphism at which the recrystallization took place.

Metagabbro Amphibolite

In the Normanville Area and the western part of the Gras Lake-Felix Lake Area thin amphibolite bodies are interlayered with the metasedimentary series. The larger bodies of amphibolite in the Mount Wright syncline have gabbroic centres. The change from gabbro to amphibolite was studied in detail by Gross (1955). In general it involves the addition of water, recrystallization of the original minerals to oligoclase, hornblende, and garnet, and development of foliation parallel to that of the surrounding rocks.

The amphibolite is a medium grained, dark green rock, composed essentially of plagioclase and hornblende, with smaller amounts of biotite, garnet, ilmenite, and in places quartz. A weak foliation results from the alignment of hornblende and biotite, and small lenses of mafic and felsic

constituents.

Mineral compositions of amphibolite in the Normanville and Gras Lake areas are given in Tables 19 and 27 in the Appendix. Average samples contain 26% to 46% plagioclase (An_{20-30}), 22% to 42% hornblende, 8% to 14% biotite, 3% to 10% opaque oxide, 1% to 6% garnet, and up to 7% quartz. Apatite and sphene are common accessories. Compositions are more variable in the Gras Lake Area than in the Normanville Area, possibly because the sills are thinner and more altered in the south.

The plagioclase is generally fresh, poorly twinned, and zoned from relatively calcic borders to a sodic core. Hornblende is pleochroic from yellow green to dark green, and has an extinction angle of about 28°. Most of the hornblende occurs as subhedral grains in mafic clusters, but in the Normanville Area some larger ragged poikilitic grains of primary hornblende remain. Biotite is brown or red brown and aligned parallel to the foliation. Sphene occurs with the mafic minerals, and is generally accompanied by ilmenite.

The amphibolite and the metasedimentary hornblende-garnet rocks have somewhat similar compositions. The following table compares the average amounts of important minerals in the two rock types.

TABLE 6

MINERAL COMPOSITION OF HORNBLENDE-GARNET ROCK AND AMPHIBOLITE

	Plag.	Qtz.	Bio.	Hnb.	Garn.	Cpx.	
Mean	16.6	4.8	3.3	37.9	19.0	14.0	Hornblende-Garnet Rock
Mean Dev.	13.9	5.5	4.0	19.0	6.9	9.6	
Mean	36.3	4.8	11.0	32.3	3.8	0	Amphibolite
Mean Dev.	10.2	2.4	3.5	9.8	2.8	0	

In general the amphibolite contains more plagioclase and more biotite than the hornblende-garnet rock. The hornblende-garnet rock contains much more garnet, some clinopyroxene, and has a more calcic variety of plagioclase than the amphibolite.

Intermediate Rocks

Parts of the basic sills in the Felix Lake Area consist of syenodiorite. These rocks are composed essentially of oligoclase feldspar, biotite, hornblende, clinopyroxene, and garnet. The mafic minerals may be concentrated in streaks, or distributed evenly through the rock. The intermediate rocks differ from the nearby gabbro in having some antiperthite, more plagioclase and biotite, and less amphibole, pyroxene and garnet than the gabbro. The plagioclase is more sodic than that of the gabbro.

Composition estimates of six thin sections are given in Table 27 in the Appendix. Typical syenodiorite contains 57% to 73% plagioclase (An_{15-22}), 6% to 10% biotite, 1% to 11% hornblende, 3% to 11% clinopyroxene, 3% to 9% garnet, as much as 4% opaque oxide and quartz, some orthopyroxene, and traces of apatite, and zircon. The plagioclase is antiperthitic and in two of the sections is replaced by scapolite.

Ultrabasic Rocks

Sills of medium grained black peridotite were injected into the gneisses along a zone running close to the Moisie River in the southern half of the Felix Lake Area. They are composed of dark green pyroxene, with as much as 30% olivine, and minor amounts of green amphibole. Outcrops weather to a coarse pyroxene sand. The peridotite near Pegma Lake underlies

a gabbro sill, from which it probably differentiated.

Thin sections show that the pyroxene is light green augite with an extinction angle ($Z \wedge c$) of approximately 50°. It is intergrown with and partly replaced by lighter tremolite with $Z \wedge c$ of about 20°. Olivine is partly altered to iddingsite, and a mixture of antigorite and magnetite.

Sulfides associated with the Pegma Lake peridotite, have been staked and drilled, and are described in the chapter on economic geology. Pyrrhotite and carbonate also occur in an ultrabasic sill close to the southern border of the area.

Acidic Orthogneiss

The gabbroic sills in the Felix Lake Area grade upward into acidic orthogneiss. This is a medium grained rock containing lenses of grey quartz and mafic minerals set in a matrix of sugary brown feldspar. Gneissosity may show in the alternation of mixed felsic and mafic with pure felsic layers, or in preferred orientation of mafic speckles or quartz lenses.

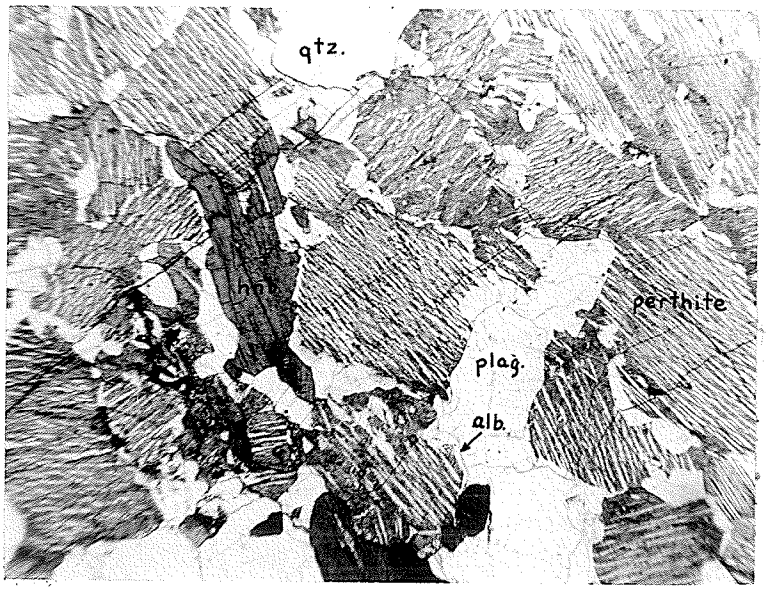
The dark colours and waxy lustre of the quartz and feldspar give the rock the appearance of a granulite. The orthogneiss is much younger than the Archean granulite and occurs in a different part of the area. In thin section the orthogneiss is more even textured and less altered than the granulite. Both rocks probably formed at high temperatures so inherited megascopically similar characteristics.

Table 26 gives composition estimates of seven thin sections of the acidic orthogneiss. A typical rock of this type contains 20% to 40% plagioclase (An_{10-15}), 30% to 56% perthitic microcline, 0% to 3% quartz,

2% to 10% hornblende, 0% to 3% biotite, 1% to 5% aegirine-augite, 1% to 4% garnet, 0% to 3% hypersthene, about 1% opaque oxide, and traces of apatite, zircon, and sphene.

Microcline forms 1.5 mm. anhedra from which the plagioclase has exsolved to fine lamellae and to grain boundaries. One-quarter to one-half of the perthite is albite. Plagioclase also occurs as 0.2 to 0.5 mm. clear equant grains interstitial to the microcline. It is more albitic than plagioclase found in any of the other rock types. Both biotite and hornblende have very strong pleochroism. Biotite is pleochroic from yellow to black, and hornblende from brownish green to very dark brown. Hypersthene is weakly pleochroic from pink to green. The clinopyroxene is light green to bottle green aegirine-augite with an extinction angle of 53° to 62°. Some of the clinopyroxene contains intergrown exsolution lamellae of orthopyroxene. Small, dark red garnets lie near the centres of plagioclase clusters; they were never seen in contact with microcline. Large euhedral zircons are associated with the opaque oxide. Some of the hypersthene is altered to a yellow-brown, uniaxial negative mineral (hematite?). The microtexture of a typical orthogneiss is shown in Plate XIV.

PLATE XIV



Fine perthitic intergrowth and albitic borders of potassium feldspar in the acidic orthogneiss. Stained section. Plane polarized light, magnification 300 x.

The acidic orthogneiss resembles the other members of the basic suite in containing extremely pleochroic biotite and hornblende, and relatively large amounts of opaque oxide and zircon. The refractive indices of its biotite (n_Y = 1.68 - 1.70), hornblende (n_1 = 1.70 - 1.72, n_2 = 1.71 - 1.73), and garnet (n = 1.81) are the highest recorded in the area.

The scarcity of biotite, and the microcline-plagioclase intergrowth indicate that the rock formed in a dry environment at temperatures high enough to dissolve much of the plagioclase in the microcline, (Tuttle and Bowen, 1958). It is a high temerature water-deficient differentiate of the Shabogamo Gabbro.

Granitic Rocks

Quartz Monzonite

Bodies of white to pale pink, generally gneissic quartz monzonite occur in the southeastern corner of the Normanville Area, and in the western two-thirds of the Gras Lake-Felix Lake Area. They are most abundant in the lower gneisses, but also intrude the Iron Formation Series and upper gneisses. Most of the bodies are conformable lenses or sills with widths of from tens to several hundreds of feet. Foliation is parallel to that of the enclosing rock. Few of the bodies are homogeneous; instead they contain remnants of gneiss, and may grade through migmatite into gneiss.

Tables 19 and 26 in the Appendix, give compositions of thin sections of quartz monzonite from the Normanville and Gras Lake-Felix Lake areas. Compositions are variable and seem to depend in part on the composition of the surrounding gneiss. Both gneiss and quartz monzonite contain more quartz and muscovite, and less hornblende and garnet in the Normanville Area than in the Gras Lake Area.

Average compositions fall in the range; 22% to 50% plagioclase (An_{15-30}), 18% to 39% microcline, 20% to 36% quartz, 2% to 5% biotite, 0% to 6% muscovite, 0% to 2% garnet, and traces of epidote, apatite, zircon, and sphene. Hornblende occurs where hornblende gneiss has been injected and partly digested.

The plagioclase is sericitized in places, but the microcline is fresh. Microcline exsolves from and replaces plagioclase. The plagioclase may also be replaced by large flakes of muscovite. A rim of albite

forms between the microcline and plagioclase. Biotite is generally light brown and may be chloritized. Grains of hornblende are anhedral, and embayed by feldspar. They have the pleochroic formula X = yellow green, Y = green brown, Z = slightly blueish green, and extinction angles ranging from 17° to 32°.

The quartz monzonite differs from the lower gneisses in having less mafic minerals, and more potassium feldspar. However, the minerals in it are similar to those of the nearby gneiss. It was probably formed by partial remelting of the gneisses, followed by injection of the fluid portion. The fluid also mixed, and reacted with the host rock forming migmatites and hybrid gneisses. Where iron formation is injected, large red garnets are developed. Local concentration of iron and reduction of hematite to magnetite takes place at the granite contact. A very iron-rich outcrop south of Halfmile Lake probably formed in this way.

Granite East of the Moisie River

East of the Moisie River the common gneiss is metasomatized and intruded by gabbro and its derivatives. Granite in this part of the area is pinkish grey, leucocratic, and characterized by red-stained spots surrounding centres of allanite. Weathered surfaces are white or red. These granites include gneissic types, but are mostly fine-grained and massive. They contain about the same amounts of quartz, plagioclase, and microcline and less biotite than the quartz monzonite. Magnetite and zircon are common accessories.

Both feldspars are fresh and well twinned. Plagioclase is albitic. Biotite and hornblende have very strong absorption and high

refractive indices. Zircon occurs as large euhedral grains.

Mineral content of six thin sections of the granite is shown in Table 26 in the Appendix. Average rocks in this group fall in the composition range; 25% to 47% plagioclase (An_{5-20}), 27% to 33% microcline, 20% to 33% quartz, 1% or 2% biotite, 1% opaque oxide, and traces of apatite, sphene, zircon, and allanite. Some samples contain garnet, hornblende or muscovite. The granite is related to the gabbroic suite in that it contains highly pleochroic biotite and hornblende, and relatively large amounts of the accessory minerals allanite, zircon, and magnetite.

A zone of red-stained potash-metasomatized paragneiss lies just east of the Moisie River between the outlet of Felix Lake and the southern border of the area. This gneiss contains a small proportion of massive granite, and was probably formed by fluids rising along a zone of weakness near the Moisie River.

CHAPTER VII

MINERALOGY

Introduction

The common rock forming minerals occur in different proportions in the various rock types, and differ in composition from rock type to rock type. The mineral proportions of the different rock types have been discussed. This chapter is concerned with the relationship of mineral composition to rock type.

Minerals having ionic substitution and occurring in most of the common rock types were chosen for study. Work was confined mainly to routine determination of refractive indices and unit cell size. These properties change with changing composition, and can be used to compare the composition of minerals in the different rock types. They are properties which can be determined rapidly, so many samples can be compared in a relatively short time.

The chapter contains two main sections, a general study of the mineralogy of the common rock types, and a more detailed study of coexisting cummingtonite, orthopyroxene, and clinopyroxene of the iron formation and of calcite coexisting with dolomite in the marble. An attempt is made to use the coexisting pyroxenes, and coexisting carbonates as geothermometers to measure temperatures of metamorphism of the area.

Procedure

The rock to be studied was crushed and sieved, and the -50 +100

mesh fraction was separated into magnetic and non magnetic parts with a Franz Isodynamic Separator. Refractive indices were then determined for garnet, and for cleavage flakes of biotite, amphibole, pyroxene, and some plagioclase. The refractive index of biotite flakes is n_Y. Curves relating refractive indices of cleavage fragments of plagioclase to composition (Tsuboi, 1923) can be found in most optical mineralogy texts, and similar curves for amphiboles and pyroxenes are given by Parker (1961). Plagioclase was determined in thin section by the Rittmann method (Emmons, 1943, p. 115). Twelve pyroxenes from the iron formation were analyzed for Fe, Mg, and Ca.

Cell sizes of garnet and calcite were determined by X-ray diffraction. The crushed marble was stained with Alizarine Red S to distinguish calcite from dolomite (Friedman, 1959). The minerals were hand picked from the -50 +100 mesh fraction under a binocular microscope, powdered, rolled in collodian, and exposed to Fe/Mn radiation in a 114 mm. diameter Philips powder camera. The garnet cell edges given are averages calculated from the "d" spacings of the (10.4.0), (10.4.2), and (8.8.0) lines. The third order reflection of the $(1.0.\bar{1}.4)$ line, ie. the $(3.0.\bar{3}.12)$ line, is used as a measure of the size of the calcite cell.

Minerals of the Common Rocks

Plagioclase - General Features

The composition of plagioclase in a rock is controlled by the composition of the rock forming material and by its temperature of crystallization. The anorthite content of plagioclase should increase with

increasing temperature of crystallization provided the rock contains sufficient calcium to form more anorthite "molecule". In metamorphic rocks the extra calcium is most likely to be present as epidote, and the plagioclase composition is likely to be controlled by reactions such as:

High Temperature				Low Temperature		
$4CaAl_2Si_2O_8$	+ $KAlSi_3O_8$	+ H_2O	$\rightleftharpoons$	$2CaAl_3Si_3O_{12}\cdot OH$	+ $KAl_3Si_3O_{10}\cdot OH$	+ $2SiO_2$
Anorthite	+ Orthoclase	+ Water	$\rightleftharpoons$	Zoisite	+ Muscovite	+ Quartz

or

$4CaAl_2Si_2O_8$		+ H_2O	$\rightleftharpoons$	$2CaAl_3Si_3O_{12}\cdot OH$	+ Al_2SiO_5	+ SiO_2
Anorthite		+ Water	$\rightleftharpoons$	Zoisite	+ Kyanite	+ Quartz

The reaction between epidote and anorthite depends partly on the availability of water and partly on the Fe^{+3}/Al ratio of the rock. As epidote contains water, and as it is able to replace much of its aluminum with ferric iron, a higher water or Fe^{+3}/Al content will tend to stabilize epidote (Ramberg, 1952). Calcium - poor rocks will contain sodic plagioclase even though highly metamorphosed.

X-ray and thermochemical studies show that plagioclase does not form a continuous solid solution series but is composed of submicroscopic mixtures of plagioclase molecules with compositions of An_{1-5}, An_{20-25}, and An_{65-70} (Kracek and Neuvonen, 1952; Nobel, 1962). According to Rutland (1961) the changes in the plagioclase structure occur at An_5 and An_{30}. DeWaard (1959) does not recognize the structural change near An_{30}. Plagioclase between An_5 and An_{20} is less stable than either of the pure phases. It is uncommon in metamorphic rocks, and can be used to mark a metamorphic isograd (Nobel, 1962).

Plagioclase in this study

Plagioclase compositions from rocks of the Gras Lake-Felix Lake and Normanville areas are shown in Figure 10. Most determinations were made by the Rittmann method but some were made by the Tsuboi method. Compositions determined by the two methods are generally similar and are not separated. Where results differ both estimates are shown and distinguished by the symbols used in the tables in the Appendix.

Most of the metamorphic rocks contain plagioclase between An_{25} and An_{35}. Only the albite-epidote grit and the porphyroblastic schist of the Normanville Area, and the potassic metasomatized gneiss of the Felix Lake Area contain much plagioclase more sodic than An_{20}. Both the grit and porphyroblastic schist contain appreciable epidote. They both occur close to the Grenville Front and are less metamorphosed than the other types of gneiss. The potassic gneiss contains mostly calcic oligoclase, and a little sodic oligoclase. Only traces of epidote occur in this gneiss. It is highly metasomatized, and probably received sodium as well as potassium during metamorphism.

Rocks containing plagioclase more calcic than An_{35} are both calcic and highly metamorphosed. They are the basic granulite of the Normanville Area, and the pyroxene-hornblende-garnet rock east of the Moisie River in the Felix Lake Area. Any calcic plagioclase that may have occurred in the Gras Lake-Felix Lake granulite was destroyed by the Grenville metamorphism. East of the Moisie River the metamorphism was strong enough to form calcic andesine in rocks of suitable composition.

The plagioclase of the igneous rocks has a greater composition range than does that of the metasediments. The most calcic plagioclase

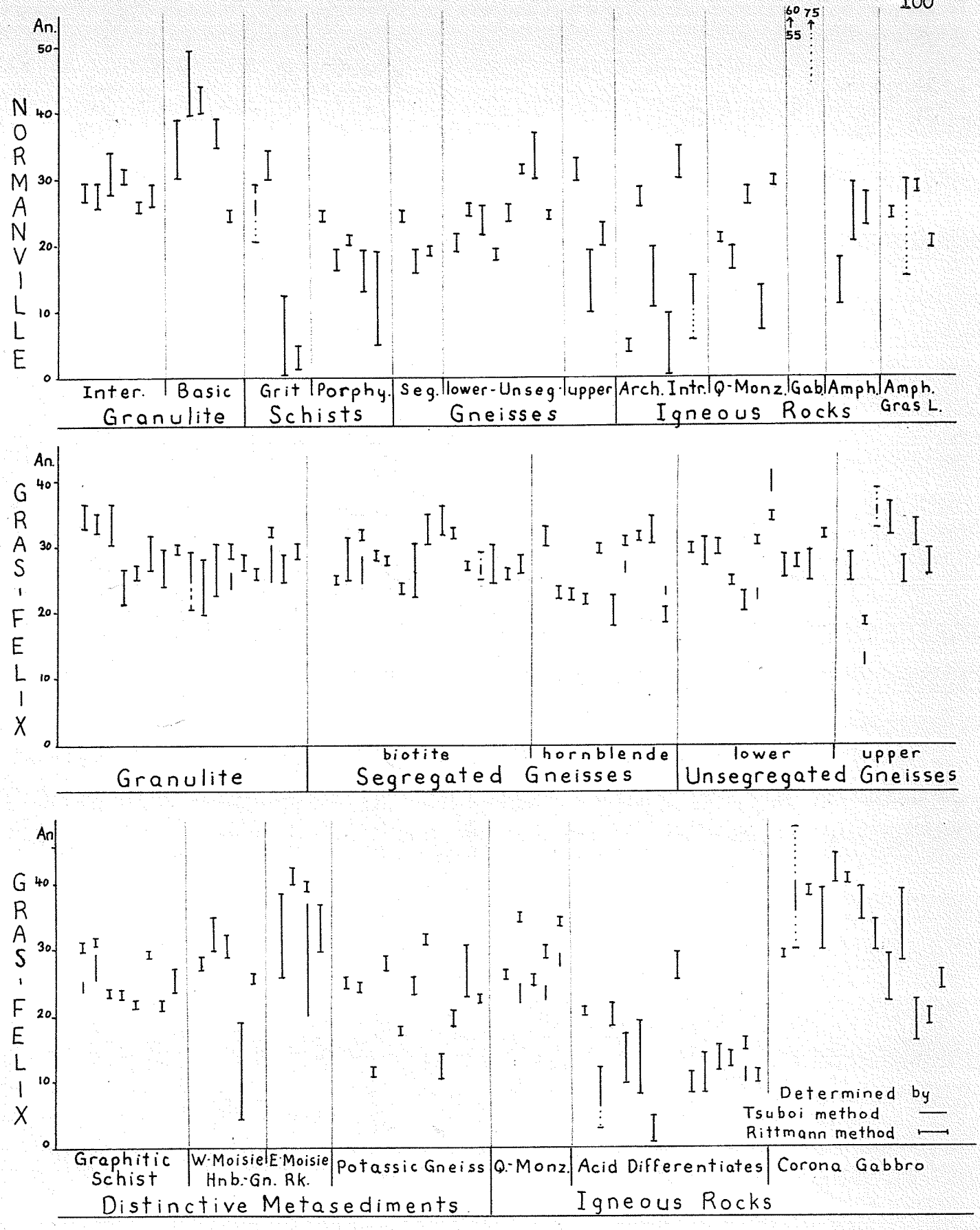


Figure 10

PLAGIOCLASE COMPOSITIONS OF COMMON ROCK TYPES

(An_{65-75}) occurs in the ophitic gabbro of the Normanville Area. In the Gras Lake-Felix Lake Area the gabbro is recrystallized and contains secondary plagioclase as sodic as An_{20}. Amphibolite and quartz monzonite contain the same plagioclase (An_{25-35}) as the surrounding gneiss. The most sodic plagioclase occurs in the Archean intrusive rocks and in the acidic differentiates from the gabbro. Both these rock types occur in the highly metamorphosed parts of the area and belong to high temperature rock suites. The composition of their plagioclase is controlled by rock composition rather than temperature of crystallization.

Biotite - General Features

The general formula for biotite is:

$$K_2(Fe^{+2},Mg)_{6-4}(Fe^{+3},Al,Ti)_{0-2}(Si_{6-5}Al_{2-3})O_{20-22}(OH,F)_{4-2}$$

The main substitutions are between ferrous iron and magnesium, and aluminum and silicon. Other common substitutions are Ti for Fe^{+3}, and Na, Ca, Ba, for K, (Deer, Howie and Zussman, 1962, vol. 3). The refractive index of biotite increases with increase in its Fe/Mg ratio, to a lesser extent with replacement of Si by Fe^{+3} and Al, and of OH by F. Because several substitutions are possible there is no direct relationship between optical properties and chemical composition.

The colour of biotite depends mainly on its iron and titanium content. Titanium-rich biotites are reddish brown and those rich in ferrous iron are green. Magnesium tends to dilute the colour caused by the iron or titanium. As with the optical properties there is no strict relationship between colour and composition (Hall, 1941).

The composition of biotite is controlled by rock composition

(Heinrich, 1946; Kretz, 1959), and by metamorphic grade. Heinrich showed that biotites from granites and pegmatites are rich in FeO and MnO, those from syenitic rocks in Fe_2O_3 and TiO_2, and those from basic rocks and marbles in MgO. Gneisses and schists contain biotites of intermediate compositions.

In quartzofeldspathic gneisses the composition of biotite changes with increasing metamorphism. Biotite in low grade rocks is generally richer in Mn and Fe and lower in Ti and Mg than biotite in high grade rocks (Barth, 1936; Miyashiro, 1956; Engel and Engel, 1960). Some discrepancies occur because of differences in coexisting minerals. Garnet, for example, incorporates iron leaving the biotite enriched in magnesium (Deer et al., 1962, vol. 3, p. 75). The change in composition results in a colour change from green-brown through red-brown to deep red-black with increasing metamorphism.

Hornblende - General Features

The name hornblende refers to a group of calcium aluminum amphiboles composed of the end members:

Tremolite-Actinolite,	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
Tschermakite-Ferrotschermakite	$Ca_2(Mg,Fe)_3Al_2Si_6Al_2O_{22}(OH)_2$
Edenite-Ferroedenite,	$NaCa_2(Mg,Fe)_5Si_7AlO_{22}(OH)_2$
Hastingsite-Ferrohastingsite (or Pargasite)	$NaCa_2(Mg,Fe)_4AlSi_6Al_2O_{22}(OH)_2$

Common hornblende generally contains important percentages of all end members, and F or Cl may proxy for OH, Mn or Ti for Fe^{+2}, and Fe^{+3} for Al etc. (Winchell, 1951, p. 431).

Because of the extensive substitution that is possible in the

hornblende structure, correlation between optical properties and chemical composition can only be approximate. Substitution of Fe^{+2} for Mg, and to a lesser extent Al for Si, and Fe^{+3} for Al cause an increase in refractive index. Extinction angles are variable, but are lower in ferrohastingsite than in other varieties. Pargasite is optically positive. Hornblendes rich in ferric iron show intense adsorption and pleochroism.

Hallimond (1943) demonstrated the relationship between the composition of hornblende and its parent rock type. Hornblendes from intermediate igneous rocks contain all four end members with slightly more tschermakite and tremolite than hastingsite and edenite. Hornblendes in schists and amphibolite extend from tremolitic and tschermakitic to hastingsitic composition. In unaltered metamorphosed limestone the hornblende is tremolite. In acid and alkaline intrusives it is generally restricted to hastingsite or ferrohastingsite. In general, higher temperatures of crystallization favour the replacement of Si by Al, and the more sodic hornblendes occur in sodic rocks.

Hornblendes from terrains of progressive metamorphism commonly show an increase in the Al/Si ratio with increasing metamorphism (Harry, 1950). Engel, Engel and Havens (1961) investigated hornblende from amphibolite of the almandine amphibolite and hornblende granulite facies. They note an increase in TiO_2, Na_2O and K_2O, and a decrease in MnO, and Fe_2O_3/FeO in hornblende passing from the lower to the higher facies.

The colour of hornblende reflects the compositional differences between hornblendes of the different metamorphic grades. Light green actinolite forms in the epidote amphibolite facies. This passes into green or olive hornblende in the almandine amphibolite facies, and into

brown hornblende in the granulite facies.

Biotite and hornblende in this study

Figure 11 is a plot of the refractive indices of biotite and hornblende occurring together in the common rocks of the area. The index n_Y of biotite is plotted against the greater of the two apparent indices from cleavage flakes of hornblende (Parker, 1961). Both apparent indices of these hornblendes and of hornblendes that do not coexist with biotite are shown later (Figure 15 b, p. 115).

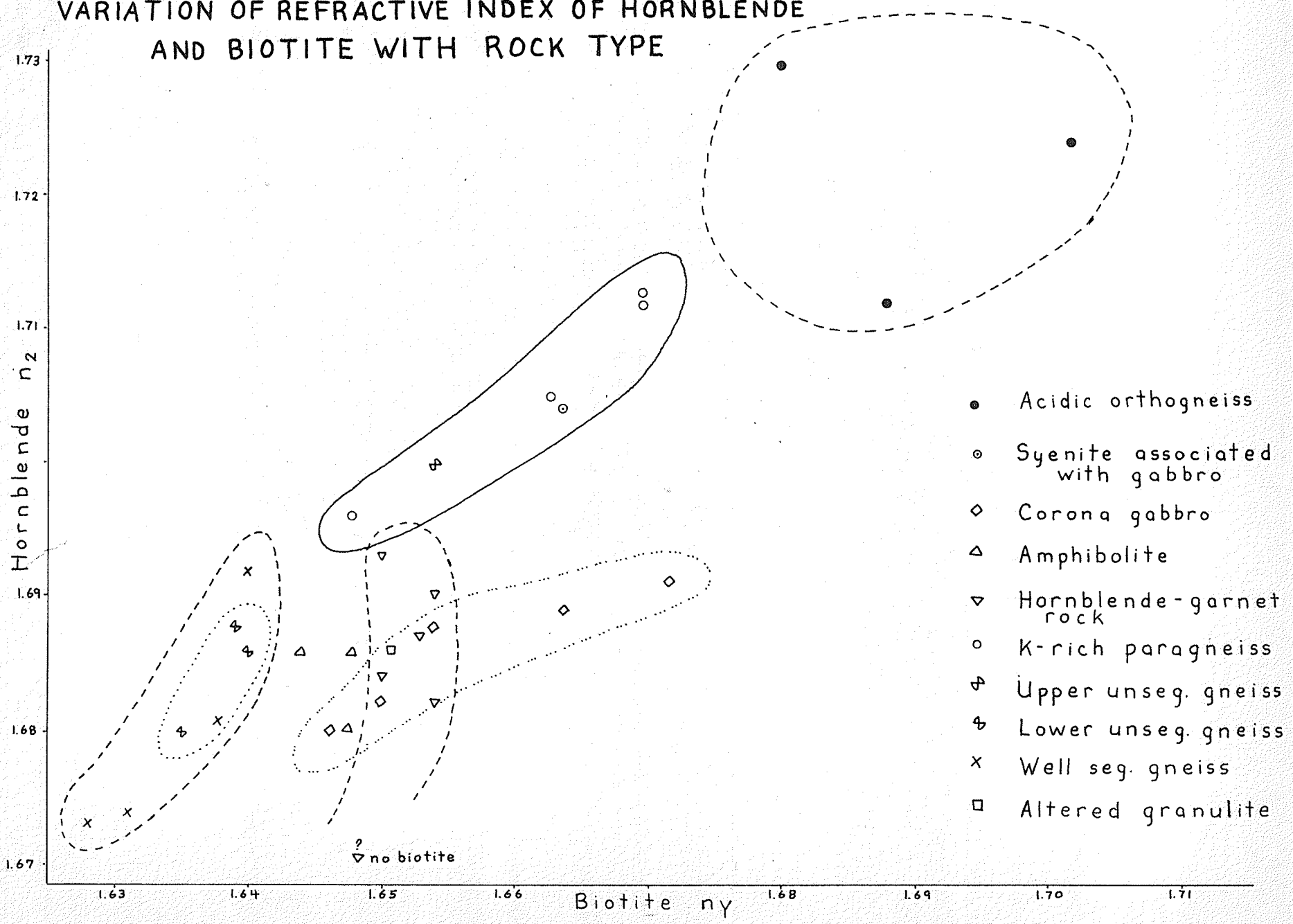
A direct relationship between the indices of biotite and hornblende is apparent, and is to be expected as the indices of both minerals increase with increase in the ratios (Fe + Ti + Mn)/Mg, Al/Si, and Fe_2O_3/FeO. Biotite and hornblende with the lowest indices are found in the lower gneisses; those with intermediate indices occur in the upper gneiss and the potassic paragneiss; and those with the highest indices in the orthogneiss derived from gabbro. This increase in refractive index is accompanied by a colour change in biotite from olive, through red brown, to dark reddish black, and a similar darkening of the hornblende.

The unaltered paragneiss contains common hornblende and biotite with $Fe^{+2}/(Fe^{+2} + Mg)$ ratios between 0.35 and 0.55 (Parker, 1961; Winchell, 1951, p. 374). In the acidic orthogneiss the amphibole and mica are iron-rich ferrohastingsite and annitic biotite. The potassic gneiss is a paragneiss metasomatized by fluids from the crystallizing gabbro. Its mafic minerals are intermediate between those of the acidic orthogneiss and the common paragneiss.

In the amphibolite, hornblende-garnet rock, corona gabbro and altered granulite the refractive index of hornblende is lower relative to

Figure 11

VARIATION OF REFRACTIVE INDEX OF HORNBLENDE AND BIOTITE WITH ROCK TYPE



biotite than it is in the gneisses. Biotite in all these rocks is red brown, apparently rich in titanium. Garnet is a major constituent of all of these rocks. Titanium and aluminum may replace silica more easily in biotite than in hornblende, thus causing a relative increase in the refractive index of biotite in those rocks in which they are abundant.

Garnet - General Features

The general formula for the garnet group is $A_3B_2(SiO_4)_3$ in which A may be Ca, Mg, Fe^{+2} or Mn, and B may be Al, Fe^{+3}, or Cr. The principal end members of the group are:

Almandine	$Fe_3^{+2}Al_2Si_3O_{12}$
Pyrope	$Mg_3Al_2Si_3O_{12}$
Spessartite	$Mn_3Al_2Si_3O_{12}$
Grossularite	$Ca_3Al_2Si_3O_{12}$
Andradite	$Ca_3(Fe^{+3},Ti)_2Si_3O_{12}$
Uvarovite	$Ca_3Cr_2Si_3O_{12}$

Uvarovite is much less common than the other five end members. Winchell (1951) divides the garnets into two series, (Fe^{+2}, Mg, Mn) Al-garnets (Pyralspite), and Ca-garnets (Ugrandite). Continuous substitution exists within each series, but not between the two series.

Garnets are isotropic. The main parameters by which they may be distinguished are cell edge, refractive index, and specific gravity. As there are more end members than measurable parameters it is impossible to determine the true composition of garnet without chemical analysis.

The best estimate of their composition can be made by using diagrams developed by Winchell (1958). With Winchells diagrams a combina-

tion of cell edge, refractive index and specific gravity can be used to limit the possible composition of the garnet to two alternatives. Chemical analysis for one element will tell which of the alternatives is correct.

Sriramadas (1957) constructed a series of eight triangular diagrams, each showing the refractive index and cell edge of mixtures of three garnet end members. He considered specific gravity unreliable because of the fine inclusions common in most garnets.

In general, iron-rich garnets have higher refractive indices, and calcium-rich garnets have larger cell edges than magnesium-aluminum garnets.

The composition of garnet is largely governed by the composition of the rock in which it formed. Wright (1938) and Troger (1962) correlate garnet composition and rock type. Troger divided the garnet family into 28 groups. Pyrope-rich garnet is confined to ultrabasic rocks; spessartite to pegmatite; grossularite to marble, calcsilicate, and pyroxenite; and andradite to scarn and alkalic rocks. Most common rocks contain almandine. The almandine of most pelitic gneisses, and of intermediate and basic rocks contains pyrope as its main subsidiary molecule. Subsidiary grossularite occurs in the almandine of calcic gneisses and amphibolite, and subsidiary spessartite in granites and clayey sandstones. Rocks crystallized under high oxygen potential contain andraditic garnet.

The effect of metamorphic grade on garnet composition has been studied by Miyashiro (1953), Engel and Engel (1960) and Sturt (1962). The main change accompanying increasing metamorphism is the substitution of (FeO + MgO) for (CaO + MnO). This results in a higher refractive index, and smaller cell edge in the higher grade garnets. Sturt uses

cell edge/refractive index, ie. a_o/n, as a measure of calcium content and so an indication of metamorphic grade.

Garnet in this study

The garnets in the present area differ somewhat in composition between the different rock types. Figure 12 is a plot of refractive index and cell edge of garnets from the common rock types, and Figure 13 is a plot of the cell edge divided by refractive index. Garnets from the same rock type generally fall within a small composition field.

All the garnets are almandine-rich, and the higher their refractive index the richer they are in iron. An almost pure almandine from the iron formation near Boulder Lake has a refractive index of 1.818, and a cell edge of about 11.56 Å. The potassic paragneiss and hornblende-garnet rock contain more grossularitic almandine than the other rock types. The garnet from the unaltered granulite is about two-thirds almandine and one-third pyrope, a composition characteristic of the granulite facies.

According to Sturt (1962) the ratio of cell edge to refractive index increases with calcium content in garnets, and can be used to measure metamorphic grade in rocks of similar composition. In pelitic schists garnets with high (FeO + MgO)/(CaO + MnO), and hence with low a_o/n, form at higher grades of metamorphism than (Ca,Mn)-rich garnets with high a_o/n. The a_o/n values of garnets from local rock types are plotted in Figure 13. The calcium contents of the local garnets apparently depend more on rock type than on metamorphic grade. Most of the high a_o/n values come from rocks rich in calcium bearing minerals such as hornblende. The lowest value (6.36) is given by garnet from the iron formation.

Although the ratio cannot be used as a simple indicator of meta-

Figure 12

VARIATION OF CELL EDGE AND REFRACTIVE INDEX OF GARNET WITH ROCK TYPE

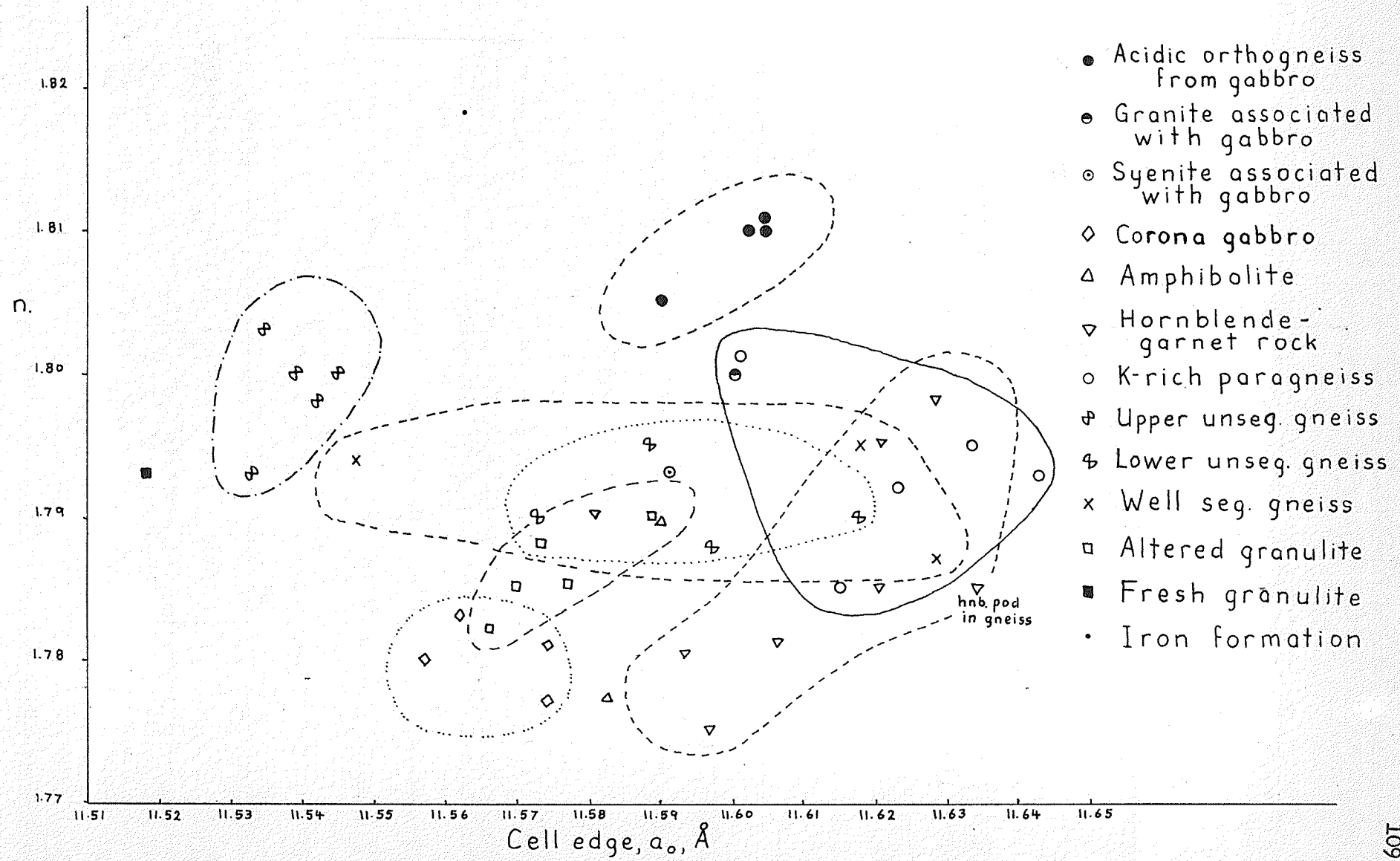
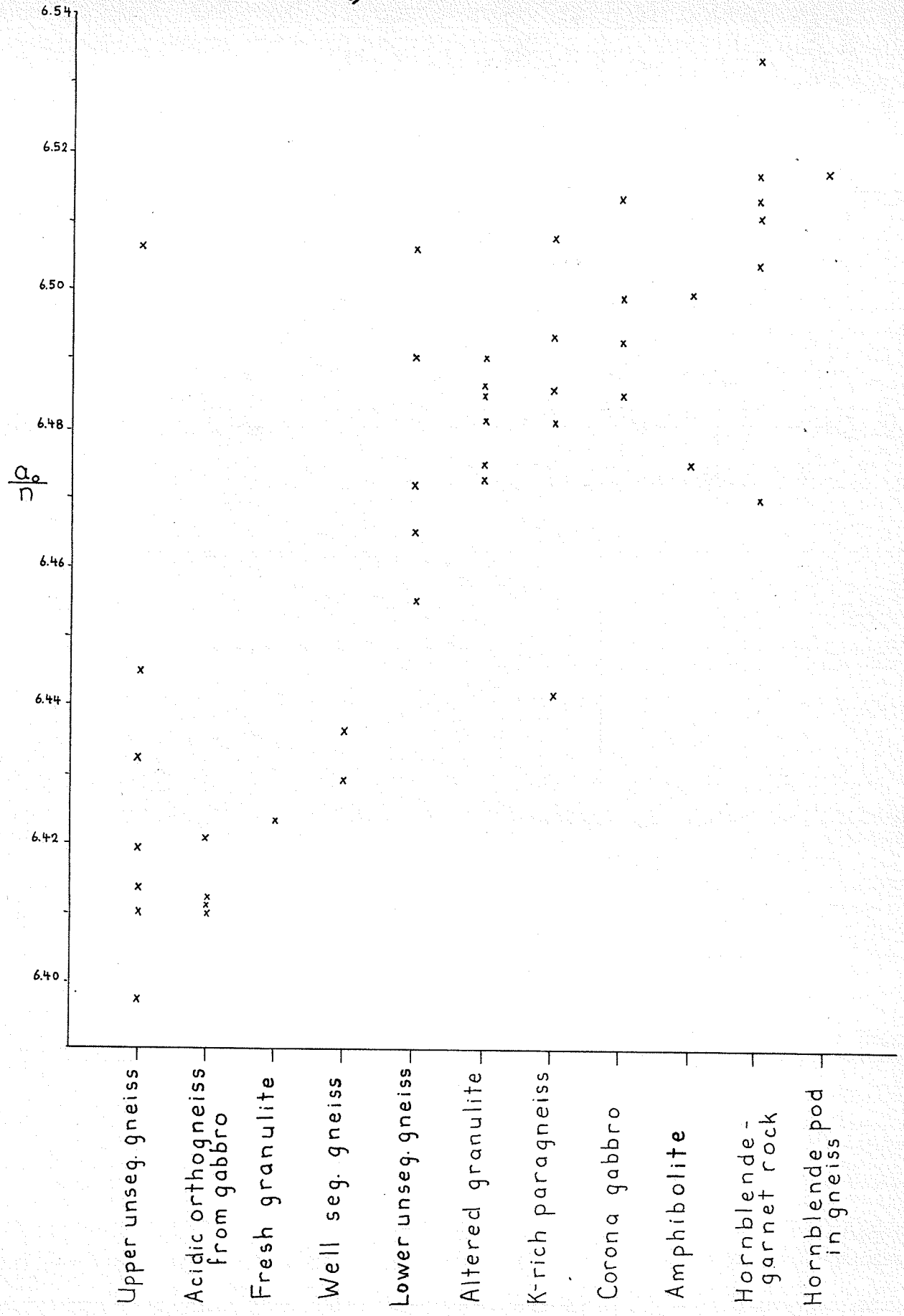


Figure 13
VARIATION OF a_o/n OF GARNET WITH ROCK TYPE



morphic grade, it can show differences in grade between rocks of the same composition, as for example the fresh and altered granulite, and the lower unsegregated and well segregated gneisses. In both these examples garnet in the more highly metamorphosed rock has lower a_o/n values than garnet in the less metamorphosed rock.

Pyroxenes - General Features

The general formula of the pyroxene group is:

$$(W)_{1-p}(X,Y)_{1+p}Z_2O_6$$

where W = (Ca,Na), X = (Mg,Fe^{+2},Mn,Ni,Li)

Y = (Al,Fe^{+3},Cr,Ti), and Z = (Si,Al).

The pyroxene group is divided into orthorhombic and monoclinic series. In orthorhombic pyroxenes "p" is close to one, and Y is small. In monoclinic pyroxenes "p" varies from zero to one, and either X or Y may predominate although X is generally the more common. The most important of the rock forming pyroxenes are:

Orthorhombic

Enstatite-Ferrosilite	$(Mg,Fe)_2Si_2O_6$

Monoclinic

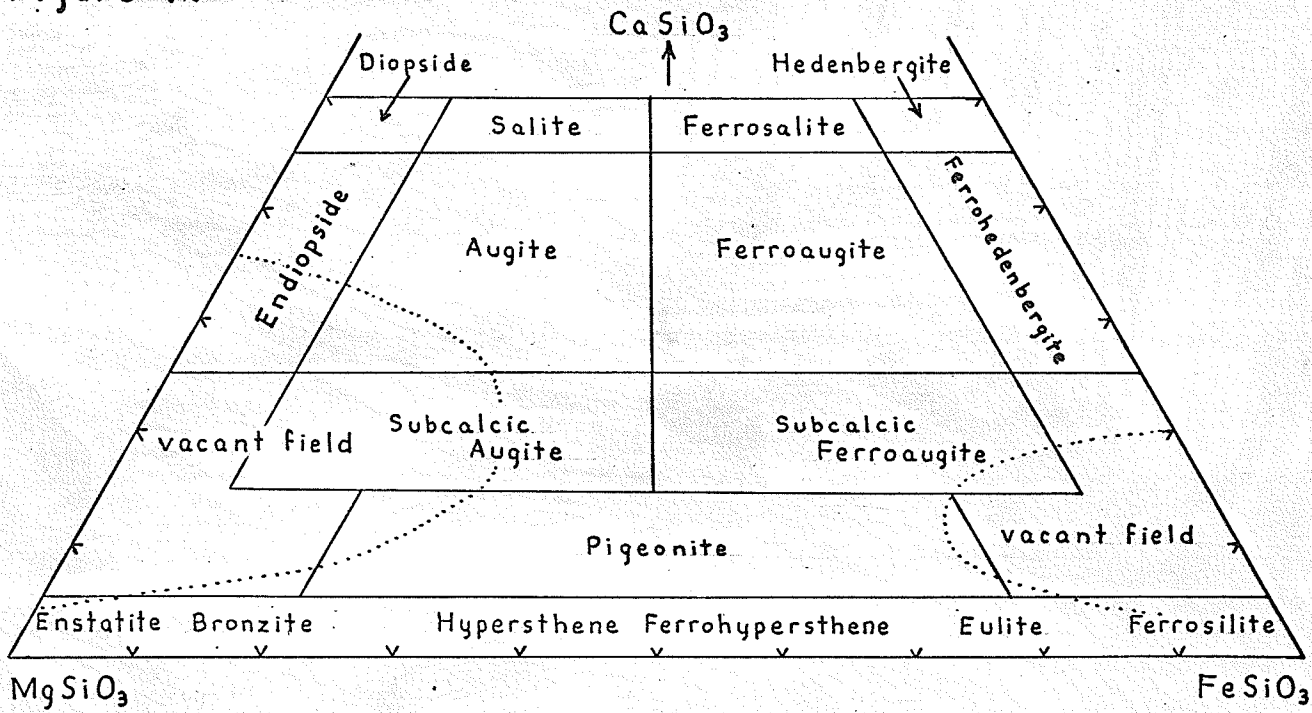
Diopside-Hedenbergite	$Ca(Mg,Fe)Si_2O_6$
Augite	$Ca(Mg,Fe,Al)(Si,Al)_2O_6$
Aegirine	$NaFe^{+3}Si_2O_6$

There is complete gradation between Diopside-Hedenbergite and Augite, and between Augite and Aegirine.

The main variables in the pyroxene group are Fe^{+2}, Mg, and Ca, and the approximate composition of most common pyroxenes can be represented

as members of the $CaMgSi_2O_6$ - $CaFeSi_2O_6$ - $Mg_2Si_2O_6$ - $Fe_2Si_2O_6$ system (Figure 14). Alkalic pyroxenes cannot be shown. Compositions in the dotted areas are unknown, and compositions in the central part of the diagram are confined to rocks cooled quickly from high temperature. In slowly cooled plutonic or metamorphic rocks, subcalcic augite and pigeonite dissociate into orthopyroxene and augite or diopside-hedenbergite. In some rocks the two phases exsolve to different parts of the same crystal (Poldervaart and Hess, 1951). Substitution of iron for magnesium increases the refractive index of pyroxene, and calcium increases its $2V_z$ (Hess, 1949; Muir, 1951). Parker (1961) has drawn curves relating composition of the main pyroxene families to the refractive indices and extinction angles of their cleavage flakes.

Figure 14



NOMENCLATURE OF PYROXENES IN THE SYSTEM $CaMgSi_2O_6$-$CaFeSi_2O_6$-$Mg_2Si_2O_6$-$Fe_2Si_2O_6$,
after Poldervaard + Hess (1951)

Augite can generally be distinguished from diopside by its smaller birefringence, greater dispersion and poorer (001) parting. Sodic augite has stronger adsorption and higher 2V and extinction angles than common augite. Aegirine-augite has a darker colour, larger extinction angle and higher birefringence than common augite.

Pyroxenes in this study

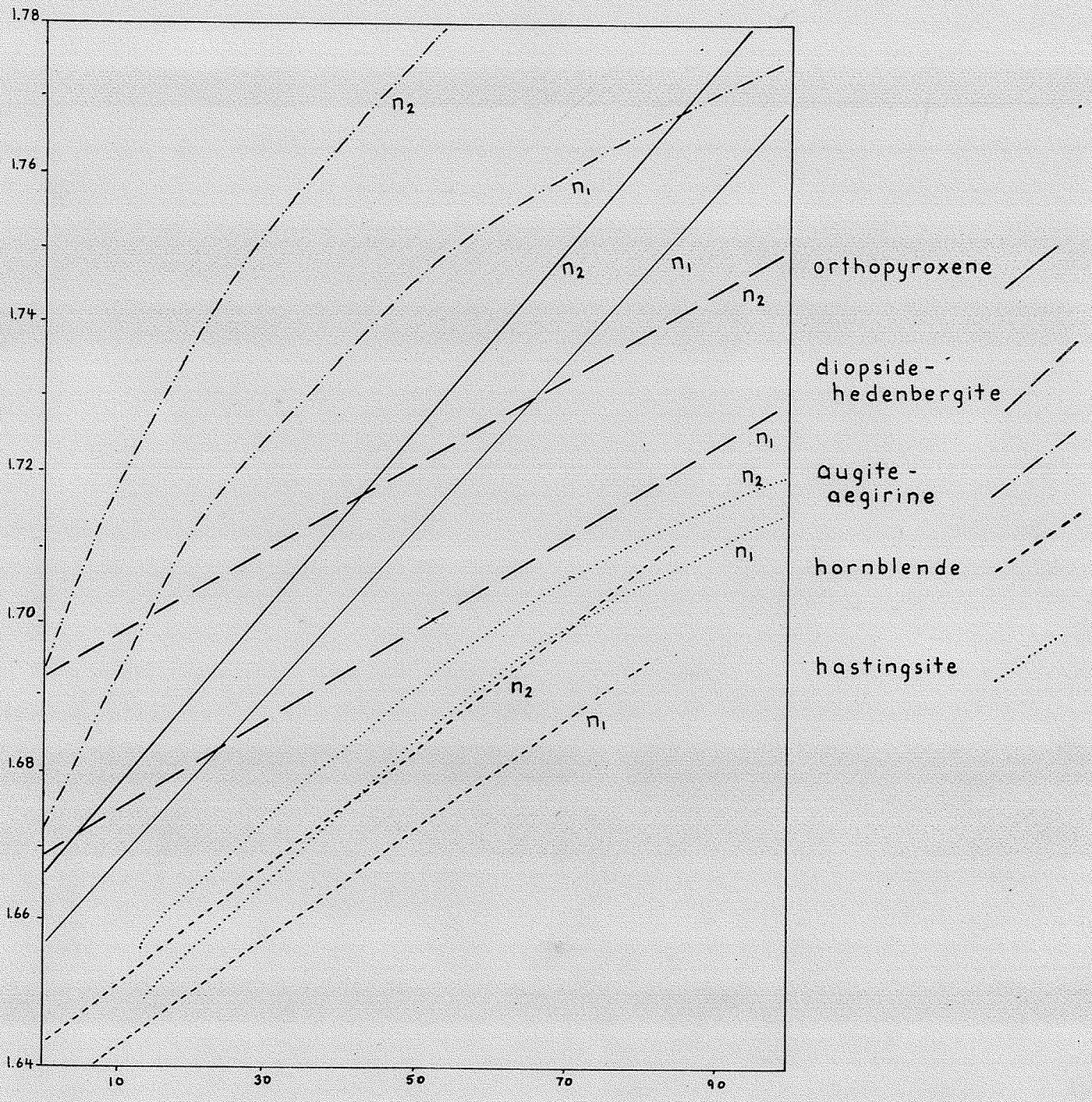
Refractive indices of cleavage flakes of amphiboles and pyroxenes from most of the local rock types are plotted in Figure 15b. Attached to the figure is a transparent overlay showing Parker's curves (Figure 15a) by which the refractive indices can be related to mineral compositions. The variation of composition of the amphiboles has already been discussed.

Orthopyroxenes occur in the Archean granulite and Proterozoic gabbro and acidic orthogneiss. The pyroxenes from the orthogneiss have higher refractive indices than the others. Their respective indices indicate a $Fe^{+2}/(Fe^{+2} + Mg)$ ratio of 0.65 to 0.80 in the orthopyroxene of the acidic orthogneiss, and 0.3 to 0.5 in the other orthopyroxenes. The orthopyroxene from the fresh granulite is slightly richer in iron than that of the altered granulite.

Clinopyroxenes occur in granulite, hornblende-garnet rock, corona gabbro and acidic orthogneiss. The clinopyroxene of the granulite is pale green, non pleochroic augite or diopside with a Z^c of 50° to 55° and 2V 57° to 58°. In the hornblende-garnet rock it is light green, with Z^c of 35° to 50° and 2V of 58° to 60°. Clinopyroxene from the gabbro is greenish brown augite with Z^c of 50° and 2V of 62°. All these pyroxenes have $Fe^{+2}/(Fe^{+2} + Mg)$ ratios of 0.35 to 0.45. The clinopyroxene in the acidic orthogneiss is bottle green aegirine-augite, with strong basal parting, an

Figure 15a.

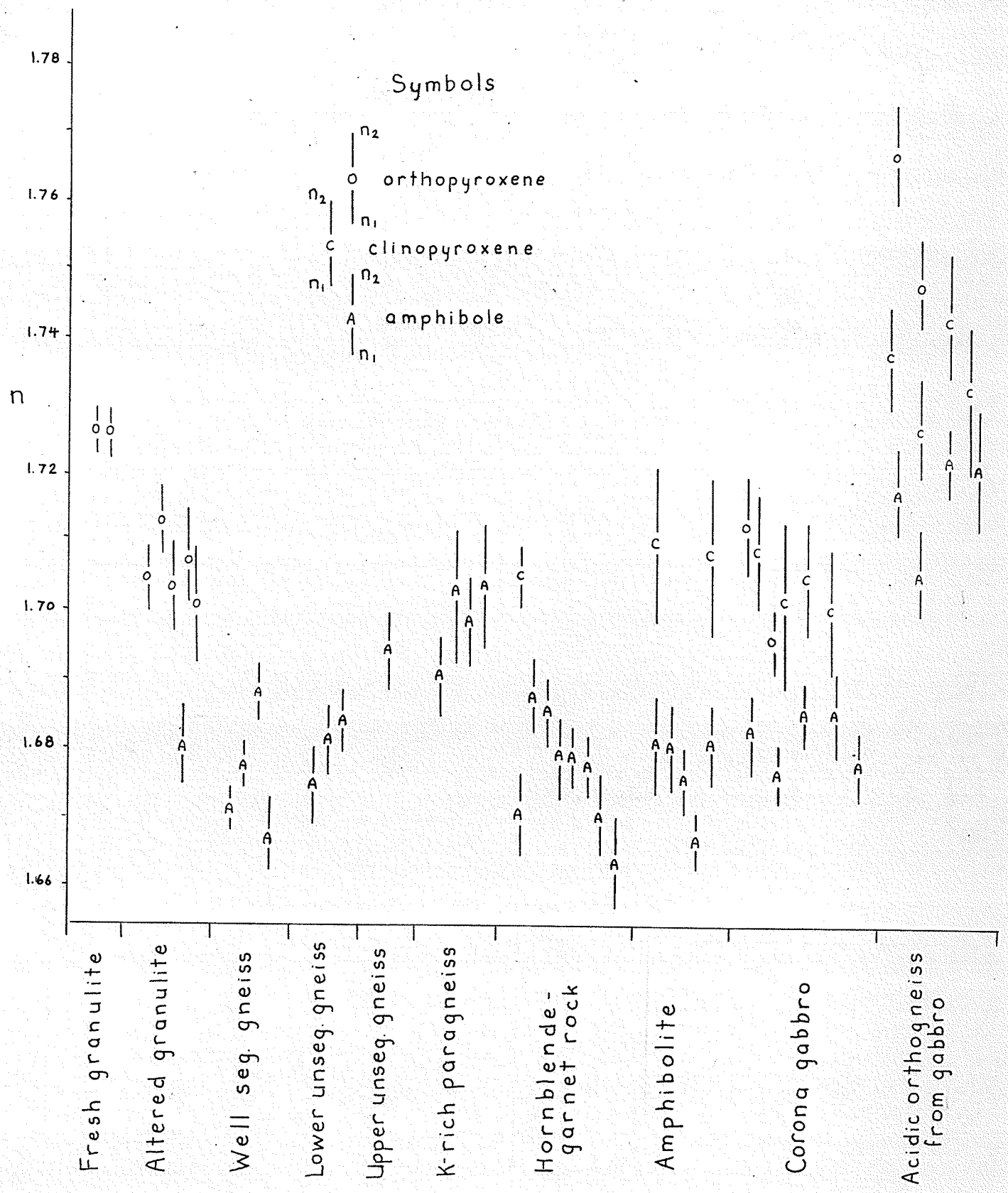
REFRACTIVE INDICES ON CLEAVAGE FLAKES OF SOME AMPHIBOLES AND PYROXENES (after R.B. Parker, 1961)



Mg	orthopyroxene	Fe^{++}
Mg Ca	diopside-hedenbergite	Fe^{++} Ca
(Mg Fe^{++}) Ca	augite-aegirine	Na Fe^{+++}
Mg	hornblende	(Fe^{++} Mn Ti)
Mg Fe^{+++}	hastingsite	$Fe^{++}Fe^{+++}$

Figure 15b

VARIATION OF REFRACTIVE INDICES OF AMPHIBOLES AND PYROXENES WITH ROCK TYPE



extinction angle, Z^c, of 65°, and a 2V of 63° to 65°. The mafic minerals from the acidic orthogneiss have higher indices than corresponding minerals from all the other rock types except the iron formation.

Minerals of the Iron Formation and Marble

Pyroxenes

Refractive indices were determined for pyroxenes from 41 samples of iron formation, and 12 of the pyroxenes were analyzed for Fe, Mg, and Ca. Their compositions are shown in Figure 16.

The clinopyroxenes are mainly ferrosalite but some are salite. Their $Fe^{+2}/(Fe^{+2} + Mg)$ ratios vary from 0.42 to 0.73. The orthopyroxenes are ferrohypersthene and eulite, with $Fe^{+2}/(Fe^{+2} + Mg)$ ratios between 0.57 and 0.82. The wollastonite molecule makes up about 4% of the orthopyroxenes, and 40% to 45% of the clinopyroxenes, and decreases in clinopyroxene with increase in the Fe/Mg ratio. Three orthopyroxenes from the olivine-pyroxene-carbonate iron formation have much lower $Fe^{+2}/(Fe^{+2} + Mg)$ ratios, than pyroxenes from the common iron formation.

The clinopyroxene is generally richer in magnesium than the orthopyroxene where orthopyroxene and clinopyroxene coexist. This relationship is apparent in Figure 16. Mueller (1960-61), Kretz (1961a), Krank (1961) and others have studied this relationship, and Ghose (1962) has explained it.

According to Ghose, the crystallographic sites M_4 in amphibole and M_{II} in pyroxene accept Fe^{+2} more easily than Mg. In calcium-rich minerals such as actinolite and diopside, these sites are filled by calcium,

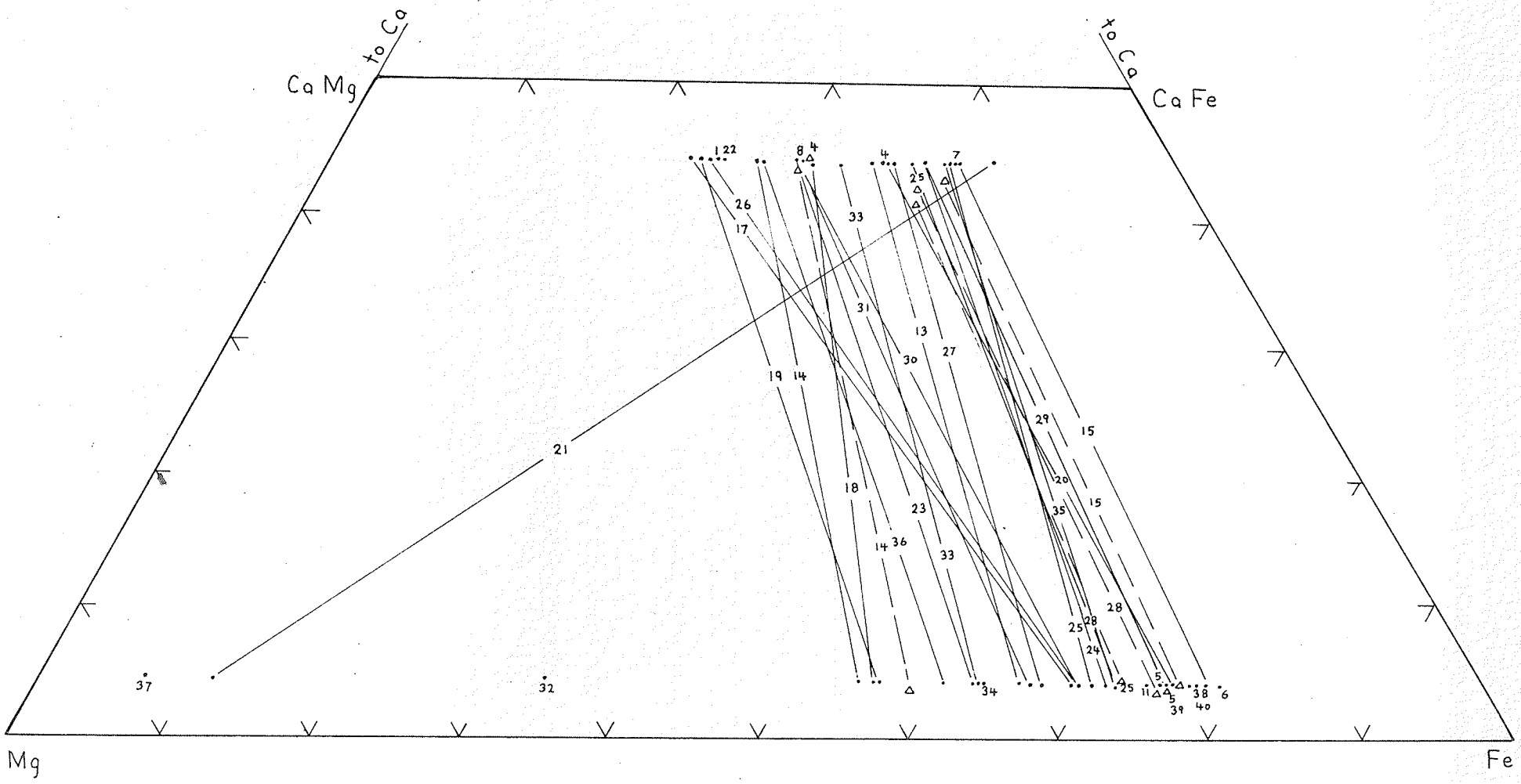


Figure 16

COMPOSITIONS OF COEXISTING PYROXENES FROM IRON FORMATION

but in cummingtonite and orthopyroxene they contain Fe^{+2} or Mg. As Fe^{+2} is preferred to Mg, it is enriched in cummingtonite and orthopyroxene, relative to the calcium-bearing minerals.

Cummingtonite

Cummingtonite and rarely actinolite occur in some samples of the iron formation. Iron and magnesium contents of these minerals and of the pyroxenes are shown in Table 7, p.122a. The $Fe^{+2}/(Fe^{+2} + Mg)$ ratio of cummingtonite varies from 0.51 to 0.83, and most commonly falls between 0.60 and 0.75. In actinolite the $Fe^{+2}/(Fe^{+2} + Mg)$ ratio varies from 0.12 to 0.65, with most samples falling between 0.40 and 0.65. The cummingtonite generally has a higher Fe/Mg ratio than coexisting clinopyroxene. This is in agreement with the work of Krank (1961), and has been explained by Ghose (1962) above.

The distribution of iron and magnesium between cummingtonite and orthopyroxene is more complex. Mueller (1961, p. 280) shows that although orthopyroxene and cummingtonite have similar affinities for iron and magnesium, magnesium tends to be enriched in iron-cummingtonite, and iron enriched in magnesium-cummingtonite relative to the coexisting orthopyroxene.

Mueller's conclusions are based on thermodynamics and a single pair of the coexisting minerals (sample No.H-9 of Krank). Mueller thought that the point where cummingtonite and orthopyroxene should have the same Fe/Mg ratio would be where their $Fe^{+2}/(Fe^{+2} + Mg)$ ratios equal 0.50.

Eight pairs of coexisting cummingtonite and orthopyroxene were studied here. The Fe/Mg distributions between cummingtonite and ortho-

pyroxene in these samples, and in Krank's sample H-9, are shown in Figure 17. Iron is concentrated in orthopyroxene relative to cummingtonite in iron-rich assemblages and in cummingtonite relative to orthopyroxene in magnesium-rich assemblages. This is as Mueller predicted. Here, however, the point of equal Fe/Mg contents in the two minerals occurs where $Fe^{+2}/(Fe^{+2} + Mg)$ equals 0.60 to 0.65 rather than 0.50 as shown by Mueller.

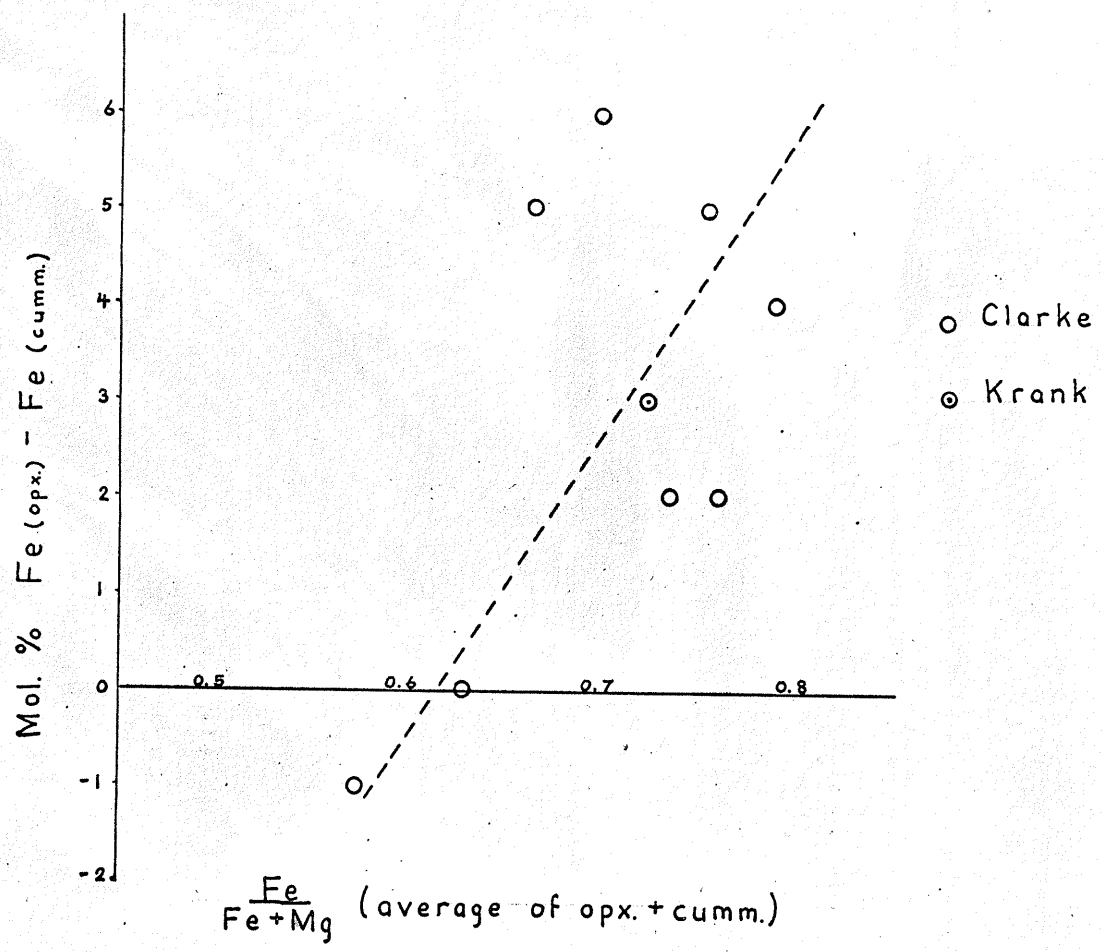


Figure 17
Fe:Mg DISTRIBUTION BETWEEN COEXISTING ORTHOPYROXENE AND CUMMINGTONITE

Pyroxene Geothermometry

The compositions of coexisting pyroxenes have received much study since Hess' (1941) paper on the subject. Much of the recent work concerns the use of pyroxene pairs as geothermometers, Wilson (1960), Brown (1961), Bartholemé (1961), Kretz (1961 a and b) and Binns (1962).

Wilson and Brown draw tie lines joining coexisting pyroxenes on the $CaSiO_3$ - $MgSiO_3$ - $FeSiO_3$ diagram. Wilson shows that the intersection of the tie lines with the $CaSiO_3$ - $MgSiO_3$ join is different in some pyroxenes from igneous and metamorphic rocks, and suggests that it may be temperature controlled. Brown does not agree that there is any fundamental difference between the tie lines of igneous and metamorphic pyroxenes. Bartholemé and Kretz also disagree with the use of tie lines as temperature indicators. Tie line intersections are affected by relatively small changes in calcium content of the clinopyroxene, and by the Fe/Mg ratio of the rock. Because they depend on several factors other than temperature, it now seems that there is no justification in the use of tie line intersections as geothermometers.

Bartholemé and Kretz calculate the equilibrium constant for the reaction:

$$CaFeSi_2O_6 + MgSiO_3 \rightleftharpoons CaMgSi_2O_6 + FeSiO_3$$

hedenbergite + enstatite $\rightleftharpoons$ diopside + ferrosilite

Bartholemé calculates K where $K = \frac{Fe}{Mg}$ (Ca-Poor) . $\frac{Mg}{Fe}$ (Ca-rich).

Kretz calculates K_D where $K_D = \frac{X_o}{1-X_o} \cdot \frac{1-X_c}{X_c}$

$$\text{and } X_o = \frac{Mg}{Mg + Fe^{+2}} \quad \text{(orthopyroxene)}$$

$$X_c = \frac{Mg}{Mg + Fe^{+2}} \quad \text{(clinopyroxene)}$$

Where $Mg + Fe^{+2} = 1$, K_D simplifies to $\frac{Mg}{Fe}$ (opx) . $\frac{Fe}{Mg}$ (cpx) so K and K_D are inverse functions.

Bartholemé shows that K for analysed pyroxene pairs equals 1.8 in metamorphic pyroxenes and 1.4 in igneous pyroxenes. Kretz's K_D values are 0.51 - 0.60 in metamorphic, and 0.69 - 0.76 in igneous pyroxenes. Bartholemé's and Kretz's methods are similar, so what is said of one applies to the other. The material in this thesis is handled by Kretz's method because it is supposed to indicate higher temperatures of equilibrium by higher K_D values.

The pyroxene geothermometer is based on the hypothesis that minerals coexisting at high temperatures have less ordered structures than they would have at lower temperatures. At very high temperatures iron and magnesium should be accepted equally by both pyroxenes; both pyroxenes would have similar Mg/Fe ratios, and K_D would be close to 1.0. With decreasing temperature some fractionation of iron and magnesium between the two pyroxenes would occur; the orthopyroxene would tend to become richer in iron (Ghose, 1962), and K_D would decrease.

Bartholemé (1961) thought the pyroxene thermometer was sound but not very sensitive. Kretz (1961,b) states that although K_D is mainly controlled by temperature, it may also be affected by the concentration of other major cations, such as calcium. Mueller (1961) is more sceptical:

> "The question of temperature and pressure, although an interesting one, must be deferred until more information becomes available. However, it seems almost certain that any temperature or pressure effects....are completely obscured by analytical errors or compositional effects."

The K_D values used by Kretz were calculated from published analyses of pyroxenes, from igneous rocks and metamorphic rocks of the pyroxene granulite facies. If temperature is the main control of K_D, pyroxenes from amphibolite facies iron formation should have lower K_D values than either of Kretz's groups.

K_D values were calculated for Krank's pyroxenes from the Mount Reed iron formation, and for pyroxenes from iron formation of the present area. In the present area, both chemically and optically determined Mg/Fe ratios were used to calculate K_D. The results are shown in Table 7.

With one exception, optical and chemical determinations of $Fe^{+2}/(Fe^{+2} + Mg)$ correspond to within 5 mol per cent, and two-thirds of them correspond to within 3 mol per cent. Accumulative errors of 3% in coexisting pyroxenes result in a K_D error of almost twice the range between Kretz's igneous and metamorphic groups. So optical methods do not give the accuracy necessary for K_D determination.

The K_D values of pyroxenes of the Mount Wright-Mount Reed iron formation are plotted in Figure 18, along with the K_D ranges of igneous and metamorphic rocks according to Kretz. Many of the chemically determined K_D values are higher than Kretz's metamorphic range, and three are higher than his igneous K_D values.

If K_D was temperature-controlled, all these values should fall within or under Kretz's metamorphic range. It must be concluded that, in these rocks at least, K_D depends on something other than temperature, and the pyroxene thermometer breaks down.

Neither is there a clear relationship between K_D and calcium content. K_D is plotted against the calcium solubility gap between pairs

Table * 7

Composition of Coexisting Pyroxenes and Amphiboles in Iron Formation

		OPTICAL				CHEMICAL						OPTICAL					
		clino		ortho		clinopyroxene			orthopyroxene			cummingtonite		actinolite		Pyroxene K_D	
Sample no.	code	Diop.	Hed.	En.	Fs.	CaO/Wo	MgO/En	Fe_2O_3/Fs.	CaO/Wo	MgO/En	Fe_2O_3/Fs	Kupp	Grun.	Trem.	Fe Act.	optical	chemical
J-19-46-59	1	55	45											58	42		
J-34-89-59	2													88	12		
J-38-122-59	3											45	55				
C-3-4-59	4	35	65			19.6/44.6	7.9/24.9	19.2/30.3				37	63				
C-3-5-59	5			22	78				1.5/3.4	6.8/21.3	47.4/75.3						
C-2-6-59	6			18	82												
C-7-23-59	7	27	73									28	72				
C-7-25-59	8	45	55									41	59				
J-34-92-59	9											17±2	83±2				
J-32-83-59	10											33±2	67±2				
C-37-159-59	11			23	77							25	75				
C-39-172-59	12											34	66	40	60		
C-1-1-60	13	36	64	32	68											0.839	
C-2-13-60	14	50	50	43	57	19.6/43.5	8.2/25.3	19.8/30.9	1.5/3.1	13.2/38.2	40.1/58.7	42	58			0.754	0.781
C-6-35-60	15	27	73	19	81	26.7/42.4	5.4/16.5	19.4/41.2	1.7/4.0	6.4/20.1	48.8/76.2	23	77			0.634	0.651
C-14-73-60	16			28	72												
C-19-111-60	17	58	42	28	72											0.282	
C-26-162-60	18	44	56	42	58	21.4/45.0	8.0/23.4	21.4/31.7	1.85/4.2	12.3/38.8	39.0/57.0	-				0.922	0.884
C-34-212-60	19	57	43	42	58											0.546	
C-39-251-60	20	35	65	21	79											0.494	
C-44-273-60	21	22	78	88	12											26.0	
C-44-277-60	22	55	45									49	51				
D-5-24-61	23	45	55	35	65											0.658	
D-18-66-61	24	30	70	26	74											0.820	
D-23-82-61	25	27	73	27	73	20.5/42.0	6.2/18.3	26.2/39.4	1.77/4.1	7.3/23.4	44.7/72.5	33	67			1.00	0.671
C-5-19-61	26	56	44	28	72											0.306	
C-8-30-61	27	34	66	30	70											0.832	
C-12-48-61	28	32	68	25	75	18.3/40.2	6.3/19.1	18.6/40.8	1.65/3.9	6.6/21.0	46.8/75.4	28	72			0.703	0.599
C-14-67-61	29	30±2	70±2	22	78							27	73			0.658	
C-16-77-61	30	45±2	55±2	28±2	72±2											0.475	
C-18-83-61	31	45	55	31	69							36	64			0.549	
C-3-17-60	32			65	35									56	44		
C-3-23-60	33	40	60	35	65											0.808	
C-11-61-60	34			35	65												
C-19-109-60	35	28	72	25	75											0.857	
C-19-112-60	36	50	50	37	63							37	63			0.587	
C-46-283-60	37			92	8												
C-46-287-60	38			20	80									35	65		
C- -299-60	39			22	78												
D-8-32-61	40			20	80												
C-9-33-61	41			25	75												

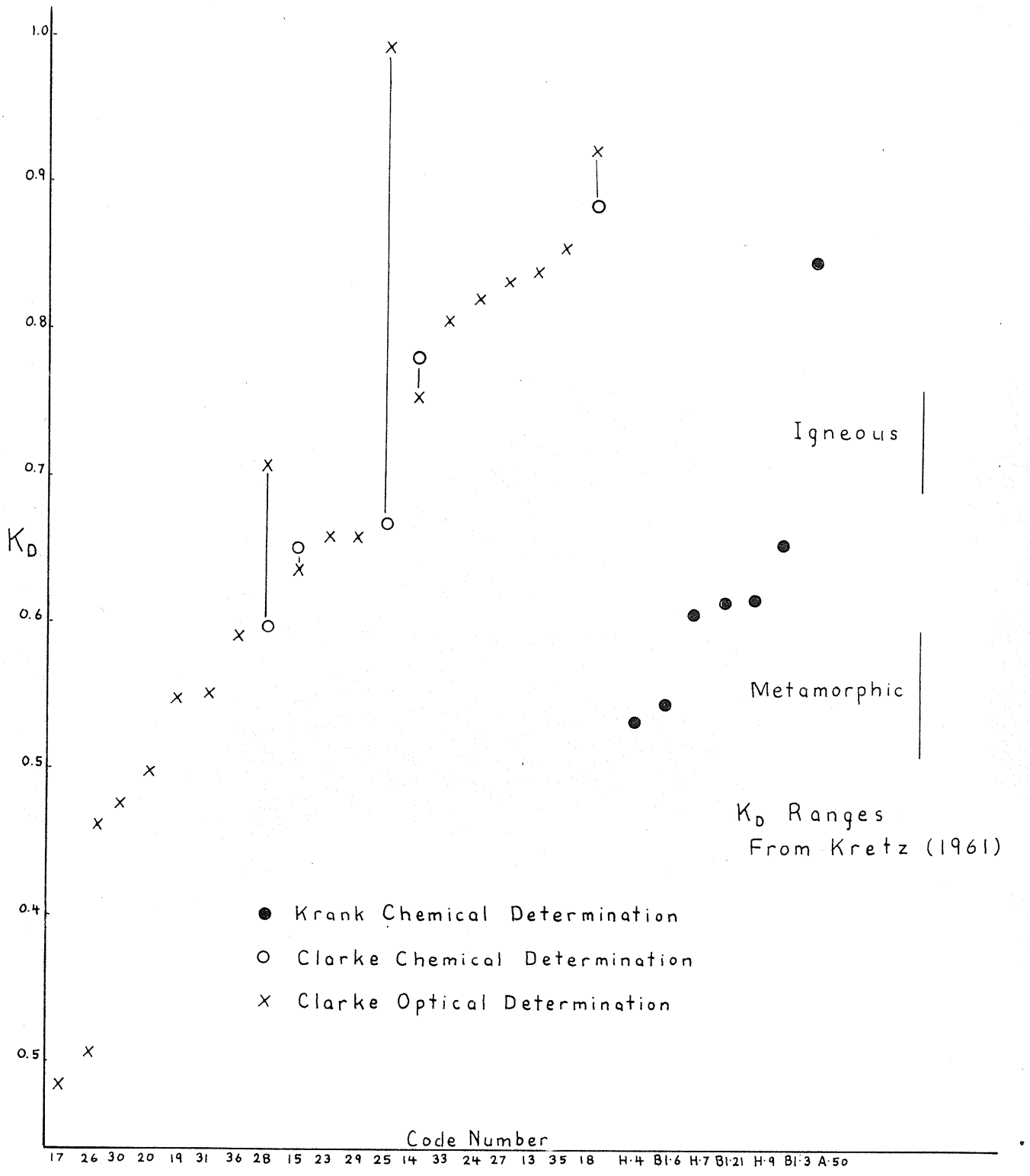


Figure 18

K_D VALUES OF PYROXENES FROM THE MOUNT WRIGHT-MOUNT REED IRON FORMATION

of coexisting pyroxenes in Figure 19. The figure includes pyroxenes from Krank's Mount Reed iron formation, and from the present area. A direct relationship between Ca-solubility gap and K_D becomes apparent, if only pyroxenes from the present area are considered. However, the author sees no reason to consider his pyroxenes separately from Krank's as both groups come from similar rocks in neighbouring areas.

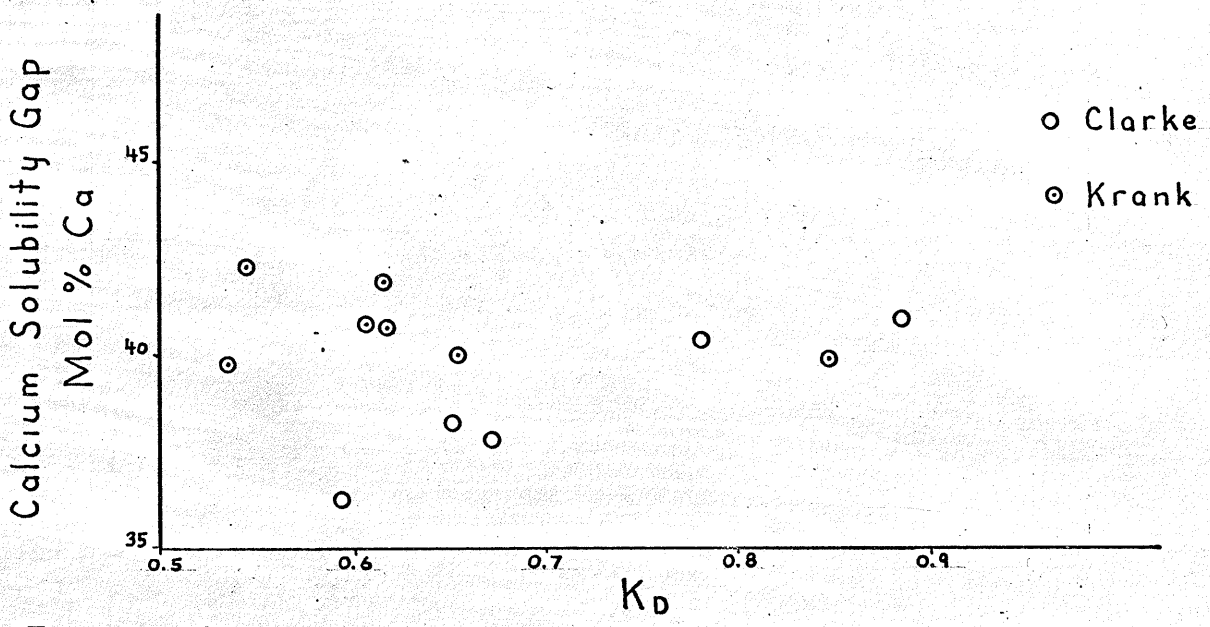


Figure 19

RELATIONSHIP BETWEEN CALCIUM SOLUBILITY GAPS AND K_D VALUES OF COEXISTING PYROXENES

Even if the relationship suggested by the Clarke pyroxenes is true, it cannot be explained by the ordering of iron and magnesium in the sites generally occupied by calcium, as the trend is in the opposite sense to that predicted by Ghose (1962). The solubility gap is known to decrease with increasing temperature (Binns, 1962). In the present relationship,

this suggests that high temperature pyroxenes have low K_D values, the reverse of what would be expected. The relationship between solubility gap and K_D shown by Clarke's pyroxenes is apparently fortuitous, and disappears when Krank's pyroxenes are considered. No simple explanation of the detailed behavior of Fe/Mg in coexisting pyroxenes is known to the author.

Carbonates

Carbonate compositions were determined by staining, refractive index and X-ray diffraction methods. Polished slices of marble were stained, and found to consist almost entirely of dolomite. Calcite content of the marble varies from a trace to about 2%, the calcite occurring as fine blebs interstitial to the dolomite, or in association with calcsilicate or phlogopite. The calcite in the latter association is secondary and apparently formed when the growing silicates removed more magnesium than calcium from the dolomite.

The type of carbonate that occurs in iron formation depends on the grade of metamorphism. Siderite (n_E = 1.635, n_O = 1.87) is stable near Jackson Lake, where the iron formation is only slightly metamorphosed. The carbonate in the more highly metamorphosed iron formation is ferrodolomite or dolomite (n_E = 1.50-1.55, n_O = 1.68-1.75).

Calcite coexisting with dolomite may be used to measure temperatures of crystallization. The carbonate geothermometer is based on experiment, and was used as early as 1958 by the Engels in their study of the Adirondack metamorphism.

The amount of magnesium accepted in the calcite structure is pro-

portional to its temperature of crystallization, Goldsmith and Heard (1961). Substitution of magnesium for calcium contracts the calcite cell hence can be determined by X-ray diffraction, Goldsmith and Graf (1958).

Table 8 shows the d spacings, and the corresponding $MgCO_3$ contents of the calcites studied. One of the samples contains $4\frac{1}{2}\%$ $MgCO_3$ indicating equilibrium at about 500°C. The others contain between 0% and 3% $MgCO_3$ which is less than the minimum amount shown on Goldsmith and Heard's diagram. These must have reached equilibrium at less than 500°C. These are minimum temperatures at which the exchange of magnesium ceased. Temperatures at the peak of metamorphism may have been higher.

TABLE 8

LATTICE SPACINGS, MAGNESIUM CONTENTS AND EQUILIBRIUM TEMPERATURES OF CALCITES FROM THE MARBLE

Sample No.	d(3,0,$\bar{3}$,12) Å	Mol% $MgCO_3$ in solution	Deduced Temperatures of equilibrium, C°
C-4-13-59	1.008	3%	< 500
C-1-6-60	1.008	3%	< 500
C-19-113-60	1.008	3%	< 500
C-19-115-60	1.013	0%	< 500
C-20-123-60	1.007	$4\frac{1}{2}\%$	≤ 500
L-29-113-60	1.0095	2%	< 500
C-2-7-61	1.009	3%	< 500
C-7-24-61	1.009	3%	< 500
C-8-27-61	1.011	1%	< 500
C-16-74-61	1.011	1%	< 500

The samples were plotted on a location map, but showed no regional trend in their magnesium content. Equilibrium temperatures in this area are thus apparently too low (below 500°C) to be compared by this method.

CHAPTER VIII

STRUCTURAL GEOLOGY

Introduction

The Labrador Trough trends S.S.E. from Ungava Bay to near Mount Wright where it was caught up in the Grenville orogeny. Within the Grenville Province the Labrador Trough rocks are complexly folded to make up the Normanville fold belt (Leech et al., 1963).

The area studied lies at the intersection of the Labrador Trough and the Grenville Front. It contains Labrador Trough sediments and Archean basement rocks on both sides of the Grenville Front. Southeast of the Front the Proterozoic rocks show two main structural trends, and the Archean rocks have these trends superimposed on pre-existing Archean structures. Northwest of the Front the Archean structures are relatively undisturbed, and the Proterozoic structures follow a single direction.

In a region affected by several deformations, the structural geology becomes extremely complex. Here, however, relatively thin and continuous beds of iron formation, marble and quartzite serve as marker horizons outlining the complex fold patterns. The combination of complex folding and good marker horizons make this an ideal area for the study of structural geology.

Structural Features

Folding and Minor Features

The main structural features of the Normanville, Gras Lake-Felix Lake and intervening Carheil-Le Gentilhomme (Murphy, 1961) areas are shown in Figure 20. Two main fold directions are apparent. In the northern

Figure 20

STRUCTURAL FEATURES IN THE AREA NEAR MOUNT WRIGHT

part of the area the most prominent folds trend northeast, and are intersected by slightly less prominent northwesterly folds. The northwest-trending folds dominate in the area between latitude 52°45'N and the southern belt of Archean granulite. South of the granulite the folds swing northeast again.

The interplay of the two fold systems developed two main fold types; simple folds, where one system is much better developed than the other, and cross folds, where the two systems approach the same degree of development. Simple folds give rise to the relatively straight, continuous bands of the Iron Formation Series that occur near the Pekans, Carheil and Le Gentilhomme rivers, near the southern border, and between Don's Pond and Seahorse Lake. These bands trend either north to northwest or east-northeast.

Where the two fold systems are developed to the same degree they form a series of domes and basins. The geometry of this type of structure is reviewed by Carey (1962) and O'Driscoll (1962). The structural geology of most of the Normanville Area, the northwestern part of the Gras Lake Area and the adjoining parts of the Peppler Lake Area (Phillips, 1959) is characterized by this type of folding. Within this cross-folded zone, isolated basins of the Iron Formation Series are arranged in a grid-like pattern between domes of lower gneiss (Figure 23, p. 152). In the Normanville Area the grid axes are oriented northeast-southwest and northwest-southeast, and have a four mile spacing. The grid axes in the Gras Lake-Peppler Lake Area trend north-south and east-west, with a five mile spacing. Recognition of the structural pattern governing the regular occurrence of iron-bearing structures is of direct economic importance,

and is covered in more detail in the chapter on economic geology.

The zone of cross-folding corresponds in position to the near shore sedimentary facies zone containing the oxide iron formation. The correspondence may be a coincidence, or perhaps the type of folding depends on the thickness or competence of the sedimentary pile, or its position relative to the developing geosyncline.

The local stress pattern is variable and is best understood by its relation to the stratigraphy. Areas underlain by Archean granulite and well segregated Proterozoic gneiss are shown in Figure 20. The poorly segregated gneisses and Iron Formation Series rocks are folded down between these masses of deep seated rock, and are generally overturned towards them. Thus the lower gneiss and granulite apparently occur in areas of domical uplift towards which the overlying rocks were forced.

The structural patterns are more uniform near the Grenville Front and east of the Moisie River. The folds along the Grenville Front are either upright or overturned towards the main Archean mass. The folds in the eastern part of the Felix Lake Area are uniformly overturned towards a zone of faulting followed by the Moisie River. Both the Grenville Front and the Moisie River Fault Zone mark major changes in lithology.

The relative ages of the two fold systems are uncertain, but it is thought that both the Hudsonian and Grenville orogenies are represented (Stockwell, p. 126, in Leech et al., 1963). The main portion of the Labrador Trough is elongated in a north to northwesterly direction, and was folded roughly parallel to its length by the Hudsonian Orogeny. The Grenville Province and Grenville structures trend generally northeastward (Gill, 1949). It might therefore be assumed that the northwest-trending

and northeast-trending folds of the present area were developed by the Hudsonian and Grenville orogenies, respectively. In such a case the northwesterly folding would predate the northeasterly folding by some 600 million years.

This assumption cannot be made because:

1) The Proterozoic sedimentary belt, of which the Labrador Trough is a part, swings southwestward from Wabush Lake towards Mistassini Lake (Figure 1, p. 2). Hudsonian folds formed parallel to this portion of the belt would trend southwest not northwest.

2) The Proterozoic sediments near Jackson Lake, in the Normanville Area, lie outside the area of strong Grenville metamorphism but are tightly folded about northeast-trending axes.

3) The northwesterly-trending folds become better developed as they pass deeper into the Grenville Province. They reach maximum development in a zone between 15 and 45 miles southeast of the Grenville Front. In this zone the northeast-trending folds are relatively unimportant.

4) Field relations and stereonet diagrams of structural elements of the area indicate that, where relative ages can be deduced, the northwest-trending folds are younger than the northeast-trending folds.

The same forces that formed the large scale structures, formed small folds of similar orientation. The geometry of these small folds can be measured directly and used as a clue to the shape of the larger folds. The nature of the small folds was partly controlled by rock type and metamorphic grade. The cummingtonite schist in the Normanville Area, for example, is commonly deformed by chevron folding, whereas, sigmoidal folds deform the nearby gneisses. Most of the small folds in the granulite are

isoclinal. Examples of these fold types are shown in Plate XV. Cross folds may be visible in a single outcrop. Cross folded outcrops of specularite iron formation, and well segregated gneiss are shown in Plate XVI. In both cases the pencil points along the axial plane of the secondary folds.

Weiss (1959) showed that where two directions of folds are superposed, folds of the second generation tend to be smaller and less persistent in trend than the first. In the Normanville Area the northeasterly trend is stronger, and has a greater period than the northwesterly. The same relationship is seen in small cross folds (Plate XVI-A). Moreover, the great majority of late chevron folds and associated shear planes trend northwest. It therefore appears, that the northeasterly folds predate the northwesterly folds in the Normanville Area.

In the Gras Lake and Felix Lake areas the southeast-trending folds are best developed, and recognizable shear folds are rare. In this part of the area conclusions regarding relative ages of deformation must come from other evidence.

Fabric diagrams

Lineation, foliation and axial planes of small folds of the three map areas were plotted on the lower hemisphere of a Schmidt net. The sampling of attitudes was controlled by traverse spacing and exposure; all attitudes lying more than a mile from a similar attitude in the same rock group are included in the diagrams. Because of the irregular sampling, the diagrams are not true statistical summaries but rather synopses of field data. It is hoped, however, that the map areas are large enough that local differences will balance out and the diagrams will reflect the

PLATE XV

A - Chevron folds in the cummingtonite schist near Greenwater Lake, Normanville Area.

-B-

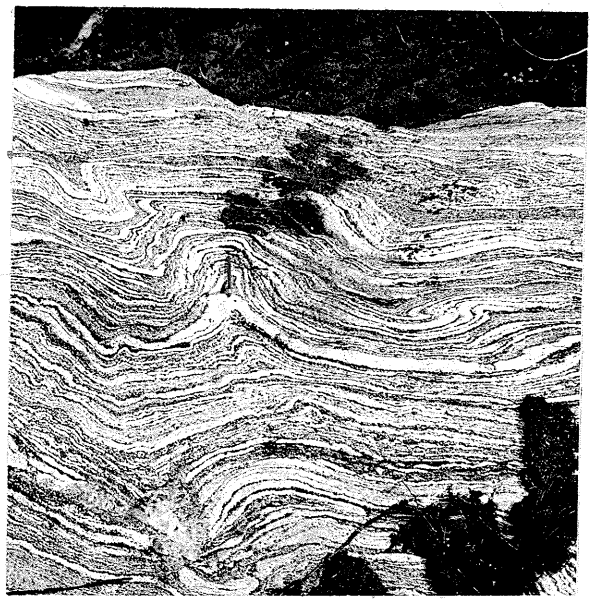
-C-

B - Sigmoidal folding of the well segregated gneiss near the Pekans River, Gras Lake Area.

C - Isoclinal folding in the Archean granulite, north of Boulder Lake, Normanville Area.

PLATE XVI

A - Small cross folds shown by quartz layer in specularite iron formation near Boulder Lake, Normanville Area. Main fold trends northeast, pencil points northwest, parallel the axes of the secondary folding.



B - Cross folds in well segregated gneiss, Gras Lake Area. Foliation trends southwest, parallel the main fold direction. Pencil points northeast, parallel the secondary fold axis.

true structural pattern.

Before considering the natural patterns, it is advisable to review the types of patterns developed by rotation of planes and lines under known conditions. Ideal stereonet patterns are shown in Figure 21. These diagrams are hypothetical examples constructed by the author and based on the work of Dahlstrom (1954), Weiss and McIntyre (1957), Weiss (1959) and Ramsay (1960).

Two types of cross folds are considered; flexure and shear folds. In flexure folding the main foliation planes are competent, and any slip acts parallel to them. Shear folds are formed by slip on planes at some angle to the primary foliation.

The structural elements of simple folds are shown in the first column of Figure 21. Lineation parallel to the axis of simple folds falls at a point maximum (diag. 1) and the poles to foliation lie along the great circle perpendicular to the fold axis (diags. 6, 11). Foliations in the limbs of the fold form two maxima, while the axial regions complete the girdle. The axial plane falls on the great circle containing the fold axis (or lineation) and the mid-point of the crestal scatter.

Where existing folds are refolded, the pattern developed depends on the nature of the second folding, and on the angle of intersection of the two axes. If the second folds are shear folds, the early lineation L_1 appears to rotate along the great circle containing the lineation and the direction of tectonic transport "a" (Ramsay, 1960, p. 80). In diagram 2 of Figure 21 the lineation has migrated 45° from L_1 to positions L_1'. Angular migration is greatest where the angle between the lineation and the direction of transport is large, and becomes smaller as the two

Lineation

Poles to Foliation

Poles to Foliation

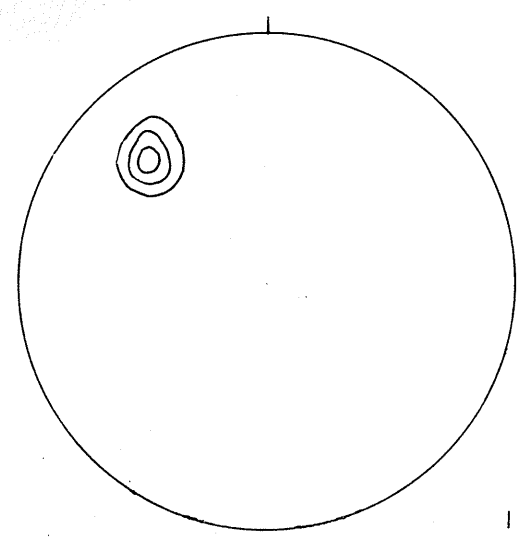
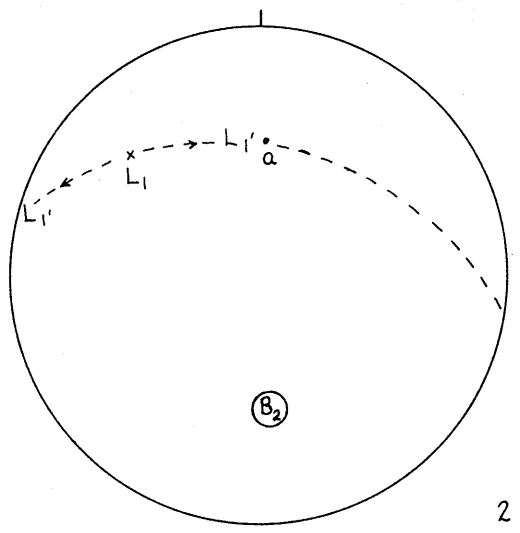
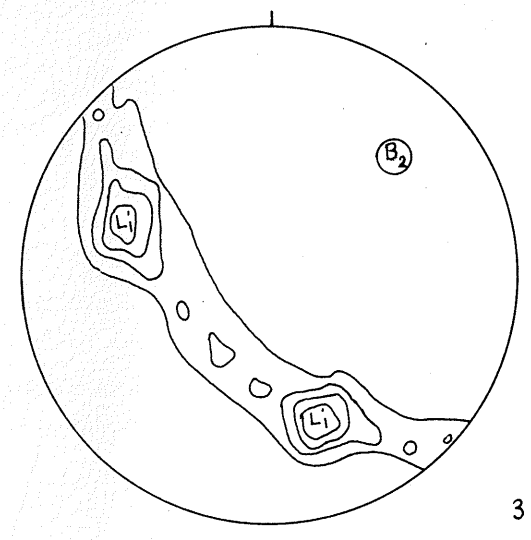
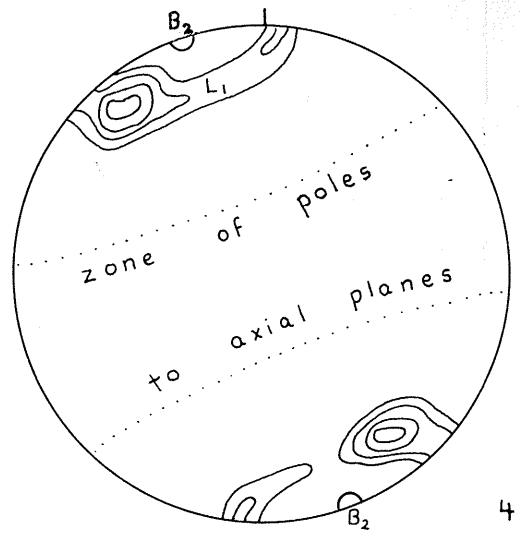
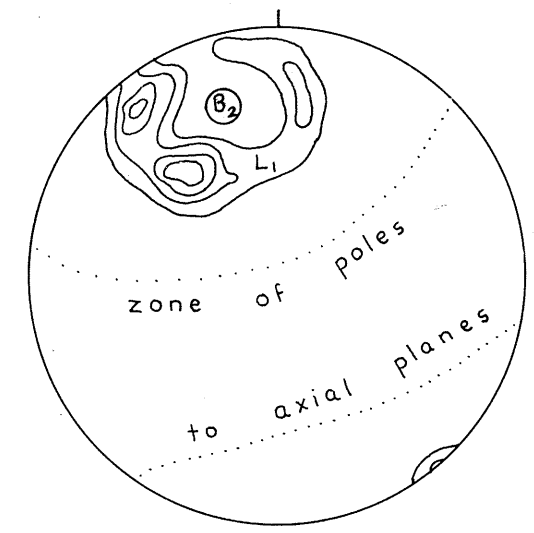
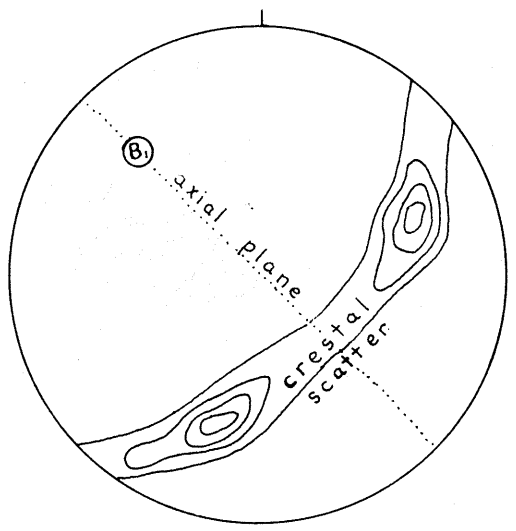
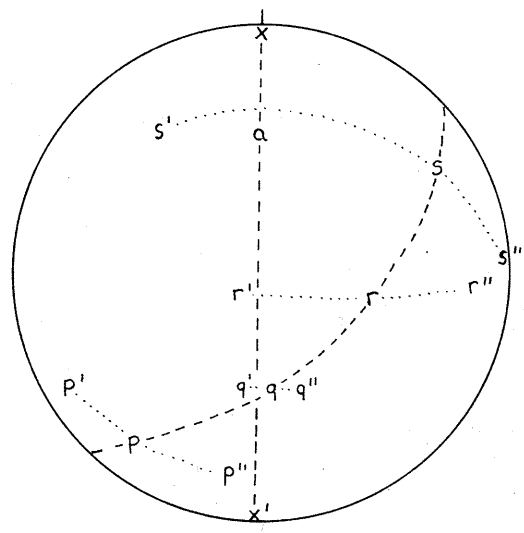
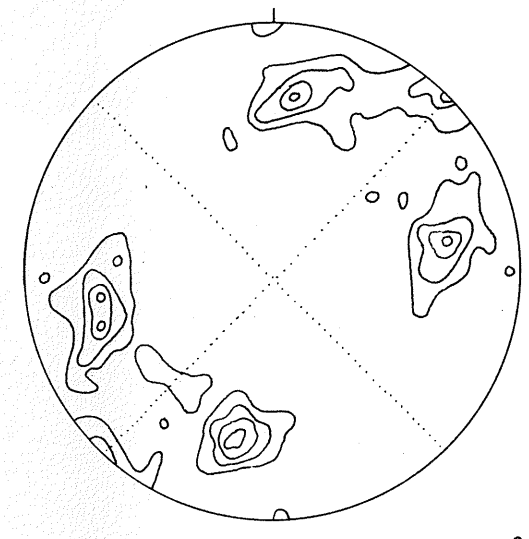
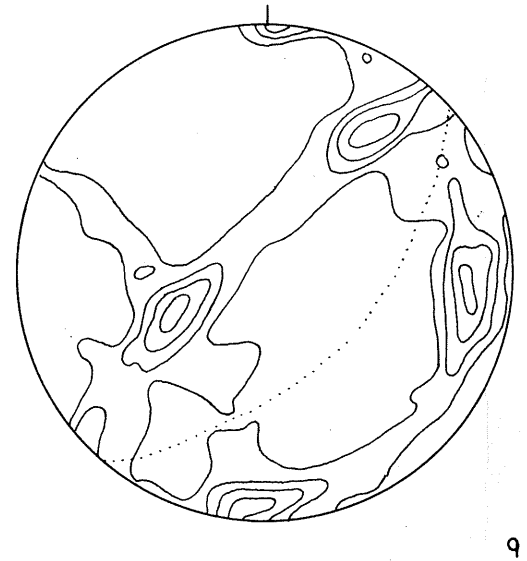
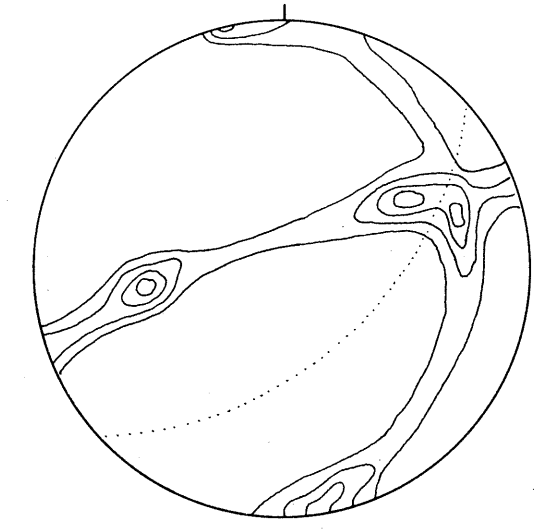
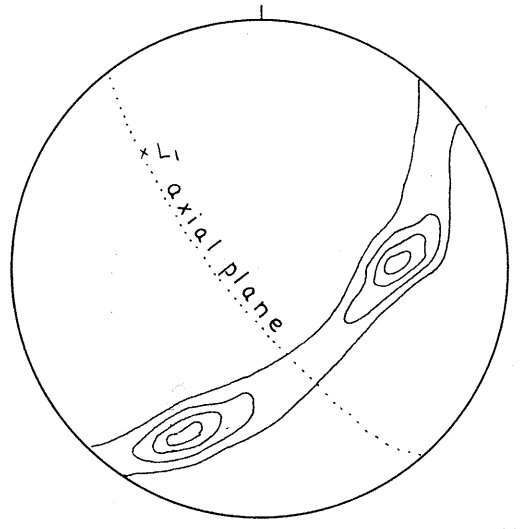
Simple Folds	Crossfolds, Shear	Crossfolds, Flexure (perp)	Crossfolds, Flexure (oblique)	Crossfolds, Flexure (oblique)
 1	 2	 3	 4	 5
 6	 7	 8	 9	 10
 11				

Figure 21

STEREONET PLOTS OF STRUCTURAL ELEMENTS OF SUPERPOSED FOLDS

1. Lineation plunging 30° to N45°W. Contours 5, 15, 35 percent.
2. L_1 N45°W 30° Refolded by shear on vertical N-S plane. Direction of transport 'a' plunges 45° N.
3. L_1 N45°W 0° Rotated about B_2, plunging 30° to N45°E. Contours 1, 3, 6, 10 percent.
4. L_1 N45°W 0° Rotated about horizontal B_2 trending N20°W, Contours 2, 3, 5, 10 percent.
5. L_1 N45°W 0° Rotated about B_2 plunging 30° to N20°W. Contours 2, 3, 5, 10 percent.
6. Pole girdle of fold plunging 30° to N45°W. Axial plane vertical, Contours 3, 5, 10, 20 percent.
7. Pole girdle of fold plunging 30° to N45°W, refolded by shear on vertical N-S plane. Direction of transport 'a' plunges 45°N.
8. Pole girdle of fold N45°W 0° rotated about N45°E 0°. Contours 2, 3, 4, 5 percent.
9. Pole girdle of fold N45°W 30° rotated about N60°E 0°. Contours 1, 2, 3, 4 percent.
10. Pole girdle of fold N45°W 30° rotated about N60°E 30°. Contours 2, 3, 8, 10 percent.
11. Pole girdle of fold plunging 30° to N45°W., axial plane dips 70° SW. Contours 3, 5, 10, 20, percent.

directions converge. With a great deal of slip L_1' becomes parallel to "a" and rotation ceases.

Where the second folding is by flexure the early lineations are rotated in a cone about the axis of the second folding (B_2), so fall on a small circle with B_2 at its centre (diags. 4 and 5, Figure 21)(Ramsay, 1960, p. 77). If the angle between the two fold axes is large, the cone is open; where the axes are perpendicular the cone becomes a plane and L_1 falls along a great circle (diag. 3). The second lineation, L_2, would be scattered because it forms on already folded beds, Weiss and McIntyre (1957, p. 586).

Although cross folded lineations have been studied by several authors, foliations have received little notice. They behave much the same as lineations but form more complicated patterns because they do not follow a single direction in the fold.

If the second deformation is by shear-folding (diag. 7) the foliations undergo apparent rotation towards a position in which they will contain the direction of tectonic transport "a". The poles of foliation (p,q,r,s) forming the pole circle of the original fold, are rotated to new positions, p'...s' and p"...s". Their paths of rotation follow great circles, the axes of which are the intersections of the slip direction (x-x') and each of the foliation planes.

The rotation is great where the angle between the foliation and direction of transport is large, and decreases asymetrically to zero as the two directions become parallel. The paths of rotation converge at the pole to the slip surface, and a strong pole concentration forms near this point if the second deformation is strong enough. If the second deforma-

tion is not much stronger than the first, its effect is to split the original pole girdle into two parts. The pole girdle is split symetrically where the second fold system forms at right angles to the first, but asymetrically (diag. 7) where it does not.

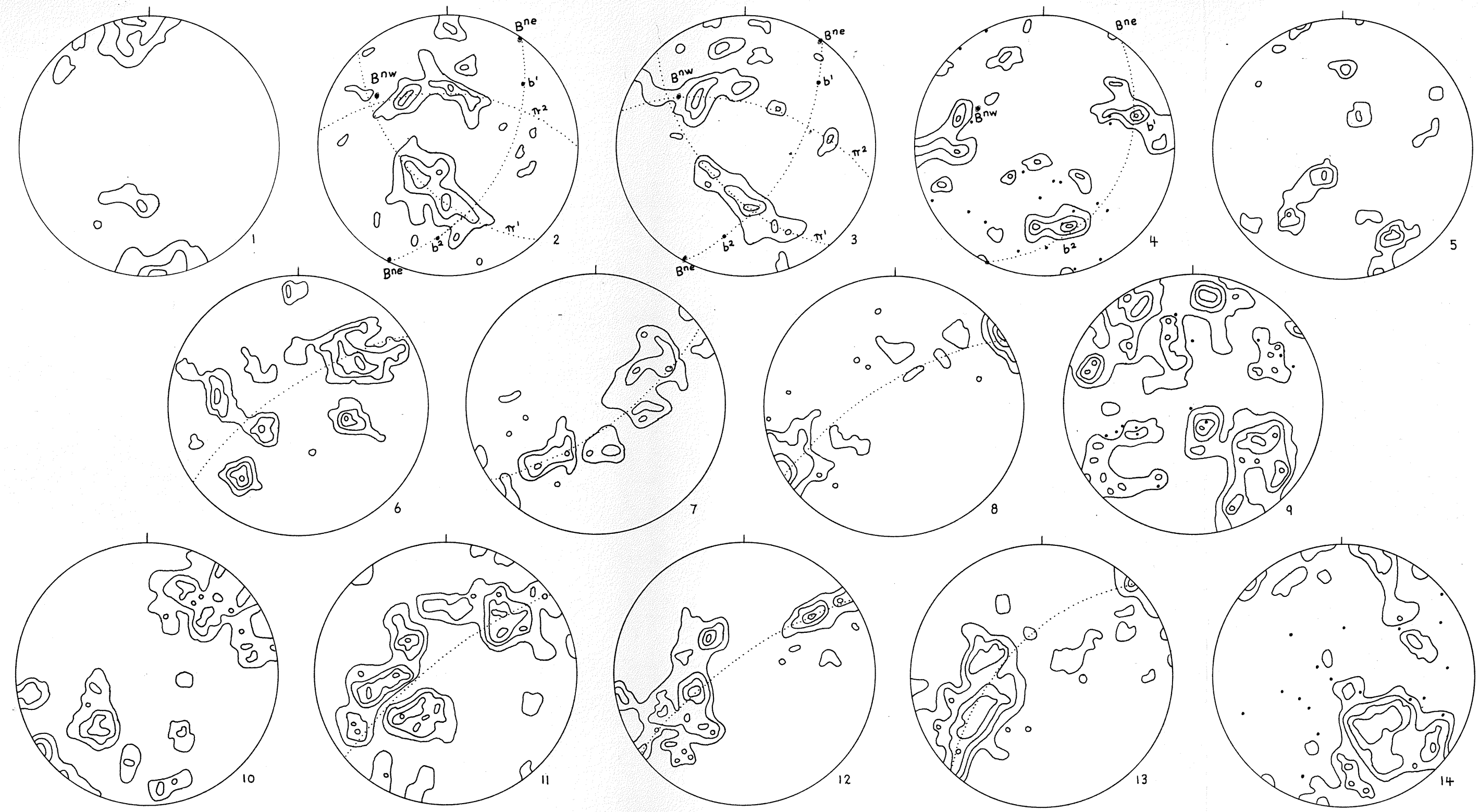
Where the second folds form by flexure (diags. 8,9,10) poles to foliation are rotated on small circle paths about the second fold axis. If the second folds have well developed limbs they split the primary girdle into two halves, about a symmetry plane which marks the location of the original girdle. Thus, the main difference between patterns formed by second generation flexure or shear folds is that the flexure folds split the original girdle symetrically, whereas, the shear folds generally do not. If the axes of the first and second folds are perpendicular (diag. 8) some poles in the primary girdle are likely to lie parallel to the second fold axis. These poles are not dispersed by the second folding so form a maximum at its axis. The crestal scatter of the second folding may form a weak girdle along the small circle followed by the second rotation (diag. 9). This type of girdle is emphasized where the first folding has stronger limb concentrations than the second folding.

Stereoplots of foliation and lineation in the Archean and Proterozoic rocks of the Normanville, Gras Lake, and Felix Lake areas are shown in Figure 22.

The foliations include mineral layering, platy mineral orientation, and the main parting plane in monomineralic marble and quartzite. These surfaces are parallel to rock unit contacts, and are believed to follow original bedding planes. Many of the rocks in the Normanville Area are cut by a cleavage, which in some rocks has served as a surface of slip

Figure 22

STEREONET PLOTS OF STRUCTURAL ELEMENTS IN THE NORMANVILLE, GRAS LAKE AND FELIX LAKE AREAS.



1. Poles to foliation, Archean granulite, Normanville Area, 143 poles, contours 2.5%, 5%, 7.5%.
2. Poles to foliation, Proterozoic metasediments, Normanville Area, 460 poles, contours 1.5%, 2%, 2.5%
3. Poles to bedding, Iron formation series, Normanville Area, 191 poles contours 1.5%, 2.5%, 3.5%.
4. Lineations, +20 poles to axial planes (dots), Proterozoic metasediments, Normanville Area, 91 lineations contours 2%, 3%, 4.5%.
5. Poles to foliation, Archean granulite, Gras Lake Area, 59 poles, contours 3%, 5%, 7%
6. Poles to foliation, Gneiss near granulite, Gras Lake Area, 73 poles, contours 2%, 3%, 5%, 7%.
7. Poles to foliation, Well segregated gneiss, Gras Lake Area, 355 poles, contours 2%, 3%, 4%.
8. Poles to foliation, Iron formation series and upper gneiss, Gras Lake, 343 poles, contours 2%, 3%, 5%, 7%.
9. Lineations and 13 poles to axial planes (dots), Gras Lake Area, 92 lineations, contours 1%, 2%, 3%, 4%.
10. Poles to foliation, Archean granulite, Felix Lake Area, 47 poles, contours 2%, 4%, 5%.
11. Poles to foliation, Gneiss near granulite, Felix Lake Area, 60 poles, contours 2%, 3%, 5%, 7%.
12. Poles to foliation, Iron formation series + associated gneiss, Felix Lake, 197 poles, contours 2%, 3%, 4%, 5%.
13. Poles to foliation, Gneiss and gabbro east of Moisie R., Felix Lake, 180 poles, contours 2%, 3%, 4%, 5%.
14. Lineations and 18 poles to axial planes (dots), Felix Lake Area, 64 lineations, contours 1%, 3%, 5%, 8%.

to produce shear folds. This cleavage is not included as foliation, but is plotted as the axial planes of small folds where appropriate.

Lineations take the form of mineral orientation, fluting crenulations, drag fold axes and the intersections of cleavage with bedding foliations. The most common types are drag folds and crenulations. All these lineations lie parallel to the regional fold axes. All types occur in the Normanville Area, but in the Gras Lake-Felix Lake Area, where the metamorphic grade is higher, fluting, cleavage and crenulations, were not encountered.

Poles to foliation of the Archean granulite in the Normanville, Gras Lake and Felix Lake areas are shown in Figure 22, diagrams 1, 5 and 10. North of the Grenville Front (diag. 1) the granulite is isoclinally folded about axes trending N 80°E; axial planes of these folds are vertical. This pattern may be only local; Duffel and Roach (1959) record mainly gentle dips in the larger area to the west.

The granulite in the Felix Lake Area (diag. 10) strikes generally southeast, and dips northeast or southwest. The main pole maxima are about southeast-trending folds but are scattered by subsidiary northeasterly folding. The axes of both fold systems are horizontal. The pole girdles follow small circles about the subsidiary (probably later) northeast fold axes, in a pattern very similar to diagram 8, Figure 21. The poles to foliation of the Gras Lake granulite, plotted in diagram 5 of Figure 22, suggest a similar pattern to those of the Felix Lake Area. The pole girdles of both diagrams 5 and 10 are scattered, and neither pattern is very well developed.

Poles to foliation of the Proterozoic rocks in the Normanville Area (diagrams 2 and 3) lie along two incomplete girdles (π' and π^2), the

poles of which (b^1 and b^2) plunge northeast and southwest, respectively. Points b^1 and b^2 lie on a great circle with its pole at B^{nw}. The poles b^1, b^2 are the axial directions of the northeast-trending folds, and B^{nw} is the axial direction of the northwest-trending folds. They correspond to axial directions mapped in the field, and to the lineation concentrations shown in diagram 4. The structural pattern of this area probably developed when an early fold system with horizontal northeast-trending axes (B^{ne}) was refolded, about axes plunging 30° to the northwest (B^{nw}).

Ramsay (1960) shows that where a fold system is refolded by a younger system, the old lineations are bent to follow either great, or small circle paths around the younger fold axis. Whether great or small circles are followed depends on whether the second folding is by shear or flexure. The different possibilities are illustrated in Figure 21, diagrams 2 to 5.

In the Normanville Area horizontal northeast-trending lineations have undergone apparent rotation about axes plunging 30° northwest, and lie in the great circle perpendicular to the northwesterly axes. This pattern may have formed by either shear or flexure folding. It seems likely that the northwest folding contains a large component of shear because the poles to foliation are not symetrical about B^{nw}, and many of the small northwest-trending folds in the field are shear folds. Small scale cross folds (Plate XVI-A, p. 135) also indicate that the northwest folding is younger than the northeast and took place by shear.

Poles to foliation of Proterozoic rocks of the Gras Lake and Felix Lake areas are shown in diagrams 7 and 8, and 12 and 13. The main trend in these areas is southeast and subsidiary trends are weak. The

Lower Gneiss in the Gras Lake Area occurs mainly in broad northwest-trending anticlines in the northwestern part of the area. The Iron Formation Series and upper gneisses generally occur in tight synclines. In the Felix Lake Area the majority of the structures are overturned to the southwest, and plunge southeast.

Cross folds are not obvious in diagrams 7, 8, 12 and 13, but may cause some spread in the pole girdles. The Felix Lake diagrams contain long irregular maxima suggesting two axes plunging to the southeast, and east-southeast, respectively. Cross folding would not be apparent in an area where two fold trends are almost parallel.

Lineations in the Gras Lake Area are plotted in diagram 9 and those in the Felix Lake Area are plotted in diagram 14. In the Felix Lake Area most of the lineations are concentrated in a small circle about a southeast-trending axis. This type of pattern could be developed by the rotation of south- or east-southeast-trending lineations about younger axes plunging to the southeast (diagram 5, Figure 21). The same pattern occurs in the Gras Lake Area, but is complicated by more northeast, and northwest-trending lineations.

The foliation of the gneiss, occurring within a mile of the Archean granulite, was plotted in separate diagrams, 6 and 11. These diagrams were plotted to investigate whether the gneiss near the granulite contained any unmistakably Archean structures. The diagrams contain girdles about southeast-plunging axes, much like the ones in known Proterozoic rocks, but split more strongly about the northeast axes. There is nothing to identify this structure as Archean, so the diagrams do not tell anything of the origin of the lower gneisses.

History of folding

The stereodiagrams record the attitudes of structural elements in the area. They can also be used to determine the average directions and relative ages of the local deformations. Interpretation of the diagrams suggests the following sequence of events:

1) Archean Deformation; In the Normanville Area isoclinal folds with vertical axial planes were developed about axes trending N 80°E. In the Gras Lake and Felix Lake areas the folds are more open, their axes are horizontal and trend S 40°E.

2) Proterozoic Deformations; Normanville Area.

The Proterozoic rocks in the Normanville Area were folded about horizontal axes trending N 35°E. This deformation runs parallel to the Grenville Front and the western border of the Labrador Trough.

A second deformation refolded the rocks about axes plunging 30° to N 55°W. The cross folds so formed show on both the geological map and the stereodiagrams of the area. The second folds are probably shear folds. Neither of the Proterozoic deformations affected the Archean granulite in the northern part of the area.

3) Proterozoic Deformations; Gras Lake and Felix Lake areas.

The Archean granulite of the southern areas was refolded about horizontal axes trending N 45°E. Northeast trending folds also occur in the southern parts of both areas, and contribute to the dome and basin structures in the western part of the Gras Lake Area. They show in the lineation diagram of the Gras Lake Area. Apart from these occurrences, northeasterly trends are rare in the southern areas.

Rocks in the southern areas contain two, slightly different south-

easterly trends. The earlier trend plunges 20° to S 70°E, and occurs mainly in the Felix Lake Area. These folds were refolded about axes trending S 30°E, during the strongest, and final deformation of the region.

The same main northeast- and southeast-trending deformations probably acted on both the Normanville and Gras Lake-Felix Lake areas. The northeasterly deformation was predominent in the north and the southeasterly deformation was predominent in the south.

The early east-southeasterly folding of the Felix Lake Area may have been caused by a local change in the stresses that caused the mainly northeasterly deformation. This is considered unlikely because northeasterly folds have deformed the Felix Lake granulite. Three Proterozoic deformations probably affected this area; the first, developing the northeasterly trends, is only preserved in the granulite, and in the southern and western parts of the area. The southeasterly trends are well developed in the Proterozoic rocks, but do not show in the granulite, which apparently acted as a resistant block during the later deformations.

Faults

Field evidence of faulting includes breccias in competent quartzite and iron formation, mylonite in the gneiss west of Hope Lake, displacement of formations and the more common slickensides and shear zones.

The most obvious and probably the most important faults of the area are steeply dipping thrusts, striking parallel to the south-southeast trending folds. These faults show as linear features on air photos and were observed on the ground. They are commonly developed near the competent rocks of the Iron Formation Series, and where movement is great enough

bring the lower rocks into contact with them. The main movement, indicated by slickensides and drag folds, near these faults is east side up and to the south, relative to the west side. The faults striking south from Don's Pond and north from Lac Bergeron, and those along the Pekans and Moisie rivers belong to this group. The north-northwest trending faults near Lac Moiré, and the cross faults in the Mount Wright syncline have the same movement and belong to the same group.

The main rivers of the area apparently follow south-southeasterly fault zones. Several shear zones are exposed along both the Pekans and Moisie rivers in the Gras Lake and Felix Lake areas. At two locations in the Gras Lake Area the Pekans River separates Iron Formation Series rocks and upper gneiss on the west side of the river from apparently lower gneiss and granulite which lies to the east. The Moisie River coincides with an abrupt change in rock type. Poorly segregated gneisses and Iron Formation Series rocks occur on its western side, whereas, migmatized gneiss and basic intrusions occur on the east. A belt of drag folding and feldspathization occurs east of the river, and ultrabasic sills have been injected in a zone along the river. Movement directions on small faults and drag folds near the river are ambiguous, however, the main movement here is interpreted as east side up.

Several small southwest trending faults cut the gneisses south of the Archean-Proterozoic contact in the Normanville Area, and in the Gras Lake Area where the regional structures swing southwest. Most of these are small thrusts with slickensides showing movement of the south side over the north. These movements must be small as the rocks to the south are younger than those to the north.

Archean-Proterozoic Contact and the Grenville Front

The contact between the Archean and Proterozoic rocks crosses the Normanville Area in a northeasterly direction (Figure 1, p. 2; Figure 2, p. 8). Duffel and Roach (1959) show the contact continuing southwestward in the same direction that it crosses the area, and Gill et al. (1937) show it passing about 5 miles north of Wabush Lake to the northeast. West of Boulder Lake the Archean rocks strike southeast until they are cut off by the Proterozoic gneiss. At this location the gneiss strikes northeast parallel to the contact, and dips away from it. About a mile and a half southeast of the contact the Proterozoic gneiss is cut by northeasterly shears. Drag folds near the contact show that the Proterozoic rocks moved up and towards the north.

Very weakly metamorphosed iron formation and albite-epidote schist and grit overlie the granulite facies rocks in the northern part of the Normanville Area. Near Jackson Lake fragments of the granulite are common in the basal grit. Thus, although the contact itself was not observed, it is thought to be essentially an unconformity, perhaps modified by deformation of the Proterozoic rocks against the Archean basement.

The grade of Grenville metamorphism increases gradually from northwest to southeast. Iron formation composed of quartz and siderite near Jackson Lake changes to cummingtonite schist near Greenwater Lake, and to banded quartz and hypersthene near Kissing Lake; albite-epidote-chlorite schist grades into oligoclase-biotite gneiss in the same area. The Grenville Front in the Normanville Area appears to be a metamorphic gradient, rather than a fault zone as it is at Mistassini (Quirk et al.

1960; Neilson, 1963; or near Lake Temagami Johnston, 1954).

A gravity survey by Innes (1957) revealed a strong gravity anomaly lying south of the Grenville Front between Mount Wright and Lake Albanel. Innes suggested that the anomaly was caused by a body of light granitic rock injected into the roots of the Grenville mountains. The magnitude of the anomaly is too great to be explained by rock densities at the surface. Its cause is probably a deep-seated geological change related to the Grenville Front.

A similar long, negative gravity anomaly underlies the western edge of the Superior block (Wilson and Brisbin, 1960), suggesting a genetic association of gravity lows and the boundaries of Structural Provinces.

CHAPTER IX

ECONOMIC GEOLOGY

Iron Deposits

In the early 1950's increased demand for iron ore, and the use of beneficiating techniques made the mining of remote and formerly sub-grade iron deposits profitable. Several very large low grade iron deposits occur in the metamorphosed extension of the Labrador Trough. Mining activity in this region has so far resulted in the Lac Jeannine, Carol Lake and Wabush Lake projects, and in outlining many other deposits. Shipments of ore concentrates from Lac Jeannine and from Carol Lake began in 1961 and 1963, respectively. The deposits within the area covered by this thesis are as large as these others but are farther from transport facilities, and will probably not be developed until the more accessable deposits are exhausted.

The iron deposits of the region were first staked by the United Dominion Mining Company. The company explored much of the area between 1947 and 1949, but decided that it was not practical to develop its property and allowed the claims to lapse (LeBordais, 1957). In 1952 the United States Steel Company began the massive exploration program that acquired the ground now being developed by its subsidiary the Quebec Cartier Mining Company. The exploration rush continued through 1957, by which time most of the promising iron occurrences were discovered. Recent activity has consisted of detailed geological and geophysical mapping, diamond drilling and mill tests aimed at evaluating known deposits.

The quartz oxide type has the best economic possibilities of the several types of iron formation. Its iron content generally averages 25% to 35% over thicknesses of from 10 to 300 feet. In some places mining widths are increased by structural thickening or repetition of iron-bearing beds. The quartz specularite iron formation is commonly coarse grained and friable, permitting easy crushing for concentration. The quartz magnetite type does not occur in as large deposits as the quartz specularite. It is more massive, finer grained and may not crush as easily. Both types of the oxide facies contain little phosphorus, sulfur or titanium. A high grade product can generally be obtained by concentrating minus 20 to minus 100 mesh material by a factor of about 2.7.

The more important deposits in the present area are held by Quebec Cartier Mining Company, Normanville Mining Company, Bellechasse Mining Corporation Ltd. and Mount Wright Iron Mines Company Ltd. All these companies hold deposits containing more than 100 million tons of ore grading 30% iron and the first two hold as much as ten times this amount. Deposits with less than 100 million proven tons are held by Holannah Mines Ltd. and Consolidated Fenimore Iron Mines Ltd. (Janes, 1957; Janes and Elver, 1958, 1959).

Most of the large deposits stand as hills above the surrounding gneiss. All these large, well exposed bodies have now been discovered, but smaller buried deposits may still be unclaimed. The Mount Wright Iron Mines property is an example of an overlooked deposit. It was staked alongside Quebec Cartier's largest deposit in 1956, two years after that deposit had been mapped and drilled. It was drilled in 1959 and found to contain some 147 million tons of ore grading about 30% iron (Koulomzine and Jaeggin, 1961).

In future search for iron deposits, areas of upper gneiss, and those areas containing erratic boulders of iron formation should be re-examined. Ore grade erratics are shown in those parts of Figure 23, that were mapped by the author. Prospecting should be concentrated in the zone containing the oxide facies of iron formation as the iron formation outside this zone is not likely to be economic at present.

In some parts of the area, cross folding has produced a regular system of domes and basins. Iron formation commonly occurs in the basins formed at the intersections of synclinal axes. The pattern of domes and basins, that controls the location of iron formation in areas mapped by Phillips, Murphy and Clarke, is shown in Figure 23. A detailed study of the outcrop patterns developed by cross folding of this sort was made by O'Driscoll (1962).

Figure 23 is necessarily interpretative. The basins may be more linear than circular, and are not all the same size. Some iron deposits do not occur at grid intersections. Outcrop patterns depend on the level of erosion and this may be deep enough to remove all the iron formation from a shallow deposit, or so shallow that the iron formation is exposed on the fold's limbs at some distance from the axis. The pattern may also be modified by faulting, as it is in the Don's Pond-Seahorse Lake deposit. Despite these disturbing factors, there is a strong regularity in the occurrence of iron formation, that could help in the search for new deposits.

Fitting axes to the basins presents some problems. In some places more than one set of axes will define the points in question. The axes were drawn to correspond as closely as possible to fold axes mapped in the field.

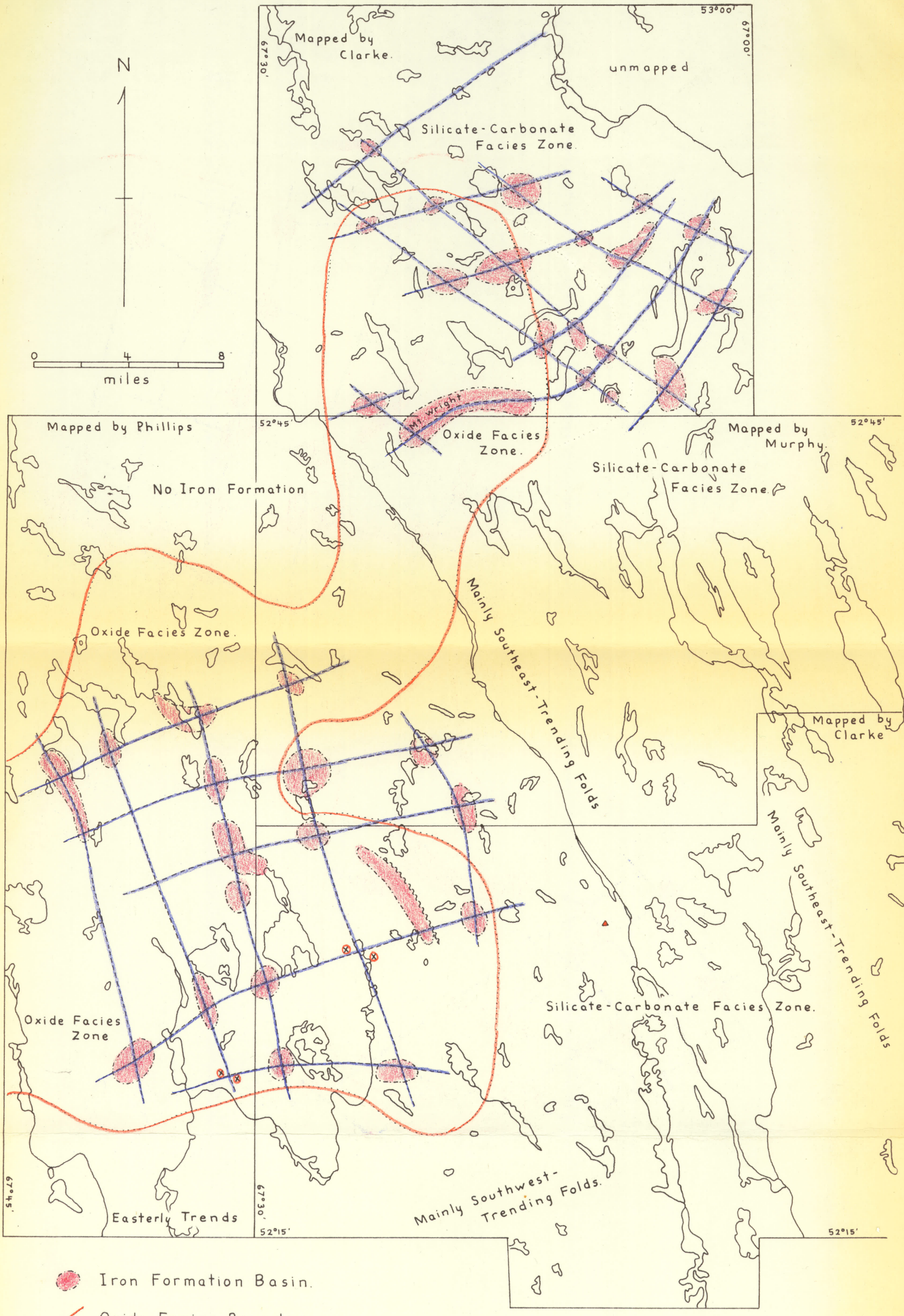


Figure 23

STRUCTURAL CONTROL OF IRON DEPOSITS IN CROSSFOLDED AREAS NEAR MOUNT WRIGHT

Two axis intersections in drift-covered areas are marked in the figure. These places may be underlain by iron formation, and are certainly worth further study.

Sulfide Deposits

Although the area is of primary interest for its iron ore, it also contains sulfide deposits associated with the gabbroic intrusions. The two most important occurrences are near Bloom Lake in the Normanville Area and near Pegma Lake in the Felix Lake Area.

Bloom Lake Deposit

The Bloom Lake deposit is held by the Quebec Cobalt Exploration Company. It consists of pods of massive white arsenopyrite, in and generally conformable with altered quartz - cummingtonite - magnetite iron formation. The iron formation appears to be a roof pendant in a gabbro sill. The best mineral showings have been removed by trenching, but judging from large blocks lying nearby, the pods ranged from several inches across to two feet long and one foot wide. The sulfide is mainly massive white arsenopyrite, with minor amounts of cobaltite, pyrite, and native bismuth reported by company geologists. Several of the pieces show cobalt bloom. The main metal contents of samples taken from the mineralized zones are shown in Table 9.

TABLE 9

METAL CONTENT OF BLOOM LAKE SULFIDE SAMPLES

Sample	Co%	Bi%	Ni%	Cu%	Au oz/ton	Ag oz/ton
1	6.0	0.16	0.43	nil	0.000	0.000
2	6.5	0.33	0.23	nil	0.000	0.000
6	0.28	0.12	0.04	0.01	0.02	0.01
7	0.01	nd.	0.01	nd.	nil	0.01
8	0.01	nd.	tr.	nd.	nil	tr.
9	nil	nil	tr.	nil	nil	tr.

Samples 1 and 2 are grab samples of sulfide material taken by the author.

Sample 6 is vein material containing a streak of sulfide mineral.

Sample 7 is a chip sample over 30 inches of trench wall with no sulfide seen in place.

Sample 8 is a chip sample over 18 feet of trench.

Sample 9 is a chip sample over 30 feet of rusty grunerite schist at the north end of trench.

Samples 6 to 9 were taken in 1951 by Dr. B.T. Denis of the Quebec Department of Mines.

Coarse grained pink to buff carbonate, and coarse grained dark green amphibole and pyroxene accompany the sulfide minerals. Close to the deposit the iron formation becomes very coarse grained and rusty weathering. In places it contains ellipsoidal porphyroblasts of magnetite, up to 1/4 inch in size, in a matrix of coarse quartz and cummingtonite.

Pegma Lake Deposit

The Pegma Lake deposit was mapped and drilled by Bellechasse

Mining Corporation and the results of this work are reported by Gleeson (1956). The largest of the showings ("c" on the accompanying map) is a zone 400 feet long and 30 to 50 feet wide in which sulfides are disseminated through peridotite at the base of a gabbro sill. Gleeson reports 1% to 1.5% combined copper and nickel, 0.3% cobalt, and traces to 0.1 oz/ton silver in this deposit.

The marble directly west of Pegma Lake contains a quartz vein, with pods of sulfide minerals (deposit "b"). Gleeson describes the vein as up to 12 feet wide, and the pods as containing 10% to 20% sphalerite, 2% to 5% pyrrhotite, and minor marcasite, magnetite, and chalcopyrite.

Minor Sulfide Deposits

Smaller sulfide showings were found in shear zones throughout the area. The location of these deposits is shown on the accompanying maps. Assays were made by the Quebec Department of Natural Resources of grab samples from some of the showings. In the Gras Lake Area and on showings ("d" and "e") in the Felix Lake Area analyses indicate only traces of copper and nickel, and negligable gold and silver. These deposits, though not economic, demonstrate the presence of sulfide mineralization associated with the gabbros and shear zones of the area.

Non Metalic Minerals

Graphite and kyanite are present in the schist overlying the silicate-carbonate iron formation. Generally they make up less than 5% of the rock, but in places they are more abundant. The mica schist directly south of the Gentilhomme Lake outlet contains about 25% kyanite over a

100-foot width. Many large blocks of a peculiar rock containing 20% kyanite and 15% pink garnet in coarse cummingtonite were found about 300 feet east of the silicate iron formation hill in the northwest corner of the Gras Lake Area. These blocks must be very close to their source, although the outcrop was not found.

Graphite makes up approximately 20% of a gneiss layer on the hillside two miles west-southwest of the junction of the Gentilhomme and Moisie rivers. Exposure was too poor to estimate the thickness of this layer, but its maximum exposed thickness was about 4 feet.

The quartzite of the Normanville Area is generally pure and could provide a source of silica if it is needed locally.

Sand and gravel, suitable for construction material are available from the eskers and sorted fluvoglacial deposits of the area. These deposits occur in old stream channels, many of which are followed by modern rivers.

CHAPTER X

SUMMARY AND CONCLUSIONS

This thesis is a study of the petrology and structural geology of the rocks near the intersection of the Labrador Trough and the Grenville Front in the Mount Wright region of Quebec. The rocks of the area include a Proterozoic metasedimentary sequence and the Archean basement on which it was deposited. North of the Grenville Front the Archean rocks are relatively fresh hypersthene granulites and granitic intrusions, and the Proterozoic rocks are slightly metamorphosed grit and iron formation. Within the Grenville Province metamorphism has raised the Proterozoic rocks and retrogressively metamorphosed the Archean rocks to the middle almandine amphibolite facies.

Generally conformable bodies of quartz monzonite and gabbro inject the Proterozoic sequence. In the southeast the gabbro is partly differentiated to peridotite and acidic orthogneiss, and granite. Gneisses in the vicinity of the differentiated gabbro are metasomatized with the addition of potassium, sodium and the oxidation of iron.

The gneisses are classified on the basis of mineral composition, mafic - felsic segregation, and stratigraphic position. The well segregated gneiss occurs in the deeper, more metamorphosed parts of the area. Higher in the series and where metamorphism is less intense, the gneiss is poorly segregated. Mineralogically distinctive rocks include epidote schist and grit and potassic gneiss below the Iron Formation Series, and the rusty-weathering graphitic schist, mica-kyanite schist, and hornblende-

garnet rock above the Iron Formation Series. The distinctive mineralogy of the first two types is caused by their unusual degree of metamorphism or metasomatism, and that of the others by the unusual composition of their original sediment.

The Iron Formation Series includes iron formation and associated quartzite and marble. The iron formation may occur as oxide, quartz-silicate-carbonate or olivine-pyroxene-carbonate facies. The type deposited was apparently controlled by Eh-pH conditions at the site of deposition. The oxide facies occurs in the northwestern part of the area, and grades into silicate-carbonate facies in the southeast. The oxide facies is generally underlain by gneiss or quartzite, and the silicate-carbonate facies by marble. These changes are thought to reflect the depth of the Proterozoic sea, shallow in the northwest and deeper, causing a more reducing environment, in the southeast.

The composition of the gneiss also changes across the region. In the Normanville Area both the upper and lower gneisses have compositions resembling an average shale. In the southern area, the composition of the lower gneiss is similar to greywacke, and the upper gneiss to shale. The Archean granulite has the composition of a greywacke.

The compositions of the common minerals differ somewhat between rock types. Most of the rocks contain plagioclase in the range between An_{25} and An_{35}. More albitic plagioclase occurs in the slightly metamorphosed albite-epidote grit, and the porphyroblastic schist of the Normanville Area, and in the acidic orthogneiss and Archean intrusions. More calcic plagioclase occurs in the highly metamorphosed calcic rocks and basic intrusions.

Refractive indices of the mafic minerals are relatively low in the lower gneiss, higher in the upper gneiss, potassic gneiss, altered gabbro, and hornblende-garnet rock, and very high in the acidic differentiates from gabbro reflecting increase in the ratios Fe/Mg, and $(Fe^{+3} + Al)/Si$. The ratio of cell edge/refractive index is a measure of the calcium content of garnet. Values of this ratio are high in garnets from rocks rich in hornblende, and low in garnets from the upper gneiss, acidic orthogneiss, unaltered granulite and well segregated gneiss.

In the silicate-carbonate iron formation the Grenville metamorphic gradient can be traced from the greenschist to the middle almandine amphibolite facies. In its least metamorphosed form the iron formation is composed of quartz, siderite and magnetite. New minerals appear in the order stilpnomelane, cummingtonite, garnet, actinolite, clinopyroxene, orthopyroxene and, if quartz is absent, olivine. The pyroxenes appear at about the kyanite zone of metamorphism, a much lower grade than they do in pelitic or quartzofeldspathic rocks.

Pyroxenes coexisting in the iron formation show several per cent enrichment of $Fe^{+2}/(Fe^{+2} + Mg)$ in the orthopyroxene relative to the clinopyroxene. The Fe/Mg fractionation between coexisting pyroxenes in the iron formation cannot be used as a geothermometer, and does not show any simple relationship to the calcium content of the pyroxenes.

Solid solution of $MgCO_3$ in calcites from the marble does not exceed 5% in any of the samples studied. The amount of $MgCO_3$ that can be held in solution in calcite depends on its temperature of crystallization, and in the present area final equilibrium was apparently reached at less than 500°C.

The Proterozoic rocks are deformed about two main structural directions; northeast to east-northeast, and southeast to south-southeast. The two fold directions are equally developed in a belt lying close to the northwestern shore of the trough, and containing the oxide facies of iron formation. In the resulting fold system, basins of iron formation occur at synclinal intersections arranged on a roughly symmetrical grid. Farther into the trough the structures trend either east-northeast or southeast, with the southeasterly trends predominating.

A series of thrust faults strikes parallel to the main southeasterly fold trend. Movement is east side up and towards the south, and commonly brings the lower gneiss up against rocks of the Iron Formation Series. Shear zones, drag folds and displacement of formations are common along the Pekans and Moisie rivers, and the rivers probably follow zones weakened by faulting.

The Archean-Proterozoic contact in the Normanville Area lies close to the Grenville Front. Archean granulite strikes southeastward until it contacts the Proterozoic gneiss striking northeast parallel to the contact and dipping away from it. The contact itself is not exposed, but is probably an unconformity modified by folding and thrusting of the Proterozoic rocks toward the Archean basement. Metamorphism increases southeastward, and the Grenville Front is accompanied by a strong negative gravity anomaly between Lake Mistassini and Mount Wright.

The area includes some of the largest deposits of concentrating grade iron ore in the region. The economically valuable oxide facies of the iron formation is restricted to a southwest-trending zone containing the near-shore deposits of the Proterozoic sea. Typical deposits contain

only 25% to 35% iron, but this is in the form of coarsely crystalline hematite which is easily concentrated into a high grade product containing little sulfur, titanium or phosporus.

Small sulfide deposits containing minor quantities of copper, nickel and cobalt are associated with the gabbro sills at Bloom and Pegma lakes. Some beds of the upper schists contain as much as 25% graphite or kyanite. Eskers containing sand and gravel suitable for construction material follow old stream channels in most of the main valleys.

APPENDIX

TABLES OF ROCK COMPOSITIONS

KEY TO ABBREVIATIONS IN ROCK COMPOSITION TABLES

Mineral Names

Act	=	Actinolite
Alb	=	Albite
All	=	Allanite
An	=	Anorthite
Anth	=	Anthophyllite
Ap	=	Apatite
Bio	=	Biotite
Cal	=	Calcite
Carb	=	Carbonate
Chl	=	Chlorite
Cpx	=	Clinopyroxene
Cumm	=	Cummingtonite
Dol	=	Dolomite
Epi	=	Epidote-family
Felds	=	Feldspar
Gar	=	Garnet
Gra	=	Graphite
Hem	=	Hematite
Hnb	=	Hornblende
Idd	=	Iddingsite
Il	=	Ilmenite
K-spar	=	Potash feldspar
Ky	=	Kyanite
Leuc	=	Leucoxene
Lim	=	Limonite
Mag	=	Magnetite
Musc	=	Muscovite
Myrm	=	Myrmekite
Ol	=	Olivine
Opq	=	Opaque oxide
Opx	=	Orthopyroxene
Phlg	=	Phlogopite
Plag	=	Plagioclase
Py	=	Pyrite
Pyrr	=	Pyrrhotite
Qtz	=	Quartz
Rut	=	Rutile
Saus	=	Saussurite
Scap	=	Scapolite
Ser	=	Sericite
Serp	=	Serpentine
Sph	=	Sphene
Spn	=	Spinel
Stilp	=	Stilpnomelane
Talc	=	Talc
Tour	=	Tourmaline
Trem	=	Tremolite
Zr	=	Zircon

Mineral Colours and Shades

b	=	brown
d	=	dark
g	=	green
l	=	light
o	=	olive
r	=	red
y	=	yellow
yb	=	orange brown
bg	=	blue green

Words

cg	=	coarse grained
fg	=	fine grained
sec	=	secondary
tr	=	trace
v	=	very
I.F.S.	=	Iron Formation Series

Plagioclase Composition

—— by Tsuboi method

⟝⟞ by Rittmann method

Table 10

AVERAGE COMPOSITION OF GNEISSES AND SCHISTS

Plag	K-spar	Qtz	Bio	Musc	Hnb	Opx	Cpx	Epi	Gar	Others	
				(6) Intermediate Granulite (Normanville)							
45	6	21	10		6[sec]	6			4		Mean
11	6	3	3		2	5			4		Mean Dev.
				(5) Basic Granulite (Normanville)							
35			9		8	6	25	5		Opq 6	Mean
6			3		4	6	6	4		Opq 2	Mean Dev.
				(8) Archean Intrusions (Normanville)							
34	27	20	6					4		Ser 3	Mean
17	21	9	4					3		Ser 2	Mean Dev.
				(6) Altered Archean Gneiss (Normanville)							
43		14	8		3			10		Opq 2	Mean
9		8	2		3			4		Opq 2	Mean Dev.
				(18) Undivided Granulite (Gras-Felix)							
48	12	16	15		2	3	1		6	Ap tr	Mean
9	12	7	10		3	4	2		5		Mean Dev.
				(3) Well Segregated Gneiss (Normanville)							
39	2	31	12	1	7			6		Carb 2,Opq tr	Mean
6	2	16	4	1	6			2		Carb 2,Opq tr	Mean Dev.
				(15) Well Segregated Biotite Gneiss (Gras-Felix)							
49	6	23	12					1	1	Chl 5	Mean
8	7	5	7					1	2	Chl 6	Mean Dev.
				(9) Well Segregated Hornblende Gneiss (Gras-Felix)							
52		19	10		10			1		Ap tr,Sph tr	Mean
8		8	4		4			1			Mean Dev.
				(8) Poorly Segregated Gneiss - Below I.F.S. (Normanville)							
34	12	27	15	8				3		Ap tr,Zr tr	Mean
12	11	7	6	5				2			Mean Dev.
				(3) Poorly Segregated Gneiss - Above I.F.S. (Normanville)							
35	9	26	15	7				1		Carb 4,Ap 1	Mean
13	4	5	0	3				1		Carb 3	Mean Dev.
				(11) Poorly Segregated Gneiss - Below I.F.S. (Gras-Felix)							
53	1	21	18		2			tr		Ap,Py,Zr,tr	Mean
5	2	5	5		2						Mean Dev.

Table 10 (Cont'd)

Plag	K-spar	Qtz	Bio	Musc	Hnb	Opx	Cpx	Epi	Gar	Others	
		(7) Poorly Segregated Gneiss - Above I.F.S. (Gras-Felix)									
48		23	16		7			tr	4	Ap tr	Mean
11		12	7		4				2		Mean Dev.
		(4) Epidote & Chlorite Schist & Grit (Normanville)									
36		29	15					12			Mean
19		16	5					8			Mean Dev.
		(5) Porphyroblastic Schist (Normanville)									
31	5	28	19	10				4		Ap 1	Mean
10	4	11	7	4				2		Ap 1	Mean Dev.
		(2) Hornblende Garnet Schist (Normanville)									
15		20	8		43			2	8	Ap,Zr,Ky,Carb	Mean
10		5	8		18			2	8		Mean Dev.
		(7) Hornblende Pyroxene Garnet Rock - W. of Moisie (Gras-Felix)									
17		5	3		38		14		19	Opq 1,Carb, Ap,Zr,Sph	Mean
14		6	4		19		10		7	Opq 1	Mean Dev.
		(4) Hornblende Pyroxene Garnet Rock - E. of Moisie (Felix)									
36			5		15		21		18	Ap,Opq,Sph	Mean
6			2		11		21		4		Mean Dev.
		(1) Quartz Mica Kyanite Schist (Normanville)									
30		20	15	20				2	8	Ky 3,Gra 1, Chl 1,Ap,Zr	Mean
		(4) Quartz Mica Kyanite Schist (Gras-Felix)									
		52	17	9					4	Ky 10,Gra 1, Ap,Zr	Mean
		4	6	11					2	Ky 4,Gra 1	Mean Dev.
		(8) Rusty Weathering Graphitic Schist (Gras-Felix)									
46	5	23	18	tr				tr	6	Gra 2,Zr	Mean
7	5	7	4						3	Gra 1	Mean Dev.
		(12) Metasomatized Gneiss E. of Moisie (Felix)									
45	23	18	4		7			tr	tr	Opq 1,Ap, Zr,Cpx,Sph	Mean
6	9	7	3		6						Mean Dev.

Table 11

AVERAGE COMPOSITION OF IRON FORMATION SERIES

Qtz	Hem	Mag	Cumm	Act	Opx	Cpx	Carb	Lim	Stilp	Others	
IRON FORMATION											
(8) Oxide Facies (Normanville)											
71	16	11	2	tr							Mean
11	10	11	2								Mean Dev.
(3) Oxide Facies (Gras-Felix)											
65	18	5			tr	tr	tr			Musc	Mean
7	14	7									Mean Dev.
(3) Slightly Metamorphosed (Jackson Lake) (Normanville)											
62		20	x				10	6	x		Mean
6		7					0	3			Mean Dev.
(5) Slightly Metamorphosed (Boulder Lake-Roach) (Normanville)											
35		21	30					3	4	Gar	Mean
20		15	20					3	3		Mean Dev.
(5) Silicate Carbonate Facies (Normanville)											
45		20	29		x		x				Mean
20		14	23								Mean Dev.
(22) Silicate Carbonate Facies (Gras-Felix)											
34		6	8		33	11	5			Gra,Gar	Mean
26		7	8		22	12	6				Mean Dev.
(3) Olivine Pyroxene Subfacies (Gras-Felix)											
		10	x		23		17			Oliv 8,Gar,Sp	Mean
		2			18		14			Oliv 5	Mean Dev.
QUARTZITE											
(3) Normanville Area											
92	x									Musc,Ky,Zr	Mean
11											Mean Dev.
(4) Gras-Felix Area											
94	x		x		x	x	x			Gra,Gar,Zr, Tour,Rut	Mean
3										Bio,Py,Epi	Mean Dev.

Table 11 (Cont'd)

Qtz	Hem	Mag	Cumm	Act	Opx	Cpx	Carb	Lim	Stilp	Others	
						MARBLE					
						(1) Normanville Area					
50				35(1)			15				Mean
						(8) Gras-Felix Area					
7				5(1)		12(2)	68			Phlg,Talc,Serp	Mean
9				5		17	29				Mean Dev.

(1)Tremolite

(2)Diopside

Table 12

AVERAGE COMPOSITION OF IGNEOUS ROCKS

Plag	K-spar	Qtz	Bio	Musc	Hnb	Opx	Cpx	Epi	Gar	Opq	Others	
(5) Quartz Monzonite (Normanville)												
34	25	31	3	5				tr				Mean
9	14	5	1	2								Mean Dev.
(5) Quartz Monzonite (Gras-Felix)												
37	28	23	4	x	5			x	1		Ap,Zr,Sph	Mean
14	10	3	2		8				1			Mean Dev.
(3) Gabbro (Normanville)												
42			5		9		4	2	4	5	Ol,Idd, Chl,Scap	Mean
18			1		7		3	1	4	2		Mean Dev.
(13) Gabbro (Gras-Felix)												
48			6		11	5	11		13	2	Ol,Idd, Sph,Spn	Mean
10			4		8	5	6		4	2		Mean Dev.
(3) Metagabbro Amphibolite (Normanville)												
35			10		40			1	4	6		Mean
3			0		3			1	1	3		Mean Dev.
(4) Metagabbro Amphibolite (Gras-Felix)												
36		5	11		32			x	4	7	Ap 2, Zr,Sph	Mean
10		2	6		10				3	3		Mean Dev.
(6) Intermediate Rocks (Gras-Felix)												
65		x	8		7	x	7		6	2	Ap,Zr,Scap	Mean
8			2		5		4		3	1		Mean Dev.
(6) Granite Derived from Gabbro (Gras-Felix)												
36	30	27	4							2	Ap tr, Zr tr	Mean
11	3	7	4							1		Mean Dev.
(7) Acidic Orthogneiss from Gabbro (Gras-Felix)												
30	44	10	1		6	2	3(1)		3	1	Ap 1, Zr tr	Mean
10	13	10	1		4	2	2		2			Mean Dev.

(1) Aegirine Augite.

(x) Present in some samples.

Table 13

MINERAL COMPOSITION OF ARCHEAN GRANULITE (NORMANVILLE AREA)

Sample	Location	Plagioclase An 20 30 40 %	K-spar	Qtz	Bio	Hnb	Opx	Cpx	Opq	Epi	Ap	Gar	Others
					Intermediate								
7a	52°55'N,67°25'W	⊢ 65		20	7[b]	4(1)	4						
10a	52°54¼'N,67°28'W	⊢ 55		20	15[b]	3(1)	3					3	Zr tr
C-25-107-59	52°55½'N,67°28½'W	⊢ 30	10	20	7[b]	5(1)	10		5		tr	10	Ser tr
C-25-108-59	52°55¼'N,67°30¼'W	- 40	10	30	11	5(1)	4		tr		tr		Zr tr
C-28-112-59	52°58'N,67°25½'W	⊢ 32	18	22	12[b]	8(1)				9			Rut tr
J-21-49-59	52°54½'N,67°29'W	⊢ 45		15	5[rb]	10(1)	15				tr	10	Zr tr
Mean		44.5	6.3	21.2	9.5	5.8	6.0					3.8	
Mean Dev.		10.5	6.3	3.2	3.2	2.2	4.7						
					Basic								
C-32-130-59	52°57½'N,67°14½'W	⊢ 25			15[b]	10[o]	20	25	5	tr			
C-33-139-59	52°59¼'N,67°23'W	⊢ 30			2[b]	5[o]		35	10	15			Chl 3
C-34-141-59	52°57'N,67°15½'W	⊢ 40		5	10[rb]	15[o]		25	5		tr		Anth 5
C-35-151-59	52°59¾'N,67°18'W	⊢ 40			10[db]	5[o]	5	30	5	5			
C-35-152-59	52°59¾'N,67°18'W	⊢ 40		20	10[ob]	5[sec]	5	10	5	2	tr		Talc 5
Mean		35.0			9.4	8.0	6.0	25.0	6.0	4.5			
Mean Dev.		6.0			3.0	3.6	5.6	6.0	1.6	4.4			

(1) Uralitic alteration of pyroxene.

Table 14

MINERAL COMPOSITION OF ARCHEAN INTRUSIONS (NORMANVILLE AREA)

Sample	Location	Plagioclase An	Plagioclase %	K-spar	Qtz	Bio	Epi	Hnb	Ser	Cpx	Opq	Others
C-25-109-59	52°54¾'N, 67°28½'W		5	60	20	10^{rb}						Saus 5
C-28-113-59	52°58½'N, 67°24¾'W	10–30	40	20	30	tr^{b}	2		5			Chl 3, Carb tr
C-32-125-59	52°58'N, 67°14½'W	30–40	45	15	10	15^{o}	5		5			Ap 2, Py tr
C-35-145-59	52°59½'N, 67°16½'W		10	45	30	5^{vdb}	10					Sph tr
C-35-150-59,	53°00'N, 67°17'W	20–30	45	5	33	10^{o}	10					
J-23-56-59	52°59½'N, 67°24½'W	10–20	20	60	15				5			
G-6-13-59	52°57¾'N, 67°16½'W	40	65		25		5		5			
G-7-16-59	52°58½'N, 67°14'W	10–30	45	10	35	5^{vdb}	2		3			Leuc tr
Mean			34.4	26.9	20.6	5.7	4.3		2.9			
Mean Dev.			17.1	21.1	8.5	4.3	3.3		2.3			

MINERAL COMPOSITION OF ALTERED ARCHEAN GNEISS (NORMANVILLE AREA)

Sample	Location	Plagioclase An	Plagioclase %	K-spar	Qtz	Bio	Epi	Hnb	Ser	Cpx	Opq	Others
C-28-115-59	52°58½'N, 67°24'W	20–30	35	10	10	10^{ob}	5		2	15	5	Trem 10
C-33-135-59	52°58¾'N, 67°21¼'W	20–30	45			10^{ob}	20	5^{bg}			5	Chl 15, Rut tr
C-33-137a-59	53°00'N, 67°23¾'W	40	25		35	10^{ob}	10		10			Leuc 5, Rut 3, Carb 2
C-35-153-59	52°59¾'N, 67°18'W		50		15	7^{o}	10	1	7			Leuc 3, Rut 1, Ap 1
C-35-155-59	52°59¼'N, 67°25'W		45		15	2^{ob}	5			10	2	Chl 10, Trem 5, Ap 1, Rut 1
C-36-157-59	52°57¼'N, 67°26½'W	30–40	60		10	10^{o}	10	10^{sec}			tr	Ap tr, Zr tr
Mean			43.3		14.1	8.2	10.0	2.7	3.2		2.1	
Mean Dev.			9.2		7.5	2.4	4.2	3.2	3.6		1.9	

Table 15

MINERAL COMPOSITION OF GNEISSES (NORMANVILLE AREA)

Sample	Location	Plagioclase An 10 20 30 40 %	K-spar	Qtz	Bio	Hnb	Musc	Epi	Carb	Ap	Others
Well Segregated Gneiss											
C-13-46-59	52°45'N,67°26¼'W	- 45	5	15	10[ob]	15[lg]		10			Sph tr,Opq tr,Zr tr
C-13-47-59*	52°45'N,67°22½'W	⊢ 43		22	18[b]	5[g]		5	4	tr	Ser 3,Opq tr,Zr tr
G-3-7-59	52°47½'N,67°27¾'W	⊢ 30		55	7[o]		3	4	3		
Mean		39.3	1.7	30.7	11.7	6.7	1.0	6.3	2.3		
Mean Dev.		6.2	2.2	16.2	4.2	5.6	1.3	2.4	1.6		
Poorly Segregated Gneiss Below Iron Formation											
C-7-21-59	52°50½'N,67°5¾'W	⊢ 30	5	10	30[ob]		15	5	5		Py tr
C-13-44-59	52°45'N,67°24¼'W	⊢ 10	40	20	10[b]		10	5		3	Zr tr,Rut tr
C-37-162-59	52°47¾'N,67°10'W	⊢ 20	25	30	10[b]		10	2		2	Zr tr
C-37-164-59	52°48¼'N,67°9¾'W	⊢ 30	10	40	15[o]		5				
C-45-209-59	52°49'N,67°18¾'W	- 40	14	34	6		4	tr			Zr tr
J-22-55-59	52°52¼'N,67°19'W	- 45		30	20[ob]		5			tr	Zr tr
J-30-74-59	52°48'N,67°18½'W	⊢ 45		25	10[o]		15	tr		3	Gar 3
G-2-3-59	52°49¼'N,67°29'W	⊢ 50		30	15[rb]			7			
Mean		33.8	11.8	27.4	14.5		8.0	2.5	0.6	1.1	
Mean Dev.		11.9	11.0	6.8	5.5		4.5	2.4	1.0	1.0	
Poorly Segregated Gneiss Above Iron Formation											
C-10-37-59	52°46'N,67°8'W	⊢ 25	15	25	15[rb]		5	1[all]	8	1	Gar 5
C-47-214-59	52°46½'N,67°8'W	⊢ 25	10	33	15[rb]		12		5	1	Zr tr
J-36-101-59	52°45'N,67°18½'W	⊢ 55	3	20	15[rb]		5	1[all]		2	
Mean		35.0	9.3	26.0	15.0		7.3	0.6	4.3	1.3	
Mean Dev.		13.3	4.2	4.7	0		3.1	0.5	2.9	0.4	

*Average of mafic and felsic layer.

Table 16

MINERAL COMPOSITION OF DISTINCTIVE SCHISTS (NORMANVILLE AREA)

Sample	Location	Plagioclase An 10 20 30 40 %	K-spar	Qtz	Bio	Hnb	Musc	Epi	Ap	Gar	Others
Albite-Epidote and Chlorite Schist and Grit											
C-32-128-59	52°57¾'N,67°14'W	55		12	20^{yg}			15			Zr tr
C-32-131-59	52°58'N,67°16'W	15		35	10^{g}			25			Chl 15,Opq tr
C-35-148-59	52°59½'N,67°16'W	20		55	20^{g}			2			Zr 1
J-24-63-59(1)	53°0¼'N,67°28½'W	55		15	10^{g}			5	1		Trem 10,Carb 3,Sph 2
Mean		36.3		29.3	15.0			11.8			
Mean Dev.		18.7		15.7	5.0			8.2			
Porphyroblastic Schist											
C-8-29-59	52°49¾'N,67°04'W	37	3	10	25^{b}		15	8			Opq tr
C-39-173-59	52°50¼'N,67°12¾'W	7	15	40	30^{o}				tr		Carb 5
J-16-34-59(2)	52°51¾'N,67°25¾'W	35		42	10^{rb}		10	3	1		Lim 1
J-22-51-59(2)	52°52¼'N,67°21'W	40		30	15^{yb}		10	5			Opq tr
J-25-65-59	52°50'N,67°30¼'W	35	5	20	15^{b}		15	3	5		
Mean		30.8	4.6	28.4	19.0		10.0	3.8	1.4		
Mean Dev.		9.5	4.3	10.7	6.8		4.0	2.2	1.5		
Hornblende Garnet Schist											
C-47-216-59	52°45'N,67°7½'W	5		25		60^{lg}		4			Carb 3,Ky 3,Zr tr
G-1-1-59	52°46'N,67°2'W	25		15	15^{rb}	25^{g}			2	15	Il 1,Sph 3,Zr tr
Mean		15		20	7.5	42.5		2	1	7.5	
Mean Dev.		10		5	7.5	17.5		2	1	7.5	
Quartz Mica Kyanite Schist											
C-10-38-59	52°46¼'N,67°7¼'W	30		20	15^{br}		20	2	tr	8	Ky 3,Gra 1,Chl 1,Zr tr

(1) cg. fragments in fg. matrix.

(2) ½ plag. in porphyroblasts.

Table 17

MINERAL COMPOSITION OF QUARTZITE (NORMANVILLE AREA)

Sample	Location	Qtz	Musc	Hem	Others
C-42-192-59	52°47½'N,67°10¾'W	100			
C-46-210-59	52°49¾'N,67°17¾'W	100			Zr tr
J-36-104-59	52°45¼'N,67°18¾'W	75	20	3	Ky 2,Chl 1
Mean		91.7			
Mean Dev.		11.1			

MINERAL COMPOSITION OF MARBLE (NORMANVILLE AREA)

Sample	Location	Qtz	Carb	Trem	Others
C-5-16-59(1)	52°45½'N,67°06'W	50	15	35	

(1)Not representative.

Table 18

MINERAL COMPOSITION OF IRON FORMATION (NORMANVILLE AREA)

Sample	Location	Qtz	Hem	Mag	Cumm	Act	Py	Lim	Others
				Oxide Facies					
C-12-39-59	52°45¼'N,67°22½'W	50	35	10					Felds 5,Zr tr,Ap tr
C-30-119-59	52°52'N,67°23'W	65	35						
C-30-121-59(1)	52°52¾'N,67°19¼'W	82	18						
C-41-181-59(1)	52°46'N,67°16¾'W	85	4	6	5				
C-42-194-59	52°47½'N,67°13'W	70		25	5				
C-42-188-59(2)	52°47¾'N,67°13'W	65	17	8		10			
C-42-194-59(2)	52°47½'N,67°13'W	55		40	5				
J-37-118-59(2)	52°50¼'N,67°16½'W	78	15	2		5			
Mean		70.9	15.5	11.4	1.9				
Mean Dev.		11.0	10.1	10.5	2.3				
				Sulfide Facies					
C-42-189-59	52°48'N,67°13'W			tr	70		10	20	

(1) Average of thin section and polished section.

(2) Polished section.

Table 18 (Cont'd)

MINERAL COMPOSITION OF IRON FORMATION (NORMANVILLE AREA)

Sample	Location	Qtz	Mag	Cumm	Opx	Carb	Stilp	Lim	Others
			Silicate-Carbonate Facies						
C-37-159-59	52°48¾'N,67°11'W	70	2		20	8			
C-38-167-59	52°51'N,67°11'W	60	8	30					
C-38-166-59(1)	52°51'N,67°11'W	?	15	30					Act 55
C-43-198-59	52°50'N,67°15½'W	40	40	20					
C-43-199-59	52°50'N,67°15½'W	55	35	10					
Mean		45.0	20.0	29.0					
Mean Dev.		20.0	14.0	22.8					
			Jackson Lake Deposit						
C-32-126-59(2)	52°58'N,67°14¾'W	70	10			10		10	
C-44-142-59(1)	52°57¼'N,67°16½'W	55	30			10		5	
G-6-14-59	52°57½'N,67°16½'W	60	20	6		10	2	2	
Mean		61.7	20.0			10		5.7	
Mean Dev.		5.6	6.7			0		2.9	
			Boulder Lake Deposit and Roach Extension						
G-59-Loc-6a	52°54¾'N,67°23'W	58	15	23			3		
G-59-Loc-6b	52°55'N,67°23'W	35	45	9			2	4	
60-9-F-54-A(3)	52°52'N,67°24¼'W	20		30			10	10	Gar 35
60-9-F-54-C	52°52'N,67°24¼'W		10	80			2	tr	Gar 10
60-9-F-54-D	52°52'N,67°24¼'W	60	35	5				2	
Mean		34.6	21.0	29.5			3.5	3.3	
Mean Dev.		20.0	15.2	20.3			2.7	2.9	

(1)Polished section.

(2)Average of thin section and polished section.

(3)Rough estimate.

Table 19

MINERAL COMPOSITION OF IGNEOUS ROCKS (NORMANVILLE AREA)

Quartz Monzonite

Sample	Location	Plagioclase An 10 20 30 40	%	K-spar	Qtz	Bio	Musc	Hnb	Epi	Cpx	Gar	Opq	Others
C-7-26-59	52°50¾'N,67°05'W		35	20	35	2^{b}	5		1				
C-13-47-59(1)	52°46'N,67°22½'W		50		40	5^{db}			tr				Ser 2,Zr tr
C-37-165-59	52°48'N,67°10'W		30	40	20	2^{db}	8						
C-45-205-59	52°49¼'N,67°18½'W		15	45	30	5^{db}	5						
J-37-116-59	52°49½'N,67°18'W		40	20	30	3^{b}	5		1				
Mean			34.0	25.0	31.0	3.4	4.6		0.5				
Mean Dev.			9.2	14.0	5.2	1.3	1.8		0.4				

Gabbro

Sample	Location	Plagioclase An 40 50 60 70	%	K-spar	Qtz	Bio	Musc	Hnb	Epi	Cpx	Gar	Opq	Others
C-37-160-59(2)	52°48¼'N,67°10½'W		15			7^{yb}		20^{lg}	2		10	2	Chl 25,Scap 15, Ap 2,Sph 1
C-37-161-59(2)	52°48¼'N,67°10½'W		45			3^{rb}		5^{lg}	3	7	1	7	Chl 10,Opx 12, Ol 2,Idd 5
C-45-208-59(2)	52°49½'N,67°18'W		65			5^{rb}		3^{lg}		5		5	Ol 10,Ant 3,Idd tr, Myrm 5,Ap 3
Mean			41.7			5		9.3	1.7	4.0	3.7	4.7	
Mean Dev.			17.8			1.3		7.1	1.1	2.7	4.2	1.8	

Amphibolite (Metagabbro)

Sample	Location	Plagioclase An 10 20 30 40	%	K-spar	Qtz	Bio	Musc	Hnb	Epi	Cpx	Gar	Opq	Others
C-12-43-59	52°45¾'N,67°23'W		30			10^{yb}		40^{lg}			5	10	Ap 5
C-41-187-59	52°46'N,67°18'W		35			10^{rb}		45^{g}	3		5	5	
C-46-213-59	52°50'N,67°16'W		40			10^{yb}		35^{bg}	tr		2	2	Ap 3,Sph 3
C-32-129-59(3)	52°57½'N,67°13½'W		42		10	2^{b}		38^{bg}	5			3	
Mean of top 3			35			10		40.0	1.2		4.0	5.7	
Mean Dev. of top 3			3.3			0		3.3	1.2		1.3	2.9	

(1)Felsic band in gneiss.

(2)Hornblende is secondary.

(3)Archean Amphibolite.

Table 20

MINERAL COMPOSITION OF GRANULITE AND ALTERED GRANULITE (GRAS-FELIX AREA)

Sample	Location	Plagioclase An 25 30 35 40	%	K-spar	Qtz	Bio	Hnb	Opx	Cpx	Gar	Ap	Others
C-4-26-60	52°19'N,67°6'W	?⊣	50	5	10	25				5		Zr tr
C-25-153b-60	52°17½'N,67°10½'W	⊢⊣	23		16	33^{db-rb}		2		27	tr	Opq tr
C-41-260-60	52°18'N,67°23'W	⊢⊣	50		10	7^{rb}	16^{lg}		4	5	1	Epi 6,Py tr
L-12-50-60	52°23½'N,67°7½'W	⊢	39		14	25^{rb}				19	tr	Chl 2,Py 1,Zr tr
L-12-50-60(1)	52°23½'N,67°7½'W	⊢⊣	25	35	35							Epi 3,Zr 1,Chl 1,Opq 1
L-16-63-60	52°19'N,67°00'W	⊢	44		34	11^{db}		2		8		Opq 1
L-16-64-60	52°18'N,67°00'W	⊢⊣	40		10	7^{drb}	3^{o}	35			3	Sph 3,Zr tr
L-37-149-60	52°20'N,67°23'W	⊢⊣	41	8	15	30^{g}				2	tr	Py 2,Zr tr
G-19-54-60	52°18'N,67°10'W	⊢	60		10	10^{rb}	3^{g}			10	1	Epi 5
G-21-57-60	52°20'N,67°18'W	---⊢	47		13	16^{lrb}	11^{g}		3	4		Py 2,Chl 1,Zr 1, Sph 1,Carb 1
G-29-87-60	52°20'N,67°17'W	⊢⊣	45		20	8^{lrb}	1			2	1	Chl 20,Carb 2,Sph 1, Epi tr,Py tr
C-13-57-61	52°24'N,67°58'W	⊢⊣	75		10	6^{rb}	tr		2	7	1	Opq 1
C-20-101-61(2)	52°21½'N,66°51¾'W	⊢⊣	50	7	7	31^{rb}		2		3	tr	Zr tr
C-21-106-61	52°20¾'N,66°55'W	⊢	45	35	10	5^{drb}				3	2	Py tr
C-31-160-61(2)	52°18¼'N,66°54½'W	⊢	45	4	6	30^{rb}	6^{g}	3		7	tr	All tr,Mag tr
C-31-161-61	52°18'N,66°55¼'W	⊢⊣	60		23	7^{drb}	tr		6	3	tr	
D-17-61-61(2)	52°21'N,67°00'W	⊢⊣	47	tr	33	15^{b}				3	tr	Py tr,Zr tr
D-23-80-61	52°19'N,66°51'W	⊢	70	5	10	2^{rb}	2^{g}	3	4	2	tr	Opq 1
Mean			47.5	12.4	15.9	14.9	2.4	2.6	1.0	6.1	tr	
Mean Dev.			9.1	11.9	7.3	9.6	3.0	3.7	1.8	4.6		

(1)Granitic layer.

(2)Mode 1500 pts. sample analysed.

Table 21

MINERAL COMPOSITION OF WELL SEGREGATED GNEISS (GRAS-FELIX AREA)

Section	Location	Plagioclase An			%	K-spar	Qtz	Bio	Chl	Hnb	Musc	Epi	Gar	Ap	Sph	Others
		20	30	40												
Biotite-rich																
C-10-52-60	52°27'N,67°8'W				50	5	20	20[o]			2	tr				Py tr
C-20-121-60	52°13½'N,67°5'W				36		44		6		1		12			Opq 1
C-28-170-60	52°22½'N,67°18½'W				60		25	10[rb]	3			tr	2	tr		Py 2,Zr tr
C-32-204-60	52°26½'N,67°18½'W				50	20	15	7[o]				2			tr	Alb 5,Zr tr, Tour tr
C-37-241-60	52°18'N,67°17'W				45	10	20	18[o]	8			tr				Py tr
C-41-261-60	52°18'N,67°23'W				53		25	18[b]				1		1		Py 1
L-8-34-60	52°17'N,67°5½'W				56	13	20	7[b]		1[g]		4		tr		Carb 1,Zr tr
L-8-41-60	52°26½'N,67°5'W				55		25		15			2		1		Carb 1,Py tr
L-28-105-60	52°28½'N,67°26'W				50	5	15	20	2			3	2	tr	2	
L-41-158-60	52°23'N,67°27'W				50	5	25	2	15		tr	1			5	Py tr
G-10-24-60	52°29'N,67°6½'W				15	35	25	15[b]			2	2		1		Carb 3,Zr tr
D-11-42-61(1)	52°26½'N,66°51'W				36		28	34[o]			tr	tr	1	tr		Py 1,Zr tr
D-42-154-61	52°29½'N,66°41'W				53		23	18[rb]		3[g]			1			Carb tr,Py tr, Zr tr
C-13-61-61	52°26'N,67°00'W				67		21	10[rb]					tr	tr		Carb tr,Py tr
C-30-155-61	52°16½'N,66°50'W				52	5	13		22	3[g]		tr	2	tr		
Mean					48.5	6.2	22.9	11.9	4.7			1.1	1.3	0.4		
Mean Dev.					8.3	6.8	5.5	7.1	5.6			0.9	1.6	0.3		
Hornblende-rich																
C-11-62-60	52°28'N,67°3'W				50		20	15[r]		15[g]		tr		tr		Zr tr
C-18-104-60	52°26'N,67°12½'W				65		12	8[b]		12[g]		1		tr	1	
C-28-171-60	52°23½'N,67°16'W				55	4	19	10[b]		8[lbg]		2		1	1	Zr tr
C-47-288-60	52°28½'N,67°26½'W				55	16	7	7[ob]		12[lbg]		2	tr	tr	2	
L-28-103-60	52°28½'N,67°23½'W				60	tr	14	17[b]		5[g]			tr	1	tr	Py 2

Table 21 (Cont'd)

Section	Location	Plagioclase An 20 30 40 %	K-spar	Qtz	Bio	Chl	Hnb	Musc	Epi	Gar	Ap	Sph	Others
		Hornblende-rich											
L-10-47-60	52°25'N,67°5'W	1	55		30	7^{d}		5^{dog}			1	1	Zr tr
D-11-44-61	52°26'N,66°52'W	–	40		33	9^{b}		13^{g}		1			Py 2,Zr tr
C-6-21-61	52°31½'N,66°45'W	1	55		30	2^{b}	5	5^{bg}	tr		tr		
C-2-8-61(2)	52°30½'N,66°48'W	1	10		tr	tr^{b}		72^{og}		11		tr	Cpx 6,Py tr
C-21-111-61(3)	52°21'N,66°46'W	1	31	30	7	16^{drb}		13^{dg}	tr		2	1	Opq 1,Zr tr, Py tr
Mean exc. C-2-8-61			51.8	5.5	19.1	10.1		9.8	0.7	0.2	0.8		
Mean Dev. exc. C-2-8-61			7.6	7.8	8.1	3.8		3.6	0.6	0.3	0.5		

(1)Mode 1500 pts.

(2)Hornblende layer in gneiss.

(3)Section contains microcline lens.

Table 22

MINERAL COMPOSITION OF POORLY SEGREGATED GNEISS (GRAS-FELIX AREA)

Sample	Location	Plagioclase An	Plagioclase 20	Plagioclase 30	Plagioclase 40	Plagioclase %	K-spar	Qtz	Bio	Hnb	Musc	Epi	Gar	Zr	Py	Ap	Others
Below Iron Formation																	
C-18-103-60(1)	52°26'N,67°9'W				1	60		20	15^{b}	5^{g}		tr		tr	tr	tr	
C-28-169-60	52°22½'N,67°18'W			1	1	39	8	18	21^{lrb}	1^{lg}			12	tr	tr		Opq tr
C-30-193-60(2)	52°25'N,67°20'W			1		45		27	26^{yb}			tr		tr	tr	tr	
C-34-214-60(1)	52°26'N,67°16'W		1			55	tr	12	16^{b}	10^{dbg}		3		tr	tr	tr	
C-36-229-60	52°27'N,67°20½'W		1	1		50	5	20	15^{o}		5			tr	tr	tr	Carb tr
C-2-3-61	52°32'N,66°51'W	1		-		52		33	14^{db}	2^{dbg}		1	tr			tr	Opq tr
C-4-12-61(1)(3)	52°33'N,66°47'W				1	60		25	10^{b}	5^{bg}		1				tr	
C-15-68-61	52°25'N,67°52'W		1	1		53		23	23^{o}			tr		tr	tr	tr	
C-30-157-61	52°17'N,66°49'W		1	1		67	3	13	14^{b}	tr^{bg}			tr		tr	tr	
C-46-237-61(1)	52°29'N,66°45'W		1	1		53		17	27^{o}			tr		tr	1	tr	
D-6-23-61	52°30'N,66°52'W			-		50		25	20^{r}				4	tr	2	tr	
Mean						53.4	1.4	21.3	18.3	2.1		0.6		tr	0.5	tr	
Mean Dev.						4.6	2.0	5.0	4.7	2.4		0.5					
Above Iron Formation																	
C-17-97-60	52°22'N,67°01'W			1	1	55		10	15^{db}	7^{bg}	2	2	3			1	Sph 3,Opq 1
C-20-127-60	52°15'N,67°04'W	1	1	-		70	tr	20	5^{rb}			tr	5		tr		
L-18-69-60	52°13½'N,67°00'W				1	35		10	35	15		tr		tr	2	1	
G-13-32-60	52°24'N,67°01½'W			1	1	53		12	18^{db}	11^{bg}			6			tr	
G-14-35-60	52°21'N,67°02'W		1	1		35		40	7^{rb}	10^{lg}		1	7			tr	
G-27-77-60	52°15'N,67°13½'W			1		52		21	19^{b}	6^{bg}		tr	3			tr	
D-5-16-61	52°31½'N,66°55'W		1	1		35	tr	45	10^{r}		1		5	tr	tr	tr	
Mean						47.9		22.6	15.6	7.0		0.5	4.1			0.6	
Mean Dev.						11.0		11.6	6.5	4.3		0.6	2.0			0.3	

(1) Banded gneiss.

(2) Mode 1500 pts.

(3) Composition not representative.

Table 23

MINERAL COMPOSITION OF DISTINCTIVE ROCKS ABOVE IRON FORMATION SERIES (GRAS-FELIX AREA)

Sample	Location	Plagioclase An	20	30	40	%	K-spar	Qtz	Bio	Hnb	Epi	Gar	Musc	Ky	Gra	Ap	Zr	Others
Rusty-weathering Graphitic Schist																		
C-3-21-60	52°20'N,67°3'W	1	-			40	5	15	25r			10		tr	3			
C-37-234-60	52°18'N,67°14½'W	1	-			32	23	17	18rb		tr	3	2		3		tr	
C-39-254-60	52°16'N,67°20'W	1				56	2	21	13r		tr	3			2	2	tr	
L-6-30-60	52°30'N,67°11'W	1				46		16	23r		tr	7	2		4		tr	
G-2-5-60	52°21'N,67°3'W	1				52		14	21r			11			1		tr	
C-16-71-61	52°24'N,66°50¾'W		-			37		42	17r			2			1	tr	tr	
C-18-84-61	52°22½'N,66°47'W	1				48	7	30	10r		tr	3			tr	tr	tr	
C-29-152-61(1)	52°17½'N,66°46'W	1				53		23	17r			6			tr		tr	
Mean						45.5	4.6	22.3	18.0			5.6			1.9			
Mean Dev.						6.9	5.3	7.1	3.8			2.9			1.1			
Quartz-Mica-Kyanite Schist																		
C-20-126-60	52°15½'N,67°4'W					25?	?	50	8r					15	3			
C-5-13-61	52°32'N,66°51'W					5		50	25r			5	3	8	1	2		
C-7-23-61	52°30'N,66°48'W							47	13rb			4	31	4	tr		tr	
C-16-73-61	52°24'N,66°49¼'W							60	20r			5	2	12	tr		tr	
Mean								51.7	16.5			3.5	9.0	9.8	1.2			
Mean Dev.								3.8	5.7			1.8	11.0	3.8	0.9			

(1) East of Moisie River.

Table 23 (Cont'd)

Sample	Location	Plagioclase An 20 30 40 %	K-spar	Qtz	Bio	Hnb	Epi	Gar	Cpx	Ap	Zr	Opq	Others
		Hornblende-Pyroxene-Garnet-Rock (W. of Moisie R.)											
L-17-65-60	52°16'N,67°0½'W	35			15^{dr}	20^{g}	tr	20		2	tr	2	Sph 3,Carb tr
G-32-99-60	52°15½'N,67°22'W	9			6^{rb}	7^{b}		29	47			1	Rut 1
C-2-4-61	52°31¾'N,66°50'W	5		7	1^{drb}	60^{bg}		15	13	tr			Sph tr
C-10-36-61	52°28¼'N,66°51¾'W	47			1^{r}	34^{ob}		6	2			tr	Trem 7,Carb 5
C-10-37-61	52°28'N,66°52'W	10		17		24^{b}		31	13			tr	Opx 1,Rut tr
C-11-42-61	52°27½'N,66°46'W				tr	60^{b}		20	15	tr	tr	5	Carb 1
D-2-7-61	52°32'N,66°55'W	10		10		60^{g}		12	8				
D-7-27-61	52°30½'N,66°49'W			5	1^{b}	21^{g}	37	3	14				Carb 4,Scap 9, Sph 3,Py 1
Mean exc. D-7-27-61		16.6		4.8	3.3	37.9		19.0	14.0			1.3	
Mean Dev. exc. D-7-27-61		13.9		5.5	4.0	19.0		6.9	9.6			1.3	

Table 24

MINERAL COMPOSITION OF METASOMATIZED GNEISS EAST OF MOISIE RIVER (GRAS-FELIX AREA)

Sample	Location	Plagioclase An 10 20 30 %	K-spar	Qtz	Bio	Hnb	Epi	Gar	Cpx	Ap	Opq	Others
C-21-109-61(1)	52°21¼'N,66°47'W	35	41	14	8db		tr	tr				Chl tr,Musc tr,Py tr
C-24-123-61(2)	52°15'N,66°46'W	60	19	17	2db	1vdb					1	Sph tr
C-33-173-61(2)	52°22'N,66°38'W	55	23	21	1db	tr	tr			tr	tr	Sph tr
C-33-174-61	52°21'N,66°38'W	48	5	30	6db	6vdg	1	tr		tr	1	
C-35-187-61	52°16'N,66°35'W	46	13	34	2dr	2dog		tr		tr	1	Chl 1,Zr tr
C-40-211-61	52°26'N,66°30'W	38	30	26	3db	3	tr	tr	tr	tr	2	Zr tr
C-41-217-61	52°26¾'N,66°31'W	50	23	7	2db	13ob		4	1	tr	1	Sph tr,Zr tr
C-43-226-61(3)	52°24'N,66°43'W	50	25	15	tr	3o	tr	tr		tr	1	Chl 7
C-43-229-61	52°23'N,66°44'W	33	37	20	1db	6	tr	1		tr	1	Zr tr
D-26-96-61(1)	52°16'N,66°52'W	43	14	5	15	16dob	tr		4			Zr tr
D-31-116-61	52°26'N,66°36½'W	43	31	14	3db	7dg	tr			tr	2	Zr tr,Serp tr
D-31-119-61(4)	52°26½'N,66°36½'W	44	9	12	10db	24g	tr		tr	tr		Zr tr
Mean		45.4	22.5	17.9	4.4	6.8	0.4	0.6		tr	0.9	
Mean Dev.		6.0	8.8	6.9	3.3	5.5	0.2	0.6			0.4	

HORNBLENDE PYROXENE GARNET ROCK EAST OF MOISIE RIVER

Sample	Location	Plagioclase An 20 30 40 %	K-spar	Qtz	Bio	Hnb	Epi	Gar	Cpx	Ap	Opq	Others
C-40a-216-61	52°23'N,66°32½'W	27				7b		12	53		tr	Sph tr
C-41-219-61(5)	52°24'N,66°33'W	56		11	10b	13g	2	tr		tr		Carb 8,Zr tr
C-42-223-61	52°24'N,66°35'W	40			7drb	8o		25	9	1	5	Scap 3,Py tr
D-39-146-61	52°17'N,66°30'W	42			8r	29o		18	1	1	1	Sph tr
Mean exc. C-41-219-61		36.3			5.0	14.7		18.3	21.0	0.6	1.6	
Mean Dev. exc. C-41-219-61		6.2			1.7	10.6		4.4	21.3	0.4	1.6	

(1) W. of Moisie, near ultrabasic sill.

(2) Granitized Paragneiss.

(3) Hornblende altered to chlorite.

(4) Banded.

(5) Scarn rock?

Table 25

MINERAL COMPOSITION OF IRON FORMATION SERIES ROCKS (GRAS-FELIX AREA)

Sample	Location	Qtz	Mag	Hem	Cumm	Opx	Cpx	Trem	Act	Carb	Phlg	Musc	Gra	Gar	Others
						Marble									
C-1-5-60(1)	52°15'N,67°05'W	40					40	15		5					
C-6-34-60(2)	52°28'N,67°10'W	tr					75	15		10					
C-30-185-60	52°26'N,67°20½'W	5	1					2		90					
C-39-250-60	52°17'N,67°20½'W	1								95	3				Chl 1
D-26-100-61(3)	52°15¼'N,66°47½'W									65	1				Talc 10,Serp 25
D-26-101-61	52°15¼'N,66°47½'W	10					50	10		10					Plag 20
C-5-18-61	52°31'N,66°51½'W	1					3	8		85	1				
C-8-27-61	52°33'N,66°59'W	1					1	2		96					
C-16-74-61(4)	52°24'N,66°48'W									100					
Mean exc. C-6-34-60		7.2					11.7	4.6		68.2					
Mean Dev. exc. C-6-34-60		8.8					16.7	4.9		28.7					
						Quartzite									
C-14-73-60	52°29'N,67°5'W	93				4	?			2					Rut tr
C-29-179-60	52°21'N,67°23'W	90		5						tr		tr			Anth 3,Zr tr, Ap tr,Tour tr
C-30-153-61(3)	52°15½'N,66°48'W	70											9	10	Bio 7,Py 3
C-32-169-61	52°15½'N,66°53'W	95			2		tr						3		
D-32-120-61	52°26½'N,66°43'W	99													Epi tr
Mean exc. C-30-153-61		94.2													
Mean Dev.		2.7													
						Iron Formation (Oxide Facies)									
C-36-227-60	52°27'N,67°20½'W	60		40											
C-44-297-60	52°30'N,67°26½'W	60		15								20			Bio 2,Tour 1,Zr 1
C-9-32-61	52°28'N,66°59'W	75	15			10	tr			tr					
Mean		65	5	18.3											
Mean Dev.		6.6	6.6	14.3											

(1) Cpx may be white or green.

(2) Not representative.

(3) Altered.

(4) 95% Dol, 5% Cal.

Table 25 (Cont'd)

Iron Formation (Silicate Carbonate Facies)

Sample	Location	Qtz	Opx	Cpx	Cumm	Carb	Mag	Hem	Oliv	Serp	Chl	Others
C-1-1-60(2)	52°16'N,67°6'W	3	65	25	5		2					
C-1-3-60	52°16'N,67°5'W	2	45		6	35	7					Scap 4
C-2-13-60	52°17'N,67°2'W		60	30		10						
C-3-16-60	52°19'N,67°4'W	55	12	23	5							Gra 5
C-3-18-60	52°19'N,67°3'W		65			8	7					Bio 5,Hnb 15,Gar 2
C-6-35-60	52°28'N,67°9½'W	tr	75	10	15		tr					
C-10-59-60	52°28'N,67°4'W		75				5					Bio 5,Gra 5,Gar 10
C-13-67-60	52°28'N,67°0'W	15	70		8	5						
C-19-111-60	52°23½'N,67°5'W	45		40	2	5	2					Gra 3
C-26-162-60	52°17'N,67°12½'W		50	20		25	5					
C-34-212-60(2)	52°26'N,67°16½'W		x	x	x		x					
C-35-217-60	52°26'N,67°17'W	54	15	20	2		11					
C-35-222-60	52°26'N,67°17'W	40	10	20	3		25					
C-39-251-60	52°17'N,67°20½'W	50			40	10	1					Lim tr
C-40-256-60	52°16½'N,67°25'W	15	30	2	5		50					
C-44-272-60	52°22'N,67°28'W	46	37			13	1					Lim 1,Py 1,Minn tr
C-44-277-60	52°21'N,67°28½'W	40		30	7	3	15					Chl 8
L-3-10-60	52°15'N,67°5'W	5	60	30	tr							Gra 2
D-1-4-61	52°32'N,66°56½'W	70	25			3	2					
D-24-84-61	52°18'N,66°49'W	8	25		30							Plag 8,Bio 1,Gar 27
C-12-48-61	52°27'N,66°49'W	85	5	1	10		tr					Gra tr,Bio tr
C-16-77-61	52°24'N,66°46'W	89	6	1	4		tr					Gra 1,Ap tr,Stilp tr
C-18-83-61	52°23'N,66°45½'W	60	40	tr								
C-32-170-61	52°15½'N,66°53'W	62		6	31	1						Gra ½
Mean of 22		33.7	32.9	10.6	7.6	5.3	5.9					4.6
Mean Dev.		26.4	22.4	11.6	7.7	6.0	7.0					

Iron Formation (Olivine Pyroxene Subfacies)

C-6-36-60	52°27'N,67°9'W	45			35	10		10			Bio tr
C-38-246-60	52°16'N,67°28'W	10			3	15		5			Hnb 65,Spn tr
C-44-273-60	52°22'N,67°28'W	35		5	27	9		17			Bio 5,Spn 2,Zr tr,Gar tr
C-46-284-60	52°25'N,67°29'W				3	7		1	50	35	Lim 2,Gar 2
Mean		22.5			17.0	10.2		8.2			
Mean Dev.		17.5			14.0	2.3		5.2			

Table 26

MINERAL COMPOSITION OF ACID IGNEOUS ROCKS (GRAS-FELIX AREA)

Sample	Location	Plagioclase An	%	K-spar	Qtz	Bio	Musc	Hnb	Opx	Cpx	Gar	Epi	Opq	Sph	Ap	Zr	Chl
Quartz Monzonite																	
C-24-136-60	52°18'N,67°15½'W	30-40	20	45	25	5drb		2g			2	tr			tr	tr	
C-44-275-60	52°21½'N,67°30½'W	30-40	42	26	22	3dyb	5										
L-35-145-60	52°25'N,67°27'W	30-40	30	21	22	3db		21g				1		1	tr	tr	
G-5-16-60	52°19'N,67°02'W	30-40	25	35	30	5drb					1			1		1	2
C-30-156-61	52°17'N,66°49'W	30-40	66	13	18			1[1]g			tr		tr		tr	tr	2
Mean			36.6	28.0	23.4	4.0(1)		4.8			0.7						
Mean Dev.			14.1	9.6	3.3	1.6		7.5			0.7						
Granite Derived from Gabbro																	
C-15-88-60	52°17'N,67°8'W	30-40	15	35	25	15vdb	5						5		tr	tr	
C-28-142-61	52°17'N,66°41'W	10-30	42	29	26	2vdb		trg					tr	tr	tr		
C-39-205-61	52°21'N,66°30½'W	30-40	57	24	13	1vdb		1dg					1		tr	tr	
C-40a-213-61	52°23'N,66°32'W	20-30	43	32	23	1b						tr	1		tr	tr	
C-42-222-61	52°22'N,66°43'W	20-30	32	32	33	1b							1			tr	
C-43-228-61	52°24'N,66°44'W	10-30	29	27	41	1b						tr	tr		tr	tr	1
Mean			36.3	29.8	26.8	3.7							1.5		tr		
Mean Dev.			11.0	3.2	6.8	4.0							1.1				
Acidic Orthogneiss from Gabbro																	
C-15-90-60	52°16½'N,67°8'W	30-40	35	4	25	6vdb		20dg			tr		2	5	5		
C-24-122-61(2)	52°15½'N,66°40'W	20-30	47	40				2b	tr	4	6		1		tr		
C-25-129-61(2)(3)	52°15'N,66°39'W	20-30	14	66	16	tr		4vdo		tr	tr		tr			tr	
C-26-131-61(2)(3)	52°17'N,66°41½'W	20-30	31	42	3	2drb		5db	7	7	2		1		2	tr	
C-29-148-61(2)(3)	52°16'N,66°43¾'W	10-30	36	48		tr drb		1do	2	4	5	tr	1		1	tr	
C-29-149-61(2)(3)	52°16'N,66°44½'W	10-30	38	48		tr db		6vdb	1	4	3	tr	1		tr	tr	
C-33-177-61(2)	52°19½'N,66°40½'W	20-30	12	57	25	tr		2db	tr	1	tr		tr	tr	tr	tr	
Mean			30.4	43.6	9.9	1.4		5.7	1.6	2.9	2.5		1.0		1.4	tr	
Mean Dev.			10.0	13.0	10.4	1.4		4.2	1.7	2.1	1.9		0.3		1.3		

(1) Mean Biotite and Chlorite.

(2) K-spar perthitic, contains ¼ to ½ plagioclase.

(3) Cpx is aegirine augite.

Table 27

MINERAL COMPOSITION OF INTERMEDIATE AND BASIC IGNEOUS ROCKS (GRAS-FELIX AREA)

Sample	Location	Plagioclase An 10 20 30 40	%	K-spar	Qtz	Bio	Hnb	Opx	Cpx	Gar	Opq	Ap	Zr	Others
						Intermediate Rocks								
C-15-91-60	52°16½'N,67°7'W		75	tr		8^{drb}	12^{g}			3	2			
G-7-18-60	52°17½'N,67°7'W		58			4^{rb}	16^{og}		8	5		tr		Scap 7,Py tr
D-36-133-61(1)	52°17'N,66°34'W		57		5	9^{rb}	tr	1	13	12	1		tr	Scap 1,Sph tr
D-37-134-61(1)	52°16'N,66°38'W		60			8^{drb}	5^{ob}	2	9	10	4	1		
D-37-135-61	52°16'N,66°38'W		60			15^{drb}	2^{og}		11	5	3	2		
C-12-53-61	52°28'N,66°51½'W		80		2	6^{db}	4^{g}		1	3	tr	tr	tr	
Mean			65.0			8.3	6.6		7.0	6.3	1.8	0.7		
Mean Dev.			8.3			2.4	5.0		4.3	3.1	1.3	0.6		
						Gabbro and Altered Gabbro								
C-15-84-60(2)	52°17'N,67°7'W		20			10^{r}	20^{b}	12	10	5	5			Ol 7,Epi 10
C-15-87-60	52°17'N,67°7'W		60			5^{r}	10^{sec}	5	5	10				Epi 5,Spn tr
C-5-15-61(2)	52°31½'N,66°51'W		55			3^{r}	5^{b}	9	18	10				Pyrr 2
C-5-16-61(2)	52°31½'N,66°51'W		48			tr^{r}	tr	18	11	13		tr		Ol 1,Idd 7,Spn tr, Pyrr 1
C-26-132-61	52°17'N,66°41½'W		46			3^{r}	4^{og}	12	10	15	7			
C-26-133-61(2)(3)	52°17'N,66°41½'W		53			3^{dr}	3^{o}	5	20	13		tr		
C-34-185-61	52°21'N,66°39'W		65			1^{rb}	20^{ob}		2	12	1	tr		Sph tr
C-39-207-61(3)	52°20½'N,66°31'W		56			4^{drb}	20^{b}		3	15	1			
C-39-208-61(3)	52°22'N,66°33'W		30			15^{rb}	38^{ob}	2	4	5	3	1		
C-39-209-61	52°22'N,66°33'W		55			5^{rb}	10^{b}		7	17	2	tr		Sph tr
C-44-230-61	52°28'N,66°30'W		45			7^{rb}	11^{rb}		14	20	2	tr		
C-44-232-61(3)	52°28½'N,66°31'W		28			5^{drb}	2^{rb}	2	29	25	7	1		
C-44-233-61	52°28½'N,66°31'W		60			15^{rb}	2	2	7	12	tr			
Mean			47.8			5.9	11.2	5.1	10.8	13.2	2.2	tr		
Mean Dev.			10.0			3.8	8.2	4.7	6.4	4.0	2.0			

(1) Plagioclase antiperthitic.

(2) Relatively fresh, others are altered.

(3) Cpx is aegirine augite.

Table 27 (Cont'd)

Sample	Location	Plagioclase An 10 20 30 40	%	K-spar	Qtz	Bio	Hnb	Opx	Cpx	Gar	Opq	Ap	Zr	Others
			Metagabbro Amphibolite											
C-10-54-60	52°28'N,67°4'W	⊢	29		5	14^{rb}	34^{g}			8	7	2		
C-15-80-60	52°17'N,67°5½'W	---⊢	23		5	15^{drb}	50^{o}			2		2		
C-29-176-60	52°21'N,67°23'W	–	43		9	7^{b}	15^{lg}				13	2	1	Sph 6,Epi 1
C-44-278-60	52°21'N,67°29'W	–	50			8^{r}	30^{og}			5	7	2		
Mean			36.3		4.8	11.0	32.3			3.8	6.8	2		
Mean Dev.			10.2		2.4	3.5	9.8			2.8	3.4	0		

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67°30'W

53°00'

unmapp

L. VIRO

GREENWATER L.

BOULDER L

JACKSON

Ia

Ib

IIa

IIb

2

3

4a

4b

4d

7a

7c

A
3000
2000
1000
0
MOIRE L.
DAIGLE L.
BLOOM L.
MOGRIDGE L.
HESSE L.
PEKANS R.
52° 45'
67°30' W

67°00'W
53° 00'N

unmapped

L. VIROT

unmapped

L. HUGUETTE

11a

4b

4d

35

50

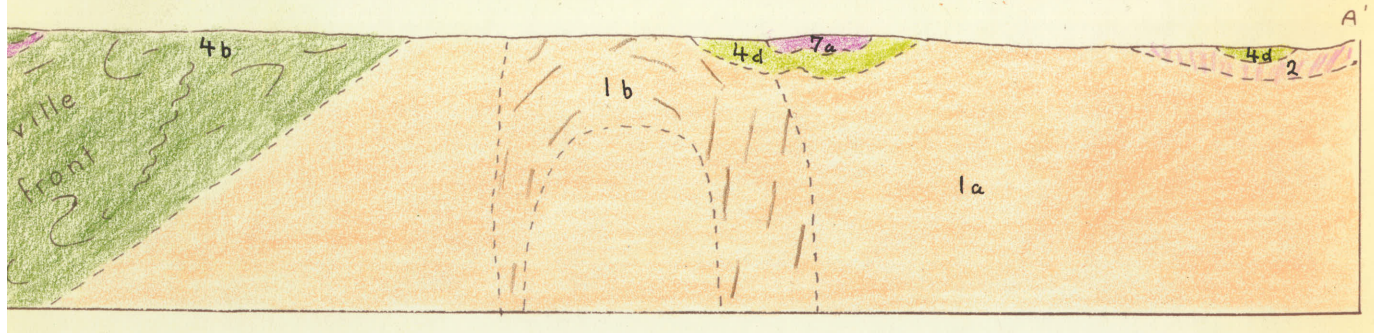
65

70

80

LEGEND

	11b	Metagabbro amphibolite	
P	11a	Gabbro	
R	10	Granitic intrusives	
O	9	Hornblende garnet biotite schist	
T	8	Mica garnet kyanite schist ± graphite	
E	7c	Oxide facies (hematite-rich)	Iron formati
R	7b	Oxide facies (magnetite-rich)	
	7a	Silicate carbonate facies	
O	6b	Muscovite quartzite	
Z	6a	Quartzite	
O	5	Marble	
I	4d	Albite epidote chlorite schist and grit	
C	4c	Porphyroblastic biotite schist	



1b Hypersthene augite granulite

1a Hypersthene granulite

SYMBOLS

- Outcrop
- Geological contact a) approximate, b) assumed
- Contact of iron formation indicated by magnetis
- Strike and dip of bedding
- Strike and dip of foliation
- Trend and plunge of lineation
- Drag fold,
- Assumed anticlinal axis, a) normal, b) overturn
- Assumed synclinal axis, a) normal, b) overturn
- Fault or shear zone
- Esker
- Mineralized outcrop
- Swamp

THE NORMANVILLE AR

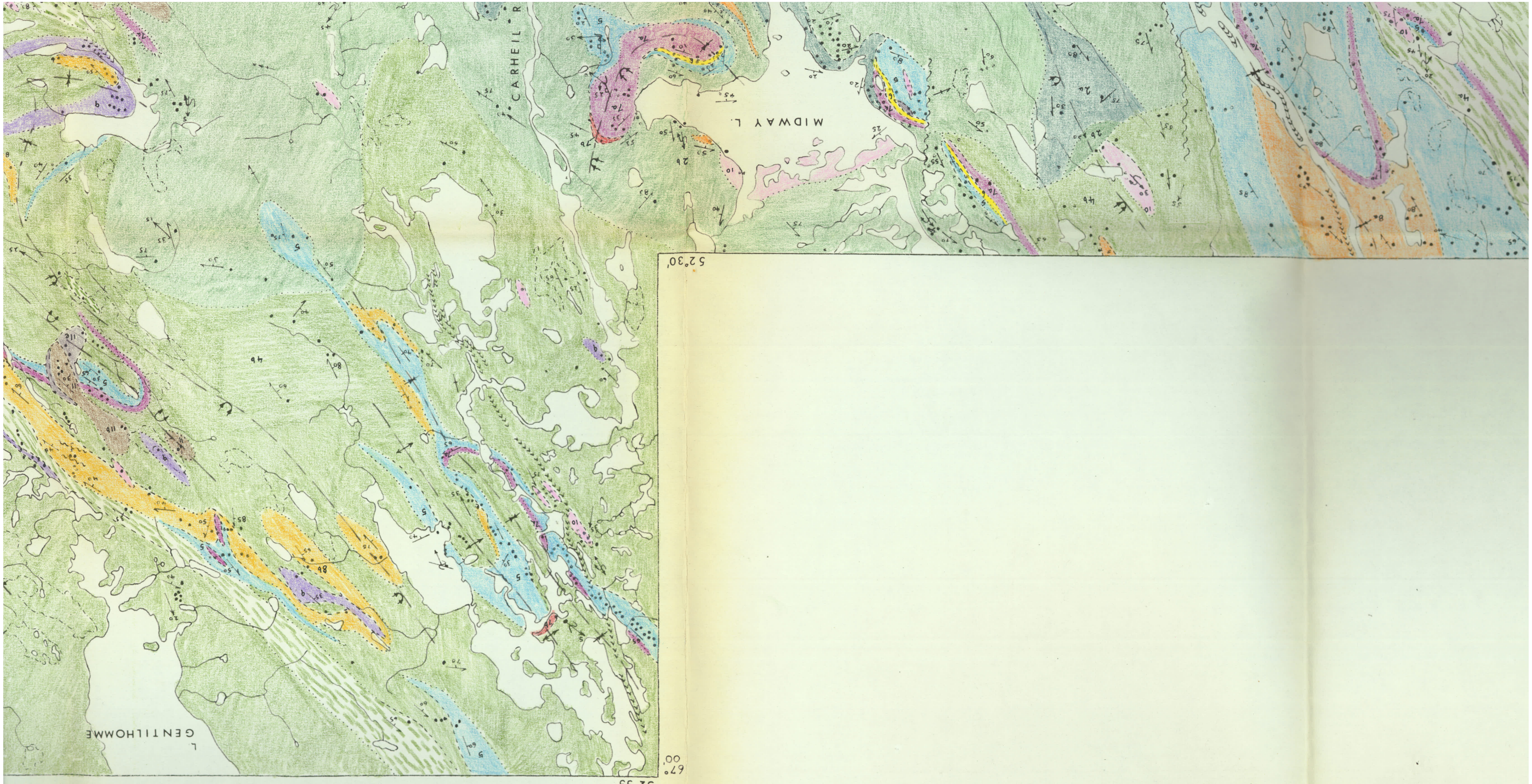
0 1 2 3 miles

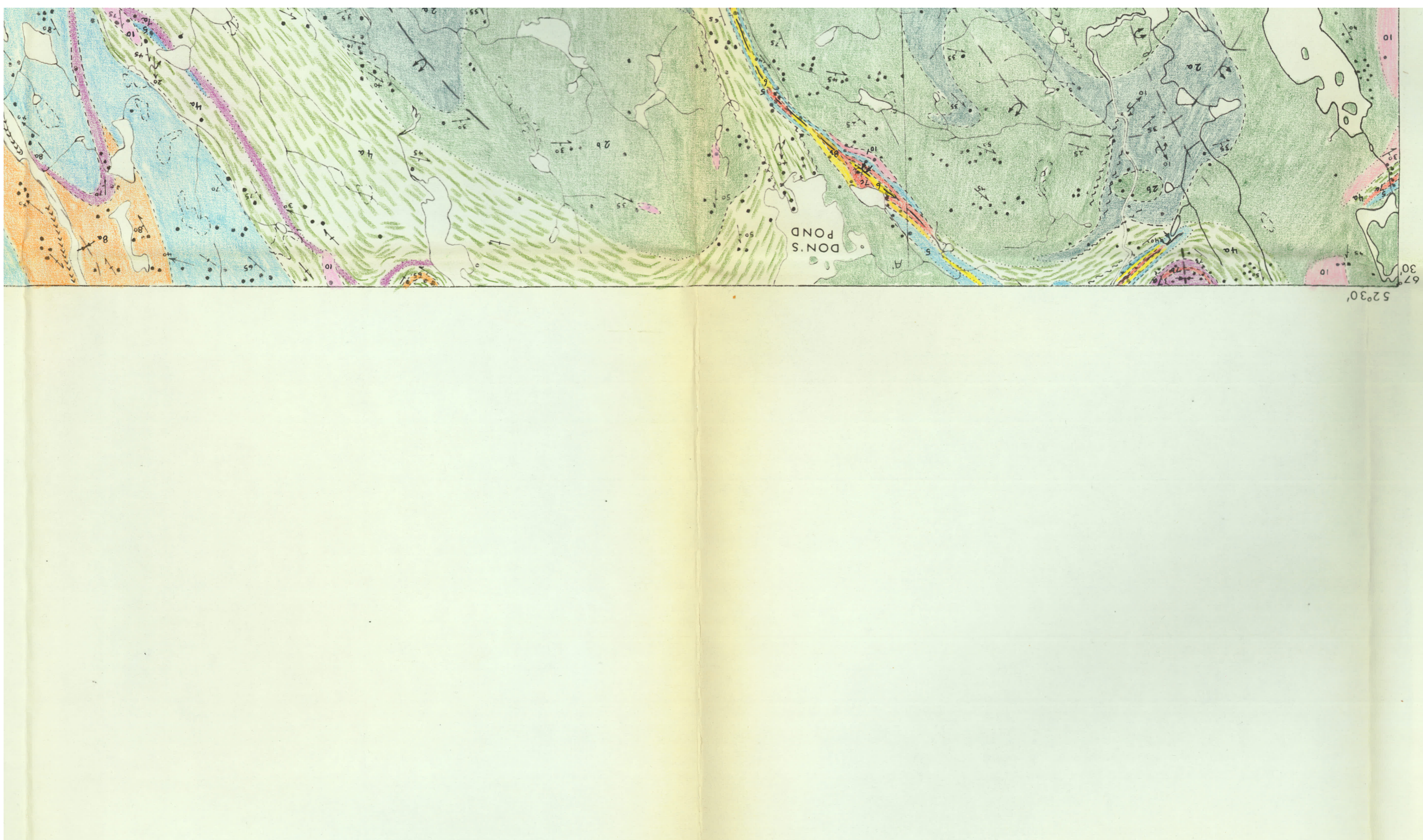
Scale 1 mile = 1 inch

Magnetic declination 29°W

P. J.

L. OPOCOPA
52°30'
66° 30'
52°35'
66° 45'

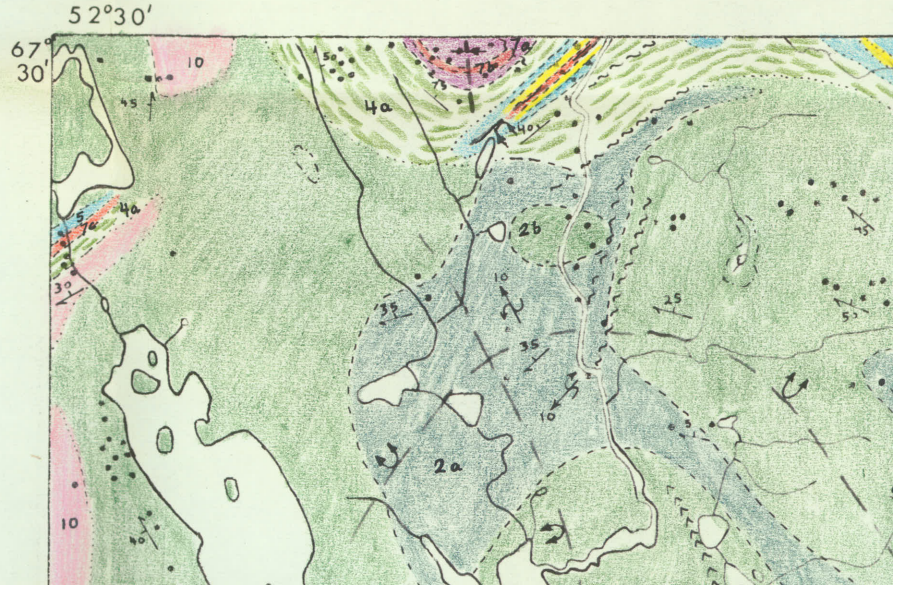

CARHEIL R.
MIDWAY L.
L. GENTILHOMME
52°30'
52°35'
67°00'


DON'S
POND
A
A'
52°30'
67°30'

LEGEND

PROTEROZOIC

14	Syenite
13	Acidic orthogneiss derived from gabbro
11 (e, d, c, b, a)	Gabbro — a) undivided, b) ophitic, c) coronite, d) pyroxene-feldspar-garnet rock, e) amphibolite.
12	Peridotite
10a	Granitized gneiss
10	Granitic intrusions.
9	Hornblende-pyroxene-garnet rock.



MOISIE R.

FELIX L.

FELIX

B'

MOISIE R.

GENTILHOMME R.

LEDUC
L
GRAS
L
HOPE
L
PEKANS
R

RON FORMATION

biotite-rich.

sumed.

gnetism.

of axial plane.

LAMELÉE L.

SEAHORSE L.

HOBDAD L.

LITTLE MANICOUGAN R

FIRE L.

L. BERGERON

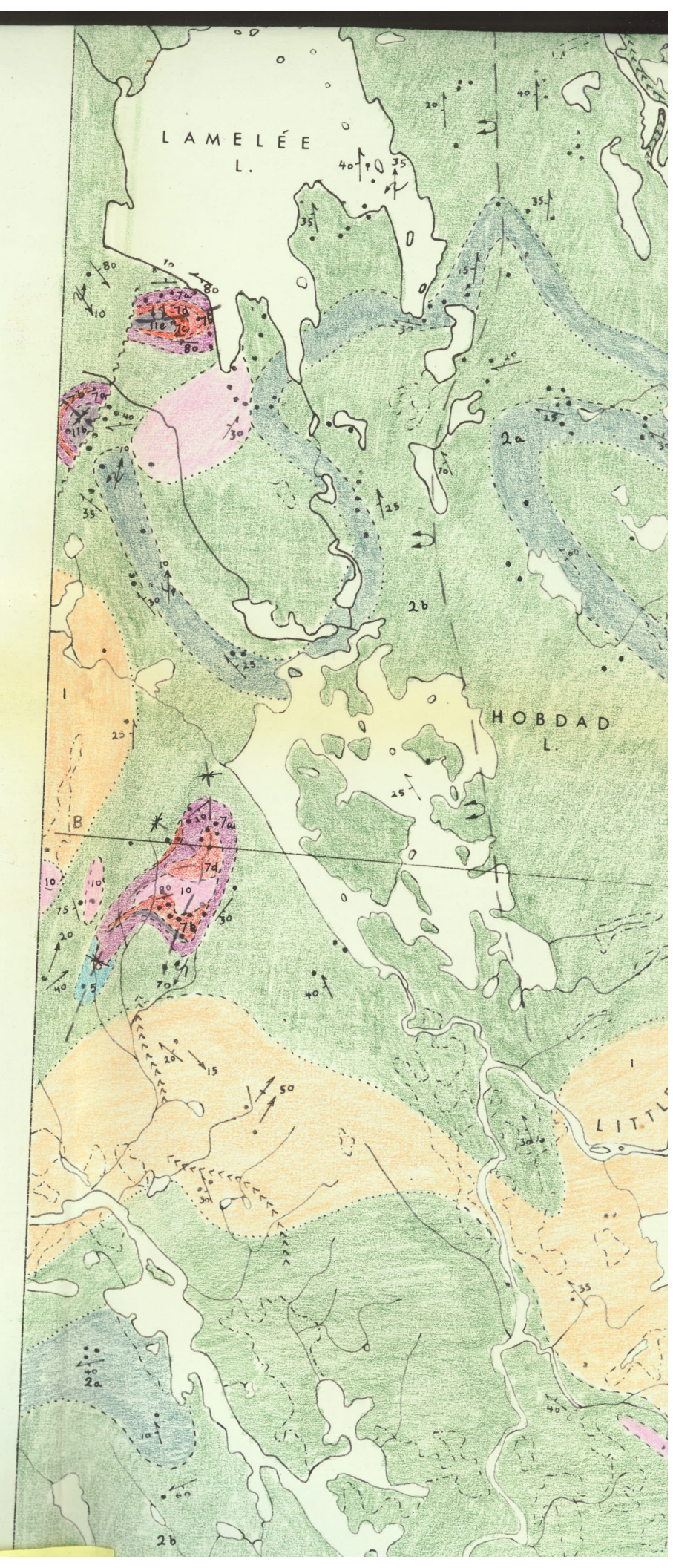
HOPE L.

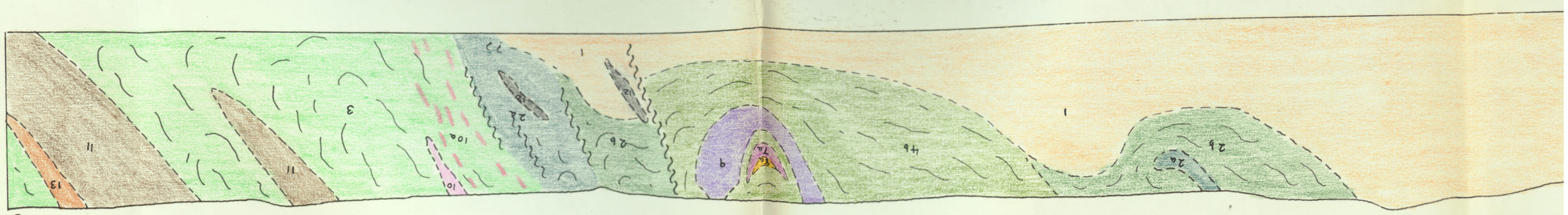
ARCHEAN ? - CENOZOIC ?

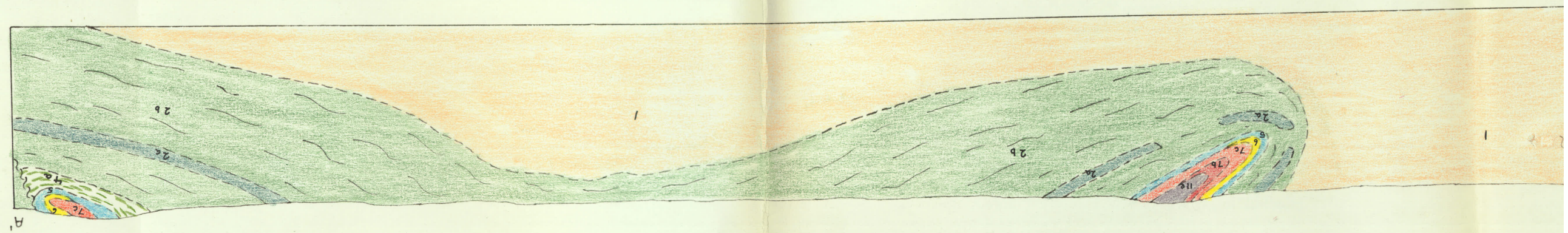
7c	Oxide facies (magnetite-rich)
7a	Oxide facies (hematite-rich)
	Silicate-carbonate facies.
	IRON FORMATION
6	Quartzite
5	Marble
4c	Unsegregated hornblende gneiss.
4b	Unsegregated biotite gneiss.
4a	Porphyroblastic or banded gneiss
a. 3 b.	Potassic gneiss, a) hornblende-rich, b) biotite-rich.
2a	Well segregated hornblende gneiss.
2b	Well segregated biotite gneiss.
1	Altered hypersthene granulite.

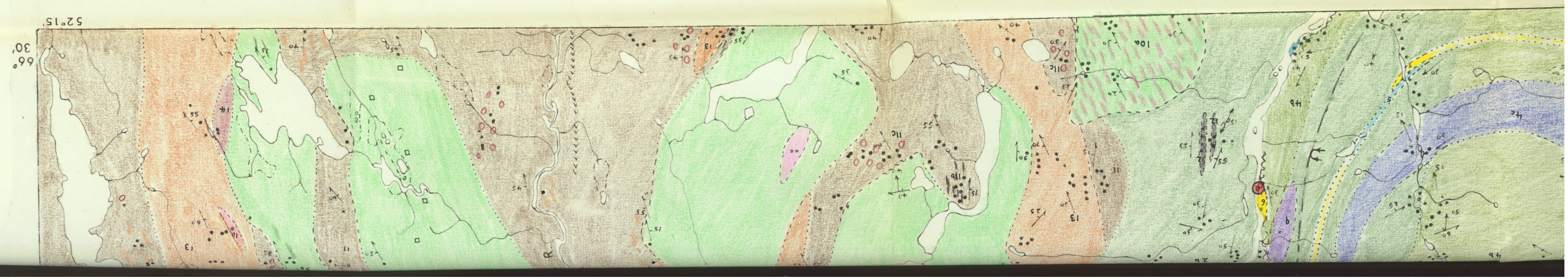
SYMBOLS

- Outcrop.
- Geological contact a) approximate, b) assumed.
- Boundary of iron formation indicated by magnetism.
- 50 — Strike and dip of bedding.
- 50 — Strike and dip of foliation.
- 50 — Trend and plunge of lineation.
- 30 50 — Drag fold, showing plunge of axis and attitude of axial plane.
- Assumed anticlinal axis.




B'
13
II
3
II
10a
10
2d
2c
2b
4b
9
1a
1
12
2d
2c
2b
1


A'
7c
7a
6
4a
2b
2c
1
2b
2a
6
7c
7b
11c
2a


52°15'
66°
30'
10a
11c
4b
4c
13
11
9
2b

67° 00'

52°15'

TODD L.

PEKANS R.

A

0

1000

2000

3000

Qa

Qg

Qt

Qs

Qb

Qp

Qe

Qh

Ql

Qa

Qg

Qt

Qs

Qb

Qp

Qe

Qh

Ql

Qa

Qg

Qt

Qs

Qb

Qp

Qe

Qh

Ql

Qa

Qg

Qt

Qs

Qb

Qp

Qe

Qh

Ql

unmapped

unmapped

unmapped

67°
30'

A

B

3000
2000
1000
0

EA

Drag fold, showing plunge of axis and attitude of axial plane.

Assumed anticlinal axis, a) normal, b) overturned, c) fan-fold.

Assumed synclinal axis, a) normal, b) overturned.

Fault or shear zone a) observed, b) inferred.

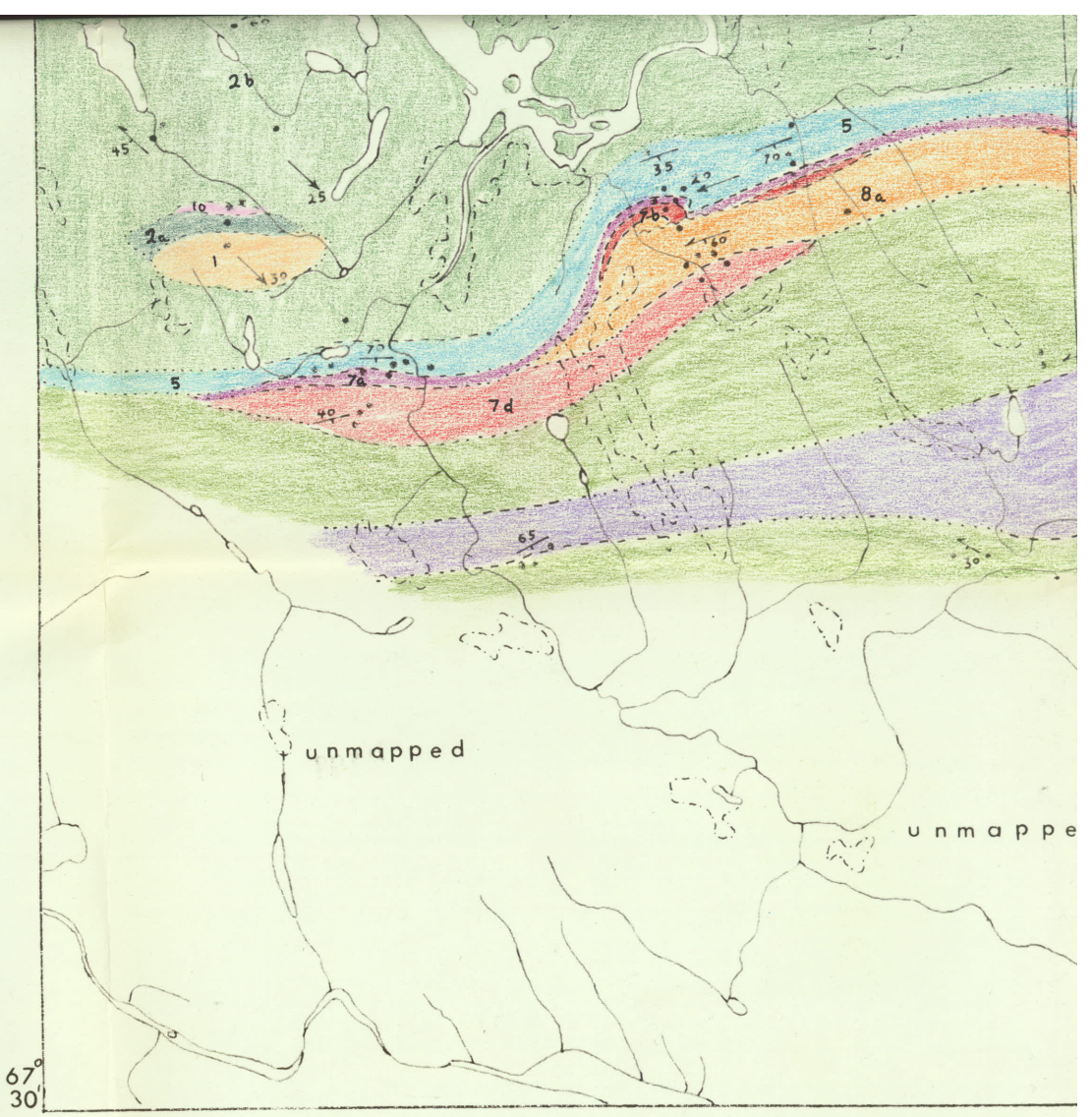
Esker

Mineralized outcrop with reference letter.

Swamp.

Frost-heaved blocks in place.

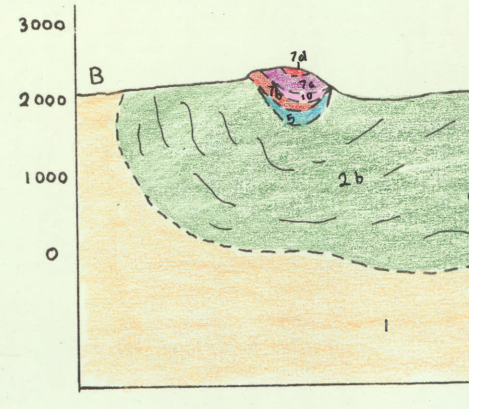
Float from the iron formation series.



THE GRAS LAKE-FELIX LAKE AREA

0 1 2 3 4
miles miles

Scale 1 mile = 1 inch

Magnetic declination 29°

P.J. Clarke 1963