The Geology of the Eastern Border of the "Labrador Trough", East of Thevenet Lake, New Quebec.

A THESIS

Submitted to the Department of Geological Sciences of McGill University in partial fulfillment of the requirements for the degree of Master of Science

by

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TABLE OF CONTENTS

I INTRODUCTION PAGE

Acknowledgements VI
General Statement 1
Location, accessibility and communication 1
Geography
Physiography
Topography 3
Glaciation 4
Drainage 6
Climate 7
Flora and Fauna 7
Mapping Procedure 8
History and previous work 9

II GEOLOGY

Regional picture 11
Geologic Characteristics of the map area 12

III STRUCTURAL GEOLOGY

Regional pattern 15
Structural features of the map area 16
1. Folds 16
2. Faults 16
3. Joints 18
4. Foliate structures 18
5. Lineation 19
6. Augenstructure 19

IV LITHOLOGY AND PETROGRAPHY

Laboratory methods 20
Megascopic and microscopic description.
Amphibolite
General Statement 20
Massive Amphibolite 21
Porphyroblastic Amphibolite 24
Garnet Amphibolite 30
Pyroxene Amphibolite 30
Lime Quartzite
Limestone and Dolomite
General Statement 37
Fe-Mg Limestone 38
Dolomitic marble and Dolomite Amphibolite complex 38
Mica-Schist 42
Granite-Gneiss-migmatite complex 48
Megascopic Description 50
Microscopic Description
Foliation and schistosity 54
Linear structures 54
Minerals present 54

V PROGRESSIVE REGIONAL METAMORPHISM AND METASOMATISM — PAGE

General Statement 58
Mineral assemblages 58
Application of facies principle 63
Biotite Isograd 66
Garnet Isograd 66
Epidote-Amphibolite facies 68
Minerals present 69
Lower, medium, high parts of the epidote-amphibolite facies . . 69
Disequilibrium 71
Progressive disequilibrium 71
Retrograde disequilibrium 71
Metasomatism 72
Summary of the evidence of progressive regional metamorphism from West to East and Northeast 74
Causes of metamorphism in the area under discussion . . 75

VI PETROGENESIS

Introduction 77
Amphibolite derived from gabbro 77
Amphibolite derived from dolomite or impure FeMg Limestone . . 78
Origin of granite-gneiss-migmatite complex 81
Origin of garnet mica schist 82

VII HYPOTHETICAL HISTORY OF THE AREA 85

VIII SUMMARY AND CONCLUSIONS 89

IX BIBLIOGRAPHY 91

LIST OF ILLUSTRATIONS

		PAGE
Figure 1.	Location of map area	2
" 2.	Air Photo Mosaic	5
Plate I.	(Fig.3 - Porphyroblastic amphibolite (" 4 - Garnet Mica Schist (" 5 - Garnet Amphibolite	25
Plate II.	(Fig.6 - Garnet Amphibolite (" 7 - Porphyroblastic Amphibolite (" 8 - Porphyroblastic Amphibolite	27
Plate III.	(Fig.9 - Porphyroblastic Amphibolite (" 10 - Staurolite Amphibolite in gneiss (" 11 - Amphibolite within gneiss	29
Plate IV.	(Fig.12 - Amphibolite within gneiss . . . . (" 13 - Garnet Hornblende schist (" 14 - Epidote Amphibolite	32
Plate V.	(Fig.15 - Pyroxene Amphibolite . . . . . (" 16 - Pyroxene Amphibolite (" 17 - Garnet Mica Schist	35
Plate VI.	(Fig.18 - Magnesian Limestone (" 19 - Actinolite Schist (" 20 - Impure calcareous rock	40
Plate VII.	(Fig.21 - Garnet Mica Schist (" 22 - Antigorite-Garnet Mica Schist (" 23 - Garnet Mica Schist	44
Plate VIII.	(Fig.24 - Garnet Hornblende Schist (" 25 - Mica-Schist (" 26 - Grunerite Schist	46
Plate IX.	(Fig.27 - Hornblende-Mica Gneiss (" 28 - Schistose Gneiss	49
Plate X.	(Fig.29 - Lenticular Gneiss (" 30 - Gneiss	52
Plate XI.	(Fig.31 - Lenticular Gneiss (" 32 - Hornblende Gneiss (" 33 - Mica Schist	56
Figure 34	Biotite and Garnet Isograds	65
" 35	Hypothetical sequence of events	86

PAGE

Table	I	Massive Amphibolite	23
Table	II	Porphyroblastic Amphibolite	28
Table	III	Garnet Amphibolite	31
Table	IV	Pyroxene Amphibolite	34
Table	V	Magnesium-Rich, Ferr. Limestone	39
Table	VI	Garnet Mica Schist	43
Table	VII	Gneiss Complex	53
Table	VIII	Chemical Analyses of Amphibolites	79
Table	IX	Chemical Analyses of Gneisses.	83

M A P S

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1. Outcrop map . . .
2. Map showing tentative geological interpretation . . .
3. Metamorphic facies superimposed on outcrop map . . .

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INTRODUCTION

Acknowledgements:

The writer wishes to thankfully acknowledge the valuable assistance and encouragement received from Dr. I.W. Jones, Chief of the Geological Surveys Branch of the Quebec Department of Mines, who kindly supplied the writer with thin sections and aerial photographs; and to Dr. R. Bergeron, Geologist for the Quebec Department of Mines. Also, his appreciation to C. Lafortune for his co-operation and assistance in the field.

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GENERAL STATEMENT:

This thesis represents a general study of the geology of an area of approximately 140 square miles, situated in Ungava, New Quebec, which covers part of the eastern "contact" of the so called "Labrador Trough" with the granite-gneiss-migmatite complex.

The study is based on field work carried out during the summers of 1954 and 1955 for the Quebec Department of Mines, and laboratory investigation at McGill University during 1955 and 1956. The object of this paper is to prove that the rocks in that part of the "Labrador Trough" show progressive regional metamorphism towards the East and North. A further attempt is made to locate the eastern borderline of the "Trough" in that area and to elucidate the relationship between the rocks of the "Trough" and the granite-gneiss-migmatite complex. Two maps with a scale of one inch to half a mile, and a series of illustrations accompany this report.

LOCATION, ACCESSIBILITY AND COMMUNICATION:

The area is situated about 30 miles S.80°W. of Fort Chimo in northern Ungava, New Quebec. It is an area ten miles wide and about 14 miles long, and lies between latitudes 69°07' and 69°18' and longitudes 58°02' and 58°09' (Fig. 1).

The area may be easily reached by air from Fort Chimo, which has an air strip and is open to shipping from July until October. The main sea plane base which provided communication and supplies for the field parties of the Department of Mines was located at Stewart Lake, a few miles west of Fort Chimo. It can be said that the entire region is very easily accessible to sea-planes on account of the numerous, usually deep and long lakes that dot the country side.

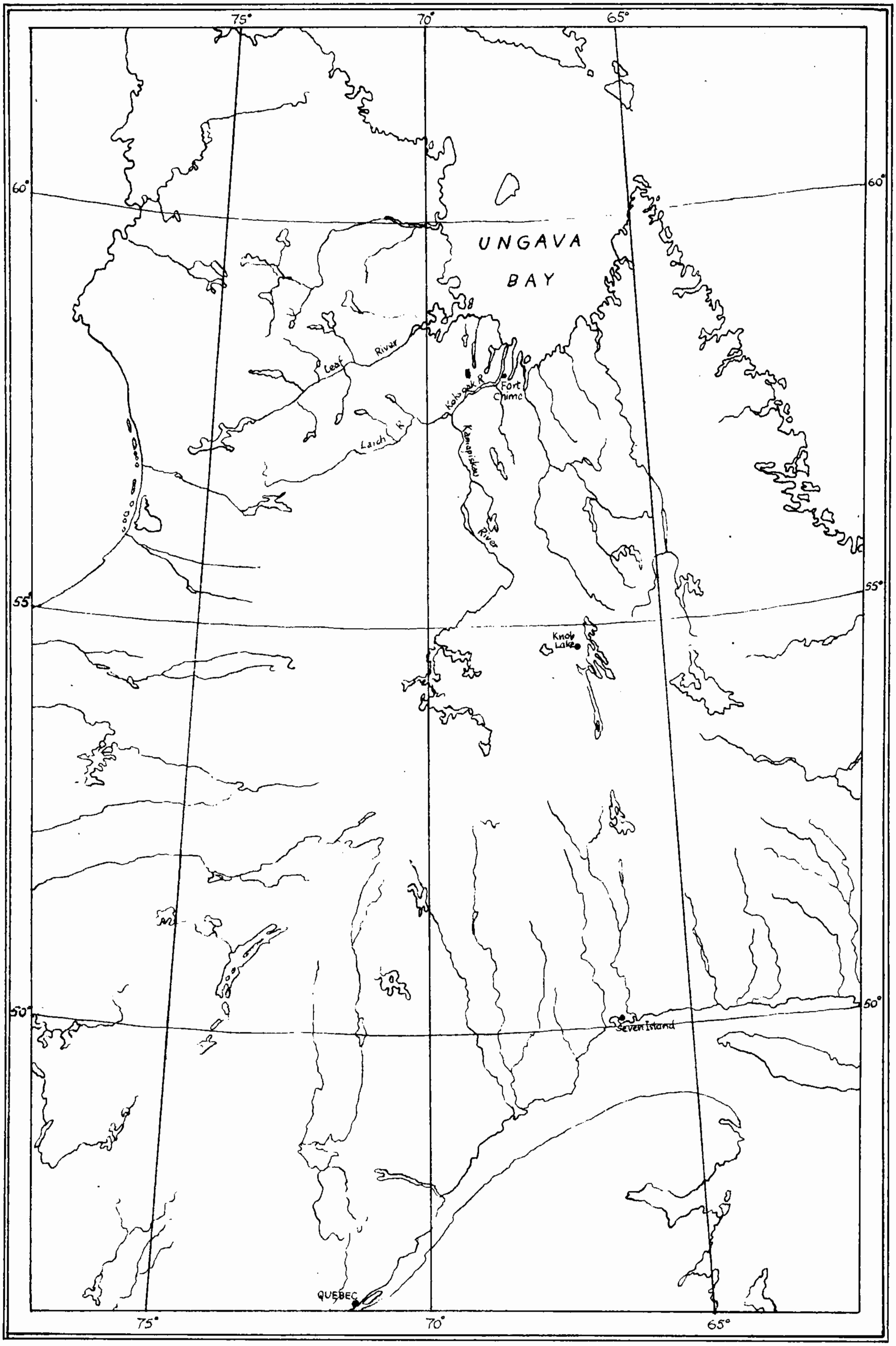

Fig. 1.

Location of the Map Area

Scale: 1 inch to 120 miles

G E O G R A P H Y

PHYSIOGRAPHY:

TOPOGRAPHY

Topographically the map area is sharply divided into two contrasting parts by a line extending northwards between the "Labrador Trough" to the west and the region of granite and gneiss to the East (Fig. 2). The latter forms a lowland with only minor irregularities and small relief. The Trough area to the west lies above this lowland. On one side is a featureless white plain and on the other great black hills extend in succeeding ridges to the horizon. The ridges are generally underlain by resistant rocks such as gabbros, volcanics or quartzites which dip at low angles to the east. Thus the ridges have a steep western side and a more gentle slope on the eastern side. The valleys are usually underlain by sedimentary rocks such as argillites, dolomites, limestones, schists or shear zones and form the beds of lakes and rivers. These reflect, in their shape and size, the structural character of the area. It was later modified by glacial action which disturbed the pre-glacial trellis drainage system by irregular deposition of drift.

The part of the "Labrador Trough" under study lies between 600 and 900 feet above sea level. The local relief is about 200 feet.

The topography east of the "Labrador Trough" is typical of the Canadian Shield. About 30 per cent of the area is covered by water and of the remaining land area approximately 50 per cent consists of bed rock. Here too the nature of the underlying bed rock and its geologic structure has had a definite influence on the development of the topography of the region. The configuration of the shore lines and of the islands of the major lakes largely conforms to the trend of the rock foliation. But this topography is strikingly different from the "Labrador Trough" in that it is essentially a slightly undulated plateau of about the same elevation (800 feet) forming the even skyline so characteristic of the Canadian Shield. On maps and aerial photographs the dendritic pattern of the gneisses may be readily distinguished from the trellis pattern of the adjacent Trough area. (Fig. 2). The gneiss area has a fold structure, but there are no physiographic features of consequence aside from the lakes.

Thus a clear structural control shapes the surface of one half of the area and in the other part there is not much left except the level surface of denudation.

GLACIATION:

Continental glaciation has eroded the lake basins and rounded, grooved, and polished the hill tops. Good evidence of plucking along the sides of the ridges can be seen. The valleys have been deepened and striae and gouges parallel to the general trend of the ridges indicate the direction of the last movement of the glaciers to be from N.30°E. to due north, the variation in direction being mainly influenced by the foliation and relative hardness of the rock formations. East of Renia Lake the parallel north-west trending ridges of amphibolite have been particularly resistant to erosion and consequently form the more prominent ridges. (Fig. 2). Bands of soft argillites and schists on

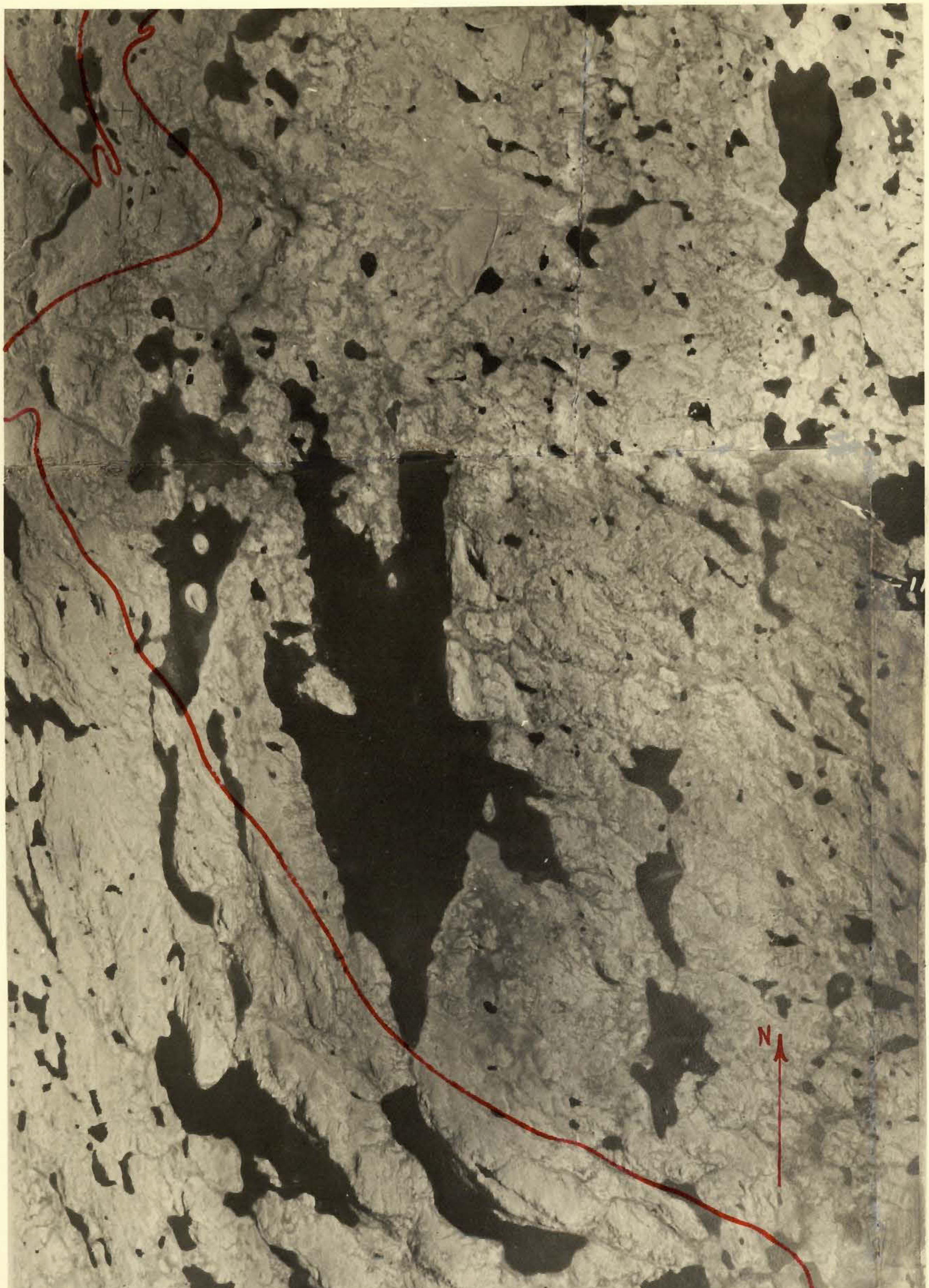

Fig. 2. Air photo-mosaic showing the location of the "contact" between the "Trough" rocks on the west and the gneiss complex on the east.
Approximate scale 1 mile - 1 inch.

the other hand have been easily eroded and are now hidden in lake basins or exposed on valley walls. West of Renia Lake, paragneisses and migmatites appear to have had variable resistance to the forces of erosion and form a plateau-like region. Glacial forms such as striae, steepend slopes, and roches moutonnées are common. The fact that southwest lee end of the roches moutonnées are steeper than the northeast end suggests that the direction of movement of the main mass of ice was in a east-north-east direction and that some of the glaciers were deflected northward by the well developed steep north facing valleys. The valleys and depressions are mostly filled with debris that has been eroded off nearby hills and outcrops. Large tracts of land, particularly two miles east of Renia Lake, are covered with this debris and consequently deprives the area of visible outcrop. Ground moraines can be observed, especially east of Renia Lake, which consist of unstratified drift material. Kettles, eskers, drumlins, kames, and other glacial features are not very common in the map area, but have been observed east of the map area. Subrounded boulders of augengneiss, some of them weighing several tons, are common and indicate that they were not carried far beyond their place of origin.

DRAINAGE:

Drainage is very poor and is the result of disturbance of a pre-existing river drainage system by pleistocene glaciation. Flowage of the surface water takes place through a series of elongated lakes connected by short stretches of fast waters with small rapids. The lakes have several inlets and outlets, a typical feature of a glacially disturbed drainage system. As has been mentioned above, a well developed trellis drainage pattern is readily discernable in the "Trough" area, whereas a dendritic pattern prevails in the neighbouring gneissic complex. There are no large rivers in the map area and it contains few swampy areas.

CLIMATE:

The climate of the northern part of the "Labrador Trough" is surprisingly mild. During the winter the temperature may be as mild as 45°, yet the average for December and January in 1951 and 1952 was 8° below zero. (Auger-1954). It is much milder and generally has less overcast weather than further south; this is probably due to the low altitude of the area (within 500 feet above sea level) and to the proximity of the sea in Ungava Bay. Nevertheless a few snow patches still persist until the end of June and snow storms in July are not uncommon. During the summer of 1954, exact measurements of temperature were taken and temperatures varying from 25° to 95° were recorded (Gelinas). The area is very windy and during most of the season south and southwest winds prevail. The precipitation is small and is supposed to be 18 inches (Bergeron-1954), although, "A day hardly passes without a drizzle"(Low-1893).

FLORA AND FAUNA:

The general aspect is one of the very meagre plant and animal life. The scarcity of vegetation in this area is caused in part by the climatic conditions which prevail there. The temperature is dependent on the direction of the wind and the northeast wind is often accompanied by snow, even as late as the end of August. Apart from a few species of conifers, such as balsam fir, tamarack, and black spruce, the region is treeless. Clusters of Labrador tea (Ledum Latifolium) everywhere dot the countryside and the ground is covered to a great extent by a tapestry of lichens of the cladonia species. Under the dehydrating action of the sun these shrink into polygonal patterns 12 to 25 inches in diameter. It is interesting to note that the aforementioned lichens absorb the abundant nocturnal dew to such a degree as to become spongy and slippery. There are also other varieties of multi-colored moss, mushrooms, and wild species of minute raspberries, cranberries, and a few kinds of sour blueberries.

The harsh climate and the small variety of plant life in the region make it difficult for much animal life to develop freely. Cariboo, contrary to one's expectations, are not found in the area because of past forest fires, disease and their extermination by the Indians. Some fur bearing animals such as foxes, muscrat, and many kinds of small rodents may be found.

Birds, on the other hand, are more plentiful. The Ptarmigan or Arctic partridge (Lagopus lagopus) is the species most frequently seen. Canada geese, seagulls, different kinds of ducks, red throated loons, white crown sparrows, duck hawks and the familiar American robin are quite common. Butterflies are rarely seen. The lakes harbour many fish; the most common are grey and red trout. Any description of this area and of Ungava would be incomplete without mention of the mosquitoes and black flies which make outdoor existence sometimes very miserable.

MAPPING PROCEDURE:

Mapping of the area was done on a scale of one inch to one half mile and was based on aerial photographs supplied by the Royal

Canadian Air Force. The photographs (scale one inch to one half mile) were used continually in the field to locate and control the traverses. They were useful in providing geological information such as continuity of rock types, structural features etc., and as a guide in obtaining topographical details. As far as possible the traverses were arranged so as to cross the trend of the formations. The data was then plotted onto a base map of the same scale supplied by the Quebec Department of Mines. No systematic and rigid pace-and-compass traverses were made.

Approximately 140 square miles were covered by this method which proved accurate and fast for observing and recording geological details.

HISTORY AND PREVIOUS WORK

Dr. Mendry is believed to be the first white man whose travels in that part of Ungava have been recorded. Fort Chimo, in Ungava Bay, was established by Mendry in 1827 as a trading post.

The first geological work in this district was carried out by A.P. Low of the Geological Survey of Canada. In 1892 he descended Kaniapiskau river and Koksoak river to their estuaries in Ungava Bay and it was he who first established a rough outline of the boundary lines of the "Labrador Trough". Subsequently to this, wide spread geological surveys have been undertaken by the Geological Survey of Canada, the Quebec Department of Mines, and various companies. Exploration was started on the Iron Belt and other sulphide deposits by such mining companies as Iron Ore Company of Canada, Hollinger North Shore Exploration Company and Fenimore Iron Mines, and their information has greatly clarified the geological picture in this region. Finally, several preliminary reports from the Government Service of Canada, the Province of Quebec, and mining companies have been made available. Among these are Thevenet Lake area 1954, immediately to the west of the map area; Harrison's and Fahrig's reports, (1952-1954) south of the map area and Auger's preliminary paper (1955), north-east of the Renia Lake area.

II - G E O L O G Y

Regional Picture:

Through the Renia Lake map area runs the dividing line between the "Trough" rocks on the west and the gneiss-migmatite complex to the east.

The "Labrador Trough" is a relatively narrow belt of folded and faulted late Pre-Cambrian volcanic and sedimentary rocks extending from the centre of the Province of Quebec towards the northwest as far north as the west shore of Ungava Bay (Auger 1954). It is an elongated geosynclinal basin, at least 600 miles long and from 5 to 60 miles wide (Dufresne 1953). In spite of the variation in width from one end to the other, the "Trough" is very constant if one considers the nature of the various members composing it. On the west, quartzite, dolomite and iron formations of the "Trough" unconformably overly the granite and granite-gneiss. They are in turn overlain by a succession of sediments, volcanics, and gabbro sills which take up the rest of the central and eastern portion of the "Trough". A strong lineament representing a structural and lithological break, separates the eastern "Trough" rocks from the gneiss complex. The latter consists of a large number of lithological varieties, most of them gneisses with all grades of dynamothermal metamorphic effects. Thermal effects are superimposed on the regionally metamorphosed rocks and in many places metasomatism has produced rocks near granite in composition. The rocks vary from black hornblende gneisses and mica schists to quartzites, migmatites, and granites. The lithology resembles the complex found in the Grenville Province; it varies both across and along the formational trend, due in part to particular, lensitic members and in part to variation in degree of metamorphism and granitization. The extreme heterogeneity may be due to variations in the amounts of two end products: one composed mostly of sedimentary material and the other of intrusive origin, but modified by the assimilation of the intruded rock. The granitized argillites, for that is what the paragneisses originally were, probably owe their present metamorphic state to thermal and metasomatic alteration in depth, accompanied by intense deformation orogenic in nature. Erosion cut down and laid bare a deeper part of the section, where all the rocks, both invaded and invading, everywhere show indisputable evidence of great movement while in a soft and plastic condition. The roots of a former mountain built belt are displayed here.

In the region south and southwest of Ungava Bay, the rocks of the "Trough" have been divided into the Kaniapiskau and Chimo group (Dufresne 1953, Bergeron 1954). The Kaniapiskau group comprises quartzites, sandstones, dolomites, and iron formations that outcrop in the western half of the "Trough". The Chimo group includes the folded and faulted succession of volcanic, sedimentary, and intrusive rocks found in the eastern half of the "Trough".

Progressive regional metamorphism has been observed from west to east.

Geologic Characteristics of the Map Area:

The "Trough" in the Renia Lake area is believed to be approximately 20 miles wide and gradually decreases in width towards the north (Auger 1954). Former shales, limestones, dolomites, iron formations, volcanics, and basic intrusives have been regionally metamorphosed to mica schists, marbles, amphibolites, and hornblende schists which, in the map area, correspond to an assemblage of rocks typical of the epidote amphibolite facies.

At the western margin of the map area, the mica schists are mainly fine grained and contain biotite, muscovite and small garnets; chlorite is either absent or retrograde. Further east the mica schists are progressively coarser grained and develop quartzo-feldspathic layers and veins. Associated hornblende schists and amphibolites contain abundant epidote and carbonates, and dolomitic rocks contain, along with carbonates, either only tremolite in large, pale green blades or both tremolite and diopside. Basic intrusives have been metamorphosed to diopside amphibolites which still retain the basic characteristics of former intrusive rocks. There is no doubt in the writer's mind that the rocks between Thevenet Lake and Renia Lake increase in metamorphic grade from west to east, from greenschist facies to high epidote-amphibolite facies (staurolite-cyanite) east of Renia Lake. The granitized rocks further east probably represent the amphibolite facies.

Directly west of Renia Lake there is a sharp lithological, structural and topographical break between the above described meta-sediments and basalts of the "Trough" on the west and the schists and gneiss complex in the east. A fault of considerable magnitude is present. East of the fault, the rocks are predominantly paragneisses that grade into migmatites and granite gneisses. Further east, the migmatites are accompanied by unrestricted and very heterogenous granitic masses characterized by a texture which is often porphyritic and by the abundance of amphibolite enclaves. Numerous pegmatites and leucocratic porphyritic dikes cut this complex and increase in number from west to east. It is likely that a fault zone along the eastern border of the "Trough" separates lower grade metabasalts and sediments from generally higher schists and gneisses to the east. That the lineament has not been recognized as a fault might be due to granitization of the rocks during or after deformation. Of course, movement may have occurred at more than one time and the fault might have been deformed by later folding.

Since the metamorphism increases gradually through the eastern "Trough" strata toward the gneisses without an evident discontinuity in grade, it is likely that metamorphism and related granitization are younger than the "Trough" strata. The writer also believes that some of the gneisses are essentially of the same material, as the "Trough" strata.

No attempt has been made by the writer to correlate the rock types of the map area with other areas to the south and north. The smallness of the area, the paucity of structural data and the complexity of folding and faulting, and the lack of distinctive characteristics of many of the rocks would make correlation too hazardous. No definite marker horizon was found, although a narrow recrystallized impure limestone seemed to follow the "contact".

STRUCTURAL GEOLOGY

Regional Pattern:

As mentioned above, the "Labrador Trough" consists of highly folded and faulted, proterozoic rocks that occupy a broad belt that trends northwest. Most folds are overturned to the southwest at moderate to steep angles and cut into numerous slices by thrust-faults that dip northeast. The southwest contact of the "Trough" with the Archaean gneisses represents a regional angular unconformity while the northeast border of the proterozoic "Trough" in the Burnt Creek area is marked by a broad zone of heavily sheared rocks that suggest a major fault (Harrison 1952). Gill (1952) refers to this belt of folded and faulted late Pre-Cambrian rocks as the "Ungava Mountain built belt". As the "Trough" is not a depression, but lies at the same elevation as the surrounding country, nor is it structurally a simple basin, this belt should be termed "Labrador Geosyncline", or "Labrador Miogeosyncline". Furthermore, the opposite sides of the "Trough" do not match, and the dips are mainly to the northeast. It has been suggested, (Gill, personal communication) that the so-called "Labrador Trough" represents a foot-hill zone of a truncated mountain built belt, typified by the granite-gneiss-migmatite-paragneiss complex to the east. The flat lying sediments in the west, increasing folding, faulting, and thrust faulting, as well as the highly disturbed condition of the rocks that show symptoms of flowage and plasticity in the east make this view highly plausible.

The predominant northwesterly trend of the sedimentary belt and the attitude of the axial plains indicate compression in a northeast, southwest direction.

Structural Features of the Map Area:

The area involved in this thesis lies along the eastern edge of the northern part of the "Labrador Geosyncline" and includes the "contact" between the foothill rocks, i.e. "Labrador Trough" and the gneiss-migmatite complex. The general structural trends are reflected by the distribution of the metasedimentary rocks and metabasalts, and especially well by the former gabbro sills, now massive amphibolites, that are shown in the southwest corner of the accompanying map. The general strike of the formations is N.30°W., but varies locally between N.80°W. and N.80°E. (Map and Figure 2). The dip is consistently between 20° and 40° to the northeast and southeast. Strong recrystallization, induced by regional metamorphism, has destroyed all primary structures of the sedimentary and volcanic rocks. The structural elements observed in these rocks include folds, faults, joints, foliate, and lineate structures.

Folds:

The sedimentary rocks and the derived schists and gneisses are intricately folded wherever they occur in the present map area. In the "Labrador Trough" area, the plunge of folds is commonly less than 30° to the northwest, but reversals of direction of plunge may occur in a distance of a few feet as shown by drag-folds. All folds are overturned to the southwest and their axial plain probably dips 20° to 30° to the northeast. They appear to be zig zag folds.

Faults:

Although many minor faults are probably present in the region there is one major break which dominates the map area. As has been mentioned previously, this fault separates the rocks of the "Labrador Trough" from schists and gneisses in the east. This line is remarkably straight in its southern course, then in the northwest corner of the area it becomes highly dentate (Map and Figure 2). Bays of gneiss reach far into the "Trough" area; no metamorphic effects were observed along it. The divergence in strike and the dissimilarity in lithology on either side, as well as the marked difference in topographic features make the assumption highly plausible that a fault is here present. The sineousity of the contact is probably the result of later folding and erosion which obliterated all the fault evidence that might have existed. The sudden termination of the folded late Pre-Cambrian rocks, the lack of metamorphic effects along the "contact", and the difference in lithology on either side indicate that the "contact" has been the locus of profound overthrust of the earth's crust which overrode the late Pre-Cambrian schists and volcanic rocks to the west and exposed the roots of former mountains in the east in the form of an Archaean gneiss-migmatite complex. The predominant north to northwesterly trend of the "Trough" rocks and the attitude of their axial planes indicate that the faulting and folding were caused by northeast-southwest compressional forces. Fahrig (1955 personal communication) states that in the southeast section of the map area, "the general impression is that a fault does exist between the western and eastern shores of Erlandson Lake, mainly on the grounds of a sharp lithologic break". Auger (1954) also states that, "the eastern border of the basin was subjected to strong orogenic action with overturning and overriding of the "Trough" sediments towards the west over the upper schists".

Inferred minor faults are believed to be present in the southwest corner of the area where former gabbro sills have been offset from each other in an echelon pattern. No direct evidences, however, were found to prove this. The rocks west of the "contact" are sheared and folded to such a high degree that normal fault evidences could hardly be detected unless the whole zone be termed "a fault and shear zone". In these complexly folded areas, although minor structures are important, the most significant factor in solving the major structures is lithologic distribution. Therefore, mapping on a larger scale than one inch to one half mile is essential and would surely be more remunerative in revealing the structure of the area.

Joints:

No systematic study of the joints was made. However, two sets are relatively prominent throughout the area: strike joints and transverse joints. But joints are usually poorly developed because in the schists the major rock adjustments were accomplished by movement along the foliation planes.

Foliate Structures:

Foliation has been defined here as the "property of a rock to break along approximately parallel surfaces" (Billings 1942). All the members of the "Trough" as well as the paragneisses show well developed foliation or schistosity parallel to the bedding. Cases were observed where foliation wraps around the noses of small folds. The variety of rock units of the gneiss complex appears to be mainly due to difference in chemical composition of the original sediments. The foliation, schistosity and gneissic structure are parallel to each other and to the banding produced by the various rock units. The foliation in the "Trough", which results from the parallel arrangement of the flaky minerals, dips east with many small, sharply crested, nearly isoclinal folds superimposed on it. In the gneiss complex, the foliation is more regular and not as crenulated. Biotite is present in abundance in most of the rocks and imparts a well developed foliation to the rocks. In the garnet mica schists, porphyroblastic grains of garnet, staurolite, and cyanite accentuate this banding by the mica plates that wrap around them. The development of foliation parallel to the bedding is probably due to a combination of two factors: incipient recrystallization parallel to the bedding caused by a geothermal metamorphism, and plastic flowage which might be expected in a mountain root zone.

Lineation:

In addition to this, most of the minerals show a parallel alignment on the plain of schistosity that produces lineation. But lineation, including all linear structures, developes in a variety of ways. In the mica schists and gneisses it is a crinkling and streaking out of the micas, and in the amphibolites and hornblende schists it is a parallel growth of hornblende needles. Several readings were obtained in the "Trough" and in the gneiss complex and indicated a plunge of 30° to 40° to the N.80°E.

Augenstructure:

Some large, irregular bodies of augen-gneiss were observed in the gneiss complex and their size as well as number seemed to increase eastward. The writer believes that these portage feldspar and quartz-augen (Plate X, Figure 29) were formed protoclastically due to crushing of the solid crystals which then were shaped into lenses. According to Brøgger (1890), it is a kind of "Fluidalstruktur" in contrast to the cataclastic structures which come about in a solid rock.

LITHOLOGY AND PETROGRAPHY

Laboratory Methods:

The laboratory work was carried out during the winter that followed the field work. About 120 specimens were collected in the field and approximately 80 thin sections have been examined under the microscope. Numerous refractive index determinations have been done and the approximate mineral composition in volume per cent of each rock type has been made with the mechanical stage. Furthermore, the following staining methods were used to determine the distribution and to facilitate rapid identification of certain minerals.

1. Meigen Method to distinguish calcite from aragonite.
2. Lemberg Method to distinguish calcite from dolomite.
3. Gabriel and Cox Method to identify potash feldspars.
4. Becke Method to distinguish quartz from feldspar.

Several mineral and rock analyses have been made by Mr. H. Dehn of the McGill Geochemical Laboratory and involved chemical analyses, flame spectrospic, and x-ray defraction methods.

Megascopic and Microscopic Description:

Amphibolites:

General Statement: Amphibolites are here defined as dark colored rocks which have as their chief constituents hornblende and plagioclase feldspar (Pirsson and Knopf 1949). Subordinate amounts of quartz, biotite, ilmenite, iron ore, sphene, garnet, calcite, and usually some alteration minerals, mainly chlorite and sericite, are frequently present.

Four different kinds of amphibolite were recognized in the map area.

1. Massive, finely granular and uniform amphibolite with

a dotted appearance due to the intimate association of minute grains of feldspar and hornblende (Plate V,Fig 16)

2. Porphyroblastic amphibolite in which large, individual hornblende or tremolite crystals are imbedded at random in a feldspar, quartz, dolomite or calcite groundmass. This is very similar to the "Feather Amphibolite" encountered in the Bancroft area, Ontario (Adams and Barlow 1910) (Plate I,Figure 3)

3. Pyroxene Amphibolite which represents higher grades of metamorphism of either calcareous or basic intrusive rocks (Plate V, Figure 15)

4. Garnet Amphibolite which is just a very dark, massive amphibolite studded with small garnets and containing the usual plagioclase-hornblende association. Megascopic schistosity is usually absent (Plate I,Figure 5).

The different amphibolites will be dealt with under different headings and the reader is referred to the tables, plates and micro-photographs to complete the picture.

MASSIVE AMPHIBOLITES:

The massive amphibolite is a dark massive rock very common in the map area. It usually forms ridges on account of its superior hardness. Segregation layering of hornblende plagioclase and quartz may or may not be present. Megascopic schistosity is not necessarily conspicuous because the amphibolites in the map area generally contain no mica. However, the lineation is very pronounced and beneath the microscope there is usually an obvious preferred orientation of hornblende prisms. In general, there is much variation in grain size and in the abundance of different minerals. But normal green to dark olive green hornblende is the most abundant and characteristic mineral in all the thin sections studied. As may be seen from the accompanying table (Table I), it consists of 30 to 75 per cent of the rock and usually occurrs in elongated slender prisms, about 0.4 by 0.8 mm. in size.

Some crystals show different shades of green, and appear to be bleached; it was noticed that this peculiarity was typical of amphibolites that may have been derived from calcareous or chloritic sediments. Inclusions of sphene, epidote, and calcite were observed. Hornblende is often associated with plagioclase, calcite, and epidote and seems at places to have been produced by the reaction of the two last named minerals. Also alteration of hornblende to epidote was observed. Out of five specimens the average indices proved to be:

$$Nx = 1.653\text{-}1.666$$
$$Ny = 1.664\text{-}1.666$$
$$Nz = 1.668\text{-}1.669$$

$c \angle z = 14 - 16^{o}$; $2V = 55 - 65^{o}$; its absorption formula is

X = yellow green to pale green
Y = light green to olive green
Z = green to dark green

Plagioclase is next in abundance and ranges in composition from An_{20} to An_{35} and shows good albite twinning. It usually occurs in small xenoblastic grains. Quartz is always associated with feldspar and varies in abundance from 2 to 15 per cent. Epidote, usually in sharp crystallized prisms is either colourless or very pale yellow and blue, but nevertheless highly birefringent. It also forms clusters of irregular size in plagioclase and is probably its alteration product. Also deep blue (between x - nicols) euhedral crystals of zoisite about 0.1 mm. in size were found to be associated with anorthite. Its refractive indices are

$$x = 1.698$$
$$y = 1.700$$
$$z = 1.705$$

Chlorite and calcite are probably retrogressive alteration products of hornblende. Sphene in the form of wedge shaped crystals or in clusters or irregular globules, as well as occasional brown biotite,

TABLE I

Mineral composition of massive amphibolite in percentage of minerals

Specimen Number	C15	C4	C3	67	43	36	37	45	49	14	74
Hornblende	45	45	60	30	50	55	75	70	58	68	60
Oligoclase	35	35								25	
Andasine							10	15	30		
Anorthite					20	20					
Plagioclase			30	20							25
Quartz	15	10	8	15	10	2	8	8	5	2	12
Epidote			5	2	10			8	7		
Zoisite		7				9	8				
Calcite						2				5	
Biotite	1	1	1			.5			1		
Chlorite						5				.5	2
Sphene	5	1	1	1	1			2	2		
Apatite				.5		.5					.5
Iron ores			.5			.2					

apatite and iron ores are the accessory minerals. Table VIII shows a chemical analysis of a massive amphibolite (Sp. 49) within the gneiss complex and Table I shows its approximate mineral composition in volume per cent.

PORPHYROBLASTIC AMPHIBOLITE:

This rock occurs almost invariably associated with a ferro-magnesian limestone or dolomite and is exceptionally well developed in the dolomite-amphibolite complex, west of Renia Lake. Thick beds of normal massive amphibolite are intricately folded and mixed with dolomite in such a manner as to justify the term "complex". In this one quarter mile wide continuous zone, ten feet wide dolomitic beds vanish in a mass of amphibolite and re-appear some distance away. Clear evidence is indicated in the field and beneath the microscope that the dolomite or the ferro-magnesian marble has been incorporated, digested, and transformed into regular amphibolite. In a hand specimen, clusters of dolomite and calcite are surrounded by coarse hornblende and tremolite grains, 2.5 inches in length (Plate I, Figure 3). The distinctive character of this amphibolite is the form taken by the hornblende. This mineral has grown in the rock in the form of slender crystals usually about one inch long and is thickly scattered in the rock. The crystals intersecting one another and forming a mat without common orientation. At places tremolite or actinolite takes the place of hornblende and forms long porphyroblasts inbedded in a ground-mass of fine grained calcite, dolomite, and occasionally quartz and plagioclase feldspar. There is no doubt that this coarse porphyroblastic amphibolite is associated and genetically connected with the Fe-Mg limestones and dolomitic marbles of the area and fades away into them. When examined in thin section, long narrow

PLATE I

Fig. 3 (Sp. 80)

Typical porphyroblastic amphibolite with partly digested specks of carbonates , which characteristicly occurs in the dolomite-amphibolite complex.

Fig. 4.

Typical garnet mica schist with garnet phenocrysts around which micas tend to wrap.

Fig. 5.

Almandite garnets imbedded in an epidote-green hornblende-plagioclase amphibolite.

dark green hornblende often contains an abundance of little rounded feldspar and quartz inclusions as well as iron ores and biotite (Plate II, Figures 7 & 8; Plate III, Figure 9). The indices of refraction of hornblende are

$$x = 1.665$$
$$y = 1.666$$
$$z = 1.669$$

its 2V is 60°, the angle of extinction proved to be 17° and its pleochroic formula is

X = yellow green to pale green
Y = olive green
Z = dark green

Twins with 100 as the twin-plane can be observed in some sections. Numerous bleaching effects were also observed on hornblende. Some sections show retrogressive disintegration of hornblende into chlorite and calcite. Excellent examples of tremolite-actinolite replacing dolomite may be observed under the microscope. Next in abundance to hornblende, and constituting from 5 to 65 per cent of the rock, is calcite and dolomite. Staining techniques as well as refractive index examinations were used to separate calcite and dolomite. Dolomite has an average index of

$$\varepsilon = 1.520$$
$$\omega = 1.694$$

and remained unstained when treated with a potassium dichromite solution. No ankerite was found.

Plagioclase shows fair albite twinning and varies from albite to oligoclase (An_{10} - An_{30}), but it is quite probable that more calcic varieties occur. Quartz is intimately associated with the feldspar and occurs in small equigranular clusters, bands or veins. In many places it is clearly secondary. Garnet is rare and occurs in octahedral crystals up to one inch in diameter, but usually pea size. It is often completely disintegrated and is then associated with chlorite, into which it probably retrogressively altered (Plate II, Figure 8). It has a

PLATE II

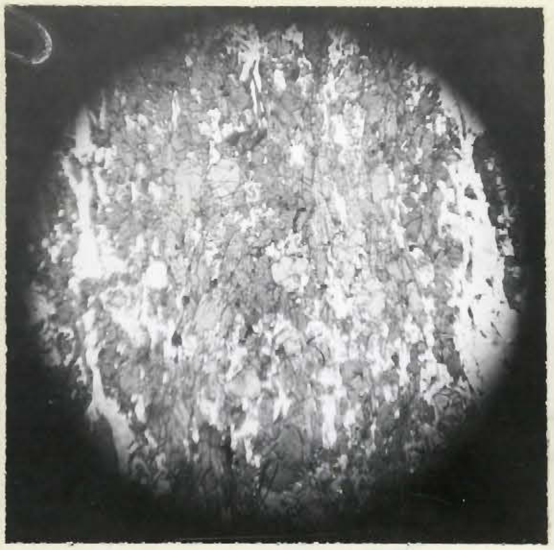

Fig. 6 (Sp. C2)

Microphotograph of a typical garnet amphibolite.

Nat. light x 26

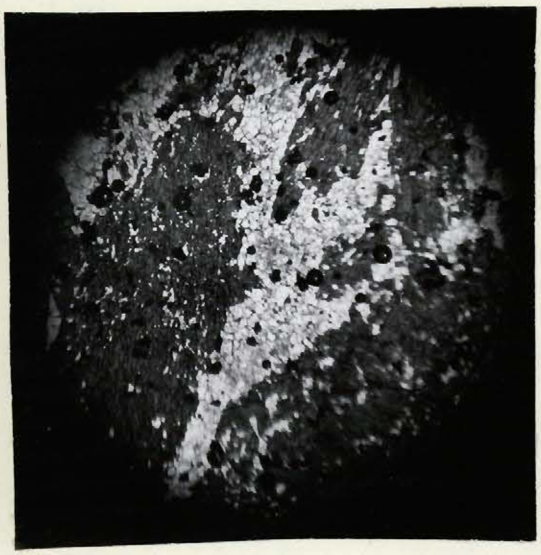

Fig. 7 (Sp. 21)

Microphotograph of a typical porphyroblastic amphibolite with poeciloblastic blue hornblende associated with calcite and abundant magnetite.

Nat. light x 26

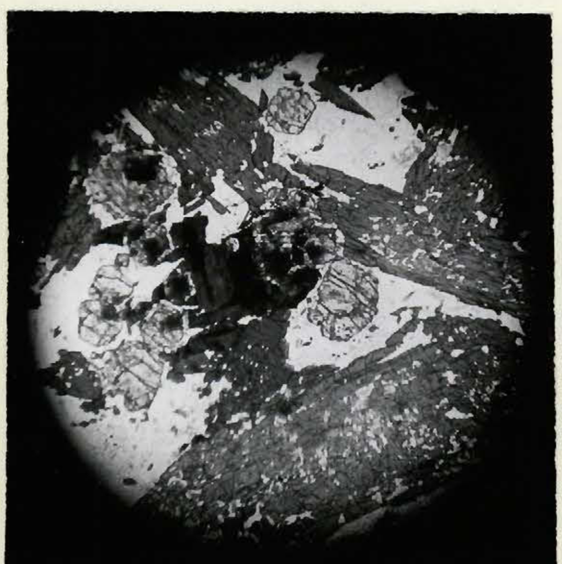

Fig. 8 (Sp. 75)

Microphotograph of a porphyroblastic amphibolite (hornblendegarbenschiefer).Large crystals of hornblende are set in a granoblastic groundmass of quartz and feldspar. Some euhedral garnet phenocrysts are also present. Calcite and chlorite form inclusions in hornblende and seem to be retrograde.

Nat. light x 26

TABLE II

Mineral composition of porphyroblastic amphibolite in percentage of minerals

Specimen Number	79	80	81	85	71	75	21
Hornblende	50		78	78	35	55	65
Tremolite		35					
Oligoclase					28		
Albite							12
Plagioclase			8			15	
Calcite	30	65				5	15
Dolomite	20			20			
Biotite			7	.2		.5	
Chlorite					1	.2	.2
Quartz			5		30	18	15
Garnet					2	5	2
Iron ores			1	.2	1		5

PLATE III

Fig. 9 (Sp. 63)

Microphotograph of a typical porphyroblastic amphibolite showing large poeciloblastic lens like hornblende set in a schistose quartzo-feldspathic groundmass.

Nat. light x 26

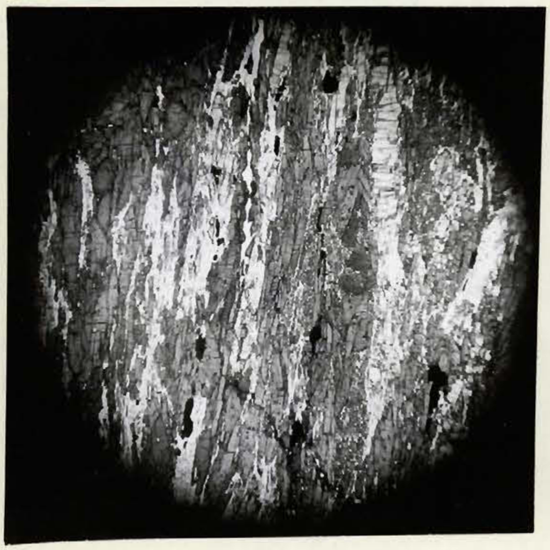

Fig. 10 (Sp. 53)

Microphotograph of an amphibolite that lies conformably within the gneiss complex. Hornblende and muscovite are associated with ribbon like staurolite. Muscovite is probably the source mineral of staurolite.

Nat. light x 26

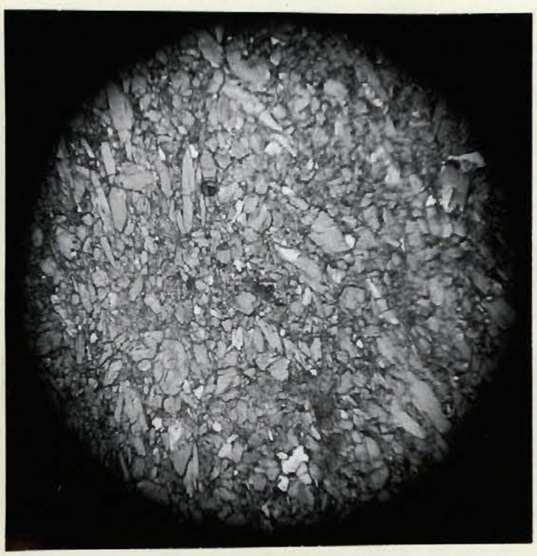

Fig. 11 (Sp. 4)

Microphotograph of a typical amphibolite within the gneiss complex. This was doubtlessly a calcareous sediment that was altered to amphibolite.

Nat. light x 26

refractive index of n= 1.82 and is probably almandite. Chlorite occurs as small pale green flakes that are always associated with garnet, hornblende, and calcite. Together with calcite it forms inclusions in hornblende and then owes its origin to the alteration of hornblende. Almost everywhere rare biotite and iron ores dot the hornblende crystals (Plate II, Figure 7; Plate III, Figure 9).

GARNET AMPHIBOLITE:

Euhedral deep red garnets 2 to 8 mm. in size make up about 10 to 20 per cent of the garnet amphibolite and are its most characteristic feature (Plate I, Figure 5; Plate II, Figure 6). Under the microscope, a pale green faintly pleochroic hornblende is seen to form about 55 to 65 per cent of the rock. It has a sieve structure and is at places an alteration product of biotite. Garnet has an index of refraction of n = 1.782 and has been identified as almandite ($Al_{70}Py_{30}$). Disintegrated remains of garnet grains associated with deep blue chlorite flakes, possibly penninite, give evidence of former euhedral crystals that suffered retrogressive metamorphism (Plate IV, Figure 13). Also, inclusions of garnet granules in feldspar indicate the replacement of the latter by garnet. Associated strained quartz and plagioclase, mostly An_{40}, show intense granulation. In a few places bands from 2 to 6 inches thick and made up almost entirely of garnets have been encountered. Sp. 6 (Table VI, Plate I, Figure 4; Plate XI, Figure 33) has been chemically analysed (Table VIII) and is a typical garnet amphibolite.

PYROXENE AMPHIBOLITE:

There are actually two different mineral associations which characterize pyroxene amphibolites. A calcite-tremolite-diopside variety

TABLE III

Mineral composition of garnet amphibolite in percentage of minerals

Specimen Number	6	12	C2
Hornblende	56	65	55
Garnet	15	10	20
Andesite		7	
Plagioclase	8		10
Quartz	12	6	9
Calcite	6	8	
Epidote	2	1	
Biotite	1		5
Muscovite	.5		
Chlorite	.5		2
Apatite	.2		
Sphene		1	
Ilmanite	.2		
Iron ores	.2		

PLATE IV

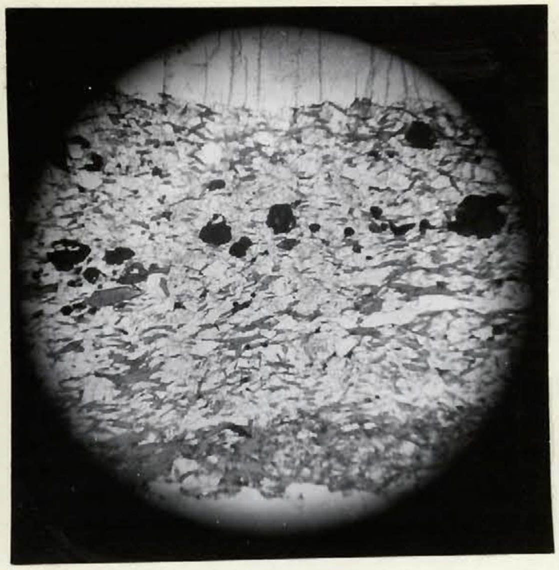

Fig. 12 (Sp. 62a)

Microphotograph of an amphibolite conformable to the trend of the structure in the gneiss complex. Dark tourmaline crystals imbedded in a quartzo-feldspathic, calcareous groundmass with abundant actinolite needles.

Nat. light x 26

Fig. 13 (Sp. 73)

Microphotograph showing ribbon-like layers of garnet between quartzo-feldspathic bands. Some garnet and hornblende have chlorite inclusions.

Nat. light x 26

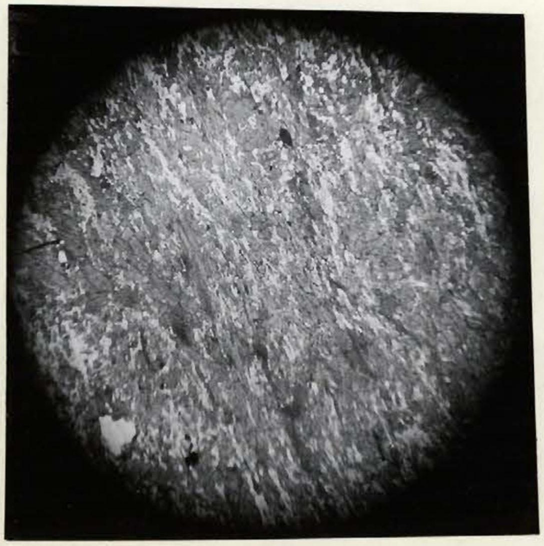

Fig. 14 (Sp. C4)

Microphotograph of an amphibolite carrying hornblende and bluish clinozoisite crystals associated with oligoclase. A typical mineral assemblage of the epidote-amphibolite facies.

Nat. light x 26

and a hornblende-diopside variety. Both contain diopside as their characteristic mineral. In the former variety, diopside occurs as porphyroblast pseudomorph after tremolite and still retains the typical features of the latter, i.e. it occurs in long, pale green prismatic crystals with moderate birefringence and faint pleochroism. Calcite, secondary quartz, and some plagioclase (An_{40}) is usually present. There is no doubt that this calcite-tremolite-diopside variety represents a metamorphosed calcareous rock. It occurs mainly southwest of Renia Lake.

The hornblende-diopside variety on the other hand shows a different origin. It is a dark massive rock made up of about 65 per cent slightly pleochroic hornblende grains. Its pleochroic formula is usually: X = pale green and its refractive indices: x = 1.639

X = pale green		x = 1.639
Y = green		y = 1.646
Z = dark green		z = 1.647

The optic angle is about 60° and the extinction angle ranges between 14 and 19° (Plate V, Figures 15 & 16). It usually occurs as ragged porphyroblastic grains with a very pronounced sieve structure, diopside and plagioclase forming the inclusions in the hornblende. Diopside evidently replaces hornblende. The pyroxene has good parting parallel to 001 and good eight sided cross sections were observed beneath the microscope. Its refractive indices are: x = 1.675
y = 1.683
z = 1.710

It shows second order yellow interference colors and has a 40° extinction angle ($c \wedge z$). The plagioclase is An_{25} - An_{40} and shows clear albite twinning. As can be seen from Table IV secondary quartz often accompanies the feldspar and some varieties contain up to 12 per cent and are granular in appearance. Epidote occurs as small (0.25 to 0.5 mm.) columnar

TABLE IV

Mineral composition of Pyroxene amphibolite in percentage of minerals

Specimen Number	15	16	55	56	91	87	88	89
Hornblende	35	70	55		75			
Tremolite				42		53	33	67
Diopside	20	20	12	32	15	20	40	15
Oligoclase	20					15		
Andesite				12				
Plagioclase		9	22		7		15	12
Quartz	9	1	8	7	2	10	12	5
Calcite				6				
Dolomite								
Biotite						.2	.2	1
Epidote	15		3					
Sphene	.5			.5	1		.2	
Iron ores			.5					
Pyrite-pyrrhotite			.5					

PLATE V

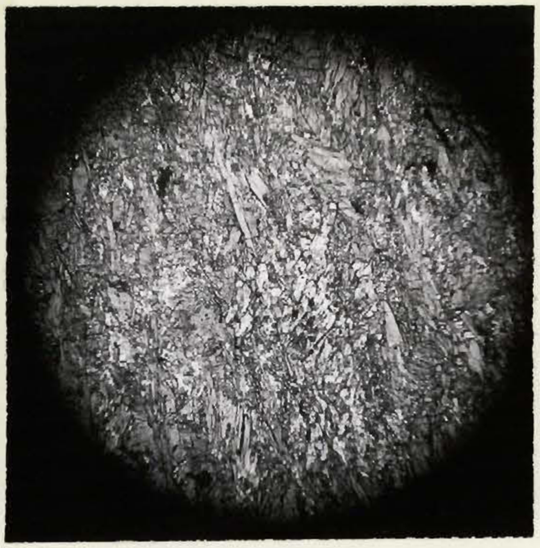

Fig. 15 (Sp. 91)

Microphotograph of a typical pyroxene amphibolite derived from a former gabbro sill. Urilitic hornblende alters to diopside due to increased grade of metamorphism.

Nat. light x 26

Fig. 16 (Sp. 55)

Microphotograph of a typical amphibolite derived from a former gabbro sill and similar to figure above.

Nat. light x 26

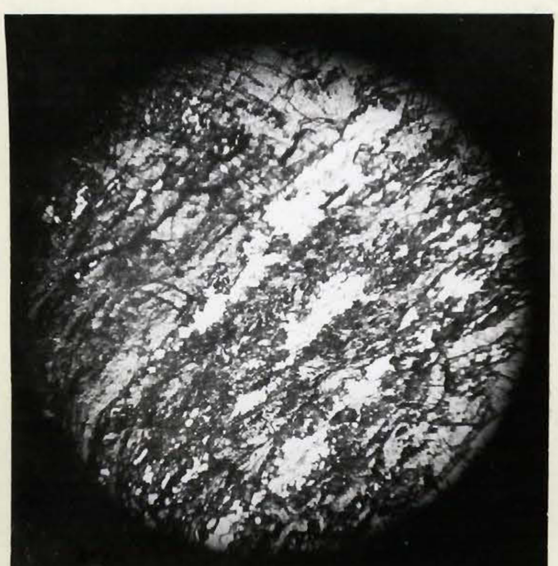

Fig. 17. (Sp. 90b)

Microphotograph of a garnet mica schist; the garnet is shattered and drawn out into bands. Biotite and carbonaceous matter are abundant.

Nat. light x 26

aggregates of high birefringent crystals with parallel extinction and with no apparent orientation in the rock. Its refractive indices are:

$$x = 1.72$$
$$y = 1.75$$
$$z = 1.87$$

In some sections epidote makes up 15 per cent of the rock and clearly replaces plagioclase feldspar. Euhedral sphene occurs either as acute lozenge shaped crystals or in aggregates of irregular grains. Pyrite and pyrrhotite are the only opaque minerals discovered and are present in minor amounts. The assumed different origin of these two unlike pyroxene bearing amphibolites will be discussed subsequently in this paper. Sp. 55 (Plate V, Figure 16) and Sp. 18 are typical examples of the above described rock. Their mineral composition and chemical analyses may be found in Table IV and Table VIII.

LIME QUARTZITE:

In the field this rock occurs as a brown-grey well foliated rock showing continuous compositional banding. The rock ranges from 1 to 2 mm. wide quartz bands that make up approximately 50 per cent of the rock. In thin section the sub-rounded quartz grains are 0.125 to 0.25 mm. in diameter and are interlocked with feldspar (Andesine) and well oriented mica flakes. Either muscovite or biotite may occur and together they constitute about 10 to 18 per cent of the rock. Some sections show evidence of granulation and silicification, the grains of quartz being long in one direction and at places forming lensitic compounds parallel to the foliation. The quartz and feldspar bands are interbedded with calcite layers of approximately the same width. These are composed of fine aggregates of calcite with obscure cleavage. The staining methods suggested by Meigen and Lemberg were applied to distinguish calcite, dolomite, and aragonite; no dolomite or aragonite has been discovered. In rare sections only elongated yellowish green prisms of epidote can be seen. The chemical composition of specimen 77 is:

SiO_2	-	43.63	MnO	-	.12
Al_2O_3	-	6.50	P_2O_5	-	.05
FeO	-	3.00	CO_2	-	17.90
Fe_2O_3	-	4.87	$(H_2)S$	-	-
MgO	-	6.44	Ign loss	-	-
CaO	-	12.78	Insoluble		-
Na_2O	-	1.17			
K_2O	-	1.53	Total		98.26 (Analyst: Mr. H. Dehn)
TiO_2	-	.27			

The writer is of the opinion that the ignition loss figure is too small and that from 1/2 to 1 per cent H_2O is present in addition to the 17.90 per cent CO_2.

LIMESTONE AND DOLOMITE:

General Statement:

Limestones occupy a very prominent place in the map area. They occur in a very highly altered condition, recrystallized, white in color and usually more or less impure owing to the presence of grains or scales of certain silicates. The silicates occur along certain bands or lines giving the limestone a stratiform appearance. The limestone is usually magnesian and often represents true dolomites. The calcareous and dolomitic limestones resemble one another so closely that it is impossible to distinguish them by sight. In some places the amount of magnesium becomes larger, and the limestone grades into a dolomite.

FeMg LIMESTONE:

The magnesium rich and ferrugineous crystalline limestones include pure white to grey limestones and dolomitic limestones often interbedded with limy amphibolites and lime silicate rocks. Bands of crystalline limestone up to 30 feet wide are of common occurrence throughout the whole map area and occur interbedded with other metasediments in the hybrid gneiss complex. The main beds occur in a belt bordering the "contact". As seen from Table V they consist of medium grain aggregates of calcite up to one quarter inch in grain size; calcite makes up approximately 60 per cent of the rock. Next in abundance are pale green actinolite crystals that occur in fibrous aggregates and rosettes. They vary in size but some fibres are as long as one inch. In thin section the actinolite porphyroblasts do not show any particular alignment and clearly originated by reaction with calcite (Plate VI, Figures 19, 20). The seldom encountered plagioclase and quartz are secondary. The characteristic fluor bearing mineral in these rocks is pale brown, slightly pleochroic phlogopite. It is probably derived by reaction of dolomite with muscovite, although its origin might also have been primary. The staining test with cobalt nitrite was applied and almost no dolomite nor aragonite could be found. The microstructure of these crystalline limestones is granoblastic as regards the calcic matrix (Plate VI, Figure 18) with modifications arising from the idioblastic and sometimes porphyroblastic development of the silicate minerals. There is no pronounced schistosity.

DOLOMITIC MARBLE AND DOLOMITE AMPHIBOLITE COMPLEX:

Dolomitic rocks are almost invariably associated with amphibolites in the map area and will be described under the same heading

TABLE V

Mineral composition of Fe-Mg Limestone in percentage of minerals

Specimen Number	8	9	30	31	38	46
Tremolite	38	45	29	25		25
Calcite	57	53	61	60		70
Plagioclase			2			
Quartz	4	5				
Phlogopite	2		8	15		5

PLATE VI

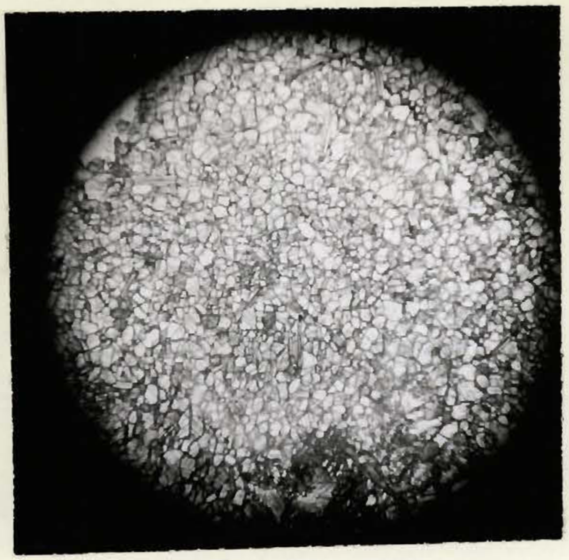

Fig. 18 (Sp. 46)

Microphotograph of an impure magnesian limestone with slender needles of tremolite

Nat. light x 26

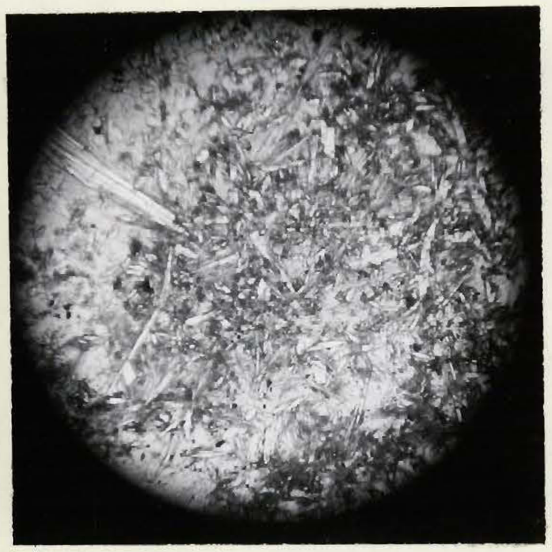

Fig. 19 (Sp. 3)

Microphotograph of a typical actinolite bearing rock derived from FeMg limestone.

Nat. light x 26

Fig. 20 (Sp. 80)

Microphotograph of an impure calcareous rock that has been digested and altered to amphibolite. Some secondary calcite is present in veins that cut through the complex amphibole-carbonate mineral assemblage.

Nat. light x 26

as the dolomite amphibolite complex.

Some of the dolomitic marbles are relatively pure, crystalline, granoblastic rocks made of even, not interlocking, and idioblastic grains of dolomite inbedded in a calcite matrix. Tremolite and actinolite in numerous needles and slender crystals as well as phlogopite flakes are commonly seen in a hand specimen in the less pure varieties. By reaction with some impurities such as phlogopite, muscovite and magnetite, tremolite gives way to a green aluminous porphyroblastic hornblende with increased metamorphism (Plate II, Figures 7,8). In the field enclaves of relatively fresh calcite dolomite ($\varepsilon = 1.521$ $\omega = 1.699$) were found included in a massive, dark green amphibolite that carried hornblende porphyroblasts varying in size and without apparent orientation. Dolomite and calcite crystals are virtually digested and made over to hornblende and all gradations from pure, white dolomitic marble to dark green and massive amphibolite can be seen in the field. The intense and intricate folding of this dolomite amphibolite complex as well as the continuous and yet chaotic lithological change across and along its strike make the interpretation of the structure very difficult and uncertain. The microscopic details have been mentioned in a foregoing paragraph that dealt with porphyroblastic amphibolites.

The time as well as the scale of mapping did not permit the writer to undertake a more detailed study of this complex. It is about one half mile wide and several miles long and is best exposed about one mile due west of the middle of Renia Lake.

MICA SCHIST:

Mica schists occur widely in the map area. They invariably crop out in the valleys between ridges of resistant rocks and can usually be found on the margins of lakes. The color ranges from silvery white to dark brown, depending on the proportions of dark mica and the amount of carbonaceous and silicious material. The essential minerals of the rock are quartz and mica, and the mica especially gives the rock its peculiar character. Both biotite and muscovite occur in irregular tablets without crystal boundaries or in foliated aggregates and thus are usually intergrown. Their parallel arrangement produces the highly fissile character of the rock.

Biotite is the usual yellowish brown to reddish brown, pleochroic variety, and often contains haloes. It is at places so abundant (up to 56 per cent) that one has the impression that the plane of schistosity of the rock is completely coated by the mineral and that biotite is the only mineral present. The mica plates are also very often curved and twisted which may be easily seen by the reflections from the cleavage surfaces, and sharply folded plications are common (Plate VII, Figure 25). The small mica flakes are for the most part parallel to the crenulation of the planes of the schistosity, which indicates deformation since crystallization. Quartz is next in abundance and makes up approximately 40 per cent of the rock. It forms irregular grains or aggregates of grains drawn into small lenses or thin layers parallel to the foliation of the rock (Plate III, Figure 10). In the highly crenulated schists in which some retrogressive metamorphism has occurred, many of the ribbon like crystals are broken down again into aggregates of grains. Plagioclase (An_{25} - An_{40}) is also fairly abundant and forms

TABLE VI

Mineral composition of Garnet-mica-schist in percentage of minerals

Specimen Number	22	23	34	60	62a	69	72	73	90b
Oligoclase			40						
Andesine		28			22				
Plagioclase	30			19		14	40	22	13
Quartz	37	27	35	40	17	8	32	15	12
Biotite	8	28	12	18	56	25			2
Muscovite	5	9	8	12		18	8		
Chlorite								5	
Calcite	7				3				
Garnet	12	8				8		25	70
Cyanite						5			
Staurolite						18			
Epidote			5						
Tremolite-actinolite				10			9		
Hornblende								32	
Graphite									2
Sphene					.5				
Iron ores						2	11		
Tourmaline					2	.5			

PLATE VII

Fig. 21 (Sp. 72)

Microphotograph of a garnetiferous mica schist with abundant actinolite needles and secondary iron oxides.

Nat. light x 26

Fig. 22 (Sp. 65)

Microphotograph of an antigorite-garnet mica schist; dark reddish biotite flakes cut through elongated antigorate bands. Judging from field relations, the rock was originally a shale that was metamorphosed to mica schist and into which Mg rich solutions were introduced. The mafic amphibolite-former olivine rich gabbro-with which the schist is in contact, was probably the source of the solutions.

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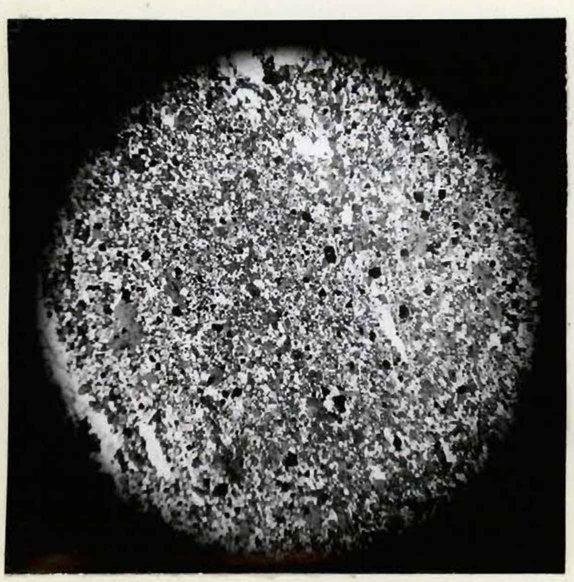

Fig. 23. (Sp. 66)

Microphotograph of a garnet mica schist with abundant magnetite. Probably metamorphosed iron formation.

Nat. light x 26

a granoblastic aggregate of approximately equidimensional grains with quartz (Plate VII, Figure 23).

Amphiboles are rare and inconspicuous except for the diablastic texture encountered in porphyroblastic dark green hornblendes. Tremolite forms long slender needles in quartz. It tends to be idioblastic and sporadic needles are of porphyroblastic dimensions (Plate VII, Figure 22). The prisms and needles are mostly oriented parallel to one another in the plane of schistosity, but many of them lie across or at random in the section which proves that they crystallized after the movement ceased.

Idioblastic porphyroblasts of staurolite up to 8 mm. long were observed in a few sections (Plate XI, Figure 33). They display the typical characteristics of this mineral and contain irregularly arranged inclusions of quartz. Some of the porphyroblasts were crushed and drawn out into 0.5 mm. wide ribbon like veinlets, flanked by granoblastic layers of plagioclase and quartz, and bands of mica (Plate III, Figure 10). Cyanite is usually associated with staurolite and has the following optical properties. The crystals show a good cleavage parallel to 100 and a parting parallel to 001. Moreover, perfect twins were observed with 100 as the compositional plane; in some sections, the crystals show practically parallel extinction, but many are oblique with a maximum angle of 30° ($X \wedge c$). The refractive indices were measured and were found to be:

$$x = 1.713$$
$$y = 1.720$$

The most conspicuous feature of the mica schists was the abundance of garnets (Plate I, Figure 4) which ranged in size from that of a coarse shot to that of a plum. These garnets may be in the

PLATE VIII

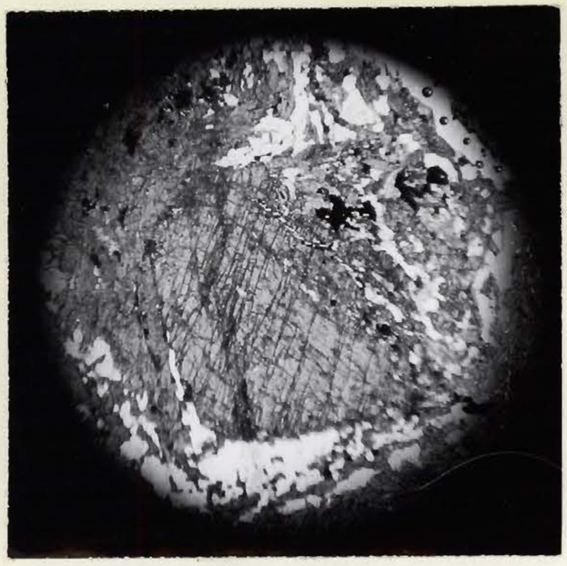

Fig. 24 (Sp. 6)

Typical garnet-hornblende schist. Some chlorite inside garnet is retrogressive.

Nat. light x 26

Fig. 25 (Sp. 22)

Microphotograph of a typical banded mica schist showing plications.

Nat. light x 26

Fig. 26 (Sp. 48)

Magnetite-grunerite-hornblende schist with retrograde chlorite. Probably metamorphosed iron formation.

Nat. light x 26

form of roundish nodules completely disintegrated at the periphery and forming a net work, or they have distinct crystal form of beautifully crystallized dodecahedrons. They might occur in bands made up of tiny granulated masses of mixed garnets and quartz (Plate VII, Figure 22; Plate V, Figure 17) probably due to post crystallization deformation of garnet porphyroblasts. Most usually however, garnets, together with quartz, form eyes around which the bands of biotite and muscovite are bent (Plate VII, Figure 24). They usually occur thickly in certain zones and then the beds are literally studded with them. Under the microscope some garnets are often cleaved parallel to the foliation planes of the rock. In many cases however, these garnets show no sign of movement and preserve their original external crystal outline. Index determinations ($n = 1.789$ to 1.795) suggest that the garnet is high in the almandine molecule with a small amount of pyrope in solid solution (Al_{70} Py_{30}). Quartz, feldspar and tremolite needles as well as magnetite are often found as inclusions in the garnets (Plate VII, Figure 24). In some sections granular aggregates of grains of magnetite characterize the rock and then usually are associated with common silicate minerals and metamorphosed limestones (Plate VII, Figures 21, 23). The author believes that these rocks are probably the result of the metamorphism of beds of impure limonite. At places, rims or inclusions of blue chlorite are found associated with crushed and disintegrated garnets. The writer believes that the development of chlorite (probably penninite) is due to retrogressive metamorphism. No evidence was found that the formation of chlorite has been tectonically controlled.

Graphite, iron ore, epidote, sphene, and tourmaline are accessory minerals. Sp. 69 (Table I, Plates I, XI, Figures 4, 33) represents a typical mica schist as found in the map area. Its chemical analysis is given on page 84 .

GRANITE-GNEISS-MIGMATITE COMPLEX:

The rocks include the granites, gneisses, migmatites, aplites and pegmatites of the map area that occur east of the "contact". The term "complex" is used on account of the complicated structure and lithology encountered in the region and is in accord with the definition of the term "complex" as given by the committee on stratigraphic nomenclature (Ashley 1933, page 445). "Where a large mass is composed of diverse rocks of any class or classes and is characterized by highly complicated structure, the term "complex" may be used".

As described above, the "contact" is reasonably straight along its middle course, but in the northwest corner of the area, bays of gneiss reach far into the "Trough" rocks and show a very dentage character.

Lithologically there are essentially two varieties of gneiss: biotite-microcline gneiss and biotite-hornblende-oligoclase gneiss. Texturally also, gneisses vary in different parts of the area and occur either as well segregated bands or layers or as lenticular gneisses which grade into well developed augengneisses to the east. No textural nor lithological separation of the gneisses is made in this thesis, mainly because the scale of mapping was not suitable for the details involved. The time spent on the complex was also insufficient to permit closer inspection, and the description will therefore be in general terms.

PLATE IX

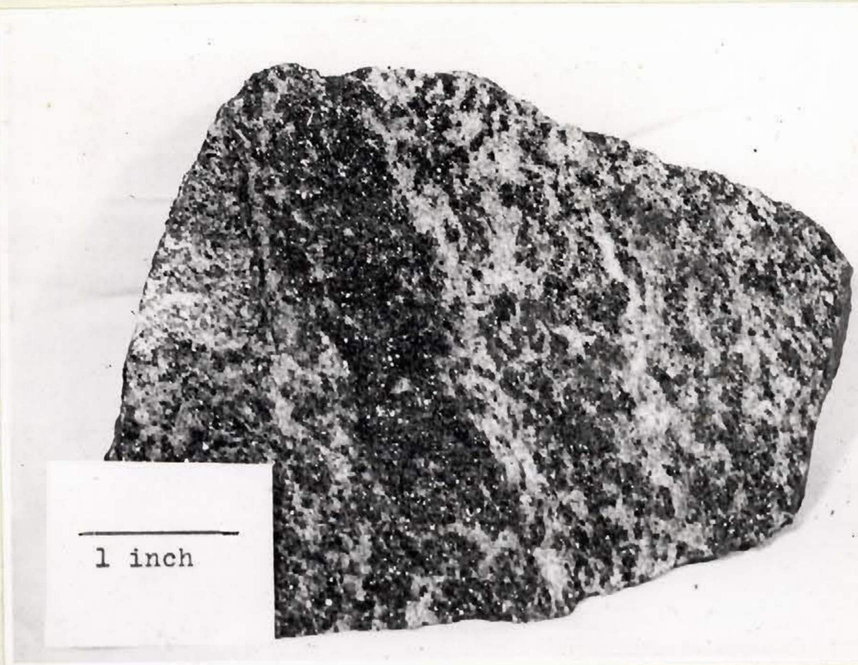

Fig. 27 Hornblende-biotite-muscovite gneiss.

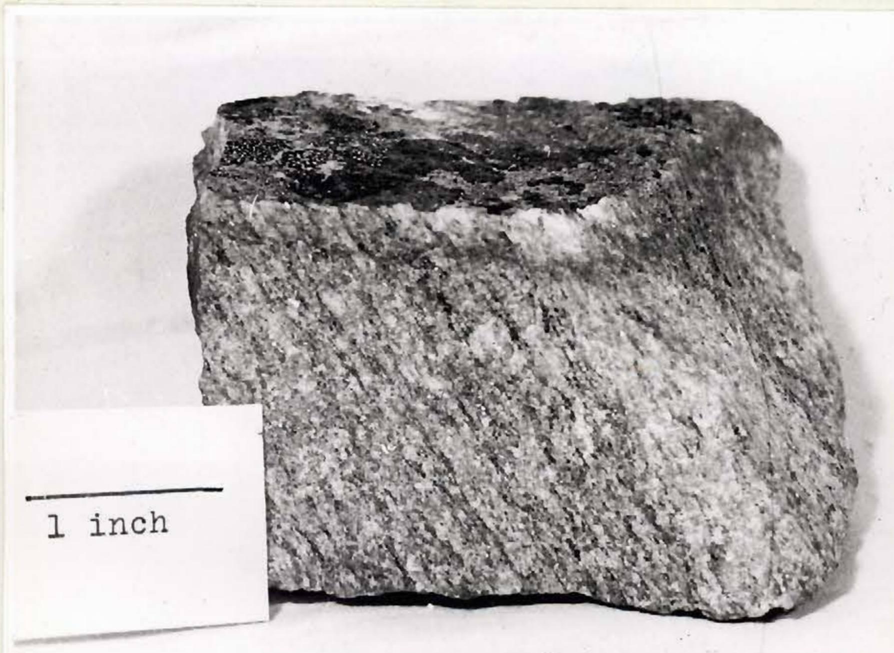

Fig. 28 (Sp. 10) Typical evenly banded schistose gneiss.

MEGASCOPIC DESCRIPTION:

Megascopically the gneisses are pale grey to deep grey or reddish rock showing corresponding variations in composition. The differences in color are due in part to the relative proportions of mica and hornblende, and in part to the fact that a large proportion of the feldspar present is grey or reddish in color. It usually has a distinctive foliation imparted by the parallel arrangement of micas which separate well defined parallel strips of quartzo-feldspathic material (Plate IX, Figure 28, Plate X, Figure 30). The conspicuous minerals are pink feldspar, quartz, biotite, muscovite and hornblende. No garnet has been found in the gneisses. Most of the gneiss is an evenly color-banded acidic rock that contains a variable but often considerable amount of biotite and muscovite. Though the amount of mica varies continuously, it is for the most part evenly distributed. It occurs generally in bands, varying from 1 mm. to sometimes as much as 2 feet in width. This increase and decrease in different bands of evenly disseminated mica imparts various shades of grey and pink to the banded gneiss. These films decompose more readily than the rest of the rock and give rise to planes of weakness along which fragments become detached.

In the eastern part of the map area, amphibolite inclusions may be observed. They are irregular in shape but coincide in foliation with the inclosing gneiss. Sharply folded gneissic and amphibolitic bands are at places cut off by aplitic and pegmatitic dikes. These pegmatites vary in width from mere strings about one inch across up to dikes many feet across. With greater width, the pegmatites lose their dike like form and become more or less lenticular masses. They are chiefly made up of potash feldspar and quartz. Their grain size is irregular, and a rapid variation from place to place from coarse to fine-grain is characteristic. Specimen C_8 is a typical representative of medium grained pegmatite and its chemical analysis is as follows:

SiO_2	-	72.66	MnO	-	.18
Al_2O_3	-	11.16	P_2O_5	-	0.06
FeO	-	0.34	CO_2	-	-
Fe_2O_3	-	2.92	$(H_2)S$	-	-
MgO	-	3.61	Ign loss	-	.40
CaO	-	1.05	Insoluble	-	-
Na_2O	-	4.56			
K_2O	-	3.98	Total		101.11
TiO_2	-	.19			

Highly contorted bands in ptygmatic folds show flow structures and evidence of plasticity clearly increases eastward. The distribution of these variations in composition and structure suggest a hybrid group of rocks that corresponds to "migmatites" as they were called by Sederholm.

In the western part of the map area, the most characteristic feature of the gneiss is the parallel banding. Any aplitic dikes that may be present are strictly conformable to the foliation of the gneiss. There is, however, another feature of the gneiss that is characteristic. The quartz and feldspar grains are in rounded or augen shaped grains distributed in layers 1 to 2 mm. thick (Plate X, Figure 29). These layers are separated by thin seams of muscovite and biotite in which biotite predominates. Also, outcrops with porphyroblastic microcline and orthoclase

PLATE X

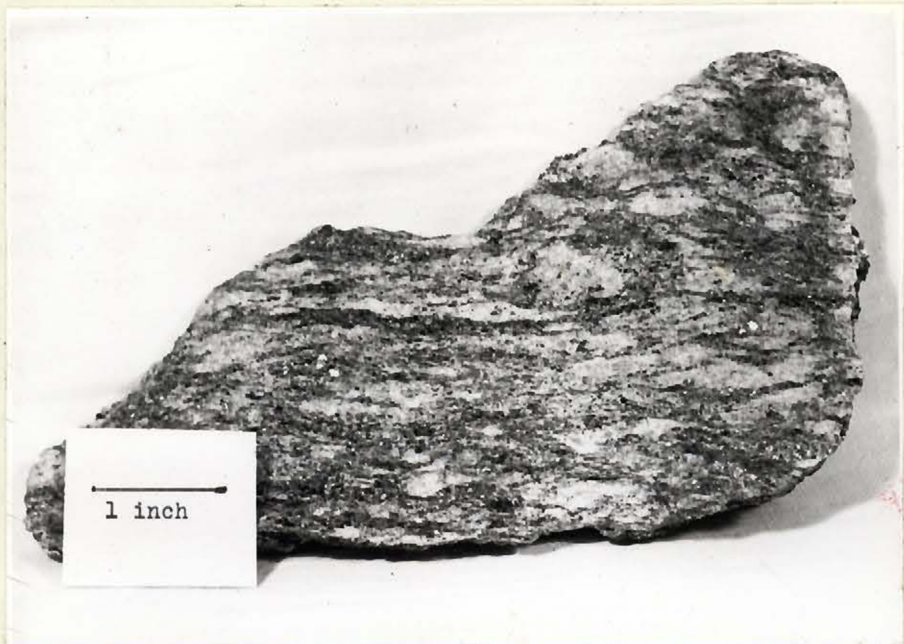

Fig. 29. Lenticular gneiss showing rough parallel arrangement of the constituent minerals. Potash feldspar and quartz form lenses with micas tending to wrap around them.

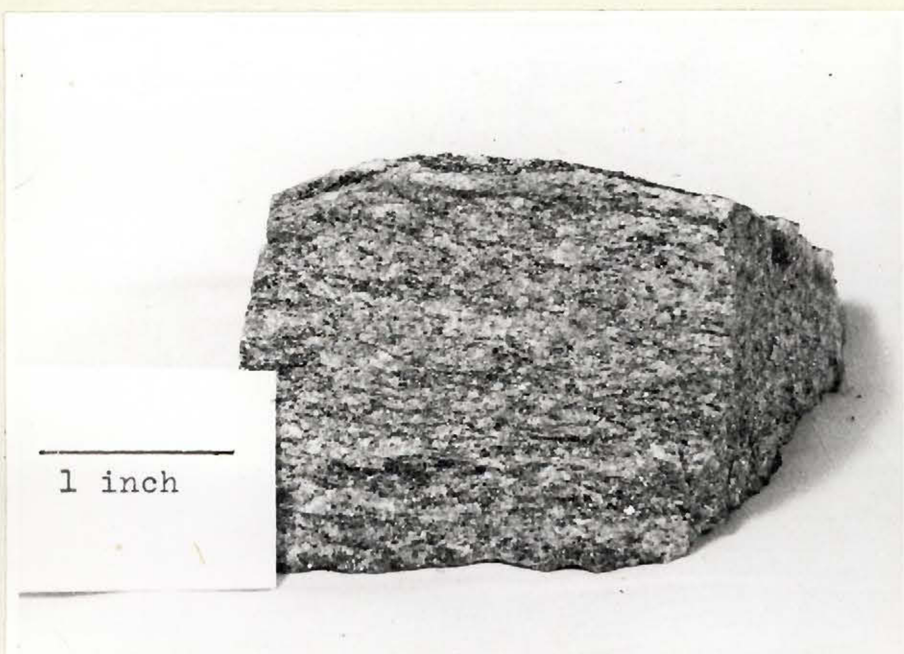

Fig. 30. Gray gneiss showing subparallel, lumpy foliation.

TABLE VII

Mineral composition of the Gneiss complex
in percentage of minerals

Specimen Number	1	10	13	26	27	28	50	51	C5	C8	C9	C11	C12	C13	C14	C16
Orthoclase	32															
Microcline			45	13	42	32			49					48		38
Feldspar		49						30		39		41	39			
Albite											59					
Oligoclase	19						41		11			19	21		39	11
Andesine				28	9											
Plagioclase		11														
Quartz	40	27	42	31	32	41	35	39	26	40	19	37	18	30	36	25
Biotite	5	8	6	14	5	7	13	5	4		11		10	15	7	15
Muscovite		5	5					3	7	5	2					
Epidote	1			12	11		2	2	2	12	9	2	2	3	5	9
Clinosoisite						13										
Hornblende													8		5	2
Calcite							.5									2
Diopside							7									
Sphene				1		2	.2						1		5	
Iron ores				.5		1	.2	.2					.2	1		.5
Apatite		.2								.15	.5			.5	.6	

are exposed. The first impression is that the average grain size is 4 to 8 mm., but closer inspection shows that many of the larger units are actually aggregates of many subangular grains of orthoclase or microcline and quartz 0.1 mm. in size (Plate X, Figure 29). Conspicuous phenocrysts are rare, but some 1 cm. long have been noted. They suggest augengneisses with potash feldspar and quartz making up the lenses.

MICROSCOPIC DESCRIPTION:

Foliation and Schistosity:

The foliation is due to parallel flakes of mica and, to a lesser extent, to the lens-like shape of other minerals or mineral aggregates.

Linear Structures:

Well marked linear structures of tectonic origin lying in the plane of foliation or schistosity are common. In nodules, the shortest axis is perpendicular to the schistosity and the intermediate and longest axes lie within the plane of schistosity. Also lineation is produced by the parallelism of minerals with one long dimension, such as hornblende. The inclusions lie in the plane of the foliation; they must have been oriented while the rock was still fluid.

MINERALS PRESENT:

The Gabriel and Cox method of identifying potash feldspars (Twenhofel, 1941) by staining them with cobalt nitrite was very successfully applied to approximately 30 thin sections.

Most of the potash feldspar is microcline and shows good polysynthetic twinning. It forms about 40 per cent of the rock and occurs either as augen-like phenocrysts 1 to 1 1/2 mm. along the long axis or in the groundmass as irregular patches and veinlets apparently replacing plagioclase (Plate XI, Figure 31). It forms small inclusions in oligoclase and seems to replace it. Muscovite and sericite are associated with microcline and are probably derived from it. Orthoclase occurs together with microcline and also has a tendency to form porphyroblasts. It is also quite common in the form of veinlets surrounding plagioclase and quartz, - an indication that potash bearing solutions probably have been introduced.

Carlsbad twinning was often observed in plagioclase that range from An_{20} to An_{40}. The borders of the crystals are often irregular and wavy due to granoblastic texture. Quartz is widely distributed and occurs in several habits: as lens shaped aggregates, with strange shadows in which the lenses represent original more or less equidimensional grains which have been flattened and granulated during the deformation; or in small subrounded grains associated with similarly shaped feldspar in the groundmass. Biotite is usually the dark brown reddish variety with pleochroic haloes and together with muscovite imparts the typical gneissic foliation to the rock. At places the micas are not aligned and then form phenocrysts implaced at random in the rock. Epidote is very common. It is found in granular aggregates or as slender needles almost invariably associated with oligoclase and andesine. The presence of considerable epidote suggests that the original plagioclase has been oligoclase-andesine which has been broken down into mainly oligoclase and epidote. Biotite is also found to be associated with epidote. Positive, elongated crystals of clinozoisite were identified. Deep green hornblende is the characteristic amphibole (Plate XI, Figure 32).

PLATE XI

Fig. 31 (Specimen 60)

Microphotograph of a typical lenticular gneiss in which the quartzo-feldspathic components are aggregated into thicker and thinner lenses, around which reddish biotite is wrapped.

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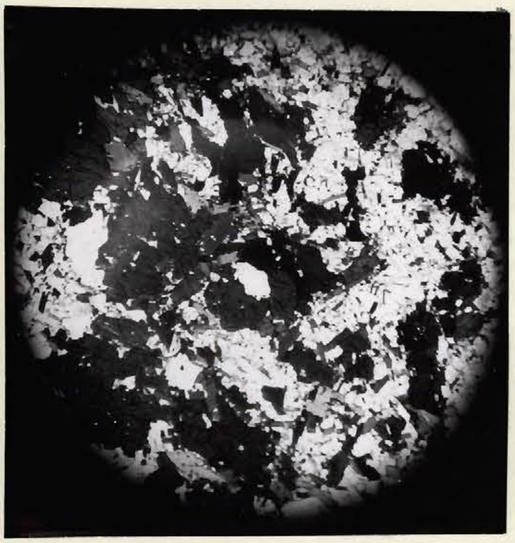


Fig. 32 (Specimen 33)

Microphotograph of a hornblende gneiss. Abundant epidote, dark green pleochroic hornblende and oligoclase classify the rock into the epidote-amphibolite facies.

Nat. light x 26

Fig. 33. (Specimen 69)

Microphotograph of a mica schist containing abundant garnet (upper right), staurolite, cyanite, tourmaline and sillimanite that do not show common orientation.

Nat. light x 26

Its properties are as follows:

Pleochroic formula (X = straw yellow green
(Y = deep olive green
(Z = dark green

Refractive indices (x = 1.665
(y = 1.666
(z = 1.669 with 2V - 65° and an extinction

angle of 22° ($c \wedge Z$). Sphene, iron ore, minor calcite and diopside and apatite are the accompanying accessory minerals.

Sp. C14 has been chemically analysed (Table IX) and its mineral composition is given in Table VII. It represents a hornblende gneiss.

Sp. 52 and 10 are typical representatives of the above described schistose gneiss (Table VII and Plate IX, Figure 28). Their chemical analyses are compared with analyses of gneisses from other areas in Table IX.

V - PROGRESSIVE REGIONAL METAMORPHISM AND METASOMATISM

General Statement:

The object of this paper is to submit evidence that a great series of comparatively unaltered rocks spread over a wide area passes gradually into crystalline schists and gneisses. Progressive regional metamorphism increases from west to east. Shales, argillites, dolomites, arenaceous rocks, and iron formations as well as intrusive and volcanic rocks outside the map area are metamorphosed to mica schists, crystalline limestones, quartzites, amphibolites and gneisses in the area under study. The approximate location of the biotite and garnet isograds is outside the map area. While working in the field under Sauvé and Bergeron of the Quebec Department of Mines in 1954 and 1955, the writer was able to establish the biotite isograd. The garnet isograd was located with the help of thin sections and information supplied by Bergeron and Gelinas.

In the map area the metamorphic grade of the rocks is epidote-amphibolite; further discussion on this topic will be reserved for a later section of this paper.

Mineral Assemblages:

In the following chapter the writer proposes to discuss the distribution of the different minerals in the light of progressive regional metamorphism and to prove increasing grade of metamorphism from west to east. The appearance of minerals from west to east is as follows:

1. Chlorite, albite, quartz, light green hornblende, green biotite.
2. Biotite, blue-green hornblende, oligoclase or andesine, garnet, staurolite, cyanite
   Dolomite + muscovite $\longrightarrow$ phlogopite
   Dolomite + quartz $\longrightarrow$ actinolite (tremolite)

3. Dolomite + quartz $\longrightarrow$ diopside
   Hornblende $\longrightarrow$ diopside

Quartz has a wide range of stability and occurs in nearly all rocks of the map area, except in some crystalline marbles and some diopside amphibolites. In general, it can be assumed that there was sufficient silica to form saturated minerals.

Plagioclase was not thoroughly studied, but the writer is under the impression that the anorthite content of the plagioclase increases from west to east from An_{10} to An_{40}.

No potash feldspar has been seen in the thin sections of the rocks west of the "contact".

The amphiboles are chiefly found in amphibolites, which are partly of volcanic and intrusive and partly of sedimentary origin. Hornblende largely takes the place of chlorite, and with increasing metamorphism hornblende increases in amount and the individual crystals become larger and ultimately they appear as porphyroblasts (Plate II, Figures 7, 8). An interesting feature of the amphiboles is their color distribution. It was observed that the hornblende in the western part of the area had a deep green color that becomes lignter toward the east. For the dark green variety:

$x = 1.664$ $\quad$ $2V = 60^\circ$
$y = 1.665$ $\quad$ $c \wedge Z = 13^\circ$
$z = 1.668$

These properties place it into the Fe-rich variety of hornblende. The amphibole further east however, is the normal light green hornblende with:

$x = 1.660$ $\quad$ $2V = 70^\circ$
$y = 1.668$ $\quad$ $c \wedge Z = 16^\circ$
$z = 1.672$

Winchel's tables (1951) show it to be the more aluminous variety.

In the gneiss complex the common amphibole is again the dark green variety with:

$$x = 1.664$$
$$y = 1.666$$
$$z = 1.668$$

Wiseman (1934) has studied the change in composition of the amphiboles in areas of progressive metamorphism and has found that Al_2O_3 and the FeO:MgO ratio increases with increasing intensity of metamorphism. The development of hornblende is probably the result of a chemical reaction between chlorite and calcite or chlorite and epidote. Some hornblende is also uralitic; this is displayed by preservation of original augite and ophitic texture of the former gabbro sills. In the western part of the area hornblende and actinolitic amphibole are frequently associated with chlorite. Turner (1938) believes that the alternative development of chlorite with calcite or with abundant actinolite depends upon the amount of available H_2O and CO_2 and whether such bases as lime are removed from the reacting system by circulating solutions. According to Wiseman (1934) and Tilley (1925), actinolite can persist in the low grades only as a metastable component. The formation of hornblende in preference to certain other minerals depends also on the nature of the rock and the dynamic factors to which the rock is subjected. According to Billings (1937, page 550), "one probable factor favoring the development of hornblende instead of chlorite is massiveness of the rock. In well bedded tuffs, which can readily shear, the formation of amphibole is apparently prohibited and chlorite-epidote rocks develop instead."

Some hornblende is also associated with dolomite and has doubtlessly been derived from the latter. This problem will be discussed in connection with the origin of amphibolite.

Chlorite is a typical mineral of the low temperature zone and generally decreases in amount as successive zones of higher grade are entered. It is found associated with hornblende and garnet, mainly in the western part of the map area. It then occurs as small slightly pleochroic tablets. In some sections it is definitely of retrograde origin. Nevertheless, the fact that the development of chlorite may be dependent on the prevailing stresses as well as on its structural location should not be overlooked.

Most biotite is the product of the recrystallization of initially argillaceous material and some might be the result of reaction between dolomite, sericite and quartz. Chlorite also combines with muscovite to produce biotite. The plates increase eastward in number and size and near Renia Lake biotite crystals of porphyroblastic dimensions can be found. Also, it has been observed that from west to east nearly colorless, pale brown or green biotite shows gradual deepening in color. In the gneiss complex, the typical biotite is a red brown variety, characteristic of high grade biotites.

Garnet occurs in mica schists and amphibolites, generally in euhedral crystals. (See Plate II, Figure 8) Optical, physical and chemical data suggest almandite with a small amount of pyrope and spessartite in solid solution. The source of manganese of the garnets is probably the sedimentary material. The garnet owes its development to chlorite that reacted with the manganiferous material in the sediment. The reason for the absence of garnets in some amphibolites of sedimentary or volcanic origin is due to chemical composition of the rocks. Chlorite is used up completely in the production of biotite and the excess of chlorite surviving beyond the biotite isograd probably reacts with epidote to form amphiboles. There is therefore, insufficient chlorite left to produce garnets. A further discussion of the formation and distribution of garnet will be found in a later section of this paper under the heading "Garnet Isograd". No garnets have been found in the gneiss complex.

Staurolite and cyanite are of sporadic occurrence and are confined to aluminous and calcareous sediments. They are not visible to the naked eye but in thin section they appear in subhedral crystals and elongate fragments strewn out parallel to the schistosity. (see Plate III, Figure 10) Groups of the fragments are surrounded and separated from each other by a mat of biotite and muscovite. Staurolite and cyanite probably form at the expense of biotite and muscovite. The formation of staurolite and cyanite is dependent to a considerable extent on total composition of the rock, and their distribution is therefore abrupt and erratic. The absence of these minerals in the gneiss complex is probably due to metasomatic effects which, by the addition of lime, potash, and soda, moved the bulk composition of the argillaceous rocks to a stability field suitable for epidote, plagioclase, and potash feldspar to develop.

Calcite and dolomite occur together in crystalline limestones and dolomitic marbles, and are often associated with quartz, rosettes of tremolite-actinolite, and even diopside. From west to east calcite and dolomite give way to tremolite, and tremolite itself changes to diopside in the gneiss area. The relation between calcareous sediments and amphibolites is reserved to the section dealing with the origin of amphibolites.

Phlogopite has been observed only in impure crystalline limestones and dolomitic marbles and is probably produced by the reaction of dolomite and muscovite. It might also be of primary origin.

Epidote is very common and becomes most plentiful in some amphibolites on the west coast of Renia Lake. In view of the abundance of epidote that is usually associated with plagioclase, it is probable that it resulted from feldspar according to the reaction:

plagioclase + water + iron $\longrightarrow$ albite + epidote + aluminum + silica

Iron ores, apatite, sphene, pyrite and pyrrhotite, and tourmaline occur as minor accessories.

Application of Facies Principle:

The first zonal mapping in rocks of this type was done by Barrow in 1893. He studied an area of metamorphosed sedimentary and igneous rocks in the southwest Highlands and showed that zones of different metamorphic intensity could be distinguished by mapping the distribution of certain index minerals. Tilley extended Barrow's work in 1925 and defined a zone as an area bounded by lines or isograds, "drawn between points of first entry of the distinctive new minerals into the assemblage". (1924) Eskola (1920) grouped metamorphic rocks into metamorphic facies, "to designate a group of rocks characterized by a definite set of minerals which under the conditions obtaining during their formation were in perfect equilibrium with each other. The quantitative and qualitative mineral composition in the rocks of a given facies varies gradually in correspondence with variations in the chemical composition of the rocks". In other words, the facies principle is based on thermodynamics, that is, if the pressure, temperature, and composition are fixed, then the mineral assemblage is fixed, independent of the manner in which the conditions were applied. Eskola assumed that the series chosen was isochemical and disregarded the water content. Since then it has been proved by Yoder (1952, page 569) that, "presence of an excess or defficiency of water vapor greatly influences the mineralogy of the metamorphic rock,.... all the now accepted critical assemblages which defined the metamorphic facies may have formed under the same pressure - temperature conditions (at approximately 600° and 15,000 psi) the different facies being primarily the function of the bulk composition". Yoder was able to obtain mineral assemblages suggestive of every one of the now accepted metamorphic facies in stable equilibrium. He also stressed that the temperature of appearance of a mineral in a bed difficient in water will be different from that in a bed containing excess water, and that temperature and composition are the most important variables in rock metamorphism. Therefore, the temperature of formation of mineral assemblages cannot be accurately determined without knowledge of the changes of bulk composition of the rock. There are several other factors which profoundly affect the mineral assemblage of the rock.

1. At lower temperatures, stress is the chief factor in accounting for the difference between regional and contact metamorphism. Stress, therefore, is an important factor which aids in the formation of somd minerals, although the growth might not be dependent on stress. (Turner, 1938)

2. Massiveness of a rock in comparison to less competent rocks may result in the absence of a mineral like chlorite.

3. The location of beds with respect to folds or faults, one might expect higher intensity of metamorphism in different parts of a fold.

4. Finally, the structural control of metamorphic assemblages. In those structures which provide openings, liquids and gasses will have access and an apparent lower grade of metamorphism will take place.

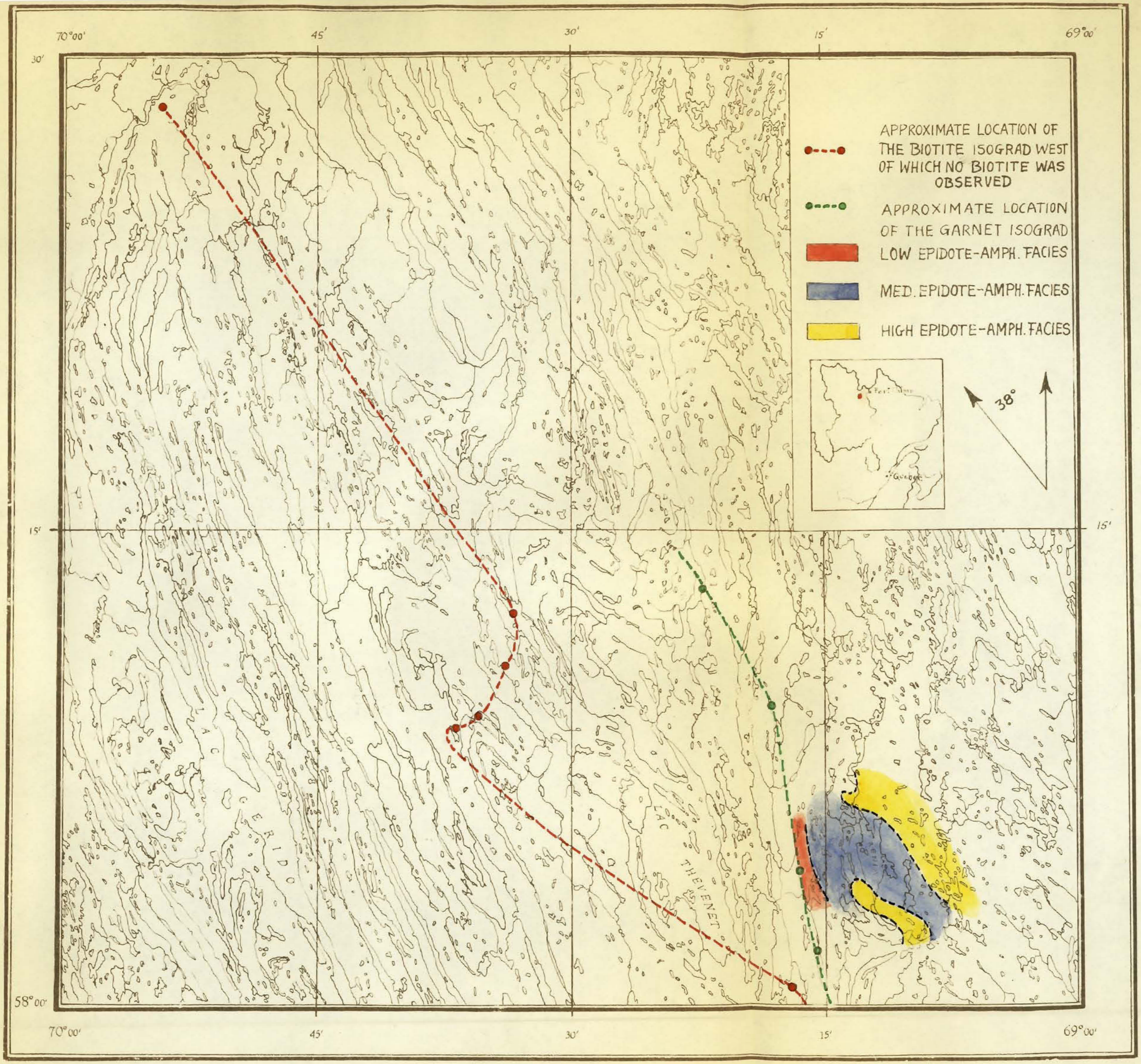


Fig. 34 APPROXIMATE LOCATION OF THE BIOTITE AND GARNET ISOGRADS AND OF THE EPIDOTE AMPHIBOLITE FACIES IN THE THEVENET LAKE AREA, NEW QUEBEC

SCALE 1 INCH TO 4 MILES

Biotite Isograd:

An original series of sediments and interbedded igneous horizons have undergone regional metamorphism of sufficient high grade to cause the appearance of biotite and garnet in pelitic rocks.

Of the isograds of Barrow and Tilley, the biotite and garnet isograds are best developed and their approximate location is shown on the accompanying map (Fig. 34). It is a transitional boundary, not a sharp contact; this is to be expected because of the multiplicity of structural, physical, and chemical variables. The isograds have a cross cutting relationship with the regional structure; they are therefore, assumed to be superimposed on the underlying rocks. The available data was insufficient to allow more than a rough approximation of the location of the biotite and garnet isograds throughout most of their length. Moreover, the ready destruction of biotite either by weathering or retrograde metamorphism make the outline of the biotite isograd even more difficult. The biotite is first yellowish brown and green but around Renia Lake assumes a typical red-brown tint characteristic of high-grade biotites. Persistence of chlorite and muscovite in temperatures apparently somewhat above that at which biotite first appears in pelitic schists, has been attributed by Billings (1937) to the greater capacity of quartzo-feldspathic rocks to sustain high shearing strain.

Garnet Isograd:

This tentative line includes the furthest points west at which garnets have been noted in the field (Bergeron 1954 and sections). In general, the garnets occur very erratically. The first garnets to appear are lumps the size of pinheads; under the microscope they are seen to be about 0.5 mm in diameter. A few hundred feet east of the garnet isograd, garnets become more abundant and larger. With the increase in number and size, there is an increase in grain size of all the minerals and development of schistosity. The presence of abundant garnets gives a wavy and lumpy appearance to cleavage surfaces because micas tend to behd around garnets. (see Plate I, Figure 4) Colors change very little but banding by segregation of minerals along certain layers, - probably former bedding planes - is more pronounced. Early garnets have been analysed and the following properties were found: specific gravity varies between 3.65 and 3.74, and the refractive index is from 1.790 to 1.795. The borax bead showed almost no reaction for manganese. According to Winchel (1951), the garnet is classified as $Al_{70}\ Py_{30}$.

Approximately one mile east of the garnet isograd, the typical rock is a garnet-mica-schist (Plate I, Figure 4 and chemical analysis, page 84), with euhedral garnets as big as one and one half inches in diameter. At places the rock is literally studded with garnets. There is also a definite increase in the proportion of biotite to muscovite from west to east. It was formerly believed that the growth of garnet only takes place if the excess of water is removed and the remaining phases are dehydrated. According to Yoder, (1952, page 623) "garnet will form in sediments whose appropriate bulk composition lies in the water difficient region at any temperature below the upper stability limit of garnet and at any temperature above which its rate of growth is adequate". The formation of garnet will therefore be dependent on its rate of growth and not so much on the attainment of a specific temperature and pressure. The problem of the origin of garnet is one of the most difficult ones. It must be formed from some of the minerals close to the garnet isograd. Based on the evidence seen in thin section, the writer is inclined to believe that garnets resulted from the combination of biotite and some remaining chlorite. Tilley (1925), followed by Phillips (1930), consider that garnet is usually formed from chlorite that remained over from the biotite zone, and Harker (1932) gives convincing illustrations of garnet pseudomorph after chlorite. In the western part of the map area, garnet is found to be associated with chlorite. The highly crushed and disintegrated nature of the porphyroblasts however, point to the fact that the rock was probably subject to later disturbances with retrogressive effects. If not retrogressive, association of garnet and chlorite is explained by Osberg (1952) to be due to garnet forming at the expense of the ferrous portion of chlorite only.

Epidote-Amphibolite Facies:

Harker has stated (1932) that progressive or zonal metamorphism in a region can be studied and the relation of the zones established before the stratigraphy and tectonics are known, and he cites the study of metamorphism in the Scottish Highlands as an example. Although the increase of metamorphic intensity can be seen in the progressive changes of each of the rock types, the description of the stratigraphy of the area would be confusing unless the changes induced by progressive metamorphism are taken into account. As might be expected, the increase in metamorphism though generally progressive, is not uniform. Some areas have been more or less affected, undoubtedly due to differences in chemical composition, stress patterns, textural and structural controls of the various rocks. The grade of metamorphism in the map area corresponds to that of the epidote-amphibolite facies, as stated by Turner (1951) and Barth (1952).

Minerals present:

There are a number of typical minerals of the epidote-amphibolite facies in the map area: Pleochroic hornblende, that is green in the west and changes to a deep blue green variety in the eastern part of the area. The mineral has not been analysed for its Al_2O_3 content, but the aluminum content of hornblende probably increases to the east. West of Renia Lake, actinolite is found. According to Turner the aluminum content of hornblende increases with progressive metamorphism, and actinolitic hornblende of the upper green-schist facies gradually changes to the aluminous hornblende of the epidote-amphibolite facies. Hornblende typically occurs in amphibolites associated with plagioclase, epidote and some quartz. Almandite ($Al_{70}Py_{30}$) is the most common garnet in typical garnet-mica schists and garnet amphibolites. No garnets were observed in the granite-gneiss complex. Yellow brown biotite flakes increase in number and size, eastward. Their color also changes to a deep red color east of Renia Lake. Fair amounts of muscovite are present but seem to decrease westward as biotite increases. Well twinned oligoclase (An_{20}-An_{30}) is the most common plagioclase in the west; although some albite also has been observed. The anorthite content seems to increase eastward to An_{40}. Epidote is almost invariably associated with oligoclase and hornblende and in some amphibolites it is scattered throughout the rock in great numbers. Calcite and dolomite combine with quartz to form tremolite and diopside rocks.

Lower, medium, high parts of the epidote-amphibolite facies:

As can be seen from the accompanying map, the epidote-amphibolite facies has been tentatively subdivided into:

(a) lower epidote-amphibolite that contains green hornblende, almandite, albite-oligoclase, yellow brown biotite, and some chlorite. Its principle chemical reactions are:

Muscovite + FeMg Chlorite + SiO_2 $\longrightarrow$ Biotite + Al-Chlorite
Chlorite + Quartz $\longrightarrow$ Garnet + Water

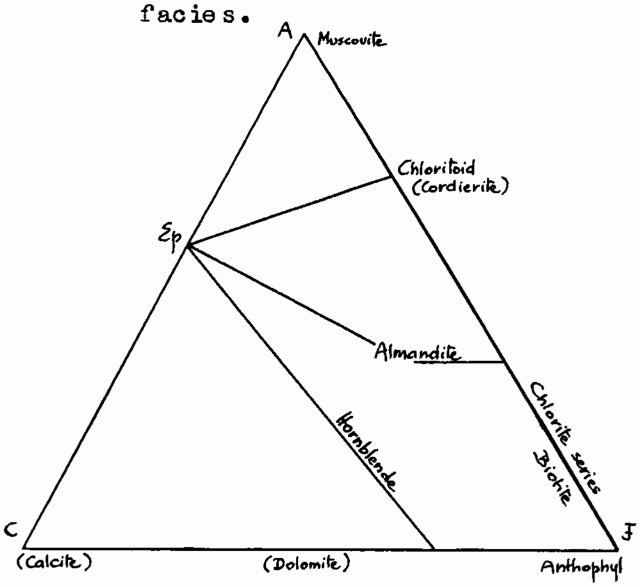
(b) the medium epidote amphibolite facies that contain green hornblende, oligoclase, abundant epidote, darker biotite and chlorite (retrogressive). Its principle chemical reactions are:

Dolomite + quartz + water $\longrightarrow$ tremolite + calcite + CO_2
Oligoclase $\longrightarrow$ Epidote

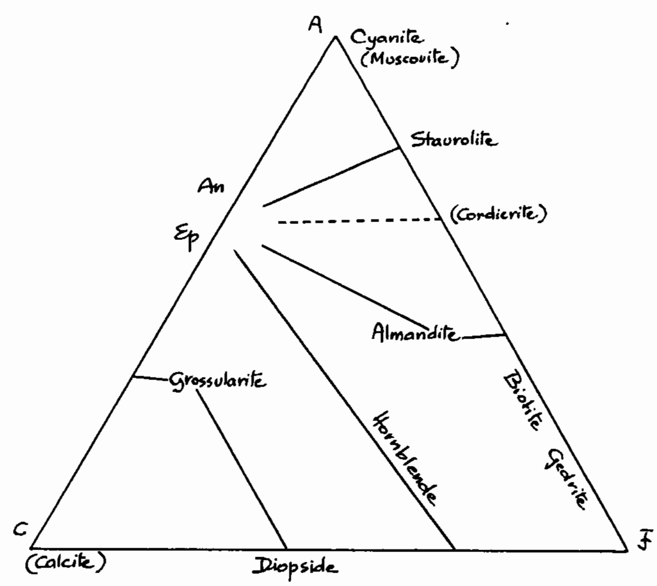
(c) the high epidote-amphibolite facies that contain dark green hornblende, oligoclase-andesine, less epidote, red brown biotite, staurolite and cyanite. Its principle chemical reactions are:

Dolomite + quartz $\longrightarrow$ Diopside + CO_2
Tremolite + Calcite + quartz $\longrightarrow$ Diopside + CO_2 + water
Mica $\longrightarrow$ Staurolite + quartz + Free K Potash

The mineral assemblages can probably be pictured by the ACF diagrams of Barth (1952) page 339 - 340) for the low and the high epidote-amphibolite facies.



Lower part of the epidote-amphibolite facies



Higher part of the epidote-amphibolite facies

Evidence presented in a later section of this paper proves that the epidote-amphibolite facies of the map area grade into the amphibolite facies further east.

Disequilibrium:

"Any mineral assemblage in which one mineral is in process of arising from another must be regarded as being in unstable equilibrium". (Tilley 1924) It was most difficult to consider whether the assemblage of minerals represents equilibrium or disequilibrium, and if the latter, which minerals are progressive and which retrograde. This problem was especially acute with chlorite, to determine whether it is a relict mineral from the lower zone, or if it is retrograde after garnet.

Progressive disequilibrium:

Progressive disequilibrium has been defined as the failure to attain equilibrium under conditions of rising metamorphic intensity. Only rarely has chlorite been observed to be present in small flakes in the groundmass and probably then it is a relict from a lower grade zone. Porphyroblasts of hornblende and biotite have been seen to be imbedded in a groundmass of sericite, calcite, albite, quartz and minor chlorite. The groundmass represents low grade conditions. When higher intensity was attained, large hornblende crystals began to form at the expense of sericite and chlorite.

Retrograde disequilibrium:

Retrograde disequilibrium has been defined as a failure to attain equilibrium under conditions of falling metamorphic intensity. In the western part of the map area, much of the chlorite is of retrograde origin. It has been observed as a shell around garnet, or as small, bent inclusions. The garnets are typically crushed (Plate VII, Figures 21 & 23). Many of the feldspars also show retrograde effects. This alteration consists of the formation of epidote and sericite from the original plagioclase. The retrograde minerals have a higher water content than the minerals from which they were derived. Harker believes that the water content of the schists is able to supply the water, but water can also be introduced from external sources. No special retrograde metamorphism however, has been discovered in the vicinity of the fault. The writer did not find any evidence that the retrograde processes bear any relation to special structural features, the evidence indicated rather that the retrograde minerals appear sporadically.

Metasomatism:

The study of the changes in chemical composition during regional metamorphism would necessitate an extremely detailed study.

In the map area feldspathization of the granite gneiss may be observed. The fact that there is an abundance of aplites and pegmatites suggests that there was an introduction of potash-bearing solutions. It is also quite probable that the former sediments have been "soaked" by siliceous emanations that carried minor carbonates and potash. Water and carbon dioxide apparently move readily through the rocks and are usually involved in metamorphic reactions. Under the microscope there is clear evidence of intergranular filling of the interstices of subrounded quartz grains and plagioclases by potash feldspar. Numerous inclusions of microcline in oligoclase have been observed that apparently replaces the plagioclase. The striking variability in mineralogical composition of the gneisses also point toward a metasomatic addition of feldspar. But how much is "granitized" granite, and how much is magmatic granite is not known. According to Auger (1954), the metamorphism observed in the rocks of the iron formation are due to the thermal energy supplied by the gabbro sills. The writer did not observe any far reaching alterations of rocks in the vicinity of these intrusives.

Some sulfur (H_2S) has been found by chemical analysis of a garnet amphibolite rock (Sp. 6) near the "contact" and might indicate a hydrothermal introduction of sulfur along this zone of weakness.

The weight percentages of the oxides as given in the chemical analyses are of less importance and should be recalculated so as to show the quantitative relations of the cation percentages and their associated ions. The mode and the various norms for the metamorphic rocks in the map area could be thus obtained.

<u>Summary of the evidences of progressive regional metamorphism from West to East and North East:</u>

1. While near the "contact", aplites and pegmatites are conformable to the structural trend of the rocks, their number and crosscutting nature increases eastward. Octopus-like arms of aplite dikes radiate from a common centre and crosscut the banded gneisses and schists. So inextricably are the rocks interwoven that it frequently becomes impossible to say how much of the mass is igneous and how much of metamorphic origin.

2. In the east, cleavage is invariably parallel to bedding.

3. Schistosity is more conspicuous from west to east.

4. Increase in ptygmatic folding and complexity of structures from west to east.

5. The number of dark, basic inclusions of the nature of amphibolites, increases eastward.

6. The composition of the rocks in the east is further removed from the mineralogy in the west.

7. There is a definite increase in grain size toward the east; for example, the slate west of the map area is so fine grained that the individual minerals cannot be distinguished with the naked eye. In the mica schists however, the groundmass is somewhat coarser and porphyroblasts of garnet, hornblende, biotite and staurolite are numerous.

8. From west to east hornblende and biotite change to higher intensity of color characteristic for progressive metamorphism.

9. K bearing constituents increase eastward.

10. Sequence of chlorite - muscovite - biotite - garnet - staurolite - cyanite and eventually sillimanite has been found near Fort Chimo. The latter occurs as small glassy needles imbedded in quartz or in form of

wavy threads or films resembling spun silk.

11. The presence of biotite and garnet isograds.

Causes of metamorphism in the area under discussion:

Progressive metamorphism has been described in a number of places in the world and the following causes have been assigned to it:

1. Heat emanations from magmatic intrusions.
2. Regional deformation under tangentially directed stresses.
3. Heat derived from deep burial with consequent rise in temperature.
4. Regional metasomatism due to waves of chemically active liquids.
5. Dry diffusion processes.

The distribution of textures and minerals is difficult to explain on the basis of pressure differences alone, and cannot be attributed to compositional differences, since the isograds cut across formational boundaries. The isograds and zonal differences are primarily due to thermal metamorphism, as has been postulated for the metamorphic zones in Scotland by Barrow (1893), Tilley (1925) and Harker (1932). The zonal distribution of temperatures resulted in a zonal distribution of minerals and textures from shales and slates, characterized by some chlorite and absence of biotite, to more intense zones, characterized by biotite, garnet, staurolite, and eventually sillimanite. The parallelism of bedding and cleavage may indicate that deep burial may have played a part; on the other hand, if it can be shown that the youngest rocks in the stratigraphic column show the most intense metamorphism, then load metamorphism is not the primary factor. Larger bodies of intrusives are more common towards the east, and as sedimentary rocks almost invariably have been recrystallized to a higher grade towards the east, there must be a connection between increasing metamorphism and intrusives. Sodium, potassium, sulfur and carbon dioxide have probably been added.

Although addition of heat from intrusive sources was the primary cause of the progressive increase in metamorphism, tangential stress due to horizontal compression was surely an important factor in controlling the character of the resulting rocks. The low grade metamorphism may have been due largely to folding along. According to Ambrose (1936, page 279), "frictional heat must be generated on planes of shear when differential movement takes place ...if the rocks are intimately sheared, although the amount of frictional heat developed along any given plane may be small, the total amount must be enormous. Provided it is generated faster than it can be conducted away, the temperature of the whole body of sheared rock must rise". It has been since proved that mechanically generated heat is insufficient to cause an appreciable rise in temperature and produce high grade metamorphic minerals. Auger (1954), who examined the northeastern part of the "Labrador Trough" believes that thermal metamorphism was a more important factor than dynamic metamorphism to produce the considerable change observed in the rocks. The writer believes that the eastward increase in metamorphism must be due to a combination of the following factors:

1. Deep burial shown by the plastic zones of gneisses and migmatites and by the parallelism of bedding and cleavage.
2. Igneous intrusions shown by the increase in size, number and structure of igneous material such as aplites and pegmatites.
3. Difference in intensity of rock deformation.

VI - PETROGENESIS

Introduction:

In many cases, metamorphic rocks are so similar in character, that it is often impossible to determine their origin with absolute certainty. Great difficulty was encountered when the writer had to determine the origin of the amphibolites. Several hypotheses have been put forward to explain the origin of amphibolites.

1. Metasomatism of limestone by magmatic fluids (Adams & Barlow 1910)
2. Reconstitution of argillaceous dolomite layers or lime shales with little or no modification in composition.
3. Metamorphism or gabbro or diorite.
4. Metamorphism of volcanic rocks including lava flows and tuffs.

In many cases, the writer was able to separate the amphibolites of sedimentary and igneous origin. Greater difficulty was encountered in establishing the volcanic or intrusive origin of amphibolites. This difficulty was augmented by the fact that unmetamorphosed volcanic and intrusive rocks in the west had nearly identical chemical and mineralogical compositions and at places very similar physical properties. Nevertheless, some amphibolites (as seen on the map) were positively identified as being metamorphosed intrusive bodies of basic composition.

Amphibolite derived from Gabbro:

In the map area, amphibolites of intrusive origin form conformable plagioclase - hornblende - diopside bodies that parallel the regional trend of the structure and schistosity. They form prominent ridges on account of their superior resistance to erosion and in every way resemble the gabbro sills encountered west of the map area. The massiveness of the rock, the relict ophitic textures, the mineral composition and the size and shape leave no doubt that the rock has been derived from former gabbro sills. These rocks are commonly weathered to a considerable extent. Originally they were composed of augite and plagioclase (andesine-labradorite), some titaniferous magnetite, and some quartz and sodic plagioclase. The augite is usually changed to hornblende and the plagioclase is more or less saussiritized. Hornblende is strongly developed and the familiar gabbroic appearance gives place to a more or less dioritic type. In thin section this pale green uralitic hornblende has numerous inclusions of diopside or augite that seem to replace it. This is clear evidence that secondary hornblende has responded to higher temperatures and has altered to pyroxene. Subordinate amounts of biotite, calcite, apatite, sphene, iron ores, pyrite, and pyrrhotite are usually present. The chemical composition of amphibolites in the area is compared with similar rocks in other areas and is given in Table VIII. The predominance of soda over potash, as well as the low percentage of lime and magnesia are characteristic features of igneous rocks. The writer is convinced that a great number of amphibolites in the map area are of volcanic or pyroclastic origin, but unfortunately he was unable to find any characteristics that would convincingly prove them to be of such origin. Possibly many quantitative experiments on the concentration of trace elements in amphibolites (Engel and Engel 1951) will be a suitable criterion for determination of the origin of these amphibolites.

Amphibolite derived from dolomite or impure Fe-Mg Limestone:

In addition to the amphibolites which have resulted from the alteration of igneous bodies, there are also amphibolites of

Table VIII Comparison of Analyses of amphibolites

	SiO_2	Al_2O_3	FeO	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	CO_2	P_2O_5	$S(H_2S)$	Ign. Loss	Insol	*XyO	Total
55	51.20	7.05	8.36	6.10	10.14	15.40	1.06	0.18	0.20	0.17	-	0.02	-	0.70	-	-	100.58
49	48.93	15.52	8.06	3.72	8.00	11.00	2.37	1.03	0.42	0.17	-	0.03	-	0.60	-	-	100.85
18	47.08	12.96	6.72	5.21	9.20	14.44	1.27	0.11	0.24	0.15	-	0.04	-	0.90	-	-	98.32
6	49.59	9.16	12.62	5.07	7.24	8.65	0.87	1.14	0.62	0.24	-	0.05	0.30	1.30	-	-	** 96.85
I	50.30	14.1			7.2	8.1	4.0	2.3						1.6		1.5	
II	49.9	15.5	8.0	3.0	7.8	8.9	3.3	0.7						1.5		1.7	100.3
III	52.4	13.6	9.8	2.7	5.5	10.0	2.3	0.4						1.7		1.6	100.0

(55 Amphibolite derived from gabbro sills, (Renia Lake Area) analysed by Mr. H. Dehn, McGill University, Geochemical Laboratory. (1956)
(18 " " " " " " " " " " " " " " " " " "
6 Garnet amphibolite in Renia Lake area, " " " " " " " " "
49 Amphibolite in gneiss complex, Renia Lake, " " " " " " " " "
I Hornblende schist (amphibolite) Vestana, Sweden, (Pirsson).
II Schistose amphibolite, Mass., derived from gabbro-basalt (Pirsson).
III Amphibolite, Mass., derived from impure argillaceous dolomite. (Pirsson).

* XyO represents small amounts of other oxides.

** This low total figure may be explained by the following considerations:

It may be assumed that S has oxidized to SO_3 and possibly has reacted with Ca or Mg. The Ca, Mg sulfates are practically infusable; 0.30 S would oxidize to 0.8 SO_3; the ignition loss is thereby lowered by approximately 0.5%.

Furthermore the high FeO content has probably caused a low "ignition loss" value, due to oxidation of FeO Fe_2O_3 (10%)

sedimentary origin. As has been mentioned in a previous chapter, dark green hornblende - calcite - plagioclase amphibolites are closely associated with, and grade into sedimentary rocks of dolomitic composition. Small, light colored inclusions of calcite and dolomite are distributed in a patch-like manner in a mass of hornblende or actinolite. In the dolomite-amphibolite complex the calcareous patches increase and decrease in number and size; the rock appears at one place as a typical amphibolite and at another, a typical crystalline dolomitic limestone or dolomitic marble. Dolomite, due to its relatively low dissociation pressure as compared with calcite, readily reacts with quartz to form either tremolite, actinolite or diopside. Calcite and quartz are found together in the epidote-amphibolite zone in arenaceous marbles near the "contact" and in lime quartzites, which indicates that they can exist together in equilibrium. In calcareous rocks, the reaction of dolomite and quartz to form tremolite and diopside has probably released CO_2. Bowen (1940) mentions that at a low temperature, calcite, dolomite and quartz can co-exist in equilibrium; but at a higher temperature, they react and a tremolite bearing rock results according to the equation:

$$5CaMg(CO_3)_2 + 8SiO_2 + H_2O \rightleftharpoons Ca_2Mg_5H_2(SiO_3) + 3CaCO_3 + 7CO_2$$

Diopside was discovered in the same type of rocks in the granite gneiss complex. This is also evidence of eastward increasing metamorphic intensity or of "progressive decarbonation" as Bowen calls it. Diopside may form directly or indirectly from the reaction of dolomite and quartz according to the equation:

$$\text{dolomite} + \text{quartz} \rightleftharpoons \text{diopside} + CO_2 \quad \text{or}$$

$$\text{tremolite} + \text{calcite} + \text{quartz} \rightleftharpoons \text{diopside} + CO_2 + H_2O$$

Bowen (1940) indicates that progressive metamorphism or dolomitic rocks is essentially decarbonation; evolution of CO_2 accompanies the reaction, and the temperature at which the reaction will occur will depend on the applied pressure of CO_2. Porosity of the rock, existence of open fissures, as well as access of solutions will be important factors in fixing the pressure of CO_2. In the opinion of the present writer, some amphibolites, west as well as east of the "contact", are definitely of metasomatic origin and are derived from former dolomitic rocks.

Origin of the granite-gneiss-migmatite complex:

As has been mentioned before, the gneiss shows a lenticular structure with potash feldspar and quartz occurring together in lenses separated by films rich in reddish brown biotite. The films alternately approach and recede from each other and show the typical undulatory parallelism of a true lenticular gneiss. (see Plate X, figure 29) The other type is an evenly banded gneiss that extends for long distances.

This complex appears to be composed of sedimentary rocks that have been changed by metasomatic igneous agencies into granitic gneisses. They retained their original attitude and structure of the sedimentary rocks that they represent. The great extent of the area affected, as well as the abrupt changes in composition and texture across strike indicate a sedimentary origin. The persistent regular layering is probably also an inheritance from sedimentary bedding. The writer has no doubt that granitic gneiss is also present; the wide distribution of pegmatites and aplites indicate the presence of granitic gneiss. Their contact with the neighbouring rocks is sharp and they probably represent that part of the magma that consolidated last and penetrated farthest into the overlying rocks. Further east however, gradational contacts as well as oriented inclusions of amphibolite increase in number and the rocks assume all the characteristics of typical migmatites. In this zone they probably have been formed partly by metasomatic replacement and partly by differential fusion of the parent sedimentary gneiss. It is an area of plastic gneiss and migmatite that has been described by Eskola as the "zone of differential anatexis or migmatic zone, or zone of mountain roots, where rocks become sufficiently mobile to be squeezed upward in any fissure and incorporate the host rock".

In spite of the uncertainty involved in determining the origin of these gneisses, the chemical analysis given in Table IX may give a clue as to their course. The high content of K_2O and Na_2O might be interpreted as being due to the introduction of potassic and sodic granitizing ichor from outside. This explains the development of feldspar porphyroblasts in the augen-gneiss and the association of oligoclase and potash feldspars. One has to keep in mind that the introduction of material from outside probably accompanied the reconstitution of the former sediments. Chemical analysis only, would therefore not be absolute proof of the origin of the gneiss complex.

Origin of the garnet mica schist:

There is no doubt that the garnet mica schists that occur in the map area were once chloritic shales that have been raised to the present metamorphic grade by an advance of isothermal surfaces. The schists invariably crop out in the valleys and between ridges of more resistant rocks; their topographic, structural, and stratigraphical

Table IX

Comparison of Analyses of gneisses

	SiO_2	Al_2O_3	FeO	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	CO_2	P_2O_5	$S(H_2S)$	Ign. Loss	Insol.	XyO*	Total
C14	50.30	20.16	6.64	4.82	2.79	6.25	4.90	2.10	0.70	0.09	-	0.23	-	0.50	-	-	99.48
C8	72.66	11.16	0.34	2.92	3.61	1.05	4.56	3.98	0.19	0.18	-	0.06	-	0.40	-	-	101.11
52	65.06	16.68	2.17	2.79	1.66	3.85	4.90	2.00	0.38	0.06	-	0.04	-	0.20	-	-	99.79
10	71.12	14.13	0.69	2.43	0.48	0.35	3.17	6.45	0.37	0.02	-	0.08	-	0.50	-	-	99.79
I	70.90	12.17	4.12	1.31	2.32	1.55	3.74	2.87	0.32	0.04	-			0.26			99.60
II	78.3	10.0	1.8	1.8	1.0	1.7	2.7	1.3						1.0		0.9	100.50
III	82.4	11.3	0.3	1.10	0.2	0.2	0.6	1.0						2.5		0.2	99.7
IV	58.10	15.40	2.45	4.02	2.44	3.11	1.30	3.24	0.65		2.63			5.00			

C14 Hornblende mica gneiss from Renia Lake Area, analysed by Mr. H. Dehn, McGill University, Geochemical Lab. (1956)
C8 Typical medium-grained pegmatite from map area, " " " " " " " "
52 Typical schistose gneiss, Renia Lake Area, " " " " " " " "
10 Schistose gneiss, " " " " " " " " " " "
I Quartz-Biotite gneiss from the Grenville series, N.W. Adirondacks (Engel & Engel)
II Fine-grained gneiss, Maryland (Pirsson)
III Schistose gneiss, Michigan (Pirsson)
IV Average shale (Clarke, 1924)

*XyO represents small amounts of other oxides.

position is therefore completely analogous to the location of shales and argillites in the western part of the "Labrador Trough".

The following table shows the chemical components of specimen 69 which represents a typical garnet mica schist encountered in the map area.

SiO_2	- 41.90	TiO_2	- 1.73
Al_2O_3	- 27.09	MnO	- 0.12
FeO	- 6.03	P_2O_5	- 0.04
Fe_2O_3	- 10.50	CO_2	- -
MgO	- 2.22	$S(H_2S)$	- -
CaO	- 1.94	Ign loss	- 1.10
Na_2O	- 2.29	Insoluble	- 3.50
K_2O	- 3.45	Total	101.91

As seen from the analysis, 3.50 remained insoluble, although the rock powder was:

1) Fused with NaOH and treated with HCl
2) Fumed with HF
3) Fused again with Alkali pyrosulfate.

The amount of SiO_2 (4I, 90) is insufficient to combine with the alkaline oxydes present (Na_2O, K_2O, MgO, Al_2O_3, CaO, MnO)

Al_2O_3 acts therefore, as an acid and reacts with one of the stronger oxydes (CaO, MgO MnO, FeO) to produce an aluminum rich mineral.

The excess of Al_2O_3 suggests the presence of corundum, - although no corundum has been found in thin section (Table VI).

VII-HYPOTHETICAL HISTORY OF THE AREA

Before attempting to trace back the history of the "Labrador Trough", the writer feels that it is necessary to give its main characteristic features.

1. Erosional unconformity on the western contact of the "Labrador Trough" with the gneisses. Structural unconformity on its eastern "contact".
2. Folding, faulting (reverse faults) increases from west to east.
3. Complexity of folding increases from west to east.
4. Extrusive and intrusive rocks increase from west to east.
5. Clastic material increases from west to east.
6. Progressive regional metamorphism towards the east.

In late Pre-Cambrian times, the undulated continental mass in northern Ungava was covered by a sea in which a thick series of sediments were deposited. During a long period of deposition, calcareous and argillaceous sediments were laid down in a slowly subsiding basin. The presence of arenaceous material suggests shallow water. The assemblage of rocks and their texture and distribution point to the following sequence of events:

The accumulation of sediments in neighbouring basins gave rise to a shallow miogeosyncline flanked on its east side by a eugeosynclinal or epicontinental basin of greater dimension and depth. Into the slowly sinking miogeosyncline, shales, dolomites and limestones were being laid down; the slightly east dipping strata favored transportation of iron rich solutions over long distances. In the adjacent eugeosyncline, however, the sequence of events was a different one.

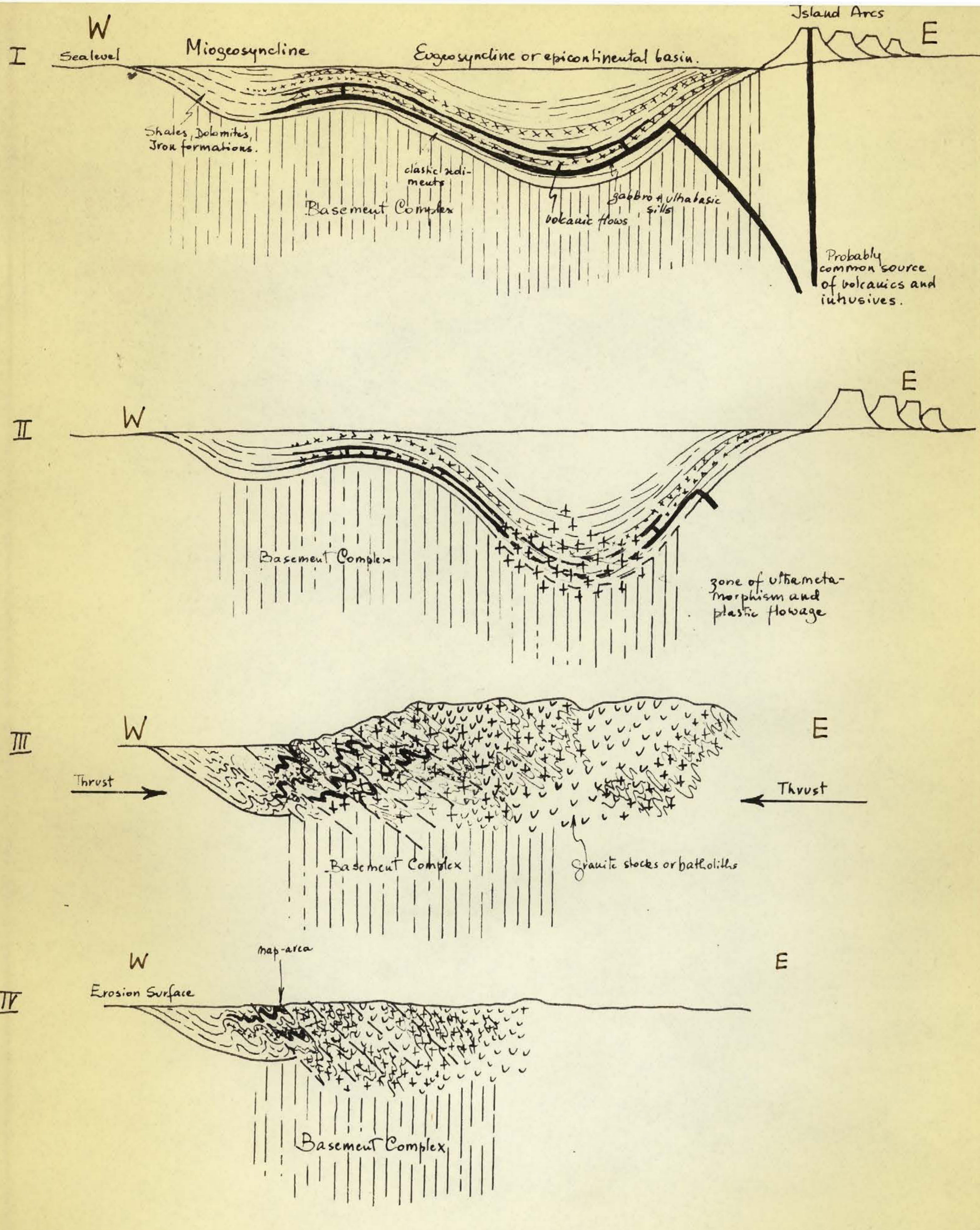


Fig. 35 Hypothetical sequence of events in the 'Labrador Trough': gneiss complex in northern Ungava, New-Quebec.

Thick series of argillaceous and clastic material accumulated in an actively subsiding and mobile basin. A chain of volcanoes in the east, possibly in the nature of island-arcs extruded great masses of pillowed and massive lava as well as pyroclastics; also plutonic sills of same composition as the lava were intruded into the overlying series of volcanics and sediments. Eventually the basin reached the plastic zone and the sediments, volcanics and intrusives became impregnated with magmatic fluids. The bottom of the trough reached the zone of ultra-metamorphism and large scale granitization began. The series was then folded and faulted into northwest trending folds by northeast - southwest compressional forces. The more mobile epicontinental basin was thrust westward over the relatively stable, low angle dipping series of the mio-geosyncline. Anticlines and synclines with their axial planes overturned to the west and southwest were formed in the activated part of the miogeosyncline and throughout the eugeosyncline by these strong orogenic forces. Along this belt of adjustment, that is, between the relatively stable portion of the "Labrador Trough" and the "gneiss complex" a series of reverse faults and low angle thrust faults developed. In the map area, the "contact" between the gneiss complex and the "Trough", in other words between the main basin and the miogeosyncline, represents one of these numerous thrust faults whereby plastic rocks of the east were thrust over the "Labrador Trough" rocks in the west. Contemporaneously with the folding and formation of the mountain-built belt, granitic material rose into the overlying series, disintegrating it and in-corporating fragments of invaded rock. The invasion of igneous material as well as the pressure and heat due to depth of burial were the main factors which then effected progressive regional metamorphism as displayed in the area. After uplift, erosion laid bare a deeper part of the section in the east, where all rocks show good evidence of movement in a soft or plastic material. They represent the roots of the former mountain built belt and the overturned anticlines and synclines of the "Labrador Trough", are its foothills. Figure 35 is a tentative sketch showing the possible sequence of events.

Evidence of postcrystalline movements is clear.

1. Some biotite flakes and amphibole crystals areparallel to the crenulation to the planes of schistosity.

2. Detrital quartz grains are crushed and drawn into lenses or into narrow ribbon-like layers that lie with their length parallel to the schistosity. In the highly crenulated schists, many of the ribbons are broken down again into aggregates of grains.

3. Early garnets have been subjected to postcrystalline movement; in the western part of the map area, the last movements were severe enough to produce some retrogression of high rank materials to those of lower rank.

4. Elongate fragments of staurolite are strewn out parallel to schistosity.

VIII - SUMMARY AND CONCLUSIONS

The Renia Lake area (10 by 14 miles) is situated east of Thevenet Lake, approximately 30 miles west of Fort Chimo on Koksoak River in Ungava, New Quebec. Mapping was done on a scale of one inch to half a mile.

The area might be divided into two topographic units representing the "Labrador Trough" in the west and the gneiss-migmatite complex in the east. In the western part of the area, long narrow amphibolite sills form long resistent ridges that are flanked by mica schists in the valleys. In the eastern part, the aspect is that of a gentle, undulating plateau with abundant lakes. Glacial erosion during Pleistocene times has scored the valleys and smoothed and polished the hilltops.

The distribution of the various rock types is shown on the geological map which accompanies this thesis. Several varieties of amphibolites have been recognized in the western part. Some are metamorphosed gabbro sills as displayed by their field relations, relict ophitic textures, and the secondary nature of the amphiboles present in the rocks. Others are intimately interbedded with calcareous rocks, and their field relations and mineral composition definitely indicate sedimentary origin. The amphibolites alternate with normal mica schists that underly the valleys. East of the "contact", lies the gneiss complex which is actually a zone of injected, replaced, and metamorphosed sediments, most of which contain quartz, feldspar, and biotite as their major constituents. Equigranular pegmatites and aplites are conformable with the foliation in the west but gradually show a cross cutting relationship further east and finally merge into a migmatite zone. This complex zone is probably part of a former epicontinental basin that became filled with great thicknesses of sediments, interlayered volcanics, and gabbro sills; then uplifted and thrust over the miogeosyncline to the west. Overturned anticlines and synclines developed in that eastern part of the miogeosyncline or "Labrador Trough" due to strong orogenic forces. One of the numerous low angle thrust faults in the adjustment zone is probably represented by the sinuous line separating "Labrador Trough" rocks from the gneiss complex in the map area. Zones of different metamorphic grade were created by deep burial and the rising of granitic rocks that accompanied folding and thrusting. West of the area, the biotite and garnet isograds were tentatively established. The map area itself contains mineral assemblages and rock types that correspond and are typical of those found in the zone of epidote-amphibolite facies.

The isograds, the increased structural and lithological complexity, and many other evidences clearly prove that the region has been subjected to a gradual increase in metamorphic intensity from west to east.

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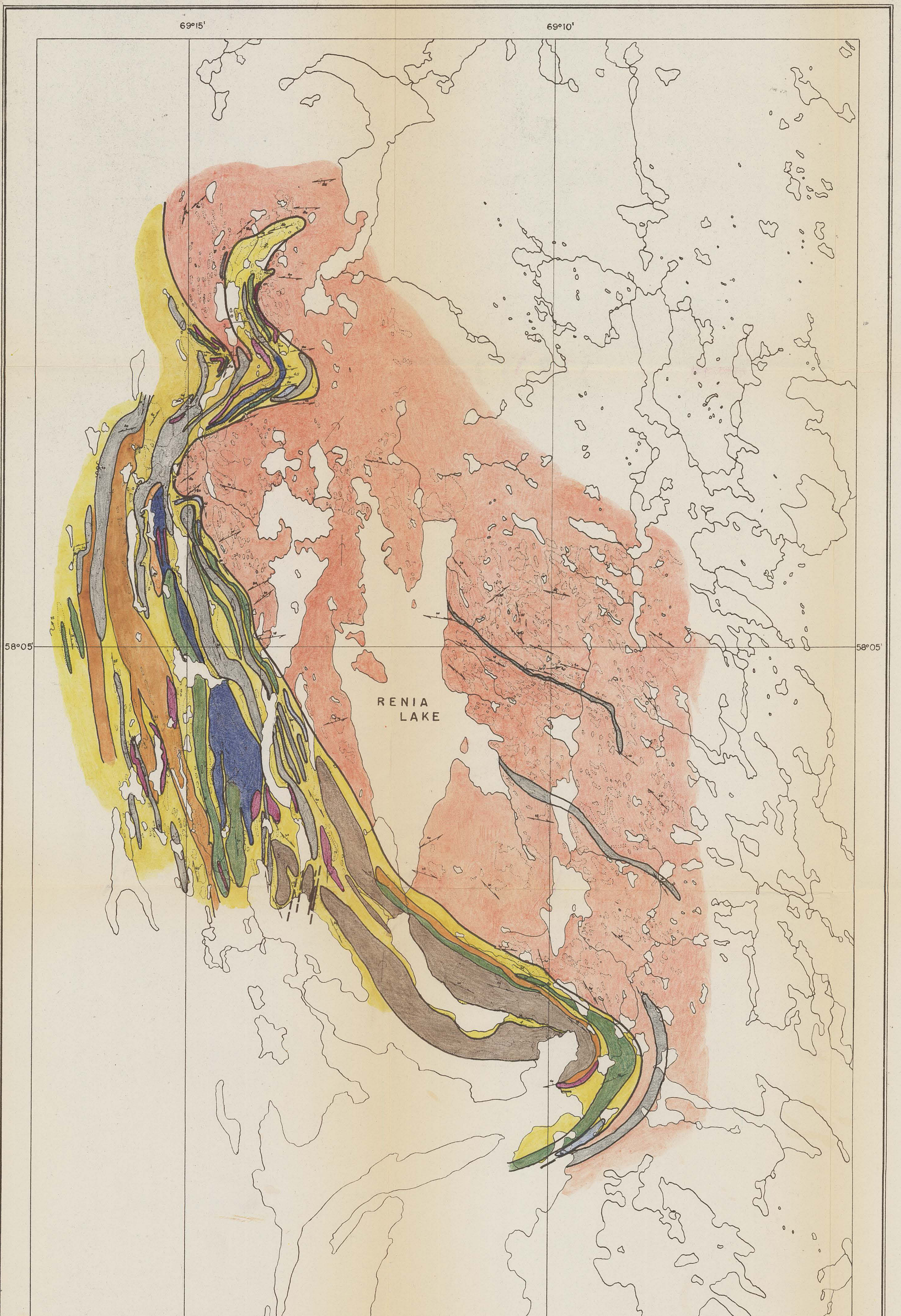
RENIA LAKE AREA

EAST OF THEVENET LAKE, NEW-QUEBEC

SCALE 1 INCH TO ½ MILE

0 ½ 1 1½ 2 MILES



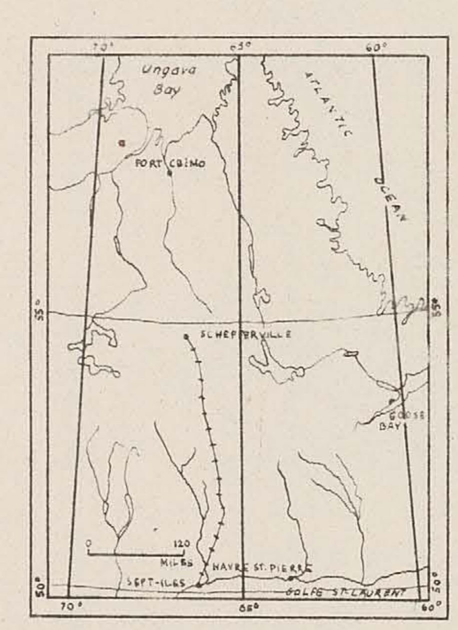
LEGEND

- AMPHIBOLITE AND/OR HORNBLENDE SCHIST DERIVED FROM DOLOMITE, IMPURE LIMESTONE, VOLCANICS OR TUFF
- GARNET AMPHIBOLITE AND/OR GARNET HORNBLENDE SCHIST
- AMPHIBOLITE AND/OR HORNBLENDE SCHIST DERIVED FROM GABBRO
- IMPURE FE MG RICH LIMESTONE
- DOLOMITE
- DOLOMITE AMPHIBOLITE COMPLEX
- LIME QUARTZITE
- QUARTZ GARNET MICA SCHIST
- GNEISS COMPLEX

SYMBOLS

- SCHISTOSITY AND FOLIATION
- ASSUMED FAULT
- GLACIAL STRIAE
- CONTACT GNEISS LABRADOR TROUGH
- DIRECTION & PLUNGE OF HORNBLENDE NEEDLES AND DRAG-FOLDS

38°



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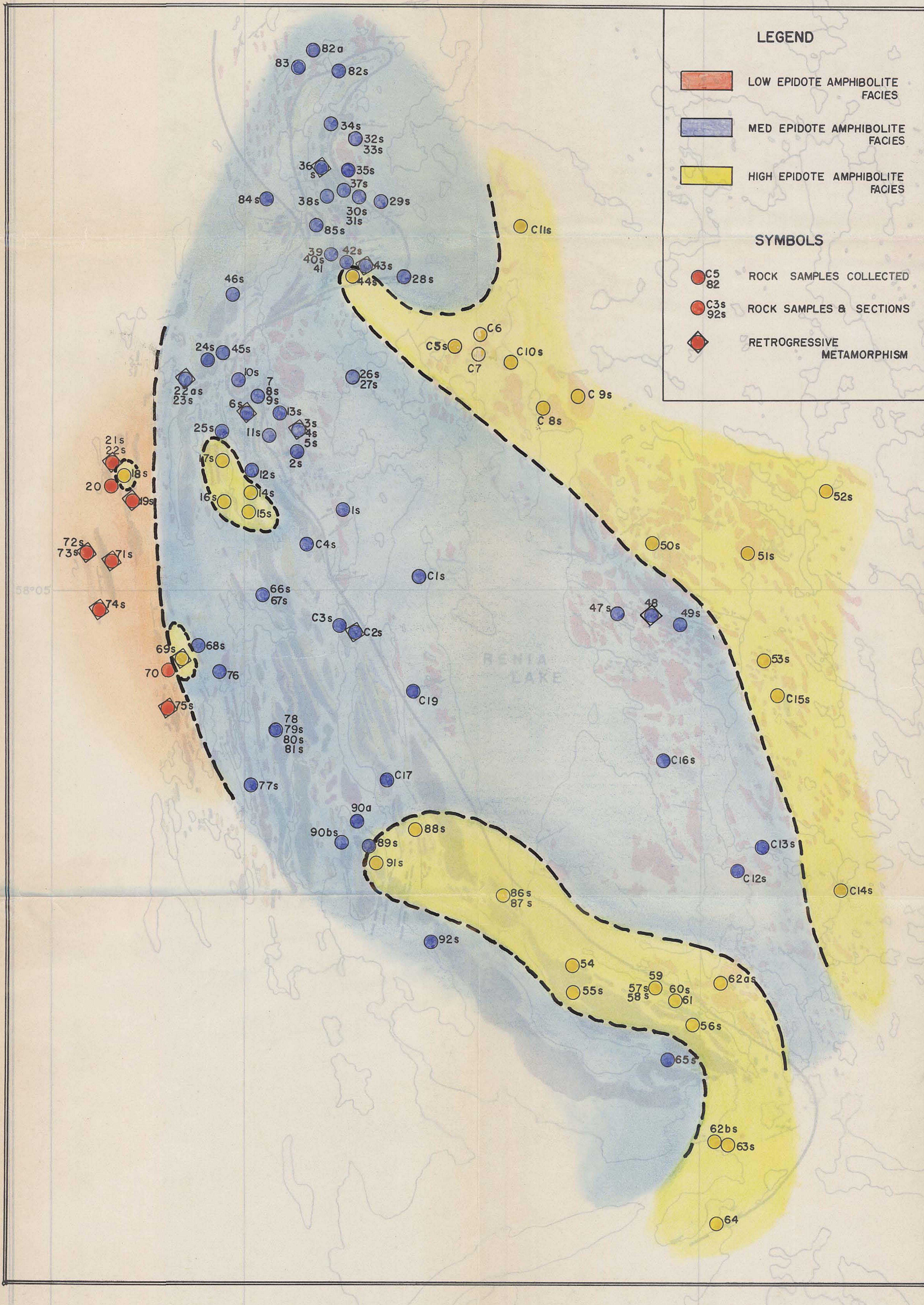

LEGEND
LOW EPIDOTE AMPHIBOLITE FACIES
MED EPIDOTE AMPHIBOLITE FACIES
HIGH EPIDOTE AMPHIBOLITE FACIES
SYMBOLS
C5 82 ROCK SAMPLES COLLECTED
C3s 92s ROCK SAMPLES & SECTIONS
RETROGRESSIVE METAMORPHISM
RENIA LAKE
58°05'

RENIA LAKE AREA

EAST OF THEVENET LAKE, NEW-QUEBEC

SCALE 1 INCH TO ½ MILE

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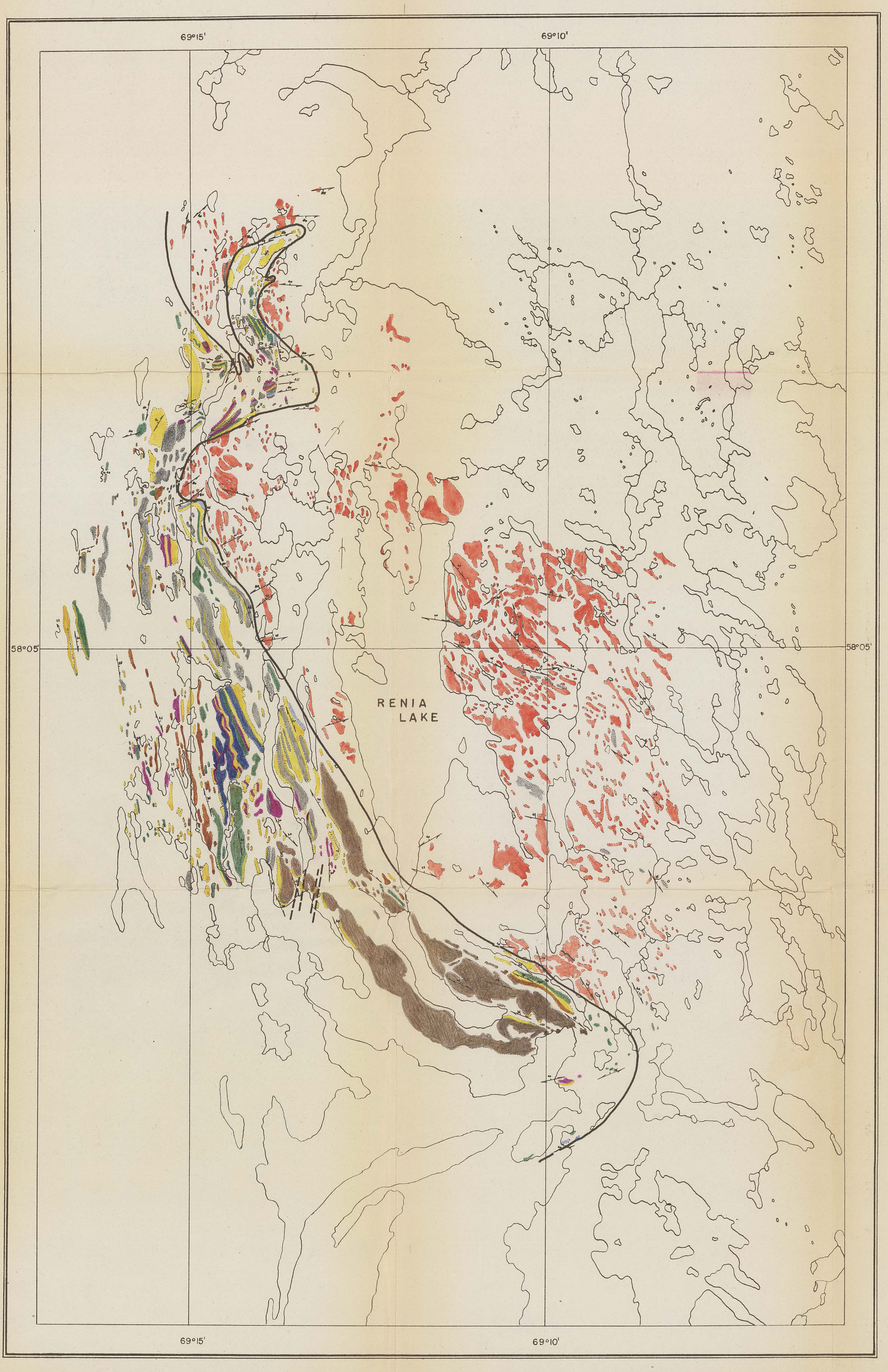

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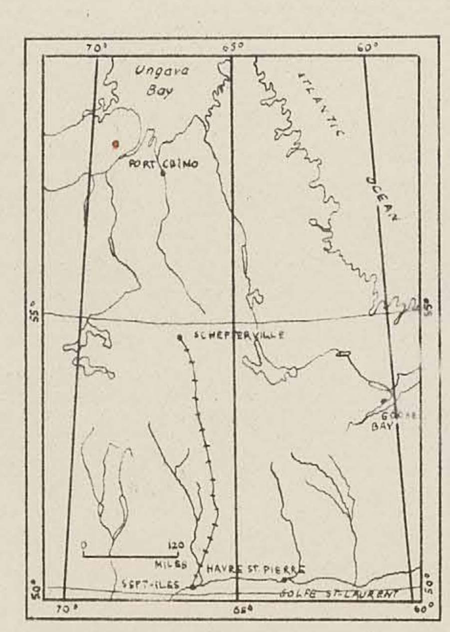

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