

DPV 514

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**MINISTÈRE
DES RICHESSES
NATURELLES**

DIRECTION GÉNÉRALE
DES MINES

FORT-COULONGE - OTTER LAKE - KAZABAZUA AREA

Pontiac -Témiscamingue and Gatineau Electoral Districts

R. KRETZ

GOUVERNEMENT DU QUEBEC
MINISTERE DES RICHESSES NATURELLES
EXPLORATION GEOLOGIQUE

FORT-COULONGE - OTTER LAKE - KAZABAZUA AREA
PONTIAC-TEMISCAMINGUE AND GATINEAU
ELECTORAL DISTRICTS

R. Kretz

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Geological Report

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DPV-514

CONTENTS

	Pages
Introduction	1
General statement	1
Location and access	1
Field and Laboratory work	3
Acknowledgements	4
Previous work	5
General Description of the Area	6
Historical Note	6
Topography	7
Rivers and Lakes	11
Climate	14
Natural Vegetation	14
Inhabitants and Resources	15
General Geology	17
Marble and Skarn (1). I Marble	23
General Description	23
Marble of the Kazabazua River sub-area	31
Minerals	33
Metamorphism	55
Origin	66
Marble and Skarn (1). II Skarn	69
General Description	69
Minerals	83
Metamorphism and Metasomatism	94
Gray plagioclase Gneiss, Amphibolite, Quartzite (2)	99
General Description	99
Minerals	114
Planar and linear features of gneiss and amphibolite	134
Small quartz-feldspar bodies	137
Metamorphism	142
Origin	147
Mafic and Ultramafic Rocks (3)	154
Metagabbro (3b) and Ultramafic rock (3c)	156
Dike rocks	172
Potassium feldspar Gneiss (4)	183
Veined gneiss (4a)	183
Quartz feldspar granulite (4b)	195
Potassium feldspar-biotite gneiss and potassium feldspar- hornblende gneiss (4c)	196
Minerals	197
Metamorphism	202
Origin	204
Granitic, Syenitic, Dioritic rocks, Anorthosite (5)	205
Heterogeneous gray leucogranite and pegmatite (5a), and granite and granodiorite (5b)	206

	Pages
Heterogeneous pink leucogranite and pegmatite (5c), granite (5d), and syenite (5e)	211
Homogeneous gray or pink granite and granodiorite (5f), diorite (5g), syenite (5h), nepheline syenite (5i), and anorthosite (5j)	222
Origin	232
Ordovician Sedimentary Rocks	234
Structural Geology	234
I Rock Deformation	235
Introduction	235
The Eastern Zone	236
The Western Zone	247
The Central Zone	254
Secondary Planar elements	257
Deformational History	259
II Fractures, Faults, Mylonites, Breccias	260
Fractures	260
Faults	260
Mylonites	265
The Coulonge Breccia	265
Pleistocene and Recent Geology	269
Summary of Late Pleistocene and Recent events	269
Ice-flow Direction	270
Gracial Till (7d)	271
Stratified Drift (7a, b, c, d, e)	272
Preliminary Study of Clay and Sand	284
Mineral Deposits	288
Asbestos	288
Garnet	289
Mica	289
Graphite	291
Molybdenite	291
Iron	292
Uranium - Thorium minerals	292
Problems of Grenville Geology	295
References	300
Appendix - Location of rock specimens	307

TABLES

1 - Table of formations	18
2 - Calcite and calcite-dolomite marble	28
3 - Dolomite marble	28
4 - Olivine-bearing marble and humite-bearing marble	29
5 - Serpentine-rich marble and brucite-bearing marble	29
6 - Pink calcite marble	30
7 - Analyses of calcite and dolomite from marble	30

	Pages
8 - Analyses of silicate minerals from marble	38
9 - Analyses of potassium feldspar from marble	48
10 - Analyses of serpentine and brucite from marble	48
11 - Magnesium content of calcite in calcite-dolomite marble ..	56
12 - Mineral associations in marble	61
13 - Minerals in hand specimens of skarn	70
14 - Analyses of calcite from pink calcite skarn	84
15 - Analyses of pyroxene, amphibole, and phlogopite from skarn	84
16 - Analyses of garnet from skarn	89
17 - Analyses of scapolite from skarn	89
18 - Analysis of apatite from pink calcite skarn	92
19 - Plagioclase gneiss and amphibolite	102-103
20 - Quartzite	102
21 - Analyses of garnet, biotite, and hornblende from plagio- clase gneiss and amphibolite	103
22 - Analyses of calcic pyroxene and hornblende from plagio- clase-calcic pyroxene - hornblende gneiss	120
23 - Analyses of plagioclase from calcic pyroxene-hornblende gneiss	124
24 - Analyses of sphene from calcic pyroxene-hornblende gneiss	130
25 - Minerals and mineral proportions (modal analyses) of the layered amphibolite and associated quartz-feldspar layers shown in Figure 18	141
26 - Iron, calcium, potassium, and sodium content of some plagioclase gneisses and amphibolites	150
27 - Minerals and approximate mineral proportions in five bodies of mafic and ultramafic rock	158
28 - Gabbro and altered gabbro	175
29 - Mineral proportions in diabase dikes	175
30 - Potassium feldspar gneiss	188
31 - Amphibolite layers in veined gneiss	189
32 - Analyses of minerals from veined gneiss	199
33 - The Bell Mount Complex	213
34 - Dioritic and syenitic rocks	225
35 - Marine fossils	274
36 - Chemical analyses of clay	285
37 - Mineral Occurrences	290
38 - Principal Occurrences of uranium - thorium minerals	293

FIGURES

1 - Location of the map-area	2
2 - View across a portion of the Ottawa valley	8
3 - Subdivision of the map-area	22
4 - Layers of dolomite marble in calcite-dolomite marble	26

	Pages
5 - Calcite-dolomite marble	35
6 - Crystals of amphibole in a matrix of calcite	40
7 - Equilibrium curves for reactions involving calcite, dolomite, quartz, tremolite, diopside and forsterite	60
8 - Metamorphic map	64
9 - Dolomite marble	78
10 - Fine-grained biotite gneiss	112
11 - Two sheets of amphibole cutting biotite-garnet gneiss	113
12 - Variation in the size of garnet crystals	118
13 - Variation in the size of biotite crystals	118
14 - Variation in the composition of plagioclase	124
15 - Gneissic texture in hornblende gneiss	136
16 - Gneissic texture in hornblende-biotite-garnet gneiss	138
17 - Gneissic textures	139
18 - Amphibolite with quartz-feldspar veins	141
19 - Variation in the hornblende and biotite content	149
20 - Concentrations of certain element oxides	150
21 - Typical metagabbro	155
22 - Metagabbro of the Litchfield metagabbro	163
23 - Thorne metagabbro	163
24 - Typical diabase	179
25 - Veined gneiss	185
26 - Variation in mineral content of veined gneiss	186
27 - Inverse relationship between biotite and feldspar content of veined gneiss	189
28 - Subdivision of granitic, syenitic and dioritic rocks	207
29 - Layered structure in pyroxene granite	215
30 - Leucogranite	216
31 - Interlayered leucogranite and amphibolite	218
32 - Variation in radioactivity and potash content in amphibolite	218
33 - Intermixed syenite and amphibolite	228
34 - Syenite	229
35 - Stereographic projection of planar and linear elements in the southern part of the Kazabazua River sub-area	240
36 - Stereographic projection of planar and linear elements in the northern part of the Kazabazua River sub-area	241
37 - Minor folds	244
38 - Folded quartz-feldspar layers in marble	246
39 - Isoclinally folded marble	250
40 - Folded quartz-feldspar layers in amphibolite	250
41 - Isoclinally folded gneiss and amphibolite	252
42 - Isoclinally folded biotite gneiss	252
43 - Stereographic plot of planar and linear elements	255
44 - Strain in a body of rock	258
45 - The Coulange breccia	267
46 - Vertical section through stratified drift deposits	278
47 - Kazabazua sand dunes	280
48 - Hummocky topography	282

49 - Coarse gravel	282
50 - Grain-size analyses of sand	286
51 - Distribution of Archean gneisses, Proterozoic metasediments and Paleozoic sediments	297
52 - Location of rock specimens	308-309

MAPS

1 - Fort-Coulonge - Otter Lake - Kazabazua - 1:63 360
2A - Kazabazua River sub-area - 1:10 000
2B - Greer Mount - Ladysmith sub-area - 1:15 840
2C - Calumet sub-area - 1:7 920
3 - Structural map - 1:63 360
4 - Pleistocene and Recent Geology - 1:63 360

INTRODUCTION

General Statement

The Fort-Coulonge-Otter Lake-Kazabazua area lies north-west of Ottawa and Hull, and forms a portion of the Grenville province of the Canadian Precambrian Shield.

Various meta-sedimentary and meta-volcanic rocks of high metamorphic grade are present, including forsterite marble, biotite-garnet gneiss, and amphibolite. Associated with these are relatively small bodies of gabbroic and ultramafic rock, which have also been affected by metamorphism. Various potassium feldspar gneisses, and granitic, syenitic, and dioritic rocks are present; some of these are heterogeneous and may be of metasomatic origin, while others are homogeneous and are regarded as magmatic rocks which have been affected by metamorphism and deformation. All of the above rocks are cut by easterly-trending diabase dikes.

Only a very small portion of the area is underlain by flat-lying sedimentary rocks of Ordovician age. Glacial till, gravel, sand, silt, and clay are widespread. Some clay and sand were evidently laid down in the former Champlain Sea, which invaded a portion of the area.

Since about 1910, exploratory work has been carried out from time to time on small deposits of mica, molybdenite, iron, graphite, asbestos, and radioactive minerals, but at present, no minerals are being produced.

Location and Access

The map-area, (Map 1) forms a rectangular area measuring 36 by 17 miles (59 by 28 km). It is bounded by latitudes $45^{\circ}45'$ and $46^{\circ}00'$ north and by longitudes $76^{\circ}00'$ and $76^{\circ}45'$ west,

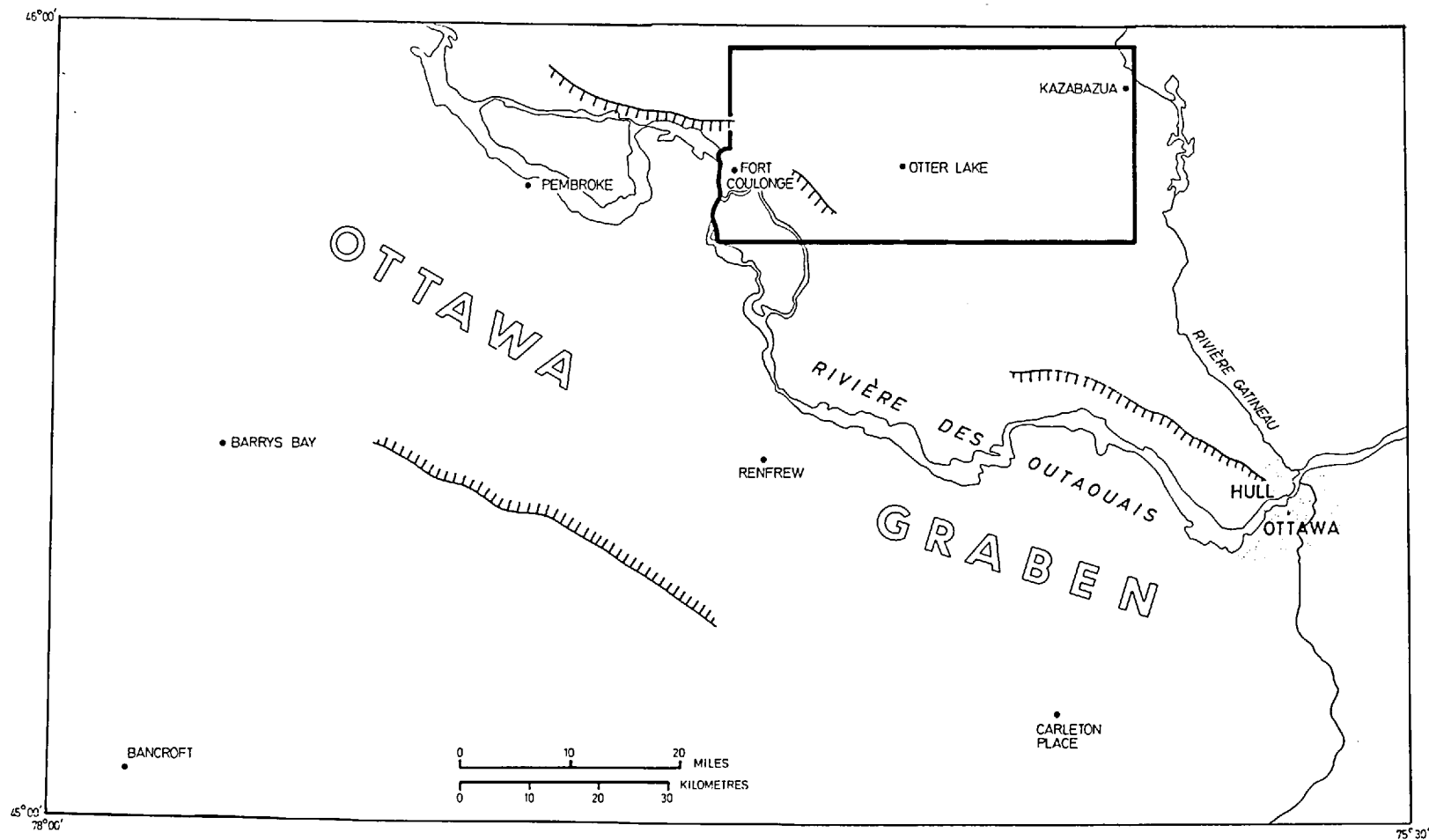


FIGURE 1 - Location of the map-area in relation to the Ottawa valley, which forms a graben structure. The Ottawa valley lowlands are separated from the Laurentian highlands to the northeast and the Madawaska highlands to the southwest by escarpments, the most prominent of which are shown.

and includes, in addition, a small area lying between $76^{\circ}45'$ and the Québec-Ontario boundary.

The village of Fort-Coulonge, on the Ottawa River lies on the western margin of the area, and the village of Kazabazua, in the Gatineau valley, lies in the north-east corner. The village of Otter Lake, which is centrally located, lies 45 miles (73 km) north-west of the cities of Hull and Ottawa (Fig. 1). Most of the area lies in Pontiac county, the remainder in Gatineau county. It embraces all of Cawood and Leslie townships, and large portions of Aldfield, Alleyn, Alwin, Grand-Calumet, Clapham, Huddersfield, Litchfield, Low, Mansfield, Pontefract, and Thorne townships, and a very small portion of Masham township.

The map-area is accessible from Hull and Ottawa by Highway 148, in the Ottawa valley, and by Highways 5 and 105, in the Gatineau valley. Highways 148 and 105 are joined by highway 301, which passes diagonally across the area. Numerous secondary roads exist, including good gravel roads that extend up the Coulonge and Picanoc valleys. All of these make most portions of the area readily accessible.

Field and Laboratory Work

This report consists mainly of field and laboratory data obtained by the writer during the periods 1955-1957 and 1968-1974, and includes, in addition, a compilation of unpublished field data collected by D.M. Shaw in 1954 and by D.R. Baker in the same year. Field data, as presented in the geological maps (Maps 1, 2A, 2B, 2C) were obtained by two methods:

- 1) Standard geological mapping in which pace-and-compass traverses were run at half-mile intervals, and the shores of large

lakes and rivers were traversed by canoe, and

2) detailed mapping, using base maps of about 1000 feet to the inch, during which a large proportion of all rock exposures in a designated area were examined.

The small inset map in Map 1 shows the portions of the map-area that were covered by Shaw, Baker, and the writer, and the kind of mapping employed. Thus the eastern one-third of the area was mapped, using standard methods, by Baker (1956), and the western two-thirds, also by standard methods, by the writer (1957a, 1957b). The northern part of Grand-Calumet township (in the south-west corner of the area) was mapped in detail by Shaw (1955), and select portions of the map-area, including a part of Grand-Calumet township, were examined in detail by the writer (Maps 2A, 2B, 2C). In addition, about one third of the area mapped by Baker (1956) was re-examined by the writer.

The laboratory data presented in this report consist mainly of the results of a microscopic examination of numerous rock specimens, and chemical analyses of some of the contained minerals. Most of these data were obtained in the writer's laboratory at the University of Ottawa.

Acknowledgements

A special word of appreciation is extended to Professor F.F. Osborne, who supervised the field work during 1955 and 1956, and to Professor H. Ramberg, who supervised a thesis project dealing with some rocks from the area. Several other geologists have visited the writer in the field and discussions

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Local residents have been most co-operative. Mr. A. Richard and Mr. A. Zimmerling, both of Otter Lake, have been especially helpful in providing information on local mineral occurrences.

Most of the chemical analyses presented herein were carried out by Diane Garrett, and many of the photographs were taken by Edward Hearn. Some of the field and laboratory work was supported by the National Research Council of Canada.

Previous Work

Early surveys which included all or portions of the map-area were carried out by Logan (1863), Vennor (1877), Ells (1908), Goranson (1925), and Retty (1932). These early observations delineated approximately some of the principal rock types and provided information on some of the structural trends that occur within the area. Mineral occurrences of the area were previously described by de Schmidt (1912), Eardley-Wilmot (1925), Spence (1929), Ingham (1943), and Shaw (1958).

Geological Surveys in adjacent areas were carried out by Osborne (1944), Mauffett (1949), Kretz (1957c), Sabourin (1965), Katz (1969), and Bourne (1970).

GENERAL DESCRIPTION OF THE AREA

Historical Note

The Ottawa Valley was for many centuries inhabited by tribes of Algonquin Indians. In 1615, the French explorer, Samuel de Champlain travelled up the Ottawa river by canoe, charted its course, and promoted the fur trade with the Indians. In 1650, after the Algonquins were driven from the valley by the Iroquois, the Outaouais Indians from Lake Huron became the dominant fur traders and travellers on the river, which now bears their name.

In about 1690 the Ailleboust family, who had acquired the Seigneury of Bois-de-Coulonge, established a fur trading post four miles above the present site of the village of Fort Coulonge. The trading post was at one time surrounded by a stockade, and became known as Fort-Coulonge. For nearly two and a half centuries, large birch-bark canoes laden with furs travelled down the Ottawa River. The fur trade was still active in 1860, as is indicated by a report that nearly 10 000 furs, mostly beaver and muskrat, were traded at Fort-Coulonge during that year. Shortly thereafter, the fur trade rapidly declined.

Some of the largest forests of red and white pine in North America were found in the Ottawa valley, and by about 1830 the loggers had moved as far north as Fort-Coulonge. In 1835, G. Bryson was logging on the Coulonge river, and at the same time, Philemon Wright, who settled on the side of present-day Hull, was logging on the Gatineau river. Most of the wood that was cut during these years as rafted down

the rivers and exported to Europe. Lumbering reached a peak in about 1860 or 1870, and a few years later most of the pine forests had been cut down.

As the loggers moved farther north, small numbers of settlers moved into the Ottawa Valley and the adjacent highlands. Most of the settlers arrived between 1840 and 1890, and were of French, Irish, English, Scottish, German, and Polish origin. Settlement of the area was aided by the construction of two railway lines in about 1890, one up the Ottawa valley, through Fort-Coulonge, and another up the Gatineau Valley, passing near Kazabazua. Although much of the land in the area, particularly in the highlands is not well suited to farming, much effort was expended by the early settlers to clear the land and make a living. Unfortunately, many of the farms in the highlands are now abandoned.

Additional information on the history of the Ottawa valley may be found in a book by Kennedy (1970), from which material for the above note was obtained.

Topography

At the latitude of the map-area, the Ottawa valley forms a broad lowland region, bounded on the north by the Laurentian highlands and on the south by the Madawaska highlands (fig. 1). The valley was evidently formed by vertical movement on a number of north-westerly trending faults, as described by Marshall Kay (1942), and forms a type of graben structure.

About 1/10 of the map-area, in the south-west corner, lies in the Ottawa valley. The Grand-Calumet channel of the Ottawa River, which passes along the east side of Ile du Grand-



FIGURE 2 - View across a portion of the Ottawa valley near Vinton, with the Laurentien highlands in the distance.

Calumet, flows at an elevation of about 350 feet above sea level. The valley floor, which lies at an average elevation of about 400 feet shows considerable variation in topography. Thus portions of Ile du Grand-Calumet consists of hills rising to an elevation of 550 feet, the northern part of the Island forms a sand plain at an elevation of about 360 feet, and the area north-east of Fort-Coulonge is characterized by a number of terraces at elevations of about 500 feet above sea level. North of Fort-Coulonge and north of Vinton, the edge of the valley is marked by a prominent escarpment - presumably a fault escarpment - with a relief of about 500 feet (Fig. 2). Elsewhere, the transition from valley floor to highland is more gradational.

About 9/10 of the map-area lies in the Laurentien highlands. Within the map-area, the highlands consist of a large number of rounded hills, many of which are elongated to form a number of parallel ridges. The hills are separated from each other by valleys which vary greatly in width, and by a number of lake-filled basins.

Most of the hills rise to elevations of 1000 to 1200 feet above sea level; the highest hill in the map-area lies north of Hickey lake, and rises to an elevation of 1420 feet above sea level.

Parallel ridges and valleys are well developed in the east central part of the map-area, east of Otter Lake village, where the ridges trends north 30° east, parallel to the strike of layering in the underlying rocks. The ridges consist of easterly-dipping gneisses, and the valleys are underlain,

for the most part, by marble; hence the topography is clearly a product of a differential rate of erosion of the underlying rock.

Parallel ridges and valleys are also found in the western part of the area, west of Leslie lake. Here the ridges trend north 50° west, parallel to the strike of layering and gneissic texture in the underlying complex of dominantly granitic and syenitic rocks.

A more irregular topography can often be attributed to the fact that layering in the underlying rock is nearly horizontal, or the strike of the layering shows much local variation.

The most prominent valleys in the highland region are (from west to east) the north-west trending Coulonge and Picanoc valleys, the north-east trending Otter Lake-Petit Lac Cayamant and Grove Lake valleys, and the northwest trending Gatineau valley. The trend of these valleys is a reflection of the dominant trend in the underlying rocks. The valleys presumably formed at places where the underlying rock was relatively susceptible to erosion; thus the Gatineau valley was carved in a broad belt of marble, and the Coulonge valley was localized in rock which contains a fairly large proportion of marble. The remaining three valleys (the Picanoc, Otter lake - Petit Lac Cayamant, and Grove lake valleys) are all remarkably straight and do not appear to be localized by lithology. Hence they may have formed along zones of fracturing or faulting, which would naturally provide favorable sites for erosion and valley formation.

A second set of valleys within the highlands trends westerly to north-westerly. These are relatively small in size and are well developed in the southern half of the area, for example between Ladysmith and Otter Lake village. Some of these valleys follow known faults, and they may all be fault-controlled. The combined effect of both faulting and lithologic layering on the formation of ridges and valleys is shown west of Litchfield lake.

In the Ottawa valley and in some of the larger and deeper valleys in the highlands, relatively thick deposits of sand, gravel, and other unconsolidated sediments are present. The topography of these deposits, which may show much variation, will be described in a subsequent section, dealing with Pleistocene and Recent geology.

Rivers and lakes

To the west of the map-area, the Ottawa River, which is one of the largest rivers in eastern North America, separates twice in its easterly-flowing course, to form two islands known as Ile des Allumettes and Ile du Grand Calumet. The northern half of the second of these two islands lies within the map-area.

Two major tributaries of the Ottawa River pass through the area; these are the Coulonge river, which enters the Ottawa at Davidson, near Fort-Coulonge, and the Gatineau river, which passes through the north-east corner of the map-area, and enters the Ottawa near Hull.

All of the streams of the map-area flow into the Ottawa River, either directly or via the Coulonge or Gatineau rivers.

The Quyon and Serpentine rivers, in the southern part of the area flow directly into the Ottawa, while the Picanoc and Kazabazua rivers, and Stagg, Blackwater, and Venosta creeks, in the central and eastern part of the area flow into the Gatineau river.

The Coulonge river, which drains a large area to the north, enters the map-area, following a southerly course. Six miles north-east of Fort-Coulonge, the river enters a steep-walled north-westerly trending channel in which it forms a spectacular water falls known as Grande Chute. The channel appears to be the site of a major fault zone, and possibly the point of intersection of two faults. Below the falls, the river meanders toward the Ottawa River. At Fort-Coulonge, within only 800 feet of the Ottawa, it turns northward and finally enters the Ottawa at Davidson, four miles to the north.

The Picanoc (a smaller river) also enters the map-area from the north, and for about 10 miles it follows a remarkably straight south-easterly course. Just north of Otter Lake village, the river widens, then turns abruptly to the north-east, and again follows a straight course for several miles. It then follows a more irregular course to the Gatineau river. The widened portion of the river is Otter lake. It is possible that the river at one time emptied into the Ottawa, or followed a different course to the Gatineau, but that the channel north of Otter Lake village became blocked, forcing the river to seek a more northerly route.

The Kazabazua river is located entirely within the map-area. Its headwaters lie in the east central part of the area, and

from here it follows, for the most part, a sinuous and meandering course to Kazabazua village and the Gatineau river. Just before entering the Gatineau, it flows, for a short distance, underground through marble, and has created at the village, a small natural bridge.

Many lakes are found in the highlands, as in other parts of the Canadian Shield, but they are mainly of relatively small size. In general, two kinds of lakes may be recognized, those that occupy a basin in bedrock, the bedrock normally being covered by a veneer of till, and lakes that occupy basins in relatively thick deposits of sand and gravel. Some of the lakes that occupy rock basins are Hickey, Huddersfield, Sopwith, Moore, Ellen, and Sinclair lakes. The elongation of some of these lakes or their bays reflects the structural trend in the underlying rocks; fine examples of this are found in the shapes of Hickey, Moore, Ellen, and Sinclair lakes, and lac du Rang. Johnson and Litchfield lakes occupy fault-controlled valleys, and are elongated parallel to the underlying faults.

Danford lake and the surrounding smaller lakes, in the western margin of the Kazabazua sand plain, are examples of lakes that occupy basins in sand. Other examples are found south-east of Otter Lake village, where a few small lakes occupy shallow depressions on the Grove lake sand plain; some of these evidently do not have an outlet. Lakes that occupy basins in sand and gravel are normally round or irregular in shape, and the shape bears no relationship to the structure of the underlying rock.

Climate

The map-area falls in the cool temperature climatic zone of North America, and receives a moderate amount of precipitation. The mean July temperature is 20°C and the mean January temperature is -11°C, while the mean annual temperature is 5°C.

The annual precipitation at Fort-Coulonge in the Ottawa valley is essentially the same as in the highlands, the average value being about 33 inches per year. In arriving at this average, 10 inches of snow are calculated as 1 inch of rain.

Natural vegetation

Originally the Ottawa valley and adjacent highlands were entirely covered by forest. Within the map-area, about 1/2 of the lowland area and about 1/20 of the highlands have been cleared.

The dominant forest association, as found on till-covered hills, consists mainly of broad-leaved trees, with some interspersed conifers. The major broad-leaved tree is the sugar maple (Acer saccharum), others being the yellow birch (Betula lutea), beech (Fagus grandifolia), red maple (Acer rubrum), basswood (Tilia americana), white ash (Fraxinus americana), white birch (Betula papyrifera), red oak (Quercus borealis), and trembling aspen (Populus tremuloides). The associated conifers include balsam fir (Abies balsamea), white spruce (Picea glauca), and eastern white pine (Pinus strobus).

On excessively drained soils, as found on the Calumet and Kazabazua sand plains, conifers dominate over broad-leaved trees. The dominant trees found here are the eastern white pine, red pine (Pinus resinosa), jack pine (Pinus banksiana), balsam

fir, white spruce, white birch, trembling aspen, and red oak.

On poorly-drained soil, as found in some valley bottoms, conifers, such as black spruce (Picea mariana), white spruce, tamarack (Larix laricina), balsam fir, and white cedar (Thuja occidentalis) dominate. The broad-leaved trees, where present, include black ash (Fraxinus nigra), elm, willow, and aspen.

A concise description of the natural vegetation of portions of Gatineau and Pontiac counties may be found in a report by Lajoie (1962), from which information for the above note was obtained.

Inhabitants and Resources

The estimated population of the area is 5000; most of the inhabitants live on small farms and in villages in the Ottawa and Gatineau valleys. The villages are, from west to east, Fort-Coulonge, Vinton, Otter Lake village, Ladysmith, Danford Lake village, Venosta, and Kazabazua. Other centres, that consist of only a post office or a few buildings, but which provide convenient reference points are Bell Mount (4 miles west of Otter Lake village), Greer Mount (4 miles west of Ladysmith), Sandy Creek (8 miles north-west of Otter Lake village), Cawood (9 miles south-west of Venosta), and Aylwin (2 miles north of Kazabuzua).

The three principal industries of the area are farming, forestry, and tourism.

Farming is a small but important industry. Lajoie (1962), in a soil survey of the area has shown that numerous kinds of soil have developed as a result of much variation in parent

material and in drainage. Soils best suited for farming are found in the Ottawa valley (in portions of Grand Calumet and Litchfield townships) and in the Gatineau valley (in portions of Low township), where the parent material is silt or clay. However, extensive deposits of sand are also found within these valleys, and also in other valleys within the highlands, and this material has in general produced soils low in fertility. On the hills, in the highlands, the dominant parent material is till, and although some land was cleared for farming, the soil is very stony, and is generally lacking in fertility. Much of the cleared land in the highland region is naturally or by planting, reverting to forest.

Forestry is the principal industry of the area. At present a large saw mill is located west of Kazabazua and at Davidson; smaller saw mills operate intermittently at a few other places. However much of the wood that is cut is used in the pulp and paper industry, and is transported by river or by truck to mills at Portage-du-Fort and the Hull area. Forestry provides a supplementary income for most of the resident farmers.

Tourism is increasing in importance; summer cottages and fishing camps are found on nearly all lakes of the area. The areas about Otter Lake village and Danford lake are especially popular for summer campers.

GENERAL GEOLOGY

The surveyed area is almost entirely underlain by a variety of crystalline rocks of known or presumed Precambrian age. Flat-lying Ordovician sedimentary rocks were found at only one locality. Most of the bedrock is covered by a veneer of Pleistocene till and Pleistocene to Recent clay, silt, sand, and gravel.

The subdivision of the lithologic units of the area is shown in the legend to the geological map (Map 1) and in the table of formations (Table 1). The following brief description of the general geology of the area may be regarded as an accompaniment to the geological map (Map 1); further details will be given in subsequent sections of this report.

All of the crystalline rocks that were encountered were assigned to one of five groups, based on mineral content and texture. These groups are 1) marble and skarn, 2) gray plagioclase gneiss, amphibolite, and quartzite, 3) mafic and ultramafic rocks, 4) pink potassium feldspar gneiss, and 5) granitic, syenitic, and dioritic rocks, and anorthosite. Each of these groups consists of three or more rock units or rock types, as indicated in the legend to Map 1.

Within the map-area, as in other parts of the Grenville province, it is common to find different rock types interlayered and intermixed on a small scale. It is therefore convenient to set up a number of map units, each of which normally consists of two or more rock units. The particular rock units that were observed within an outcrop area are then indicated by use of symbols as shown in Map 1. Thus an area mapped as 1

TABLE 1 - TABLE OF FORMATIONS.

Cenozoic	Recent and Pleistocene	clay, silt, sand, gravel
	Pleistocene	till
Paleozoic	Ordovician	conglomerate, sandstone, dolomite (Oxford formation)
Paleozoic or Precambrian		diabase dikes
Precambrian		granitic, syenitic, dioritic rocks, anorthosite potassium feldspar gneiss matic and ultramatic rocks plagioclase gneiss, amphibolite, quartzite marble, skarn

(dominantly marble) may be underlain by a variety of rocks including marble, skarn, amphibolite, and pegmatite, with marble apparently being the dominant or most abundant rock type.

Marble (1), together with plagioclase gneiss, amphibolite, and quartzite (2) underlie a large portion of the area, and appear to be, at least in part, the oldest rocks of the area. The marble is predominantly calcite marble and calcite-dolomite marble, but pure dolomite marble is also present. The gneiss and amphibolite contain different combinations of the minerals sillimanite, garnet, biotite, hornblende, and calcic pyroxene, and range from leucocratic to mesocratic; quartzite is not common. Some of the above rocks are similar to those that elsewhere in the Grenville province have been referred to as Grenville marbles and gneisses, or Grenville-type marbles and gneisses, but they cannot be correlated with confidence to similar rocks in Grenville township to the east or in the Bancroft area to the south-west.

The marble, gneiss, and amphibolite have been subjected to metamorphism and deformation, and with rare exceptions, top determinations are not possible. It is therefore impossible at present to set up a stratigraphic section, which would indicate that certain rocks are older or younger than others. Locally marble, gneiss, and amphibolite are interlayered, and appear to be contemporaneous, but it is unlikely that all of the rocks placed in groups 1 and 2 are of the same age.

A variety of mafic and ultramafic rocks (3) occur mainly as layers or small plutons in marble, gneiss, and amphibolite, described above. The most common variety is a plagioclase-

hornblende gneiss, with a conspicuous segregation of minerals, here referred to as metagabbro. Small masses of ultramafic rock, mainly pyroxenite, are found in association with metagabbro. Apart from diabase dikes, which are also placed in this group, all of the mafic and ultramafic rocks have been affected by metamorphism. In some, an igneous texture ('lath-shaped' plagioclase crystals) is partly preserved. Most of these are considered to be igneous rocks that have been metamorphosed, and they would then be younger than the marble, gneiss and amphibolite, but earlier than the most recent metamorphism.

Various pink potassium feldspar gneisses (4) form another major group of rocks. These are distinguished from plagioclase gneiss by an abundance of potassium feldspar often occurring, together with quartz, as a large number of small parallel veins. Potassium feldspar gneisses are distinguished from the granitic rocks, described below, by their finer grain size (1 mm). Locally they may be seen to grade along strike to gray plagioclase gneiss, and some of them at least are considered to be metasomatic rocks, produced from plagioclase gneiss. The metasomatism may have coincided with the most recent metamorphism.

A great variety of rocks that may generally be referred to as granitic, syenitic or dioritic rocks (5) forms another major group. Some are heterogeneous and some are homogeneous, but nearly all are gneissic or foliated, and evidently were affected by metamorphism. The largest body, referred to as the Bell Mount Complex, consists mainly of heterogeneous

leucogranite and calcic pyroxene syenite, with intermixed plagioclase gneiss and amphibolite, and potassium feldspar gneiss. The granitic and syenitic rocks in the complex may be, to a large extent, of metasomatic origin. Granitic, syenitic, and dioritic rocks in some of the smaller bodies are more homogeneous, and may be igneous rocks that have subsequently recrystallized. Smaller dikes and irregularly shaped bodies of pegmatite are extremely common throughout the area and cut all other rocks except the diabase dikes. All of the granitic, syenitic, and dioritic rocks did not form at the same time, but they are in general considered to be relatively young. Anorthosite, which is abundantly present to the east of the map-area, occurs as only a few very small bodies.

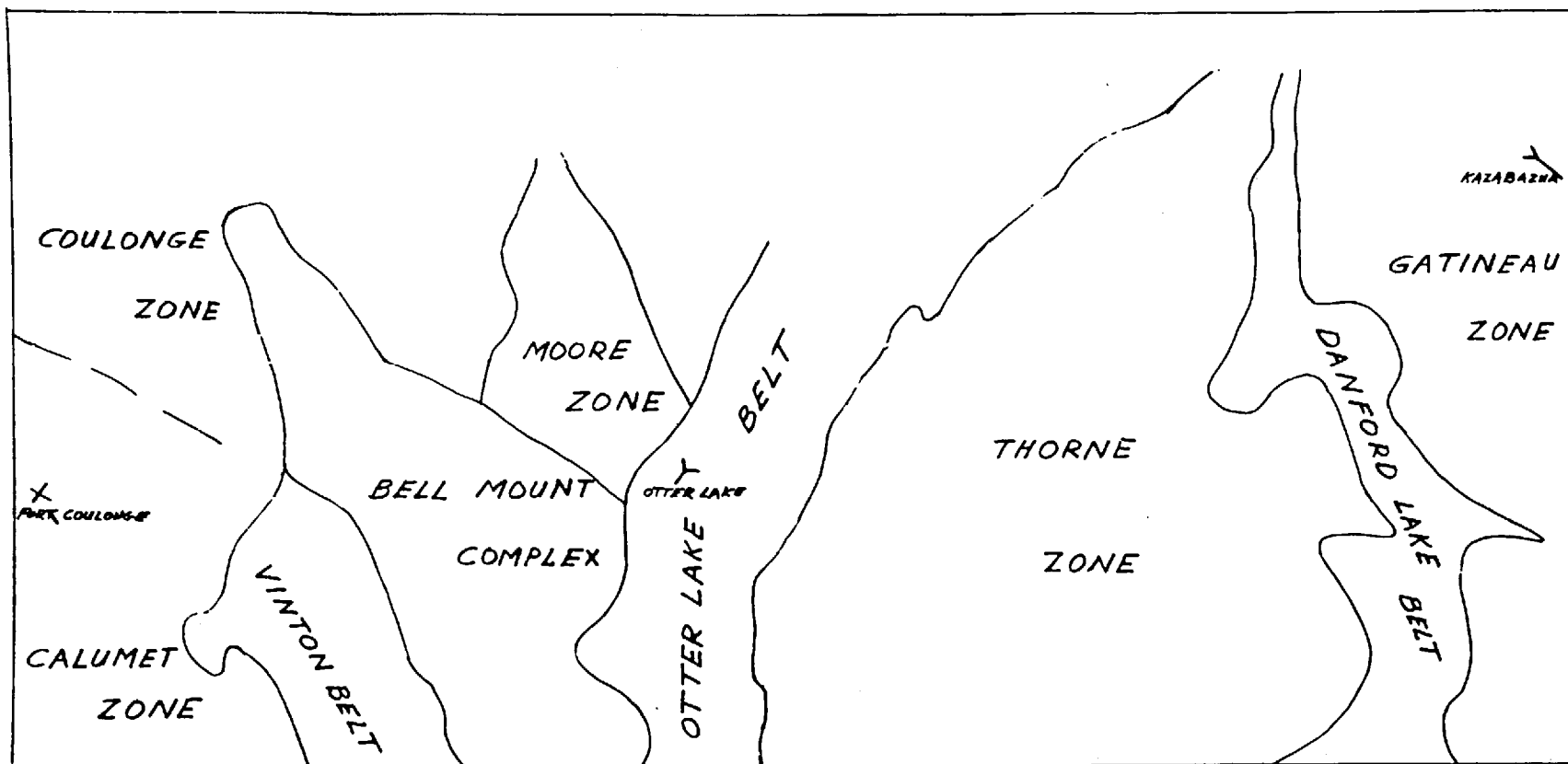


FIGURE 3 - Subdivision of the map-area.

The youngest crystalline rocks are a set of easterly-trending diabase dikes, which have not been affected by metamorphism.

On the western margin of the area a few outcroppings of flat-lying conglomerate, sandstone, and dolomite are found. These rocks are tentatively assigned to the Oxford formation of Ordovician (Beekmantown) age.

The unconsolidated deposits of the area consist of Pleistocene till, and Pleistocene to Recent clay, silt, sand, and gravel. Areas underlain by relatively thick deposits of this material are indicated on the geological map (Map 1).

MARBLE AND SKARN (1)

I. MARBLE

General Description

White marble, composed mainly of calcite or dolomite occurs throughout the map-area, and is commonly associated with and interlayered with gray plagioclase gneiss and amphibolite. Four zones may be delineated in which marble forms an important component, as shown in Fig. 3; these are referred to as the Gatineau, Thorne, Coulange, and Calumet zones.

The Gatineau zone is a broad belt of predominantly marble, about 10 miles wide, that extends up the Gatineau valley. The western border of this zone passes through the map-area near Danford and Venosta lakes, and the eastern border lies in the map sheet to the east, which was surveyed by Mauffette (1949). The next zone to the west is the Thorne zone, which forms a large area in the east central part of the area. This zone consists predominantly of interlayered marble and gray plagioclase gneiss and amphibolite in the ratio of approximately 4:6.

The zone continues for a few miles to the south, into an area surveyed by Sabourin (1965), and appears to be entirely surrounded by pink potassium feldspar gneiss. The zone is named after Thorne township, where the variety of rocks found therein may be readily examined. The Coulonge zone, an area bordering the Coulonge river in the western part of the area, consists of marble, gray plagioclase gneiss and amphibolite, pink potassium feldspar gneiss, and various granitic rocks, all closely intermixed. Marble, which makes up 1/10 of the total, locally forms lens-shaped bodies large enough to map separately. This zone extends beyond the western and northern borders of the map area; to the east and south it is bordered by potassium feldspar gneiss and a granite-syenite complex. The Calumet zone, in the south-west corner of the area consist of marble, amphibolite and various granitic rocks, including a pluton of granodiorite. Approximately 1/5 of the Calumet zone consists of marble.

The dominant variety of marble in all four zones is calcite and calcite-dolomite marble; pure dolomite marble is relatively more abundant in the Calumet zone.

Outside of the four zones, marble is commonly encountered in small amounts, occurring as layers and lenses 1 to a few meters thick. Some of this marble is identical to that found within the zones, but some is pink calcite marble, which is practically confined to the inter-zone regions.

On the geological map, 7 varieties of marble are identified, but for description purposes, it will be convenient to refer to 10 varieties, as follows (map symbols are given in parentheses);

common calcite and calcite-dolomite marble	(1a)
silicate-rich calcite marble	(1a)
dolomite marble	(1b)
olivine-bearing marble	(1c)
humite-bearing marble	(1d)
serpentine-rich marble	(1e)
brucite-bearing marble	(1f)
pink calcite - green pyroxene marble	(1g)
pink calcite - potassium feldspar - scapolite marble	(1g)
pink calcite - garnet marble	(1g)

Common calcite and calcite-dolomite marble is by far the most common variety. Typically, rocks of this unit are white to pale blue in colour, weathering gray, and consist almost entirely of calcite or calcite with 10 to 20 per cent of dolomite. Smaller amounts of graphite, amber phlogopite, and white pyroxene and amphibole are commonly present. The rock, as seen in the field, may or may not possess a faint layering. Where present, the layers are 1 to a few cm thick and are marked by variation in the colour of calcite or by variation in the amount of graphite or phlogopite present. In addition, layers of dolomite marble may be present, as shown in Fig. 4, or continuous and discontinuous layers of amphibolite, quartzite, or biotite gneiss. Most of the layering described above may be bedding.

Representative mineral assemblages of common calcite and calcite-dolomite marble from the Calumet, Coulange, Throne, and Gatineau zones are presented in table 2. Minor amounts of plagioclase appear to occur more frequently in marble of the

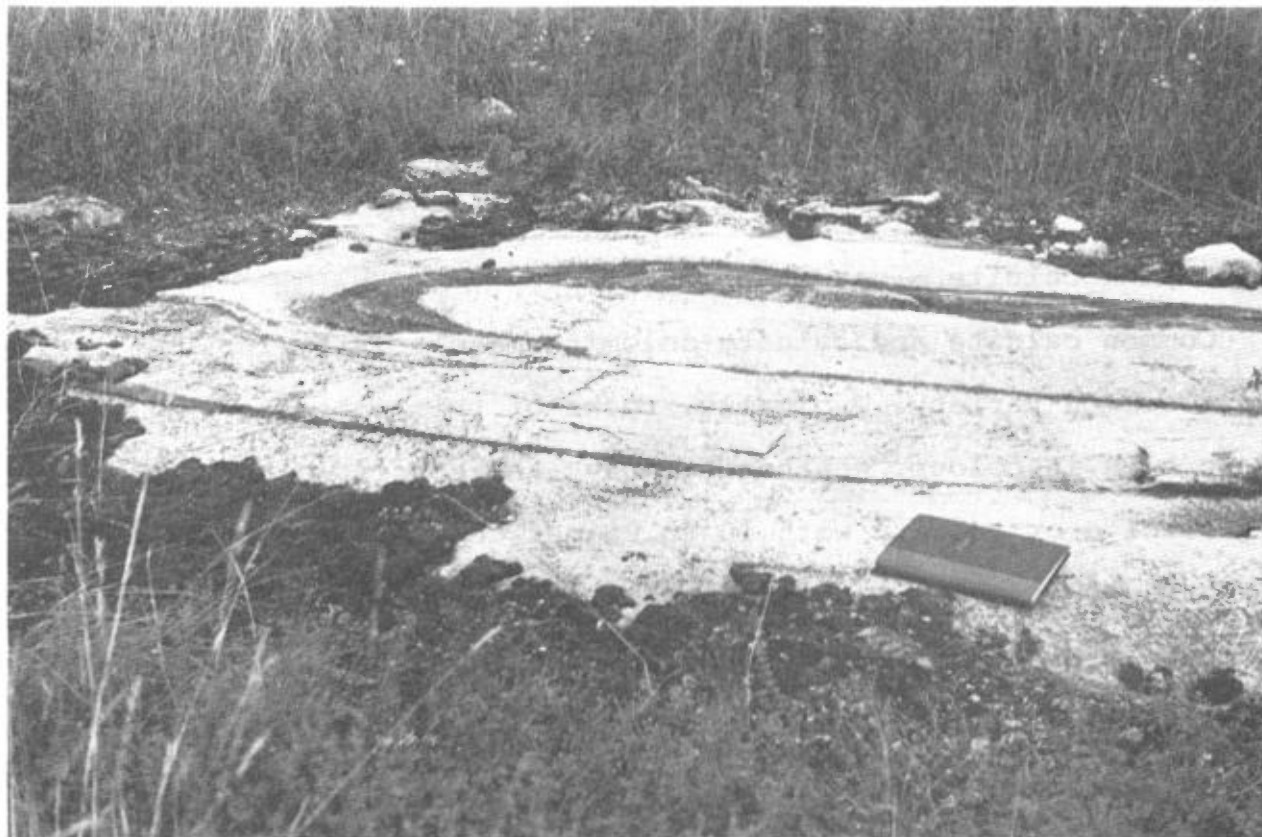


FIGURE 4 - Layers of dolomite marble (dark) in calcite-dolomite marble (light), Kazabazua River sub-area.

Gatineau zone than in the other zones.

Silicate-rich calcite marble is characterized by the presence of about 30 to 50 percent of silicate minerals, usually green amphibole and pyroxene, together with plagioclase, potassium feldspar, quartz, and sphene, the remainder consisting of white calcite. This rock is rare, and where present occurs as layers in common calcite and calcite-dolomite marble or in plagioclase gneiss and amphibolite. The minerals found in two specimens are given in Table 2.

Dolomite marble is normally a brilliant white on a fresh surface, and weathers dark gray. It usually occurs as layers in calcite and calcite-dolomite marble, as shown in Fig. 4, but in the Calumet zone it occurs as large bodies, containing numerous inclusions of white pyroxene skarn. Dolomite marble commonly contains a small amount of calcite, and may contain minor plogopite, amphibole, and other minerals, as shown in Table 3.

Olivine-bearing marble is calcite-dolomite marble with a few per cent of forsterite, usually much altered to a dark green aggregate of serpentine and magnetite. The rock occurs sparingly in the Gatineau, Thorne, and Coulange zones; in the Calumet zone it is very rare or absent. Similarly, humite-bearing marble is calcite-dolomite marble with a few per cent of yellow-brown humite-group mineral present, usually erratically distributed in the rock. Humite marble occurs in all four zones and is also found outside of these zones. Representative mineral assemblages of olivine-bearing and humite-bearing marble are presented in Table 4.

TABLE 2 - CALCITE AND CALCITE-DOLOMITE MARBLE (1a)

Zone:	Calumet					Coulange					Thorne					Gatineau					Silicate-rich calcite-marble	
	371-56	874-72	881-72	885-72	891-72	302-56	234-56	215-56	236-56	248-56	9-55	G4-66	G26-68	68-55	1083-74	759-70	778-70	1091-74	1105-74	1069-74	Thorne 185-55	Gatineau 758-70
Specimen number:																						
calcite	98	90	90	90	80	90	90	80	80	70	98	98	90	70	90	90	80	90	90	98	70	50
dolomite	2	-	10	2	-	2	2	10	10	30	-	2	2	2	20	10	-	-	2	10	-	-
phlogopite	.1	2	2	2	-	2	2	10	2	.1	2	2	2	2	2	2	2	-	2	.1	-	-
amphibole	-	2	-	-	.1	2	2	2	2	.1	2	2	2	10	2	-	-	.1	.1	.1	2	-
pyroxene	-	2	-	-	.1	2	-	2	.1	-	.1	-	2	-	2	2	2	-	-	-	10	10
quartz	-	2	-	.1	10	.1	.1	-	-	-	-	.1	-	-	-	-	10	.1	-	.1	.1	10
K feldspar	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	.1	2	10
plagioclase	-	.1	-	-	-	-	-	-	-	-	-	.1	-	-	-	2	2	.1	-	-	10	20
scapolite	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	.1	-	-
tourmaline	-	*.1	-	-	-	-	-	-	-	-	.1	-	-	-	-	-	-	.1	-	.1	-	-
sphene	-	.1	-	-	.1	-	-	-	-	-	-	-	-	-	-	.1	.1	.1	-	.1	.1	.1
epidote	-	-	-	-	-	-	-	-	-	-	.1	-	-	-	-	-	-	-	-	-	-	-
serpentine	-	-	-	-	-	-	-	.1	-	-	-	-	-	*	-	-	-	-	-	-	-	-
apatite	-	.1	.1	-	-	-	-	.1	-	-	-	.1	.1	.1	-	-	.1	.1	-	.1	.1	.1
graphite	.1	.1	.1	.1	-	-	-	-	.1	-	.1	.1	*.1	.1	.1	.1	-	2	.1	.1	.1	2
magnetite	-	-	-	-	-	-	-	-	-	-	.1	-	.1	*	-	-	-	-	-	-	.1	-
pyrite	.1	-	.1	-	.1	*.1	-	-	-	*	-	-	.1	-	-	-	.1	-	-	.1	-	-
pyrrhotite	-	-	-	-	-	.1	-	.1	.1	-	-	-	-	-	.1	2	-	.1	-	-	-	2

*identification not confirmed

Key: numbers in the table denote visual estimates of the volume percent of mineral present, as follows:

.1	less than 1 percent	50	45-55 percent
2	1-5 percent	60	55-65 percent
10	5-15 percent	70	65-75 percent
20	15-25 percent	80	75-85 percent
30	25-35 percent	90	85-95 percent
40	35-45 percent	98	more than 95 percent

TABLE 3 - DOLOMITE MARBLE (1b)

Zone:	Calumet					Coulange		Thorne		Gatineau
Specimen Number:	622-70	629-70	351-56	623-70	627-70	193-56	288-56	677-69	15-55	1087-74
calcite	-	.1	2	-	2	2	2	.1	2	2
dolomite	98	98	98	90	80	98	98	98	98	98
phlogopite	-	2	-	-	-	-	2	-	.1	-
amphibole	.1	2	2	10	20	-	.1	-	2	-
pyroxene	-	-	2	-	-	-	.1	-	-	-
quartz	-	-	-	2	-	-	-	-	-	-
serpentine	-	-	-	.1	-	-	.1	-	-	.1
talc	-	-	.1	-	-	-	-	-	*.1	-
graphite	-	-	-	-	-	.1	.1	-	-	-
pyrite	-	-	-	-	-	-	.1	-	.1	.1

*identification not confirmed

Key: See Table 2

TABLE 4 - OLIVINE-BEARING MARBLE (1c) AND
HUMITE-BEARING MARBLE (1d)

	Olivine-bearing marble									Humite-bearing marble See note below							
Location:	Coulonge Zone		Thorne Zone			Gatineau Zone											
Specimen Number:	329-56	305-56	646-68	193-55	1078-74	760-70	948-73	1090-74		322-56	340-56	G132-69	G5-66	1082-74	694-70	36-56	711-70
calcite	80	60	70	40	80	60	60	80		70	10	90	80	70	80	70	2
dolomite	2	30	30	30	10	10	10	-		2	70	10	20	10	30	10	90
phlogopite	10	2	2	2	.1	-	10	.1		10	10	2	.1	2	2	10	2
amphibole	-	2	2	-	2	-	-	2		.1	-	.1	2	-	2	2	-
pyroxene	-	.1	2	10	-	2	-	-		-	-	.1	-	-	-	-	.1
olivine	2	2	2	10	2	20	2	10		-	-	-	-	10	-	-	-
humite	2	-	-	-	-	.1	-	-		20	10	.1	2	2	2	2	2
K feldspar	-	-	-	-	-	-	-	.1		-	-	-	-	-	-	-	-
sphene	-	-	.1	-	-	-	-	.1		-	-	-	-	-	-	-	-
serpentine	10	10	2	2	-	2	20	.1		-	.1	.1	.1	2	-	10	.1
apatite	.1	.1	.1	-	.1	-	-	-		-	.1	.1	.1	-	-	-	-
graphite	-	.1	-	-	-	-	-	.1		-	-	-	.1	-	.1	-	-
magnetite	.1	-	-	.1	-	.1	.1	-		.1	.1	*.1	-	.1	-	.1	-
spinel	-	-	2	2	.1	-	-	2		-	-	-	.1	-	.1	-	-
pyrite	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	*.1
pyrrhotite	-	-	-	-	.1	.1	-	.1		-	-	-	.1	-	.1	-	*.1

*identification not confirmed

Key: See Table 2

Note: Location of humite-bearing marble and species of humite mineral:

322-56	Coulange Zone	clinohumite
340-56	Coulange Zone	clinohumite
G132-69	Thorne Zone	clinohumite
G5-66	Thorne Zone	clinohumite
1082-74	Thorne Zone	clinohumite
694-70	Huddersfield Twp., Yates property	norbergite
36-56	Leslie Twp., Bell Mount.	clinohumite
711-70	Huddersfield Twp., Picanoc Road	clinohumite and humite

TABLE 5 - SERPENTINE-RICH MARBLE (1e) AND
BRUCITE-BEARING MARBLE (1f)

Zone:	Serpentine-rich marble						Brucite-bearing marble		
	Coulange			Thorne			Thorne		
Specimen Number:	295-56	223-56	307-56	G10-66	75-55	G6-66	929-73	G138-70	1081-74
calcite	70	70	40	60	60	50	70	60	60
dolomite	2	-	30	10	10	10	2	10	20
phlogopite	2	2	2	.1	2	.1	-	-	-
pyroxene	.1	-	-	-	-	-	-	-	-
olivine	-	.1	-	-	-	-	-	-	2
humite gp.	-	-	-	-	-	-	-	*2	.1
serpentine	20	30	30	30	30	40	2	-	2
brucite	-	-	-	-	-	-	30	10	10
apatite	-	-	-	*1	-	-	-	-	-
magnetite	-	-	-	.1	-	-	-	-	-
spinel	-	-	-	-	-	-	-	*.1	.1
pyrrhotite	-	-	-	-	-	-	-	.1	.1

*identification not confirmed

Key: See Table 2.

TABLE 6 - PINK CALCITE MARBLE (1g)

	pink calcite - green pyroxene marble					pink calcite - potassium feldspar - scapolite marble					pink calcite - garnet marble	
Specimen Number:	311-56	832-71	94-56	942-73	1032-74	583-69	249-55	440-55	236-55	611-66	605-70	559-69
calcite	90	90	80	70	80	90	80	80	80	50	50	80
phlogopite	2	2	-	10	-	-	-	-	-	-	.1	-
amphibole	-	2	10	2	10	-	.1	-	-	.1	2	-
pyroxene	10	2	10	10	-	10	2	10	10	20	20	2
garnet	-	-	-	-	-	-	-	-	-	-	-	10
quartz	-	.1	-	-	10	-	2	.1	-	2	-	2
K feldspar	-	-	-	-	-	2	10	2	2	2	20	-
plagioclase	-	-	-	10	2	-	-	-	2	-	-	-
scapolite	*	2	-	-	2	2	10	2	2	20	10	2
sphene	.1	.1	-	-	.1	.1	2	.1	.1	2	2	.1
epidote	-	-	-	-	.1	-	.1	.1	-	.1	-	.1
serpentine	-	.1	-	-	-	-	.1	-	.1	.1	-	-
apatite	-	.1	-	-	.1	-	.1	.1	.1	.1	2	-
graphite	-	-	-	-	-	-	-	-	*	-	-	-
magnetic	*	-	-	-	-	.1	-	-	.1	-	-	-
pyrite	.1	.1	-	.1	.1	.1	.1	.1	.1	-	.1	-

*identification not confirmed

Key: See Table 2

Note: 942-73 is from the Thorne Zone, 1032-74 from the Gattineau Zone, and the remainder fall outside of the four zones.

TABLE 7 - ANALYSES OF CALCITE AND DOLOMITE FROM MARBLE

	White Calcite							Pink Calcite			
Rock Unit:	1a	1a	1c	1a	1a	1d	1c	1g	1g	1g	1g
Specimen Number:	892-72	870-72	105-55	886-72	G1-66	36-56	329-56	559-69	583-69	311-56	94-56
CaO	53.94	53.66	52.15	53.33	52.09	51.50	50.57	53.47	54.09	54.10	53.58
MgO	0.95	1.48	1.88	2.25	2.63	2.96	3.41	0.16	0.35	0.50	0.96
MnO	0.01	0.08	0.14	0.02	0.03	0.07	0.04	0.02	0.02	0.14	0.06
*FeO	0.12	0.61	0.17	0.12	0.16	0.19	0.18	0.14	0.39	0.39	0.48
SrO	0.16	0.16	0.17	0.12	0.17	0.15	0.27	0.50	0.37	0.93	0.14
BaO	0.16	0.17	0.15	0.23	0.24	0.17	0.21	0.19	0.16	0.21	0.18

	Dolomite										
Rock Unit:	1a	1b	1b	1c	1d	1d	1d				
Specimen Number:	248-56	623-70	193-56	G46-68	G132-69	340-56	622-70				
CaO	30.03	31.03	30.17	29.89	30.00	30.12	29.90				
MgO	21.38	21.88	21.61	21.05	21.04	21.56	22.05				
MnO	0.08	0.01	0.02	0.02	0.01	0.06	0.01				
*FeO	0.29	0.02	0.02	0.63	0.28	0.33	0.01				
SrO	0.02	0.09	0.02	0.04	0.04	0.07	0.03				
BaO	0.09	0.11	0.12	0.11	0.09	0.14	0.12				

*total iron expressed
as FeO

Analyst: Diane Garrett

Serpentine-rich marble is a rock containing 20-40 per cent of serpentine, together with calcite and some dolomite. It occurs as layers in calcite and calcite-dolomite marble, and as irregular masses within this rock. It was found in all four zones but appears to be rare in the Calumet zone. Brucite-bearing marble contains 10-30 percent of brucite, together with calcite and some dolomite. This rock was found at only three localities, all within the Thorne zone. It is readily identified in the field by the pitted surface resulting from the preferential weathering of nodules of brucite. Representative mineral assemblages of serpentine marble and brucite marble are given in Table 5.

Pink calcite marble is a distinctive rock, composed mainly of pink calcite; dolomite is absent. Most of these fall into one of two groups, depending on whether the silicates present are green pyroxene and dark phlogopite or green pyroxene, potassium feldspar, scapolite, and sphene. A garnet-bearing variety is rare. A few white marbles rich in potassium feldspar are also placed in this group. Pink calcite marble occurs mainly outside of the four zones referred to above, where it forms layers 1 to a few meters thick in potassium feldspar gneiss. Representative mineral assemblages of pink calcite marble are presented in Table 6.

Marble of the Kazabazua River sub-area

The Kazabazua River sub-area (Map 2A) may be regarded as the type locality for marble within the map-area. Here various kinds of marble are found in a relatively small area, and their relationship to other rock types is well illustrated.

Within the sub-area, calcite and calcite-dolomite marble

occur as layers and lenses ranging in thickness from a few cm to 180 meters. The interlayering of marble and plagioclase gneiss and amphibolite on a large scale is clearly shown on the detailed geological map (Map 2A). On a smaller scale, individual layers are locally about 6 meters thick (at co-ordinates 50.2, 19.7)*, or a few cm thick (at 48.33, 20.45).

The marble commonly contains inclusions of foreign rock. South of the Kazabazua river, in the vicinity of (48.8, 20.0), a large number of irregularly-shaped bodies of gray granitic rock, a few meters in dimension are found in the axial region of a folded layer of marble. Elsewhere, thin layers, fragments of layers, and small irregularly-shaped bodies of amphibolite, biotite gneiss, pyroxene and amphibole skarn, and aplite or pegmatite may be enclosed by marble. Inclusions of skarn and amphibolite may be rimmed by phlogopite, and pegmatite may be rimmed by pyroxene.

Fine exposures of calcite and calcite-dolomite marble may be examined near (49.9, 21.0), where the marble contains thin layers relatively rich in dolomite, in dolomite and phlogopite, and in amphibole. Layers of nearly pure dolomite, as shown in Fig. 4 are also present, as well as mylonite zones, composed mainly of fine-grained calcite and graphite. The various kinds of layers are all approximately parallel.

Humite-bearing marble may be examined at (49.8, 21.0), where clinohumite is locally present in a thick layer of calcite-dolomite marble. Serpentine-rich marble is found at (48.4, 21.5), where calcite-dolomite marble and serpentine-rich

* Reference co-ordinates throughout this report are given as minutes of latitude north of 45° and minutes longitude west of 76 degrees. Thus (50.2, 19.7) designates a location at 45°50.2' North, 76°19.7' West.

marble are interlayered, and at (49.2, 20.1), where serpentine marble contains pods of serpentine skarn and inclusions of diopside rock, rimmed by serpentine. Brucite marble may be examined at (48.1, 20.7), adjacent to a body of metagabbro.

Pink calcite marble was found at only two localities. At (20.2, 19.7), where marble and plagioclase gneiss are interlayered, some of the marble is pink and contains green pyroxene and potassium feldspar. At (48.25, 19.7) a small amount of pink marble, containing green pyroxene and dark phlogopite, is exposed on a cliff which is composed mainly of white marble and plagioclase gneiss.

Minerals

Information on the minerals of the marble units will be described below. This information was derived from a microscopic examination of 100 specimens, some X-ray work, and the chemical analysis of numerous minerals. The information will further characterize the rocks, and will provide the data needed to carry out a brief consideration of the metamorphism and origin of the rocks.

Calcite

In the great majority of the common calcite and calcite-dolomite marbles, calcite forms more than 90 per cent of the rock; locally the proportion decreases to about 70 per cent as the result of an increasing proportion of dolomite, and rarely to about 50 per cent as the result of increasing proportions of silicate minerals. In the dolomite marbles, calcite normally forms less than 5 per cent of the total, or is not present at all. In the absence of calcite, magnesite could conceivably be

present, but this mineral was not detected.

Although normally white, calcite may be gray, pale blue, pale yellow or pink in colour, the latter is sometimes observed where marble is in contact with pink granite rock. Some of the variation in colour may be seen in a highway cut, immediately south of Kazabazua. Although the cause of colour variation was not examined in detail, the pink calcite of the pink calcite marbles is evidently richer in iron than the common white calcite. In 11 out of 12 analyses of pink calcite, from 4 to 10 iron atoms were found to be present for every 1000 cations, while only 4 out of 30 white calcites contained as much iron. Pink calcites also tend to be richer in strontium.

Calcite normally occurs as grains 1 to 5 mm in diameter, but smaller grains are found in mylonitic marble, and grains up to 4 or 5 cm in diameter are not uncommon, especially in the Gatineau zone. Grains are roughly equidimensional, with no tendency to platy or elongate shapes, and grain boundaries are normally highly irregular. Lamellar twinning is usually well displayed, but some grains may contain smaller grains, free of twinning, presumably the result of strain-eliminating recrystallization.

Grains of calcite containing small inclusions of dolomite were found in some calcite and calcite-dolomite marbles, and in many olivine and humite-bearing marbles, which normally contain a higher percentage of dolomite. The inclusions were not detected in any of the pink calcite marbles, where dolomite as discrete grains is absent, and the calcite crystals have, for the most part, a lower magnesium content. The inclusions

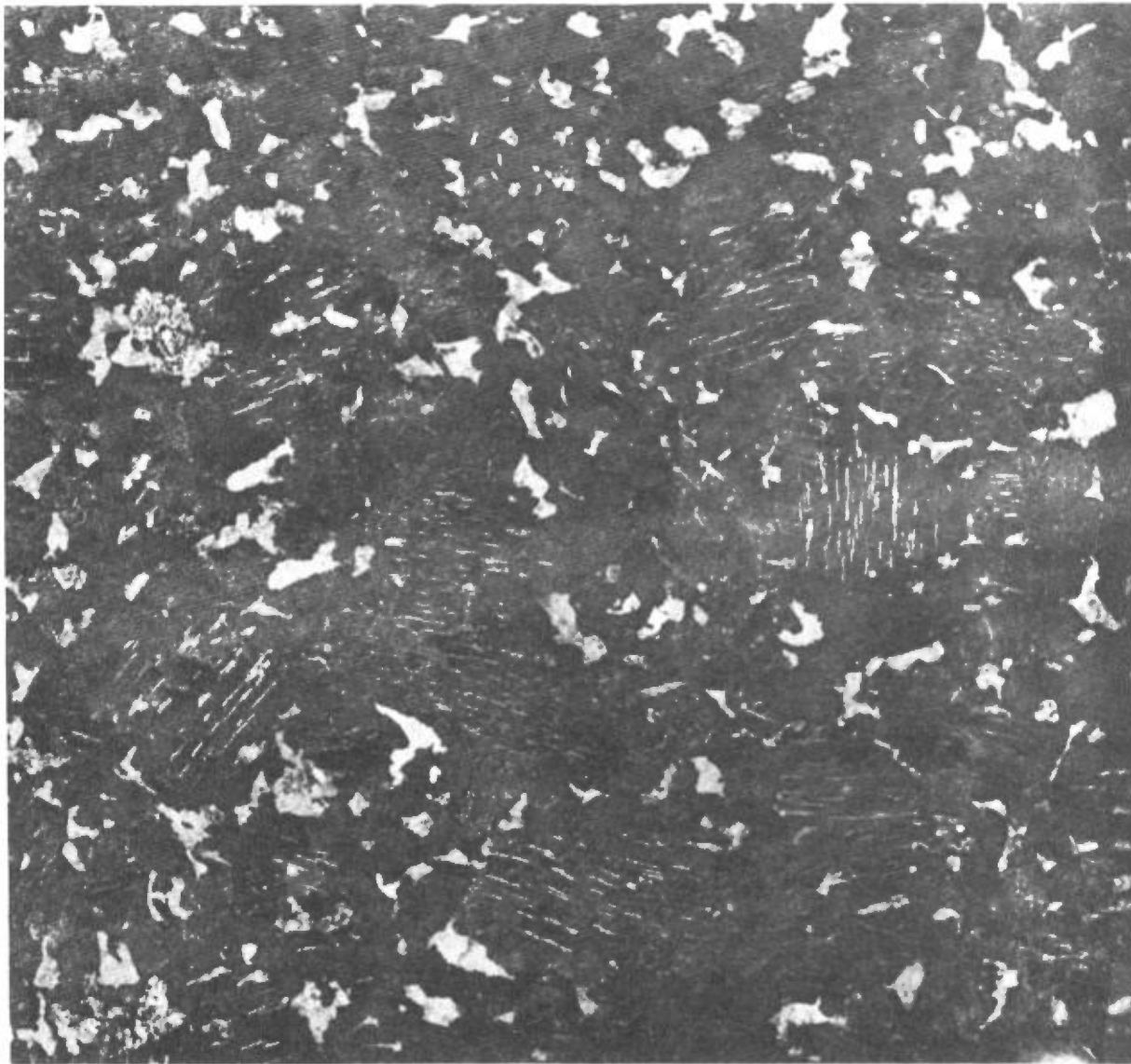


FIGURE 5 - Calcite-dolomite marble (77-55), showing stained calcite (dark) and unaffected dolomite (light), the latter occurring as discrete grains and as lamellar inclusions in crystals of calcite. Distance across photograph is 4 cm.

may sometimes be seen in thin sections, but show up best on etched and stained rock slabs, as is shown in plate 3, and occasionally may be seen in the field on weathered surfaces. The inclusions normally form a number of parallel lamellae or lenses, or parallel rods, but radiating lamellae or rods, and irregular blebs were also observed. The orientation of the lamellae varies; in some rocks they lie parallel to the long diagonal of the calcite cleavage rhombohedron and perpendicular to the calcite c axis, while in other rocks they lie parallel to the cleavage planes. Also, the crystallographic axes of a set of dolomite inclusions are normally parallel, but they may or may not coincide with the c axis of the enclosing calcite. The dolomite inclusions are presumed to be the product of an exsolution reaction that occurred during cooling of the rocks, with different rates of cooling and other factors playing a part in determining their shape, distribution, and orientation.

Representative analyses of calcite are listed in table 7. These are atomic absorption analyses of minerals that were carefully separated and purified. The magnesium concentration ranges to 3.4 weight per cent MgO, and considerable variation is also found in the concentration of manganese, iron, strontium, and barium.

Dolomite

In calcite-dolomite marble, the dolomite content is normally a few per cent of the total, but locally it may increase to 20 or 30 per cent. The dolomite usually occurs as grains that in shape and size resemble the accompanying calcite, but in some rocks they tend to be smaller, as shown in Fig. 5.

Dolomite may be uniformly distributed or it may be concentrated in certain layers. Locally it occurs as non-equidimensional grains arranged in parallel to produce a foliation. Rarely it forms rims about crystals of olivine and phlogopite.

In dolomite marble, the dolomite crystals are normally 1 to 5 mm in diameter and are nearly equidimensional or irregular in shape. Occasionally grain boundaries are straight, producing a mosaic texture.

Representative analyses of dolomite are listed in Table 7. Some of the dolomite from the Calumet zone is remarkably pure; for example that from specimen 622-70, contains less than 0.20 weight per cent of combined manganese, iron, strontium, and barium oxides.

The analysis of coexisting calcite and dolomite has shown that in terms of cation fractions, dolomite contains about 3 times as much iron as calcite, while calcite contains about 2.5 times as much strontium as dolomite. Manganese is nearly equally partitioned between the two minerals. The distribution of barium is more erratic, but it is normally more abundant in calcite than in the associated dolomite.

Phlogopite

Phlogopite is the most common silicate mineral in the marbles of the area, and was found in nearly all of the common calcite and calcite-dolomite marbles that were examined. It is equally prevalent in the olivine, humite, and serpentine marbles, but is less common in the dolomite marbles, occurring there in only half of the specimens that were examined microscopically. It was

TABLE 8 - ANALYSES OF SILICATE MINERALS FROM MARBLE

	<u>Phlogopite</u>							<u>Amphibole</u>							
Rock Unit:	ld	la	la	la	la	lg	la	lb	ld	la	la	ld	la	lg	ld
Specimen Number:	711-70	68-55	G3-66	302-56	874-72	311-56	870-72	627-70	G5-66	68-55	G4-66	36-56	874-72	94-56	137-55
Al ₂ O ₃	12.70	14.09	14.50	14.06	12.03	12.72	14.73	n.d.	13.97	12.10	1.48	12.33	2.54	15.13	13.93
*FeO	0.28	0.69	1.24	2.01	3.80	4.78	5.10	0.02	0.35	0.74	1.13	1.89	3.87	10.43	22.05
MgO	27.82	26.16	25.04	25.52	23.15	23.65	21.98	24.27	21.32	20.95	22.03	22.94	20.73	15.31	6.75
MnO	0.00	0.00	0.00	0.00	0.01	0.05	0.01	0.02	0.00	0.01	0.00	0.06	0.06	0.05	0.13
CaO	0.09	1.27	0.49	0.39	1.06	0.07	0.99	13.22	12.55	13.15	12.40	11.56	15.17	12.07	11.91
SrO	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.00	0.02	0.00	0.01	0.01
Na ₂ O	0.70	1.12	0.19	0.19	0.09	0.42	0.27	1.68	2.17	2.83	0.73	2.19	0.35	2.03	1.06
K ₂ O	9.57	8.09	9.45	9.44	8.68	9.17	8.01	0.65	1.18	1.14	0.30	0.54	0.43	1.73	1.36
[Fe]	0.56	1.46	2.70	4.23	8.43	10.18	11.52	0.05	0.91	1.94	2.62	4.42	9.48	27.65	64.70

Rock Unit:	<u>Pyroxene</u>							<u>Olivine</u>	<u>Clinohumite</u>				<u>Garnet</u>
	la	lg	lg	lg	lg	la'	lg	lc	ld	ld	ld	ld	lg
Specimen Number:	874-72	94-56	583-69	559-69	G11-66	137-55	236-55	105-55	711-70	340-56	322-56	36-56	559-69
Al ₂ O ₃	0.38	2.39	0.80	0.93	1.36	0.98	1.90						16.22
*FeO	3.30	4.76	8.09	10.49	15.72	16.78	16.88	11.15	0.98	1.57	2.53	2.82	11.84
MgO	16.31	14.90	13.08	11.18	8.61	8.06	6.94	38.56	57.81	52.76	52.31	57.29	0.30
MnO	0.08	0.07	0.05	0.22	0.23	0.20	0.22	0.11	0.05	0.08	0.14	0.11	0.21
CaO	23.92	24.04	22.84	23.18	21.18	22.40	21.40						33.56
SrO	0.03	0.02	0.04	0.05	0.07	0.04	0.05						
Na ₂ O	0.08	0.32	0.20	0.22	0.71	0.28	0.49						
K ₂ O	0.02	0.01	0.01	0.02	0.02	0.02	0.03						
[Fe]	10.23	15.21	25.74	34.51	50.62	53.90	57.70	13.96	0.94	1.64	2.64	2.68	

*total iron expressed as FeO

n.d. not detected

[Fd] = [Fe/(Fe+Mg)] 100

Analyst: Diane Garrett

la common calcite and calcite-dolomite marble

la' silicate-rich calcite marble

lb dolomite marble

lc olivine-bearing marble

ld humite-bearing marble

lg pink calcite marble

not found in brucite marble nor in silicate-rich calcite marble.

Phlogopite normally occurs as small amber-coloured crystals, but the colour may vary, and was found to range from colourless, in some olivine-bearing marble, to black, in some pink calcite marble. Occasionally it is blue or green. Colourless phlogopite resembles muscovite, which was reported to be present by Shaw (1955) and Baker (1956) but was not found by the writer.

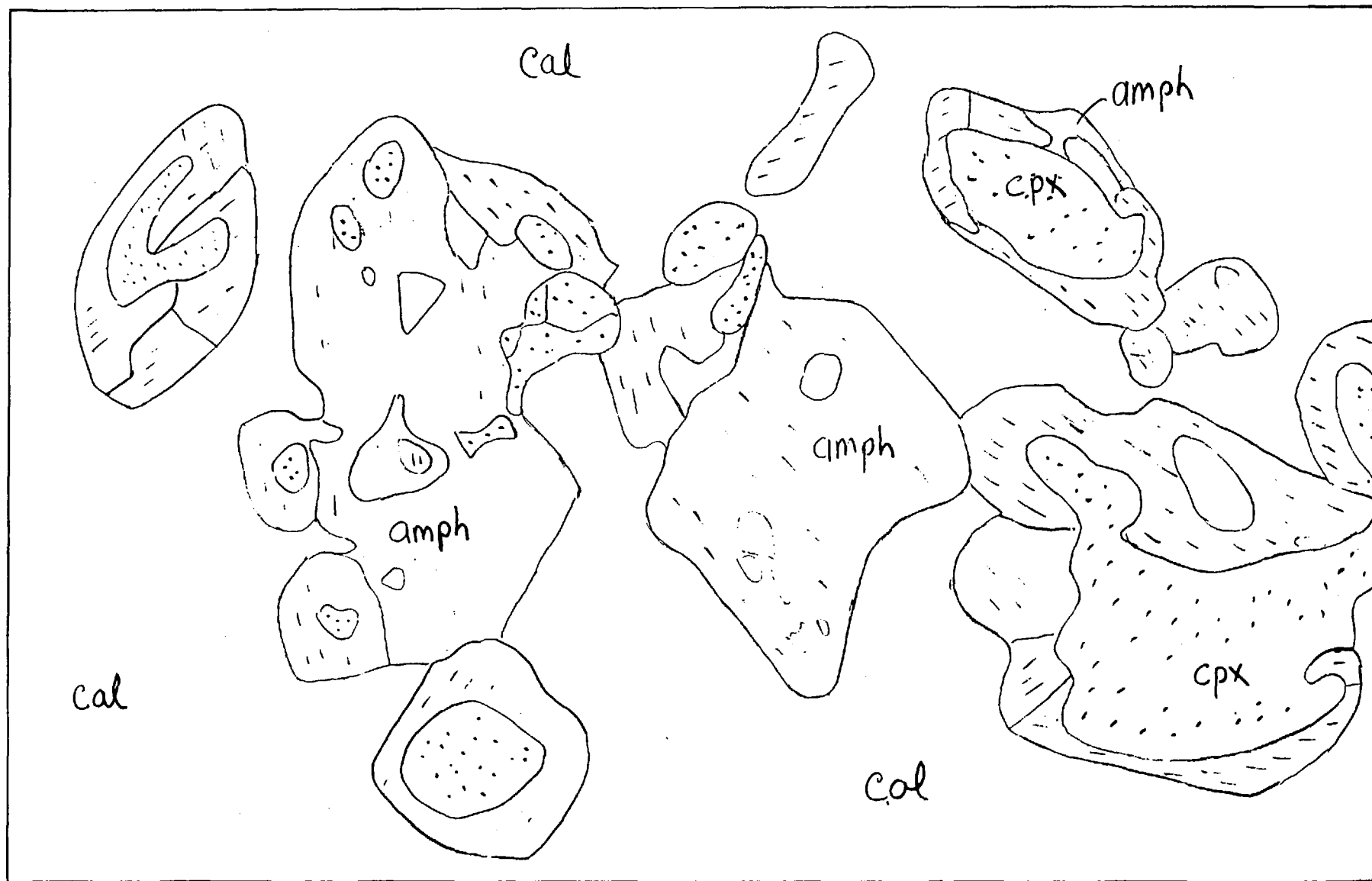
Phlogopite typically occurs as short tabular crystals with a ratio of height to diameter of approximately 1/3; rarely this ratio is 10 or more. Normally the crystals, with a mean diameter of about 1 mm, are uniformly scattered throughout the rock, or are somewhat clustered in the form of pods or layers. The crystals are usually oriented at random, but locally they may be oriented in parallel, thus defining a foliation.

In the majority of rocks, phlogopite crystals show no signs of deformation, but in some, short prismatic crystals have been folded, and in others they have been smeared-out to produce lath-shaped grains.

Some analytical data on phlogopite are listed in Table 8, which shows that appreciable amounts of iron and sodium may be present. In Table 8 the minerals are listed in an increasing order of iron content, which corresponds to a change in colour from colourless through pale amber and amber, to dark amber.

Amphibole

Calcic amphibole is a common constituent of the marbles, and was found in 80 per cent of the specimens that were examined microscopically. It is normally present in small amounts, but



- 40 -

FIGURE 6 - Crystals of amphibole (amph, dashed pattern) and pyroxene (cpx, dotted pattern) in a matrix of calcite (cal) in marble G7-66, showing rims of amphibole about pyroxene. Distance across figure is 2.7 mm.

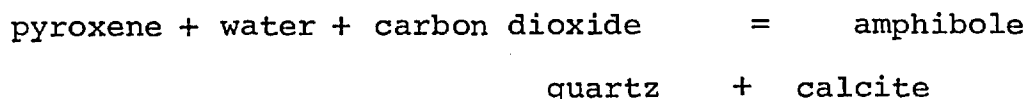
locally, in Grand Calumet township, up to about 20 per cent of white tremolite is present in both calcite marble and dolomite marble. Similar concentrations of green amphibole are found in the relatively rare silicate-rich calcite marble. Amphibole may be rather difficult to identify in the field, particularly if it is present in very small amounts.

Amphibole varies greatly in colour; the following have been observed: white, pale green, pale pink, pale brown, pale gray-green, olive-green, medium green, dark green, and black. On the basis of 13 chemical analyses it is evident that the colour darkens with increasing iron content, and that for a given iron content, aluminous amphiboles are darker than low-aluminum amphiboles. The former probably contain a higher proportion of ferric iron.

Amphibole commonly occurs as 'rounded' grains that are nearly equidimensional or are somewhat extended in the c direction. Prismatic $\{110\}$ faces may be poorly developed. Less commonly it occurs as long prismatic crystals that may be randomly oriented, radiating, or arranged in parallel to define a lineation. Locally in Grand Calumet township prismatic crystals of tremolite may reach several cm in length.

Amphibole also occurs as rims about crystals of calcic pyroxene, as shown in Fig. 6. Such rims may be a single crystal, oriented so that its crystallographic axis nearly coincide with the corresponding axis of the central pyroxene crystal, or it may consist of several differently-oriented crystals. Commonly small rounded inclusions of quartz are present in the amphibole

rims, suggesting that the following reaction has taken place:



Some analytical data for amphibole are given in Table 8, which shows that this mineral in calcite and calcite-dolomite marble and in pink calcite marble may be either high in aluminum (12-17 per cent Al_2O_3) or low (less than 3 per cent Al_2O_3). The iron content, expressed as the ratio $\text{Fe}/(\text{Fe} + \text{Mg})$ may vary greatly. A tremolite from Grand Calumet township (627-70, Table 8) contains very small amounts of iron and aluminum but an appreciable amount of sodium. Amphibole in common calcite and calcite-dolomite marble may have an iron ratio as high as 0.11, and in pink calcite marble, the ratio appears, on the average, to be somewhat higher. These amphiboles may be high or low in aluminum. The most iron-rich amphiboles are found in silicate-rich calcite marble, where the iron ratio may reach 0.65 (137-55, Table 8).

Amphibole rarely shows signs of alteration. In some rocks it is partly altered to serpentine, and in mylonitic rocks it may be partly replaced by calcite.

Pyroxene

The occurrence of calcic pyroxene is similar to that of amphibole, except that it is rarely formed in dolomite marble and in humite marble, and is more common in pink calcite marble. This mineral may be difficult to identify in the field, particularly if the crystals are small and wear a cloak of amphibole.

The colour of pyroxene ranges from white through pale green, to dark green. In common calcite and calcite-dolomite

marbles and in those bearing olivine, it is usually white to pale green, and in the pink calcite and silicate-rich marbles, where it is richer in iron, the colour is green to dark green. Typically, pyroxene occurs as nearly equidimensional, anhedral grains, less than 2 mm in diameter. In pink calcite marble it often forms short prismatic crystals with fairly well-developed prismatic faces (usually 8 of these are present), but with rounded edges and rounded terminations. In general, grains of pyroxene may be uniformly distributed in a rock or may form clusters.

Some pyroxene analyses are presented in Table 8; only one of these (874-72) is from common calcite marble, the remainder are from pink calcite marble and silicate-rich marble. The minerals contain an appreciable amount of iron. Strontium is generally higher and sodium lower than in amphibole.

Pyroxene is commonly altered to amphibole, as described above. In places it has evidently altered to serpentine, elsewhere to talc, and it may be partly replaced by calcite.

Olivine

Olivine is not a common mineral within the marbles of the area. Where present it occurs as rounded grains about 1 to 3 mm in diameter, that make up 2 to 30 per cent of the rock. The grains may be randomly distributed or they may form clusters of a few grains of near-parallel crystallographic orientation. Inclusions of calcite and spinel may be present.

Olivine is almost invariably altered in part to serpentine, but the extent of this alteration may vary greatly from grain to grain in the same rock. A partly-altered grain typically shows a network of serpentine, in which are found clusters

or stringers of very fine grained magnetite, which indicate that the olivine contained some iron. Only one partial analysis of olivine is given in Table 8, and this mineral contains about 14 per cent of fayalite component.

Humite-group minerals

Within the map-area, minerals of the humite group (without specifying the minerals of the group) may be said to be widespread but uncommon. Humite-bearing marble appears to occur mainly as patches within common calcite-dolomite marble.

The colour of the minerals ranges from pale yellow to yellow-brown, and in places resembles that of serpentine, with which it may be confused. Usually, however, it is readily identified in the field.

Identification with regard to mineral species is best done by use of X-rays. Within the map-area only clinohumite, humite, and norbergite have been identified; chondrodite was found in the Pontefract-Gillies area to the north. Clinohumite appears to be the dominant species; in two rocks, clinohumite and humite were found together.

Typically, humite-group minerals occur as rounded grains, 1 to 2 mm in diameter, which may be erratically distributed or may form distinct clusters. Clinohumite may show twinning.

In two olivine-bearing rocks, the associated humite-group mineral was found to be clinohumite, as expected, but in one (694-70), the identified humite-group mineral is norbergite, which occurs as discrete grains and as rims about olivine.

Four partial analyses of clinohumite are given in Table 8, which shows that this mineral is generally low in iron. Further

information on the chemistry of humite-group minerals, including some from the map-area may be obtained from a report by Bourne (1974).

Humite-group minerals appear to be resistant to secondary alteration. Thus unaltered crystals of clinohumite have been seen adjacent to crystals of olivine that are almost completely altered to serpentine. Locally, however, a minor amount of alteration to serpentine has evidently taken place.

Garnet

Garnet, a common constituent of the gneisses is exceedingly rare in the associated marbles. Where present it occurs as erratically distributed, small red-brown crystals, associated with green pyroxene and pink calcite. The analysis given in Table 8 shows this mineral to consist mainly of the grossularite component.

Quartz

The occurrence of quartz is of interest in relation to its stability in the presence of carbonate mineral. Within the common calcite and calcite-dolomite marble, quartz occurs frequently, in very small amounts, and was detected in about half of the specimens that were examined microscopically. Very locally it is present in amounts up to 10 per cent, giving rise to a distinctive calcite-quartz marble. It may also occur, to the same extent, in silicate-rich marble. Quartz is locally found in dolomite marble and in pink calcite marble, but not in the remaining rock units. Hence it was not found in the presence of olivine or humite.

Where present in very small amounts, quartz occurs as small isolated anhedral grains, 0.2 to 0.8 mm in diameter, or as small grains or grain aggregates, containing many small, round inclusions of calcite. It may also occur as inclusions in amphibole which forms rims about pyroxene, as described above.

Where present in larger amounts, within the calcite-quartz marble, quartz occurs as 1 cm aggregates of grains that show signs of internal strain. At one locality in the Gatineau zone, the aggregates are lens-shaped, and define a gneissic texture, and at another in the Calumet zone, they are pencil-shaped, and define a lineation.

Quartz has been detected in several dolomite-bearing rocks, but in most of these, the dolomite is present in amounts sufficiently small to be of secondary (exsolution) origin. However it also occurs in some dolomite-rich marble, always in small amounts, but definitely in contact with dolomite, and with no sign of reaction between them. Indeed, in one of these rocks (1091-74) there appears to be a preferred association between dolomite and quartz.

Potassium feldspar

Potassium feldspar occurs most conspicuously in some of the pink calcite marbles, where it occupies from a few to 20 per cent of the rock, and forms crystals of about 1 to 3 cm in diameter. In these rocks it is invariably associated with scapolite and sphene. A similar rock, in which the calcite and feldspar are white is found at the north end of Grand-Calumet township.

The potassium feldspar crystals may or may not show twinning, and locally contain visible lamellae or irregularly-shaped

grains of albite. X-ray photographs taken by C. Childe indicate that the potassium feldspar in a specimen of pink calcite marble is monoclinic, in as much as the 131 and $\bar{1}31$ reflections show little or no separation.

Chemical data for potassium feldspar from two specimens of pink calcite marble from the highlands (236-55 and G11-66) and from the Calumet locality (895-72) are given in Table 9. In two of the minerals, nearly 20 per cent of albite component is present. The first two and possibly the third as well are perthitic.

Potassium feldspar occurs rarely and in minute amounts in the common calcite and calcite-dolomite marbles. The presence of this mineral in dolomite-bearing marble is of interest in relation to the possible reaction of potassium feldspar and dolomite to produce phlogopite and calcite. In only one rock from the Gatineau zone were the two minerals found together, and here only a small amount of dolomite is present, all of which may be secondary in origin.

Plagioclase

Within the common calcite and calcite-dolomite marble, plagioclase was found at only a few places, mainly in the Gatineau zone, and usually only in trace amounts. In the silicate-rich marble it may form nearly 20 per cent of the rock. It is occasionally present in pink calcite marble in amounts ranging to 10 per cent, but was not detected in any of the other varieties of marble. It may be more prevalent than is indicated above, for in minute amounts, and in the absence of twinning, this mineral is not easily recognized.

TABLE 9 - ANALYSES OF POTASSIUM FELDSPAR FROM MARBLE

	<u>236-55</u>	<u>G11-66</u>	<u>895-72</u>
Al_2O_3	19.4	20.0	19.6
* Fe_2O_3	0.063	0.043	n.d.
CaO	0.18	0.57	0.47
Na_2O	1.09	2.39	2.58
K_2O	16.00	12.71	12.82
Or	89.8	75.6	74.8
Ab	9.3	21.6	22.9
An	0.8	2.8	2.3

*total iron expressed as Fe_2O_3

n.d. not detected

Analyst: Diane Garrett

TABLE 10 - ANALYSES OF SERPENTINE AND BRUCITE FROM MARBLE

	<u>Serpentine</u>		<u>Brucite</u>
	<u>329-56</u>	<u>G6-66</u>	<u>G138-70</u>
Al_2O_3	n.d.	n.d.	n.d.
MgO	40.45	40.26	62.43
*FeO	2.25	0.88	1.93
MnO	0.012	0.032	0.019
[Fe]	3.03	1.21	1.70

*total iron expressed as FeO

n.d. not detected

$[Fe] = [Fe / (Fe + Mg)] 100$

Analyst: Diane Garrett

329-56 olivine-bearing marble

G6-66 serpentine-rich marble

G138-70 brucite marble

Where present in amounts sufficiently large to estimate the composition, the plagioclase is not particularly rich in calcium. Estimates of composition in a few rocks, using the Michel-Lévy method, ranged from An_{20} to An_{35} .

Scapolite

Scapolite occasionally makes an appearance in the calcite and calcite-dolomite marble, where it may form about 2 per cent of the rock or less. It is much more common in some of the pink calcite marble where it makes up 2 to 20 per cent of the rock. Scapolite was not found in dolomite marble, nor was it found in the presence of olivine and humite.

Scapolite normally occurs as white equidimensional grains that together with calcite, pyroxene, and other minerals forms a mosaic texture. A partial chemical analysis of scapolite from a pink calcite marble (249-55) gave Al_2O_3 , 25.20; CaO , 16.45; Na_2O , 3.53; and K_2O , 0.75; which yields a $Ca/(Na+Ca)$ ratio of 0.84.

In some pink calcite marbles, scapolite crystals embedded in calcite are rimmed by epidote, which has evidently formed by reaction between scapolite and calcite, with the addition of water and removal of carbon dioxide.

Scapolite alters rather easily to a non-descript brownish material or to white mica. In some mylonitic rocks, it has been partly or completely replaced by calcite. Rims of epidote, where present, were not affected by the replacement process, and where all of the scapolite was replaced by calcite, these rims form a clue to the prior existence of scapolite.

Tourmaline

Tourmaline was found in about 1/5 of the common calcite and calcite-dolomite marble specimens that were examined in detail, but not in any of the other marbles. It may form isolated aggregates of grains, 1 to 2 cm in diameter, but normally it occurs as very small, near-hexagonal prisms that make up much less than 1 per cent of the rock. The best way of detecting small amounts of tourmaline and some other minerals, is to dissolve a fragment of marble in dilute hydrochloric acid, and then examine the residue.

The colour of tourmaline, as seen in the field or with the aid of a binocular microscope is brown, but may be pale green. The indices of refraction, $n(O) = 1.638$, $n(E) = 1.619$, suggest a composition close to that of the magnesium-bearing tourmaline, dravite.

Sphene

Sphene was identified with confidence in 8 of the 40 common calcite and calcite dolomite marble specimens that were examined microscopically, and with one exception, these are all from the Gatineau and Calumet zones. In these rocks it occurs as small grains, present in very small amount.

In the silicate-rich calcite marble, and in pink calcite marble, sphene is almost invariably present, normally as lens-shaped crystals that may make up 1 per cent or so of the rock. Sphene was not found in any of the other varieties of marble.

Epidote

Minerals of the epidote group are rare in the marbles,

and occur more frequently in pink calcite marble than in the others. Here the mineral forms rims about scapolite, as described above, or about potassium feldspar, or occurs as irregularly-shaped grains, and in all observed occurrences it is presumed to be a secondary mineral.

Serpentine

Serpentine is a fairly common mineral, occurring in all varieties of marble in small amounts, except the forsterite marble where it may be present to 10 or 20 per cent, and the serpentine-rich marble, where it is present to the extent of 20 to 40 per cent.

Serpentine invariably occurs as very fine grained material that is difficult to characterize. In colour it may be yellow-green, green, or brown. Serpentine of different colour and possibly different composition or structure may occur together.

Different stages in the alteration of olivine to serpentine may be observed; magnetite may or may not be a product of this reaction. The alteration of calcic pyroxene to serpentine is uncommon.

In serpentine-rich marble, serpentine may occur as nodules, similar to those produced by the alteration of olivine, or as serpentine-calcite intergrowths. Nodules of pure serpentine, 2 to a few cm in diameter may also be present, as well as rims of serpentine about nodules of white diopside skarn. In serpentine-rich marble, magnetite is rarely if ever present.

Some chemical data for serpentine from olivine marble and from serpentine-rich marble are given in Table 10. Serpentine from the olivine-bearing marble is associated with magnetite, and

contains more than twice as much iron as that from serpentine-rich marble; the latter may have formed by a different reaction.

In some very fine grained and possibly mylonitic calcite-dolomite marble, nodules of serpentine were evidently partly replaced by calcite.

Brucite

Brucite occurs as bluish-gray granules, about 1 mm in diameter, each consisting of concentric zones in which many tiny crystals have a common orientation, the orientation varying from one zone to the next. Some granules are nearly square or rectangular in section and may be pseudomorphs of periclase. In one rock, the granules partly or completely enclose small spherical aggregates of serpentine.

A partial analysis of brucite from the Kazabazua River sub-area is given in Table 10.

Apatite

Apatite is usually present in minor amounts in marble, but is uncommon in olivine, humite, and serpentine marbles, and was not detected in dolomite and brucite marble. Typically it occurs as small, near-spherical grains that may be colourless or blue.

Graphite

Graphite is very commonly and conspicuously present in calcite and calcite-dolomite marble, less so in forsterite, and humite marble, and was not found in serpentine and brucite marble. In the pink calcite marbles it is exceedingly rare.

Graphite normally occurs as platy crystals, which may be randomly oriented or arranged in parallel to produce a foliation. The crystals are susceptible to damage by deformation, and in

some rocks they have been bent or squeezed, and where deformation has been sufficiently intense to produce a mylonite zone, graphite occurs as tiny fragments dispersed throughout the rock or concentrated in streaks, which define both a foliation and a lineation.

Magnetite

Magnetite, where present, occurs in minute amounts, either as small discrete grains, $\frac{1}{2}$ mm in diameter, or as tiny aggregates in serpentine, a by-product of the olivine to serpentine reaction. Magnetite may be altered to hematite or limonite.

Spinel

Aluminous spinel was found in brucite marble and in roughly half of the specimens of olivine and humite marbles that were examined microscopically, and is virtually absent from all other varieties of marble. Usually it occurs as pale blue octahedral crystals, which in one specimen ranged in size from very small to 1.7 mm, with a mean size of 0.3 mm.

A semi-quantitative analysis of spinel from humite-bearing marble, obtained by N. Miles, showed about 13 weight per cent of each of MgO, FeO, and ZnO, and about 45 per cent of Al_2O_3 .

Sulphides

Common calcite and calcite-dolomite marble usually contains a small amount of pyrite or pyrrhotite, or both. The prevalent sulphide in dolomite marble is pyrite and in olivine marble, pyrrhotite. Neither mineral was found in serpentine-rich marble. Pink calcite marble almost invariably contains pyrite, never pyrrhotite.

Pyrite occurs as tiny crystals which normally show crystal

faces. In one rock the prevalent form was found to be the cube, in another the octahedron, and in a third, a combination of the two forms. Pyrrhotite occurs as irregular grains, lacking crystal form.

At several places in the field, a hydrogen sulphide odour was detected in the air when marble was broken with a hammer. This gas was emitted principally by dolomite marble, but also by calcite-dolomite marble. It was also detected in the laboratory upon grinding a coarse powder of pure dolomite, and it evidently occupies tiny cavities within the crystals. The rock from which the powder was obtained did not contain an iron sulphide mineral.

Crystals of pyrite are commonly altered to hematite or limonite, which forms a coating about them.

Mineral veins

Very narrow dolomite veins have been observed in calcite-dolomite marble at several places in the Thorne zone and also in the Gatineau zone. They show up on the weathered surface as a number of fine parallel lines. They strike east or southeast and dip steeply, parallel to the dominant fracture set in the adjacent gneisses. Tiny veins of calcite in dolomite marble have also been noted.

A specimen of olivine marble from the Bell Mount Complex of dominantly granitic and syenitic rocks, east of the Coulonge zone, was found to contain a small vein composed of calcite, phlogopite, serpentine, and fluorite.

At two localities in the Calumet zone, small hematite-bearing veins were found in dolomite marble. This mineral

occurs as black platy crystals, together with quartz and calcite.

Metamorphism

The marbles of the area are evidently metamorphic rocks, derived for the most part from sedimentary limestone. The metamorphism of the rocks will now be considered with the aim of obtaining some information on the conditions of metamorphism.

The description of minerals, that appeared above, has led to the conclusion that some of the minerals are secondary in the sense that they crystallized after the peak of metamorphism, presumably but not necessarily at a lower temperature. These are as follows:

dolomite (where exsolved from calcite)
amphibole (where forming rims about pyroxene)
quartz (where associated with amphibole rims)
epidote
serpentine
brucite

The following are taken to be primary:

calcite	garnet	apatite
dolomite	quartz	graphite
phlogopite	K-feldspar	magnetite
amphibole	plagioclase	spinel
pyroxene	scapolite	pyrite
olivine	tourmaline	pyrrhotite
humite gp	sphene	

The status of dolomite, amphibole, and quartz, which appear in both groups, is sometimes in doubt. Where dolomite is present in amounts less than about 5 per cent, it will be excluded from the primary mineral assemblage, for it may have all

TABLE 11 - MAGNESIUM CONTENT OF CALCITE*
IN CALCITE-DOLOMITE MARBLES

Specimen Number	Zone	Estimated % Dolomite impurity (as discrete grains)	$\frac{[(\text{Mg}/\text{Ca}+\text{Mg})]100}{\text{Corrected for Impurity}}$		Dolomite Lamellae Visible
			Measured		
68-55	Thorne	1	6.11	5.61	-
105-55	"	-	4.77	4.77	x
G4-66	"	1	5.31	4.82	-
G5-66	"	2	5.10	4.01	x
G6-66	"	1	6.34	5.85	-
G132-69	"	1/5	3.47	3.38	-
627-70	Calumet	1	8.57	8.07	x
881-72	"	1	3.53	3.03	x
886-72	"	1	6.03	5.54	-
892-72	"	1/2	2.64	2.39	-
248-56	Coulouge	1/2	2.93	2.68	-
302-56	"	1/2	4.52	4.26	x
322-56	"	-	6.87	6.87	-
329-56	"	1	9.07	8.57	x
340-56	"	1	6.95	6.46	x

Zone	Maximum $\frac{[\text{Mg}/(\text{Ca}+\text{Mg})]100}{\text{Corrected for Impurity}}$	T°C **
Thorne	5.85	560
Calumet	8.07	630
Coulouge	8.57	640

*atomic absorption analysis by Diane Garrett

**according to experimental data of Goldsmith and Newton (1969)

exsolved from calcite subsequently. Where amphibole occurs as rims about pyroxene or where it does not form rims but contains many tiny inclusions of quartz, it is regarded as secondary. Quartz, which occurs as tiny inclusions in amphibole, is also considered to be of secondary origin.

The calcite-dolomite reaction

The first reaction to be considered is that which governs the magnesium content of calcite in the presence of dolomite. Goldsmith and Newton (1969) have shown that this amount, expressed as the atomic ratio $Mg/(Ca + Mg)$ increases from 0.05 at 500°C, to 0.07 at 600°C, to 0.11 at 700°C. Thus the magnesium content of calcite forms a potential geological temperature indicator.

The presence of lamellae of dolomite in calcite of some of the marbles of the area was noted and illustrated above. If these are exsolution lamellae, as they appear to be, the magnesium content of calcite crystals from which dolomite has exsolved would be lower now than at the time of metamorphism. Therefore, during the separation of calcite for chemical analysis, an attempt was made to separate calcite grains together with their lamellae.

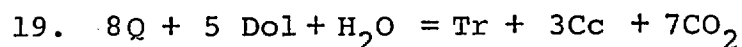
Data on the magnesium content of calcite from the Thorne, Calumet, and Coulange zones are listed in Table 11. Those samples of calcite that are low in magnesium may have exsolved much of it in the form of dolomite, some or all of which moved beyond the crystal boundaries, and thus was not recovered during the mineral separation procedure.

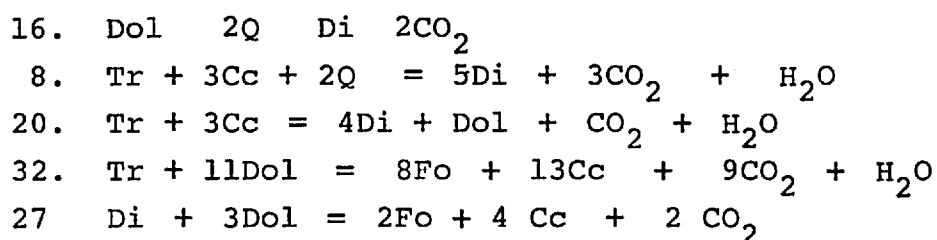
The presence of exsolution lamellae in some rocks but not in others suggests that the progress achieved by the reaction varied from one rock to another. Hence, for each zone, the highest magnesium analysis, presumably from a rock in which only a small amount of exsolution occurred, is taken as the best estimate of the original magnesium content and the best estimate for the peak in metamorphic temperature. A temperature of 630-640°C is thus indicated for the Coulange and Calumet zones, and this may have been the temperature for the Thorne zone as well.

Because of exsolution, as discussed above, the method is not sufficiently sensitive to establish differences in peak temperature for the different zones. The data do however indicate that temperatures of 630-640°C or slightly higher were achieved during the metamorphism of the marble.

Reactions involving calcite, dolomite, quartz, amphibole, pyroxene, and olivine

Several reactions involving the above minerals have been studied experimentally, and an examination of mineral associations of the present study in relation to the experimental results may provide further information on the conditions of metamorphism within the study area. For this purpose, the experimental results of Skippen (1971) will be used, and his mineral abbreviations and reaction numbers will be retained. The abbreviations are, : Q, quartz; Cc, calcite; Dol, dolomite; Tr, tremolite; Di, diopside; and Fo, forsterite, and the reactions of interest, with low-temperature minerals on the left are:





The corresponding equilibrium curves, at 2000 bars ($\text{CO}_2 + \text{H}_2\text{O}$) gas pressure, are shown in Fig. 7, which has been divided into three regions. The central region, labelled 5- is bounded by curves 32 and 27 (labelled 5), which mark the first appearance of forsterite, and by curves 19 and 16 (labelled 1), which mark the disappearance of the association quartz plus dolomite.

Particular combinations of the six minerals of interest, as found in the common calcite and calcite-dolomite marble, dolomite marble, and olivine and humite marble of the study area are indicated in Table 12. Although the silicates normally contain some iron and other elements, as noted above, and amphibole may be rich in aluminum, the minerals will be regarded as being capable of interacting in the manner indicated by the above-listed reactions. The corresponding reaction temperature may of course differ somewhat from the experimental temperatures of Fig. 7, but the relative position of the reaction curves may not change greatly.

The natural mineral associations have been divided into four groups, depending on where the mineral association falls on Fig. 7; H_2O and CO_2 are assumed to be members of the association. Some contain all minerals necessary for a reaction and fall on a reaction curve, while others can be assigned to

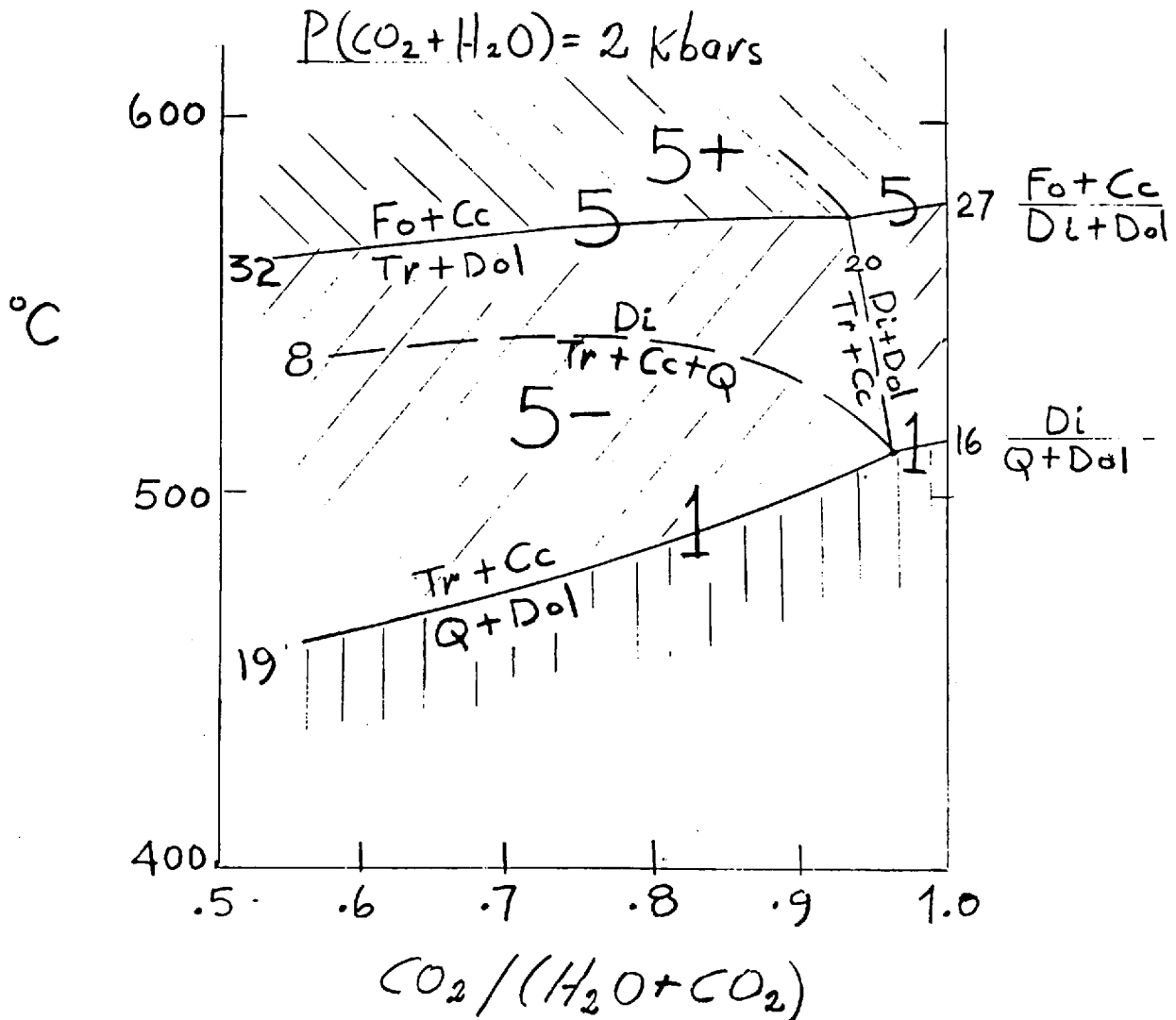


FIGURE 7 - Equilibrium curves for reactions involving calcite, dolomite, quartz, tremolite, diopside, and forsterite, as determined by Skippen (1971). Small numbers refer to mineral reactions, as given in text; large numbers refer to groups of observed mineral associations.

TABLE 12 - MINERAL ASSOCIATIONS IN MARBLE.

	Gatineau Zone										Thorne Zone									
	759-70	778-70	1071-74	1091-74	1105-74	1069-74	1087-74	760-70	948-73	1090-74	G7-66	G1-66	G3-66	G9-55	G103-69	G2-66	G131-69	G4-66	G48-68	77-55
calcite	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
dolomite	x	x	.	.	x	.	.	.	.	.	x	x	x	x	.	.	.	.	.	.
phlogopite	x	.	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
amphibole	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
pyroxene	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
olivine	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
quartz	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
K feldspar	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

	Coulouge Zone										Calumet Zone									
	302-56	234-56	215-56	236-56	248-56	193-56	288-56	329-56	305-56	322-56	340-56	295-56	371-56	870-72	874-72	881-72	885-72	886-72	892-72	891-72
calcite	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
dolomite	x	x	x	x	x	x	x	.	x	x	x	.	x	.	x	.	.	.	.	.
phlogopite	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
amphibole	.	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
pyroxene	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
olivine	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
quartz	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
K feldspar	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

	Other									
	119-56	47-56	694-70	36-56	711-70	119-56	47-56	694-70	36-56	711-70
calcite	x	x	x	x	x	x	x	x	x	x
dolomite	.	.	.	.	.	.	.	.	.	.
phlogopite	.	.	.	.	.	.	.	.	.	.
amphibole	.	.	.	.	.	.	.	.	.	.
pyroxene	.	.	.	.	.	.	.	.	.	.
olivine	.	.	.	.	.	.	.	.	.	.
quartz	.	.	.	.	.	.	.	.	.	.
K feldspar	.	.	.	.	.	.	.	.	.	.

x present, considered primary

o present in very small amount; no textural evidence for secondary origin; considered primary

. textural evidence for secondary origin; considered secondary

n identification not confirmed

- absent

particular areas on the diagram. The four groups are listed below; numbers in parentheses indicate the number of rock specimens (within the group examined microscopically) found to contain the particular mineral association.

a) Mineral associations that fall on curves 19 or 16 (symbol 1, Fig. 7).

on 19: Q-Dol-Tr-Cc (2)

on 16: Q-Dol-Di (1)

b) Mineral associations that fall below curves 32 and 27 and above curves 19 and 16 (symbol 5-, Fig. 7).

below 32 and 20, above 19: Tr-Cc-Dol (16)

on 8 : Tr-Cc-Q-Di (2)

on 20 : Tr-Cc-Di-Dol (8)

below 8, above 19 : Tr-Cc-Q (5)

below 27, above 16 and 20 : Di-Dol (1)

c) Mineral associations that fall on curves 32 and 27 (symbol 5, Fig. 7).

on 32 : Tr-Dol-Fo-Cc (1)

on 27 : Di-Dol-Fo-Cc (2)

on junction of 32
and 27 : Tr-Di-Dol-Fo-Cc (2)

d) Mineral associations that fall above curves 32 and 27 (symbol 5+, Fig. 7)

Fo-Cc-Dol (4)

Fo-Cc-Tr (1)

Fo-Cc (3)

The remaining mineral associations are placed in two additional groups, as follows:

e) Mineral associations that are stable within a wide area of Fig. 7, and are not very useful as metamorphic indicators.

Di-Q-Cc	(3)
Di-Tr-Cc	(5)
Di-Cc	(4)
Tr-Cc	(1)
Q-Cc	(1)
Cc-Dol	(2)

f) Mineral associations representing a Mg/Ca ratio greater than 1.0; magnesite may have been present initially.

Tr-Q-Dol	(2)
Tr-Dol	(1)

The above information indicates that most of the marble of the field area evidently crystallized at temperatures corresponding to the region 5- in Fig. 7. The common presence of amphibole indicates that some water was available, but because several associations fall on curve 20, in the right-hand side of the diagram, the H_2O/CO_2 ratio may have been, in general, relatively small.

Rocks containing olivine have evidently crystallized at a relatively high temperature (5 or 5 + in Fig. 7), and an attempt was made to locate an olivine isograd, which would appear on the metamorphic map as a line joining points denoted 5. However, Fig. 8 shows that olivine is irregularly distributed throughout the map-area, with the possible exception that it is absent in the sampled portion of the Calumet zone. Thus an olivine isograd may possibly exist along the boundary between the lowlands and the highlands.

If the calcite-dolomite temperature of 630-640°C for the Calumet zone is reliable, the absence of olivine in these

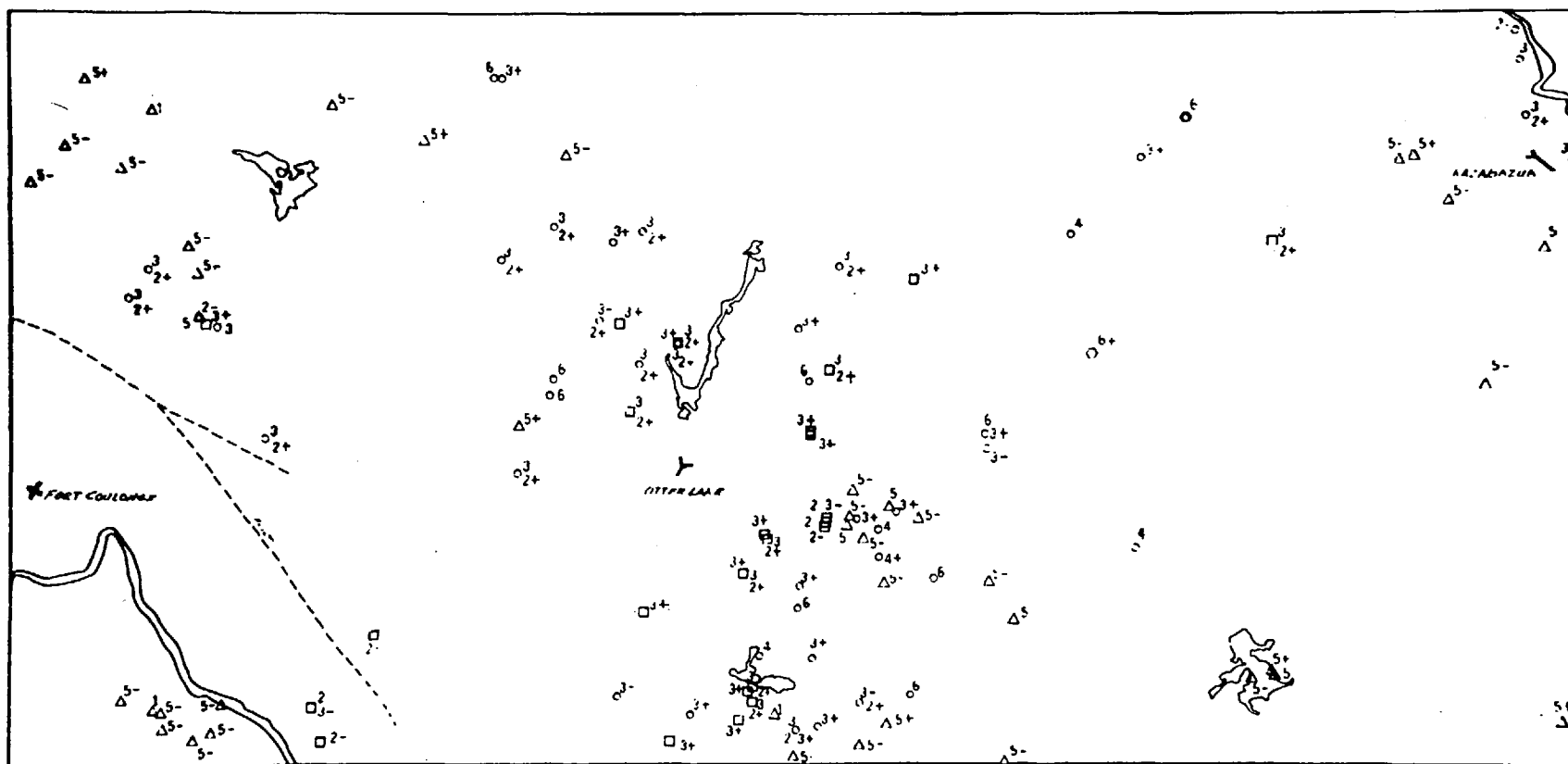


FIGURE 8 - Metamorphic map, Fort-Coulonge-Otter Lake-Kazabazua area.

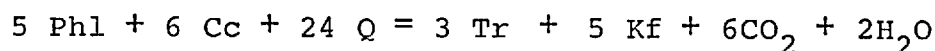
1 - quartz + dolomite + H ₂ O = tremolite + calcite + CO ₂	4 - hornblende = garnet + calcic pyroxene + quartz + H ₂ O
quartz + dolomite = diopside + CO ₂	
2 - muscovite + quartz = sillimanite + K feldspar + H ₂ O	5 - tremolite + dolomite = forsterite + calcite + CO ₂ + H ₂ O
	diopside + dolomite = forsterite + calcite + CO ₂
3 - biotite + sillimanite + quartz = garnet + K feldspar + H ₂ O	6 - hornblende + quartz = orthopyroxene + plagioclase + H ₂ O

- △ marble
- plagioclase gneiss, amphibolite, quartzite
- potassium feldspar gneiss
- metamorphosed dioritic rocks

rocks indicates that the gas pressure must have exceeded 2 kbars, i.e. curve 5 for the pressure conditions that prevailed in the study area, must lie about 100 degrees above its position as shown in Fig. 7.

Reactions involving phlogopite and potassium feldspar

Two reactions involving phlogopite (Phl) and potassium feldspar (Kf) will be considered briefly. The breakdown of phlogopite in the presence of calcite and quartz, according to the reaction

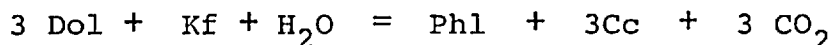


was investigated by Hoschek (1973) and the reaction curve lies a little below curve 8 in Fig. 7. The association phlogopite-calcite-quartz is fairly common in the study area (Table 12), while an apparently stable coexistence of amphibole and potassium feldspar was found in only one specimen. Hence, the conditions necessary to cause the above reaction to proceed to the right were, in general, not realized within the marble of the study area, and for the pressures that prevailed, the reaction curve is evidently located above curve 8, probably a little above curve 32.

Amphibole and potassium feldspar were occasionally found together in pink calcite marble and very frequently in certain granitic and syenitic rocks, but in all of these rocks the amphibole contains an appreciable amount of iron, The reaction temperature in these rocks was evidently lowered by the presence of iron, and also by a high $\text{H}_2\text{O}/\text{CO}_2$ ratio.

The production of phlogopite from dolomite and potassium

feldspar, according to the reaction



was investigated by Puhon and Johannes (1974) who located the reaction curve a little above curve 19 in Fig. 7. Now the association phlogopite-calcite is exceedingly common in the study area; while the association dolomite-potassium feldspar was not found at all (Table 12). All those mineral assemblages that were placed on curves 19 and 16, based on the presence of quartz and dolomite, contain in addition, phlogopite and calcite, with no sign of reaction between them to produce potassium feldspar. Hence, under the prevailing pressures, the curve for the above reaction should evidently lie a little below curve 19.

The above considerations of metamorphism lead to the conclusion that the peak temperature in the marbles of the area as a whole was evidently in the vicinity of 630-640°C or slightly higher, and that temperatures locally attained in the highlands exceeded those that prevailed in the lowlands. Within the highlands, different peak temperatures were evidently realized in different places, in an apparently irregular manner, so that the olivine-forming reaction was initiated in some rocks but not in others.

Origin

The common calcite and calcite-dolomite limestones are considered to be metamorphosed sedimentary limestone. Younger limestones, unaffected by metamorphism, commonly contain some detrital and authigenic minerals that could account for the presence of silica, alumina, and alkalis needed for the

production of silicates, which are commonly present. Graphite may be of organic origin.

The silica-rich calcite marble may have been relatively impure limestone, i.e. calcite-dolomite limestone with a higher proportion of detrital sand and clay particles. In view of the relatively high iron content of amphibole and pyroxene in these rocks, the original impurity likely contained some iron, perhaps in the form of chlorite or volcanic ash.

The dolomite marble is presumably also of sedimentary or diagenetic origin. The purity of these rocks is remarkable.

The olivine-bearing and humite-bearing marble resemble the common calcite and calcite-dolomite marble in chemical composition, and are considered to have a common origin. The source of fluorine to produce humite-group minerals is not known. In most places an external source is not obviously present, and the humite may simply represent local concentrations of fluorine which was initially in the limestone or adjacent sediments. However, small bodies of a fluorite-bearing granite occur in Huddersfield township, and bodies of this kind may have provided a source of fluorine for some humite occurrences.

The origin of the serpentine-rich marble is poorly understood. These are not simply olivine-bearing marbles in which all of the olivine has altered to serpentine, for the olivine marbles normally contain a variety of other minerals, for example magnetite, which are normally not present in serpentine-rich marble. Also, whereas the olivine marbles contain only 10 to 20 per cent of olivine, the serpentine-rich marbles

contain up to 40 per cent of serpentine. The latter may possibly be metasomatic rocks in as much as silica and water were introduced to common marble, and serpentine was produced directly from dolomite. In any case, the crystallization of serpentine presumably occurred subsequent to the major metamorphism, and at a lower temperature.

Two of the brucite marbles occur adjacent to bodies of metagabbro, while the third is not obviously situated near a rock of possible igneous origin. It seems likely that the brucite found near metagabbro formed from periclase, which originally crystallized in the rock as a result of high temperature contact metamorphism.

The pink calcite marbles normally form lenses or layers, enclosed by pink potassium feldspar gneiss or heterogeneous pink granitic and syenitic rocks. The latter rock types are considered to be, at least in part, of metasomatic origin, having received potassium from an external source. The pink calcite marbles, especially those that contain potassium feldspar, may have a similar origin. The initial rock may have been a common calcite-dolomite marble, from which pink calcite marble could be derived by an introduction of various elements. Apart from potassium, which would be needed for the production of potassium feldspar, iron would be required for amphibole and pyroxene, sodium and chlorine for scapolite, and titanium for sphene. However, some of the bodies of pink calcite marble appear to be highly irregular in shape, and may possibly have formed as the result of the partial replacement of granitic or syenitic rock by calcite.

MARBLE AND SKARN (1)

II SKARN

General Description

Various rocks, composed principally of calcic pyroxene, calcic amphibole, scapolite, and certain other calcium and magnesium-containing minerals are widespread throughout the map-area, and will all be referred to as skarn. The rocks placed in this group occur as relatively small bodies, ranging from nodules in marble, a few cm across, to lens or tabular bodies in gneiss, several meters thick and a few hundred meters long. The rocks are characteristically very heterogeneous, and changes in the kind and amount of minerals present may vary greatly in short distances. In most rocks the crystal size is highly variable, with giant crystals of pyroxene, phlogopite, scapolite and apatite, several cm across, occurring quite frequently. Many of the known occurrences of molybdenite, uranium-thorium minerals, mica and asbestos within the map-area are found in these rocks, and for many years they have attracted the attention of prospectors, mineral collectors, and mining companies.

For the purpose of describing the rocks, they have been subdivided as follows; map symbols are given in parentheses:

white pyroxene skarn	(1p)
and associated quartz rock	(1s)
serpentine skarn	-
green pyroxene skarn	(1q)
amphibole skarn	-
phlogopite skarn	-
pyroxene-scapolite skarn & granulite	(1q)

TABLE 13 - MINERALS IN HAND SPECIMEN OF SKARN.

	White Pyroxene Skarn			Ser- pen- tine Skarn	Green Pyroxene Skarn							Amphibole Skarn					Phlog- opite Skarn	Pyroxene-scapolite Skarn							Pyroxene- scapolite Granulite					Pink Calcite Skarn				Pyrox- ene- garnet Skarn				
	324A-55	630-70	937-73C	937-73B	G141-70	353-55	427-55	440A-55	117-56	594A-69	805-70	441-55	G84-69	923-73	109-55	385-56	G89-69B	13-55	G89-69C	589-69	268-55	G8-67	G87-69	733-70	691-70	409-55	43-55	248-55	130-56	1059-74	716-70	91-56-3	841-72	502-55	590-69	304-55	585A-69	
Pyroxene	98	80	98	-	-	90	98	80	+	+	80	+	-	-	-	30	-	-	-	40	40	30	40	40	40	10	30	60	20	20	10	+	-	-	+	20	10	
Amphibole	-	20	-	-	-	10	.1	10	+	+	-	-	90	98	90	60	98	-	-	-	.1	.1	-	-	.1	10	.1	2	20	-	.1	-	-	-	-	-	-	-
Phlogopite	2	-	-	-	-	2	-	10	+	+	10	-	10	-	10	10	-	98	98	-	.1	.1	-	2	-	.1	-	-	-	-	2	-	-	+	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	80	30
Epidote	-	-	-	-	-	-	.1	-	-	+	-	-	-	-	-	-	-	-	-	-	-	.1	-	-	-	-	.1	2	2	-	.1	-	-	-	-	-	-	20
Allanite	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Serpentine	-	-	-	90	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calcite	.1	-	2	10	30	-	.1	2	+	-	-	-	-	2	.1	-	-	-	-	.1	-	.1	-	2	2	2	.1	2	2	30	10	+	98	+	+	.1	-	
Quartz	-	-	-	-	-	-	.1	-	-	-	-	-	-	-	*.1	-	-	-	-	-	-	-	-	.1	-	-	.1	.1	2	-	10	+	.1	-	-	.1	-	
K' feldspar	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	2	-	20	40	+	-	-	-	-	-	-
Plagioclase	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.1	-	-	2	-	-	+	-	-	-	-	
Scapolite	-	-	-	-	-	-	-	-	-	-	10	+	-	-	-	-	.1	-	-	60	60	70	50	50	60	70	70	30	50	20	10	+	-	-	-	-	50 ^m	
Sphene	-	-	-	-	-	-	.1	-	-	+	-	+	-	-	-	-	-	-	-	.1	.1	2	.1	.1	2	-	2	.1	.1	2	10	+	-	-	-	-	.1	
Fluorite	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	
Apatite	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	2	-	.1	-	-	-	-	.1	.1	.1	-	.1	+	2	-	-	-	-	
Graphite	-	-	-	-	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magnetite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*.1	-	*.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.1	
Pyrite	-	-	-	-	-	-	-	-	-	-	-	-	-	2	.1	-	-	-	-	-	-	-	-	-	-	-	-	.1	.1	-	.1	-	-	-	-	-	-	-
Pyrrhotite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	*.1	-	
Molybdenite	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* identification not confirmed; m altered to white mica; + present, amount unspecified; - absent. Key: see Fig. 2

pink calcite skarn	(17)
pyroxene-garnet skarn	-

Representative mineral assemblages of the different varieties are given in Table 13.

White pyroxene skarn

Wherever common calcite and calcite-dolomite marble occurs, inclusions of a rock composed almost entirely of white pyroxene are likely to be found. Thus they are present in the marbles of the Gatineau zone, and in somewhat greater abundance in the eastern part of the Thorne zone, particularly in the area between Danford Lake village and Cawood (Baker, 1956). They are also found in the western part of the Thorne zone, for example in the Kazabazua River sub-area (Map 2A), and to the south, near Barnes lake, where the pyroxene is pale green in colour. They are found frequently in the Coulonge zone, where locally the inclusions are lens-shaped and arranged parallel to the trend of layering in the surrounding rocks. They appear to be less common in the calcite marbles of the Calumet zone.

The inclusions typically measure a few cm or tens of cm across, and may be ovoid, tabular or irregular in shape. The rock is made up of an aggregate of apparently randomly oriented grains of calcic pyroxene, 2-3 mm in size; small amounts of white calcite and light amber phlogopite may be present.

In the Calumet zone, an area of about one square mile is underlain by a mixture of dolomite marble, white pyroxene skarn, and a quartz rock. These remarkable rocks will be described as one of the examples to follow.

Serpentine skarn

Nodules of white pyroxene skarn in marble are commonly surrounded by a rim of rock composed of 70 to 90 per cent of serpentine, the remainder being calcite. This rock, which is referred to as serpentine skarn also occurs as discrete nodules, a few cm to a metre across, particularly in serpentine-rich marble. Veins of asbestos may be present.

At one locality in the Kazabazua river sub-area (48.1, 20.7), a body of serpentine skarn contains many parallel layers of calcite, about 1 mm thick, producing a rock similar to Eozoon Canadense (Logan, 1866), which was thought to be a fossil.

Green pyroxene skarn

A rock containing about 80 per cent or more of green to dark green calcic pyroxene, with small amounts of mica, amphibole, calcite, and other minerals is here referred to as green pyroxene skarn. It forms small-to medium-sized bodies in or adjacent to marble, but it also occurs as conformable layers, a few meters thick in potassium feldspar gneiss, and as irregularly-shaped bodies in pink pyroxene granite and syenite. Although gradations may be seen from white to green pyroxene skarn, accompanied by an increase in iron, the latter are far more common. This appears to be true for the area as a whole, including the portion examined by Baker (1956).

Green pyroxene skarn typically consists of an aggregate of randomly oriented pyroxene crystals, ranging in size up to 1 cm or more. The remaining minerals, mainly calcite, scapolite, and black mica are usually very unevenly distributed

in the rock, and may form pockets of coarse crystals. Gneissic texture or layering is scarcely if ever present.

Amphibole skarn

Amphibole skarn is a rock composed almost entirely of calcic amphibole, together with pyroxene, phlogopite or biotite, and calcite. The amphibole ranges in colour from pale green to black. The rock occurs as nodules in marble and as bodies a few meters across associated with green pyroxene skarn. Amphibole crystals, which are commonly 2 to a few mm in length may be aligned to produce a conspicuous lineations; a foliation and layering are also locally discernable.

Phlogopite skarn

Rocks composed almost entirely of amber phlogopite occur in the common calcite and calcite-dolomite marble, where they form nodules, a few cm across, or rims about inclusions of amphibole skarn or amphibolite.

Pyroxene-scapolite skarn and granulite

Rocks composed of green pyroxene and white scapolite in about equal amounts, with a small amount of sphene and other minerals are fairly common in the map-area. In the coarser rocks, referred to as skarn, crystals of pyroxene and scapolite, up to a few cm in length may be intergrown to produce a radiating aggregate, or they may be irregularly disturbed in the rock body. The finer grained varieties, referred to as granulite, consists of a mosaic of equidimensional pyroxene and scapolite grains, 1 to a few mm in diameter. The latter rocks may possess a subtle to conspicuous layering on a scale

of 1 to a few mm.

Pyroxene-scapolite skarn and granulite may be found together with green pyroxene skarn, and the occurrence of these rocks is very similar.

Pink calcite skarn

Some very heterogeneous, usually coarse-grained rocks, composed largely of salmon-pink calcite are here referred to as pink calcite skarn. The rock forms lenses, layers, or irregularly-shaped bodies within plagioclase gneiss, potassium feldspar gneiss, or granitic rocks. In places they cut across layering in the enclosing rocks, and may be referred to as veins or dikes.

In addition to calcite, one or more of the minerals pyroxene, phlogopite, potassium feldspar, scapolite, apatite, and fluorite may be present, and these usually occur as large crystals, with well-developed crystal faces. These minerals may be concentrated along the margins of the body or may be irregularly distributed throughout the body.

Pink calcite skarn is less common than green pyroxene skarn and pyroxene-scapolite skarn, but is often closely associated with them. It is found most commonly in Huddersfield and Grand-Calumet townships.

Pyroxene-garnet skarn

Pyroxene-garnet skarn was found at only a few places, where it occurs as layers in potassium feldspar gneiss, or as irregularly-shaped bodies associated with other varieties of skarn and with marble and pegmatite. The rock consist of 1 mm

grains of dark green pyroxene and red-brown andradite garnet, and the proportion of these two minerals varies, to produce a distinct layered structure. In places epidote and white mica are fairly abundant; the latter is presumably an alteration of scapolite.

Further information on the occurrence of skarn rocks is provided by the following description of seven skarn localities.

Nodules of white pyroxene skarn rimmed by serpentine skarn,

Ladysmith

North of Ladysmith and east of the highway, at (46.9, 22.5), inclusions of white pyroxene skarn are found in calcite-dolomite marble, serpentine-rich marble, and dolomite marble. Some are lens-shaped, about $\frac{1}{2}$ meter in largest dimension, and lie parallel to the layering in the marble. Some of the inclusions are rimmed by serpentine skarn.

One of the nodules was found, upon microscopic examination to consist of about 98 per cent of diopside and 2 per cent of calcite. The calcite is erratically distributed, so that portions of the rock consist of pure diopside. Grains of pyroxene are about $\frac{1}{2}$ mm in diameter, except where in contact with calcite, where they may be much larger.

The zone of serpentine skarn surrounding the above inclusion is a few cm thick and is composed of about 90 per cent of yellow-green serpentine and 10 per cent of calcite. The surrounding marble consists mainly of calcite, with some serpentine and minor phlogopite.

The origin of the diopside is not clear, but the rim of serpentine has evidently formed from diopside, as the result

of an introduction of water.

Skarn reaction zones between amphibolite and marble,

Kazabazua River sub-area

In the southern part of the Kazabazua river sub-area, east of the country road, at (48.4, 20.1) numerous inclusions of different composition are found in calcite-dolomite marble, which forms the eastern limb of a large antiform. One of the inclusions is a fragment of an amphibolite layer, 3 cm thick. It is surrounded by a double rim, the inner one is composed largely of amphibole, the outer of phlogopite.

The unaffected amphibolite consists mainly of brown hornblende, with about 30 per cent of plagioclase (An 38) and minor calcic pyroxene. The inner rim is about 4 mm thick and consists of nearly pure amphibole, with a minute amount of scapolite. At the contact of the amphibolite and the inner rim, the amphibole changes gradually in color, from brown to colorless. The outer zone, which is about 2 mm thick consists entirely of phlogopite.

The example shows the development of amphibole skarn and phlogopite skarn on a small scale. The constituents of the amphibole and phlogopite zones were no doubt derived in part from the amphibolite and in part from the marble. However it appears to be necessary to invoke an introduction of some constituents from beyond the immediate surroundings, notably potassium, and the removal of others, notably iron.

The association of dolomite marble, white pyroxene skarn,
and quartz rock, Grand-Calumet township

In the eastern part of Grand Calumet township, white pyroxene skarn occurs on a large scale, together with dolomite marble and a quartz rock.

Many of the fine rock exposures found in the fields in this part of the island consist of dolomite marble containing tabular or irregularly-shaped inclusions of white pyroxene skarn, while others consist of skarn, containing bodies composed of quartz. However the most interesting exposures are those that show all of these rocks together, for at these places one may observe that bodies of quartz rock are invariably separated from dolomite marble by a zone of pyroxene skarn. This feature may be examined at (45.6, 38.9) and at numerous other places, and an example is illustrated in Fig. 9.

The dolomite marble consists almost entirely of dolomite, with small amounts of tremolite, and locally small grains of quartz. The white pyroxene skarn consists almost entirely of diopside; some tremolite and minor calcite may be present, and locally dolomite. The quartz rock occurs as pods and layers which in many places have a very irregular weathered surface, suggesting the presence of a large number of parallel and interconnected veins.

The shape of the bodies of white pyroxene skarn varies greatly. In places they form a number of parallel layers, which may be folded; elsewhere they occur as swarms of small isolated nodules, or as larger masses, of presumed

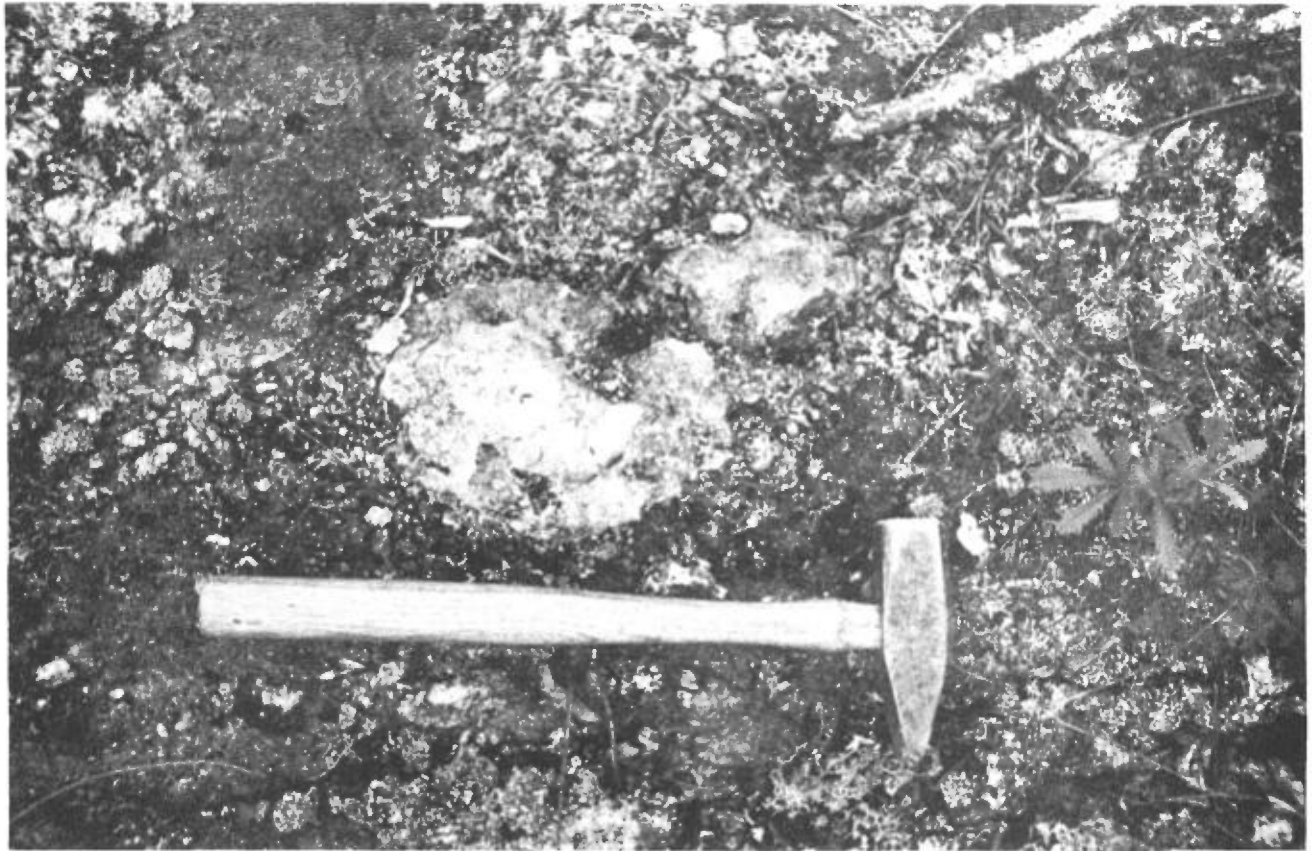


FIGURE 9 - Dolomite marble (dark gray, beneath hammer), containing a nodule of white pyroxene skarn (light gray) which contains a core of quartz rock (white), Grand-Calumet township.

irregular shape, several metres across. Two sets of parallel layers, intersecting at a small angle were observed at one place.

The contact between dolomite marble and diopside skarn may be marked by a zone, about 2 cm wide, composed of calcite and tremolite. These may have formed as a result of an introduction of water along the contact, causing dolomite and diopside to react with each other to produce calcite and tremolite. The contact between diopside skarn and quartz rock may be marked by fairly large amounts of tremolite. Here also, water may have been introduced, causing diopside to break down, to produce tremolite, calcite, and quartz. Both of these reactions are evidently secondary, or retrograde reactions.

The above occurrence of white pyroxene skarn illustrates a close relationship of this rock to dolomite marble. The pyroxene skarn was evidently produced by reaction between dolomite and silica. The bodies of quartz rock may have been present prior to metamorphism.

Green pyroxene skarn at Lawless lake

At Lawless lake (45.9, 32.2) green pyroxene skarn is well exposed in a road cut. The skarn mass lies within the Bell Mount Complex, which consists mainly of heterogeneous granitic and syenitic rocks but contains also much amphibolite and other rock types. The dominant trend of layering within the complex is north-west, but near Lawless lake it is north-east.

The skarn forms a sheet of rock, 40 feet thick, that strikes north-east and dips to the south-east, and is under-

lain by gneiss and overlain by granite. Since the road passes through the body at an oblique angle, the length of the exposure is nearly 140 feet.

The gneiss, which conformably underlies the skarn is composed of plagioclase, calcic pyroxene, and hornblende, and contains numerous conformable sheets and cross-cutting dikes of pegmatite. Some narrow skarn layers, lying at a small angle to the gneissosity are also present. The overlying pink granite contains minor hornblende and calcic pyroxene, and only locally possesses a gneissic texture. Near the contact, which is sharp but slightly irregular, the granite contains fragments of skarn while the skarn contains fragments of granite.

The skarn is composed principally of green pyroxene, as crystals that range in size from less than 1 mm to several cm. Other minerals present are scapolite, phlogopite or biotite, pale pink calcite, calcic amphibole, allanite, sphene, potassium feldspar, epidote, quartz, fluorite, apatite, and chlorite. These minerals are erratically distributed, and may form pockets of crystals (phlogopite, allanite), small radiating aggregations (quartz), large isolated crystals (scapolite), vein-like bodies (fluorite), and cavity linings (epidote).

Skarn bodies of this kind occur commonly in the area. Marble is apparently not present at the site, nor in the immediate vicinity. However it may have been present initially as a 'host rock' which was entirely consumed by skarn minerals,

which crystallized in its place.

Pink calcite skarn, Yates property, Huddersfield township

A spectacular example of pink calcite skarn is found at what is known as the Matte zone of the abandoned Yates property, in Huddersfield township (57.9, 32.5). Some development work had been done at this locality, with a view of mining the skarn for the contained radioactive minerals. Consequently it is well exposed at the surface and also in a drift, underground. The following information is based on a description by Shaw (1958) and observations by the writer.

The body of skarn has an exposed length of 800 feet and thickness of about 20 feet. It is overlain and underlain, for the most part conformably, by pink potassium feldspar gneiss. The underground opening follows the skarn layer for a horizontal distance of 170 feet, at a depth of 100 feet beneath the surface.

At the surface, the skarn is heterogeneous, with the kind and proportion of minerals varying greatly from place to place. Apart from pink calcite, which dominates, other minerals present include calcic pyroxene, fluorite, apatite, and small amounts of phlogopite or biotite, scapolite, potassium feldspar, sphene, quartz, pyrite, allanite, uranothorite, and uranophane. These minerals commonly occur as crystals embedded in calcite, and may show well-developed crystal faces. Some exceptionally large and well-formed crystals of apatite, up to 30 cm long have been found here.

Narrow zones of pyroxene-scapolite skarn and granulite

occur along the margins of the body, and fragments of these rocks locally lie within it. A specimen of granulite from this locality is listed in Table 13 (specimen 716-70).

The skarn zone, as exposed underground contains a larger proportion of pyroxene and scapolite than at the surface, and these occur together with pink calcite in different proportions. Some vein-like and irregularly-shaped bodies of skarn are present.

The body of skarn is obviously of complex origin. If it originally existed as limestone or marbles, a considerable amount of metasomatism and mobilization took place to produce the skarn in its present form.

Otter Lake skarn occurrence

Several varieties of skarn and other rocks may be examined on a small cliff face which is located south-east of Otter Lake village, to the east of the highway (50.4, 23.5).

The major rock type here is a pale pink calcite marble, containing calcic pyroxene, scapolite, and potassium feldspar. Adjacent to this is a mass of pink pegmatite, containing hornblende, altered to chlorite. Quartz-feldspar rock also occurs within the marble, as closely-folded layers. Fragments of pyroxene gneiss and amphibolite are also enclosed by marble.

Four varieties of skarn are found in and near the marble. Layered pyroxene-garnet skarn is found at the top of the cliff, a specimen of which is listed in Table 13 (specimen 585-69A). Similar rock, with up to 80 per cent of garnet, also occurs as inclusions in marble. The development of pyroxene-

scapolite granulite on a small scale may be seen where this rock forms rims about layers of amphibolite in marble. At the north-west end of the cliff a body of pyroxene-scapolite skarn (589-69, Table 13) is exposed, and is cut by vein-like bodies of pink calcite skarn, a few cm to tens of cm thick. At the contact between these two skarns, well-formed crystals of scapolite and pyroxene project into the pink calcite rock.

The above example illustrates the difficulty that is commonly encountered in arriving at an understanding of the development of a variety of closely associated and intermixed rock types.

Further information on the occurrence of skarn within the map-area, particularly in Huddersfield and Grand-Calumet townships, may be found in a report by Shaw (1958) which deals with radioactive mineral deposits in Québec.

Minerals

The following brief description of the skarn minerals is based on a laboratory study of about 80 rock specimens. In addition to microscopic examinations, index-of-refraction measurements and X-rays were used to identify minerals or confirm their identification. Chemical analyses for certain elements were carried out on about 40 minerals, and some of these are presented, together with a few mineral analyses obtained by other investigators.

Calcite

In the rocks here classed as skarn, calcite, where present, is usually salmon-pink in colour, but it may be pale

TABLE 14 - ANALYSES OF CALCITE FROM PINK CALCITE SKARN.

	Yates 55	857-72B	711-70	692-70	858-72B	858-72C
CaO	56.0	54.8	54.6	56.5	55.2	54.8
MgO	.31	.28	.29	.78	.38	.44
MnO	.13	.12	.12	.09	.12	.13
*FeO	.49	.44	.50	.19	.38	.48
SrO	.69	.69	.67	.74	.61	.64
BaO	.19	.20	.20	.19	.15	.19

*total iron expressed as FeO

Analyst: Diane Garrett

Yates 55, 857-72B, 711-70: Huddersfield twp.
(Yates, Matte zone)

692-70: Huddersfield twp. (Yates, Camp zone)

858-72B, 858-72C: Litchfield twp. (Leslie Lake
molybdenite deposit)

TABLE 15 - ANALYSES OF PYROXENE, AMPHIBOLE
AND PHLOGOPITE FROM SKARN.

	Pyroxene					Amphibole				Phlogopite		
	1	2	3	4	5	6	7	8	9	10	11	12
	630-70	117-56	Q19DS13	440A-55	304-55	Gib L.	Yates2-55	117-56	440A-55	Gib L.	117-56	440A-55
SiO ₂	-	-	53.78	-	-	48.34	-	-	-	43.74	-	-
Al ₂ O ₃	n.d.	1.69	1.29	1.07	1.05	11.17	0.03	16.24	3.2	13.74	13.0	13.0
TiO ₂	-	0.09	0.08	0.06	-	0.13	0.03	0.29	0.20	0.20	0.19	2.5
Fe ₂ O ₃	-	-	0.80	-	-	0.44	-	-	-	0.38	-	-
*FeO	0.20	1.96	3.89	6.15	19.00	0.36	1.23	4.01	7.2	0.10	1.28	12.3
MgO	19.76	16.26	15.08	14.36	6.49	21.23	22.96	18.75	16.0	26.27	24.0	16.4
MnO	0.03	0.10	0.19	0.16	0.43	0.00	0.05	0.08	0.12	0.00	0.03	0.05
CaO	22.00	23.64	24.21	21.59	19.90	11.97	15.01	12.75	-	1.89	0.21	0.27
Na ₂ O	0.04	0.30	0.50	0.30	0.43	2.74	0.84	2.62	0.50	1.00	0.54	0.15
K ₂ O	0.01	0.05	0.06	0.04	0.03	0.69	0.34	1.57	0.35	7.06	9.2	9.1
H ₂ O	-	-	0.06	-	-	1.57	-	-	-	3.52	-	-
F	-	-	0.02	-	-	0.36	-	-	-	0.66	-	-
[Fe]	0.56	6.34	14.6	19.4	62.1	1.99	2.91	10.7	20.1	0.95	2.90	29.6

n.d. not detected

- not determined

*where Fe₂O₃ shows -, total iron is expressed as FeO

[Fe]: $[\text{Fe}/(\text{Fe}+\text{Mg})]100$, Fe = total iron

3: Analyst: C.O. Ingamells (Shaw, 1963)

6,10: Analyst: J. Muiysson (Shaw, et al, 1965)

1,2,4,5,7,8,9,11,12: Analyst: Diane Garrett and R. Kretz

630-70 white pyroxene skarn, Grand Calumet twp.

117-56 green pyroxene skarn, Huddersfield twp.

440A-55 green pyroxene skarn, Clapham twp.

Q19DS13 pyroxene-scapolite skarn, Huddersfield twp.

304-55 pyroxene-garnet skarn, Leslie twp.

Yates2-55 amphibole skarn, Huddersfield twp.

Gib L. zone skarn nodule (scapolite, amphibole, plagioclase, phlogopite)
in marble, Pontefract twp.

pink, pale yellow, or white. Six analyses of calcite from pink calcite skarn are listed in Table 14. These calcites are similar in composition to those present in pink calcite marble (Table 7), and compared with calcites of common calcite and calcite-dolomite marble (Table 7) they are generally poorer in magnesium, richer in strontium, and possibly slightly richer in iron.

The absence of dolomite is noteworthy. Only locally, in Grand-Calumet township, were some dolomite-bearing rocks encountered (dolomite-diopside) that might be referred to as skarn.

Pyroxene

Calcic pyroxene, which ranges in colour from white to green and from green to nearly black, is the most common and often the most abundant mineral in the skarns of the present area. In rocks composed principally of pyroxene or of pyroxene and scapolite, the pyroxene forms anhedral, nearly equi-dimensional crystals, but where partly or completely surrounded by calcite, crystal faces may be well developed. The resulting crystals are usually short, eight-sided prisms.

Chemical analyses of pyroxene from some varieties of skarn are listed in Table 15. Pyroxene from white pyroxene skarn (analysis 1). is nearly pure diopside with very low concentration of aluminum, iron, manganese, sodium, and potassium. Analyses 2,3, and 4 are representative of pyroxene from the common green pyroxene skarn, and pyroxene-scapolite skarn, and these show the presence of small amounts of aluminum and alkalies, and notable amounts of iron, which in terms of the

ratio $\text{Fe}/(\text{Fe} + \text{Mg})$ ranges up to 0.20. A relatively high iron content, with the above ratio at nearly 0.60, is found in analysis 5, which represents pyroxene from pyroxene-garnet skarn.

Amphibole

Calcic amphibole is commonly present in small amounts in skarns of the map-area, and is abundantly present only in the relatively rare amphibole skarn. This mineral ranges in colour from white, through shades of green, to nearly black, but often is a light green that is usually associated with actinolite.

Representative analyses of amphibole are given in Table 15. The white amphibole found in white pyroxene skarn of Grand-Calumet township has not been analysed but is no doubt nearly free of iron, and is similar in composition to tremolite in the associated marble (Table 8). The first of the four amphiboles listed in Table 15 (number 6) is from a zoned nodule of skarn at Gib lake, in the northwest corner of the area (Shaw et al, 1965), and the other three amphiboles (7,8,9) are representative of a group of amphiboles from amphibole skarn, green pyroxene skarn, and pyroxene-scapolite skarn, for which chemical data were obtained. In the skarns, as in the marbles, amphibole may be either rich or poor in aluminum. The iron content shows a range that is similar to that found in pyroxene from the common pyroxene-bearing skarns. The sodium content may be fairly high, particularly in aluminous amphibole, and fluorine is probably present to some extent in all of them.

In some green pyroxene and pyroxene-scapolite skarns, amphibole occurs as oriental inclusions in crystals of pyroxene or as rims about such crystals, and it appears to have locally formed from pyroxene.

Phlogopite and biotite

Phlogopite or biotite, amber to black in colour, is almost invariably present in green pyroxene skarn and is a common member of the pink calcite skarns, and it is from these two varieties of rock that the mineral was mined many years ago. In addition, small nodules and rims, composed almost entirely of phlogopite are fairly common.

Three analyses are listed in Table 15. The first (No. 10) is from the Gib lake skarn nodule mentioned above and the other two (11,12) are from green pyroxene skarn. The first two would normally be referred to as phlogopite ($\text{Fe}/(\text{Fe}+\text{Mg})$ less than 0.1) and the last as biotite. However a number of additional analyses obtained by the writer (Kretz, 1960) suggest that a continuous variation exists in iron content from nearly zero to a $\text{Fe}/(\text{Fe}+\text{Mg})$ ratio of about 0.30. Most commonly, this ratio is less than 0.10 and the mineral, even though it is black in colour, may be referred to as phlogopite.

Garnet

Garnet is suprisingly rare in the skarns of the area. Pyroxene-garnet skarn was found at only a few localities, where garnet occurs as dark red-brown or orange-brown crystals, together with nearly black pyroxene.

Analyses of garnet from two localities are listed in Table 16 which shows the mineral to be rich in iron and fairly

poor in aluminum. Although the oxidation state of the iron was not determined, when expressed as ferric iron, the amount corresponds closely to that needed to make calcium-ferric iron garnet, andradite. Hence the minerals are evidently close to andradite in composition, with small amounts of ferrous iron, magnesium, and manganese in the calcium position, and some aluminum in the ferric iron position.

The calcic pyroxene associated with one of the garnet minerals (304-55) is also rich in iron, as shown in Table 15.

Epidote

Small amounts of a mineral of the epidote group are fairly common in green pyroxene skarn and pyroxene-scapolite skarn and granulite. The mineral occurs as discrete grains, irregular in shape, some of which contain many tiny inclusions of quartz, as found in secondary amphibole, and epidote is for the most part considered to be a secondary mineral. A more obvious secondary origin is shown where epidote lines cavities or fills fractures.

Allanite

Allanite is found in green pyroxene skarn, where it occurs as isolated crystals, or as pockets of crystals several cm across.

Serpentine

Serpentine is practically confined to serpentine skarn, where it occurs as aggregates of very fine grains, similar to that found in serpentine-rich marble. More than one mineral species may be present. Chrysotile asbestos, where present,

TABLE 16 - ANALYSES OF GARNET FROM SKARN.

	<u>304-55</u>	<u>587-69</u>	<u>Ideal Andradite</u>
Al ₂ O ₃	4.61	4.98	0.00
*Fe ₂ O ₃	30.17	30.14	31.42
MnO	0.61	0.40	0.00
MgO	0.14	0.07	0.00
CaO	31.90	29.82	33.10

*total iron expressed as Fe₂O₃

Analyst: Diane Garrett

TABLE 17 - ANALYSES OF SCAPOLITE FROM SKARN.

	<u>1</u>	<u>2</u>	<u>3</u>
	<u>G1b L.</u>	<u>Q19DS13</u>	<u>Q85</u>
SiO ₂	55.44	51.83	47.17
Al ₂ O ₃	22.89	24.29	26.29
TiO ₂	tr	.03	.03
*Fe ₂ O ₃	.00	.07	.15
MgO	.30	.02	1.00
MnO	.00	tr	.01
CaO	7.72	11.66	14.31
Na ₂ O	9.36	6.40	3.82
K ₂ O	.22	1.16	1.01
H ₂ O+	.22	.22	.93
H ₂ O-	.03	.04	.50
CO ₂	1.85	2.28	2.66
Cl	2.30	1.66	.56
SO ₃	.18	.72	1.42
F	.00	.02	.04
[Me]	33.0	47.5	66.2

*total iron expressed as Fe₂O₃

tr trace

[Me] per cent meionite

1: Analyst: J. Muysson (Shaw, et al, 1965)

2,3: Analyst: C.O. Ingamells (Shaw, 1960)

occurs as near-parallel but somewhat branching veins, up to 6 mm thick. The chrysotile fibres are oriented perpendicular to the vein walls and may extend half way or entirely across the vein.

Quartz

Quartz occurs locally in green pyroxene, pyroxene-scapolite, and pink calcite skarns, where it is found as irregularly-shaped grains, small radiating aggregates, or smokey crystals with some development of crystal faces.

Feldspar

Potassium feldspar is fairly common in pyroxene-scapolite granulite and in some bodies of pink calcite skarn. In the Matte zone of the Yates property, described above, it is found sparingly, as white to pale pink crystals, which may be 2 or 3 cm across. An X-ray powder picture of one of these showed only a slight separation of the 131 and 131 reflections.

Plagioclase is virtually absent from the skarns of the area, but it occurs in small amounts in some pyroxene-scapolite granulites. It is present in the zoned skarn described by Shaw et al (1965) where the composition is An10. Pods of pink plagioclase, much altered to epidote and white mica, are occasionally found in green pyroxene skarn.

In a description of skarns, including some rocks from the present area, Shaw, (1963) recognized one group that he refers to as 'pyroxene syenite, granite, and pegmatite'. These feldspar-rich rocks are, in the present study, grouped with the granitic and syenitic rocks.

Scapolite

Scapolite is a major component of pyroxene-scapolite skarn

and granulite and may also occur abundantly in pink calcite skarn. It is usually white on fresh and weathered surfaces, but locally it is pale yellow-green, deep violet, or bright blue.

In pyroxene-scapolite granulite, scapolite occurs as anhedral grains, about 1 mm in diameter, forming a mosaic texture with pyroxene and other minerals. In pyroxene-scapolite skarn, it forms crystals up to several cm across, which may be intergrown with pyroxene to form a radiating aggregate. In pink calcite skarn it may occur as well-formed prismatic crystals. Such crystals are found for example, at the Leslie lake (50.1,31.8) molybdenite occurrence.

Many samples of scapolite from portions of the present area, particularly from Huddersfield and Grand-Calumet townships were examined in detail by Shaw (1960), and two of the resulting analyses are listed in Table 17 (numbers 2 and 3). Another analysis (number 1) is for scapolite from the zoned skarn nodule at Gib lake, referred to above. These three analyses provide an indication of the range in composition that may be expected within this mineral as found in the map-area. The full range in composition found by Shaw (1960) is Me 21 to Me 60 per cent, where Me is the calcium 'end member'. The concentration of chlorine and sulfur in these minerals is noteworthy.

Sphene

Sphene is very common, in small amounts, particularly in pyroxene-scapolite skarn and granulite, where it forms brown lens-shaped or equidimensional crystals that locally have

TABLE 18 - ANALYSIS OF APATITE FROM PINK CALCITE SKARN.

P_2O_5	38.26
CO_2	0.88
SiO_2	1.76
SO_3	0.72
CaO	53.91
SrO	0.28
Y_2O_3	0.15
Ce_2O_3	1.23
La_2O_3	0.44
Na_2O	0.28
Fe_2O_3	0.13
F	3.92
H_2O	0.29

Source: Trzcienski, Perrault, & Hebert (1974)

Location: Huddersfield twp., (Yates, Matte Zone)

well-developed faces. Some crystals, when examined in thin sections, show a distinct zoning, the outer portions being darker in colour than the centres. Large crystals of sphene are found with scapolite at the Leslie Lake molybdenite occurrence, mentioned above.

Fluorite

Fluorite is erratically distributed in the area as a whole. It occurs quite commonly in the skarns of Huddersfield and Grand-Calumet townships (Shaw, 1958) but outside of these areas it was rarely encountered by the writer. It is abundantly present in the Matte zone of the Yates property, described above.

Apatite

Apatite is a fairly common minor constituent of pyroxene-bearing skarns, where it normally occurs as blue, nearly spherical grains, up to 3 mm across. In the pink calcite skarn at the Yates property it occurs as much larger crystals, which are green to reddish-brown in colour, and prismatic in shape. An analysis of one of these crystals was obtained by Trzcienski et al (1974) and is listed in Table 18. This is a fluorine-bearing apatite. An X-ray examination of apatite crystals from other skarn occurrence of the area indicates that they also are fluorine-bearing.

Graphite

This mineral is generally absent, except in some skarn nodules in marble. Where the concentration is relatively high (as in G87-69, Table 13) the graphite may have migrated to

the skarn from the surrounding marble.

Magnetite, pyrite, pyrrhotite

These minerals are generally absent or occur in minute amounts, but locally may achieve concentrations of 1 per cent.

Molybdenite

Most of the known molybdenite occurrences of the area, which number 10, are in green pyroxene or pyroxene-scapolite skarn. Where present, molybdenite occurs in small amounts as erratically distributed tabular crystals 1 or 2 cm across.

Radioactive minerals

Apart from allanite, various uranium and thorium-bearing minerals occur locally in different types of skarn, in very small amounts. These minerals have been investigated by Robinson and Sabina (1955) and Shaw (1958) who report the presence of uranothorite, uranian thorianite, monazite, and uranophane. These minerals commonly occur in or near rocks that contain fluorite.

Metamorphism and Metasomatism

General remarks

The subdivision of the skarns of the map-area into a number of rock types eases the task of describing them but it creates an oversimplified impression of the nature of the rocks. Although some of the rock bodies are composed of only one rock type, many are exceedingly heterogeneous, and in relation to the subdivision that was used, must be regarded as a mixture of two or three rock types that grade into each other.

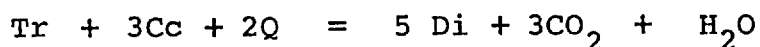
Before embarking on a discussion of the origin of a body of skarn and the metamorphic and metasomatic processes that played a part in its development, information should be available on the nature and distribution of minerals within it. Zoned bodies may be readily described, but in most of the skarn bodies that were examined within the map-area, the mineral distribution appears to be more irregular. However, many of these are only partially exposed, and a regular pattern of mineral distribution may be present but is not readily discernable.

In general, more information is needed on the association and distribution of minerals within large bodies of skarn, as found in the area. Hence, only a few questions concerning the metamorphism and origin of the rocks will be considered.

Metamorphism

Some of the mineral species that occur commonly in the skarns are also found within marble of the same area, and the conditions of metamorphism in the two groups of rocks may have been similar. Thus pyroxene, amphibole, and phlogopite occur commonly in both groups, epidote occurs sparingly in both, and where present may show signs of secondary origin, while high-temperature minerals, such as wollastonite, are not found in either. Hence the thermal peak in the two groups of rocks may have been similar.

Further information on this point may be obtained by briefly examining a reaction involving pyroxene and amphibole, which in terms of magnesium end members is:



This is reaction 8, which was considered above, in relation to marble.

Seven specimens of pyroxene-scapolite granulite and 3 of relatively fine-grained skarn, some of which are listed in Table 13, will be examined in relation to the above reaction. After eliminating from the mineral assemblages those minerals that show signs of secondary origin, 3 of the 10 specimens contain all four of the solid minerals of the reaction, and represent the reaction 'in progress', while the remaining seven contain pyroxene plus one or two of the minerals on the left, and represent the reaction 'completed'. Many other skarn rocks, which contain calcic pyroxene would likewise represent the right-hand side of the reaction. Although the skarn minerals contain iron and other elements, the above results are comparable to those found in marble and provide some additional support to the proposal that the marble and skarn have experienced approximately the same crystallization temperature.

Metasomatism

The frequent association of skarn and marble, and the observation that many minerals are common to both suggests that marble may have provided at least some of the components that are required to make skarn. However, field evidence indicates that skarn has locally formed from other rocks as well. For example, thin layers of pyroxene-scapolite granulite in marble may have been impure calcareous sediments, and some reaction zones suggest that amphibolite may also contribute to the

formation of skarn. Regardless of the nature of the original rock material, it is nearly everywhere obvious that some more mobile material was introduced, and played a large part in the formation of skarn. Thus chlorine and sulfur are required for the crystallization of scapolite, and fluorine for fluorite and apatite. Also, when the chemical composition of skarn rocks, deduced from the composition of the minerals, is compared to that of common calcite-dolomite marble, which may be the dominant original rock, the skarns are richer in silica, aluminum, iron, sodium, titanium, and the elements needed to make allanite, molybdenite, and uranium-thorium minerals, and it seems necessary to generally postulate an introduction of these elements as well. Finally, in relation to common marble, skarns have a higher Mg/Ca ratio, which is nearly 1 in pyroxene skarn and somewhat less in pyroxene-scapolite skarn, but is much smaller than this in calcite-dolomite marble. Hence some calcium may have moved away from the site of skarn crystallization.

A simple model to account for the formation of skarn in the study area is proposed below. The main components of the model are the 'initial material', which will be taken as calcite-dolomite marble, and the 'mobile material' which will be allowed to contain silica and other elements, but which may vary greatly with regard to the proportion of elements present.

The mobile material is viewed as a flux passing through a sequence of layered rock, including a layer of marble, the whole being at metamorphic temperatures. As the flux of mobile

material encounters a layer of marble it begins to react with it, beginning perhaps with the dolomite grains and layers present, converting them, with the addition of silica, to pyroxene, or with the addition of silica, aluminum, sodium, and other elements, to scapolite. While certain elements are thus extracted from the mobile material as it passes through the rock, others will be added to it, particularly calcium and carbon dioxide. The mobile material, becoming enriched in calcium will elsewhere be capable of depositing it, together with other elements, to form pink calcite skarn.

Depending on the composition of the mobile material and the nature of the initial material, different types of skarn could be produced. Thus an introduction of only silica and a removal of calcium and carbon dioxide is needed to make white pyroxene skarn from calcite-dolomite marble, and if the initial material is dolomite marble, it is not necessary to postulate a removal of calcium. Green pyroxene could be derived from calcite-dolomite marble with the addition of silica and iron, and removal of calcium and carbon dioxide, and with the participation of other elements on a small scale. Pyroxene-scapolite skarn would require the introduction of a greater variety of elements, but if the initial material is a more aluminous rock of sedimentary or igneous origin, a smaller amount of exchange would be required. Similar considerations hold for pyroxene-garnet skarn which may have been produced from an iron-rich initial material. Pink calcite skarn, where it occurs as cross-cutting veins, would represent a relatively late processes, involving a calcium-enriched mobile material.

Here the replacement has evidently gone in reverse, with calcite replacing silicates rather than silicates replacing calcite.

The source of the mobile material is not known but may be related to that which has evidently produced large-scale potassium metasomatism in parts of the area, to be discussed below.

A further discussion on the origin of skarn rocks, including some from the present area is given by Shaw (1963) who has considered in particular the skarn-forming process in relation to the geochemical behaviour of trace elements.

GRAY PLAGIOCLASE GNEISS, AMPHIBOLITE,

QUARTZITE (2)

General Description

A variety of rocks that may in general be referred to as gneiss or amphibolite occur commonly and abundantly throughout the map-area. These rocks are characterized by the presence of large proportions of white plagioclase feldspar, which, together with the darker minerals garnet, biotite, hornblende, and pyroxene, produce rocks ranging in shades of gray from light to dark. Biotite and hornblende are very commonly present, and crystals of these are normally arranged in parallel, with some tendency for segregation, to produce a mineral foliation and gneissic texture. Consequently, many of the rocks under consideration may be referred to as gneiss; some that have a weakly developed gneissic texture and are rich in hornblende are more appropriately referred to as amphibolite. A distinctive graphite-bearing gneiss, and a few occurrences of quartzite are also described under this heading. In some adjacent

and near-by areas, rocks similar to those described here are referred to as Grenville-type gneisses.

The rocks have been subdivided to some extent on the proportion of dark minerals present, but mainly on the kind of dark minerals present. Light, medium, and dark gray gneisses have, approximately, less than 20 per cent, 20 to 40 per cent, and greater than 40 per cent of dark minerals. The grouping is as follows; map symbols are given in parentheses.

light to medium gray gneiss

biotite-garnet-sillimanite gneiss (2a)

biotite-garnet gneiss (2b)

biotite gneiss and biotite-hornblende gneiss (2c)

biotite-graphite gneiss (rusty-weathering) (2d)

dominantly medium to dark gray gneiss and amphibolite

hornblende-biotite-garnet gneiss and amphibolite;

hornblende-garnet gneiss and amphibolite (2e)

hornblende-biotite gneiss and amphibolite; hornblende

gneiss and amphibolite; hornblende-calcic pyroxene
gneiss and amphibolite (2f)

calcic pyroxene gneiss, commonly with hornblende,

biotite, rarely with garnet (2g)

orthopyroxene-bearing gneiss and amphibolite (2h)

quartzite (2q)

The kind of dark mineral present can normally be determined in the field. However it may be difficult to detect minerals when present in small amounts, and the rock units as defined overlap to some extent to allow for this. Orthopyroxene may also be difficult to identify in the field, and may be somewhat more widespread than is indicated on the geological map.

Representative mineral assemblages and approximate mineral proportions of plagioclase gneiss and amphibolite are given

in Table 19, and of quartzite in Table 20.

Within the map-area as a whole, hornblende-biotite gneiss and amphibolite are the most common varieties; the others listed above are less abundant, and occur in very roughly equal proportions.

Rocks of the present category are commonly but not invariably associated, on a small or large scale, with marble, and their distribution will be described in relation to the zones in which marble occurs abundantly, namely the Gatineau, Thorne, Coulonge, and Calumet zones (Fig. 3). Another zone, in the central part of the area, contains abundant plagioclase gneiss and amphibolite, and very minor marble, and is referred to as the Moore zone. The proportion of rocks of the present group to other rocks in the 5 zones varies greatly, and when expressed as per cent of plagioclase gneiss and amphibolite present, is roughly as follows: Gatineau, 10; Thorne, 60; Moore, 90; Coulonge, 60; and Calumet, 40 per cent. The Coulonge and Calumet zones contain larger amounts of granitic rock than do the other zones.

But rocks of group 2 are certainly not confined to the five zones mentioned above, and occur, often abundantly, in the regions between the zones, where they are associated with potassium feldspar gneiss, and various granitic rocks.

The following note on the distribution of the different rock types is based on the writer's experience, together with information on the eastern 1/3 of the area, provided by Baker (1956), and the south-west corner, provided by Shaw (1955).

TABLE 19 - PLAGIOCLASE GNEISS AND AMPHIBOLITE.

	2a					2b					2c					2d					2e											
	97-56	225-56	732-70	765-70	904-73	735-70	205-55	309-55	76-56	573-69	903-73	1068-74	18-55	871-72	901-73	964-73	312-55	1064-74	224-55	341-55	459-55	668-69	4-55	56A-55	135-55	217-55	265-57	266-57	267-57	568-69	571-69	622-68
sillimanite	2	2	2	.1	10	10																										
garnet	10	10	2	10	2	20	2	2	2	2	.1	10	10	20	10	10	20	10	2	10	10	10	10	30	10	2	10	10	2	2	2	2
biotite	10	10	10	10	.1	20	30	10	20	10	.1	20	10	20	10	10	20	10	2	2	10	10	10	10	30	10	2	10	10	2	.1	2
hornblende																2	10	10					10	2	10	10	10	20	10	2	30	2
Ca pyroxene																																
orthopyroxene																																
plagioclase	40	60	50	40	40	2	40	40	60	50	50	40	70	70	50	60	40	70	40	40		50	50	40	50	40	50	50	50	50	60	60
K feldspar	10	10	10		10	10	.1	20	10		10		2	.1	10	2			30		10	2		.1		20	10	10	10	10	2	2
quartz	20	10	30	30	30	40	30	20	10	30	40	20	20	10	30	20	30	10	30	40	60	40	10	30	20	40	10	10	10	40	2	20
sphene																.1		.1														
zircon		.1	.1	.1		.1	.1	.1		.1		.1		.1	.1	.1	.1	.1	.1	.1				.1	.1	.1	-	.1	-	-	-	.1
apatite	.1	.1		.1			.1		.1	.1			.1	.1	.1	.1	.1	.1		.1		.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
magnetite		.1	.1				.1		2	.1						2		.1					.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
ilmenite	.1	.1	.1					2															.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
pyrite	.1		.1					.1	.1							.1	.1					.1			.1	.1	.1	.1	.1	.1	.1	.1
pyrrhotite																																
calcite					A	B																										
other								C		D			E						F	G	H	I										

*identification not confirmed

A muscovite, 2

B muscovite (secondary), .1

C muscovite, .1

D muscovite (secondary), .1

E epidote, 2

F graphite, .1; tourmaline, .1

G,H graphite, 2

I graphite, 2; muscovite

(secondary), 2

J cummingtonite, 2

K cummingtonite, 2

L allanite, .1

M cummingtonite, 2

N epidote, 10

O scapolite, 20

P epidote, 2; graphite, .1

Q graphite, 2

R cordierite, 10

Key: See Table 2 and legend on Map 1.

TABLE 20 - QUARTZITE (2q).

	1057-74	1066-74	779-70	734-70	761-70
sillimanite	-	2	-	-	-
garnet	-	2	-	-	-
phlogopite	10	2	-	.1	10
Ca amphibole	10	-	2	.1	2
anthophyllite	10	-	-	-	-
Ca pyroxene	-	-	10	-	10
kornelupine	-	20	-	-	-
tourmaline	-	2	-	.1	-
plagioclase	-	-	-	2	-
K feldspar	-	2	-	-	2
quartz	80	70	90	90	80
muscovite	-	-	-	.1	-
sphene	-	-	-	.1	.1
zircon	-	-	-	.1	-
apatite	-	-	-	.1	-
pyrite	.1	.1	-	-	-
pyrrhotite	-	-	-	-	2
rutile	-	-	-	.1	.1
calcite	-	-	-	.1	-
graphite	-	-	-	-	2

*identification not confirmed

Key: See Table 2

TABLE 19 (COUNT'D)

2f										2g										2h									
568-55	10	10	10	10	10	10	10	10	10	184-55	10	10	10	10	10	10	10	10	10	138-55	10	10	10	10	10	10	10	10	10
71-55	60	30	10	10	10	10	10	10	10	396-59	30	30	30	30	30	30	30	30	30	201-55	40	20	20	20	20	20	20	20	20
87-55	10	10	10	10	10	10	10	10	10	113-55	10	10	10	10	10	10	10	10	10	78-56	10	10	10	10	10	10	10	10	10
682-70	10	10	10	10	10	10	10	10	10	306-55	10	10	10	10	10	10	10	10	10	807-70	10	10	10	10	10	10	10	10	10
873-72	20	10	10	10	10	10	10	10	10	685-69	20	10	10	10	10	10	10	10	10	569-69	10	10	10	10	10	10	10	10	10
875-72	10	10	10	10	10	10	10	10	10	1073-74	10	10	10	10	10	10	10	10	10	138-55	10	10	10	10	10	10	10	10	10
902-73	10	10	10	10	10	10	10	10	10	186-55	10	10	10	10	10	10	10	10	10	201-55	10	10	10	10	10	10	10	10	10
905-73	10	10	10	10	10	10	10	10	10	98-56	10	10	10	10	10	10	10	10	10	78-56	10	10	10	10	10	10	10	10	10
962-73	10	10	10	10	10	10	10	10	10	569-69	10	10	10	10	10	10	10	10	10	807-70	10	10	10	10	10	10	10	10	10
972-69	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	1028-74	10	10	10	10	10	10	10	10	10
133-56	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
680-70	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
801-70	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
694-69	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
6106-69	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
965-73	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
280-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
176-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
887-72	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
161-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
184-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
396-59	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
113-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
306-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
685-69	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1073-74	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
186-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
98-56	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
569-69	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
138-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
201-55	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
78-56	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
807-70	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1028-74	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

TABLE 21 - ANALYSES OF GARNET, BIOTITE, AND HORNBLLENDE FROM PLAGIOCLASE GNEISS AND AMPHIBOLITE.

	Garnet					
	agb	agb	gb	gbh	gbh	gbhc
	225-56	97-56	205-55	564-55	265-57	164-55
SiO ₂	35.	37.	34.	35.	38.	38.
Al ₂ O ₃	20.5	24.0	20.7	22.3	21.0	22.0
*FeO	37.6	32.2	34.7	32.6	27.0	25.7
MnO	0.48	0.50	1.30	1.33	6.1	3.3
MgO	5.9	7.0	4.1	4.4	2.4	4.0
CaO	0.61	1.4	2.0	5.7	5.0	6.6
[Fe]	76.1	68.5	75.6	68.2	61.5	57.6
[Mn]	1.0	1.1	2.9	2.8	14.1	7.5
[Mg]	21.3	26.6	15.9	16.4	9.7	16.0
[Ca]	1.6	3.8	5.6	15.2	14.6	18.9
$[Fe] = [Fe/(Fe+Mn+Mg+Ca)]100$; similarly for others						

	Biotite					Hornblende				
	bh	bh	agb	gb	gbh	bh	bh	gbh	gbh	gbh
	87-55	568-55	225-56	205-55	217-55	87-55	312-55	266-57	265-57	217-55
Al ₂ O ₃	13.4	15.5	17.0	16.3	12.7	8.5	9.2	15.0	12.2	12.1
TiO ₂	3.4	2.8	4.9	4.1	3.1	1.95	1.73	0.84	0.72	2.40
*FeO	14.3	16.1	18.7	20.2	25.1	12.3	15.7	19.7	21.8	25.7
MnO	0.09	0.06	0.02	0.04	0.16	0.24	0.30	0.26	0.45	0.35
MgO	12.2	10.9	8.2	7.7	5.1	12.2	10.9	9.4	8.6	5.2
CaO	1.05	0.76	0.01	0.13	0.62	12.5	12.2	11.4	10.3	9.9
Na ₂ O	0.40	0.30	0.45	0.20	0.45	1.33	1.46	1.32	1.4	1.55
K ₂ O	8.1	8.5	8.4	9.1	7.0	0.74	0.83	0.50	0.64	1.35

*total iron expressed as FeO
Analyst: R. Kretz

a, sillimanite; b, biotite; h, hornblende;
c, calcic pyroxene refer to mineral
association

Biotite-garnet-sillimanite gneiss is of particular interest because of its undoubted sedimentary origin, and the possibility of using the rock as a stratigraphic horizon marker. It was found in all 5 zones with the possible exception of the Calumet zone, and it is also found in the inter-zone regions, for example at Bell Mount, near the centre of the Bell Mount Complex. However, relative to other rocks of group 2, it is considerably more abundant in the Gatineau zone, where marble occurs in great abundance.

Biotite-garnet gneiss, biotite gneiss, and light gray biotite-hornblende gneiss, all of presumed sedimentary origin, are found in each of the five zones, as well as the inter-zonal regions.

Medium-to-dark gray gneiss and amphibolite, containing hornblende and smaller amounts of biotite, and local garnet or calcic pyroxene are exceedingly common, and occur in great force in the Thorne zone where they are, on a small to large scale, interlayered with marble. The rocks also occur in the other zones, and are particularly well exposed in the Calumet zone. They also occur abundantly in some of the inter-zonal regions, for example in the Bell Mount Complex, where different kinds of amphibolite (generally garnet-free) are intermixed with granitic and syenitic rocks.

Calcic pyroxene gneiss is widespread but not abundant. Where hornblende and biotite are present in only small amounts, the rock lacks a conspicuous foliation and might be referred to as granulite. The rock is commonly finely layered, with

different mineral assemblages and proportions in different layers. Calcic pyroxene gneiss is usually associated with marble, but it may also occur in the inter-zonal regions.

Graphite gneiss is a distinctive rock, containing graphite, biotite, and a sulphide mineral, which produces a rusty weathered surface. It is commonly associated with marble, but it also occurs in the Moore zone, where marble is rare.

Orthopyroxene-bearing gneisses and amphibolites resemble the rocks described above, and vary in appearance, depending on the amount and kind of other ferromagnesian minerals present. The plagioclase may be greenish-gray in colour.

Quartzite has been found at only one or a very few localities in all zones, except the Gatineau zone, where it is more common, and was found at several places. It appears to be more abundant in the area to the east, which was examined by Mauffett (1949).

Information on the character and occurrence of the plagioclase gneiss, amphibolite, and quartzite is best conveyed by describing a few localities that have been examined in detail.

Biotite-garnet-sillimanite gneiss and quartzite associated
with marble in the Gatineau zone

The Gatineau zone, as noted above, consists mainly of marble, the remaining 10 per cent or so, being composed of garnet-bearing gneiss, quartzite, and minor amounts of other rocks. Layering and mineral foliation in the gneisses and quartzite is generally parallel to that in the adjacent marble, and the three rock types appear to be broadly interlayered (Map 1).

Biotite-garnet-sillimanite gneiss was observed at several places between Kazabazua village and the north border of the area, and is well exposed in a road cut 1 mile north of the village. Normally the rock consists of a few per cent of biotite and garnet, and less sillimanite, the major portion being plagioclase, quartz, and white potassium feldspar. Sillimanite occurs as small needle-like crystals or as lens-shaped aggregates, lying parallel to the foliation produced by parallel biotite crystals. The rock almost invariably contains numerous white to pale pink quartz-feldspar veins, lying for the most part parallel to the foliation. Two specimens from near Kazabazua are listed in Table 19 (752-70, 765-70).

Quartzite was found at several places along the eastern margin of the map-area, between Venosta and the north border. The rock may consist almost entirely of quartz or it may contain, in addition, small amounts of sillimanite, garnet, biotite or phlogopite, diopside, and tremolite. Quartzite is well exposed at Venosta, where phlogopite and long prismatic crystals of tremolite and cummingtonite are present (1057-74, Table 20). Elsewhere, quartzite containing minor phlogopite, amphibole, and calcic pyroxene (761-70, Table 20) occurs as layers about 1 meter thick in marble.

In addition to biotite-garnet-sillimanite gneiss and quartzite, some other types of plagioclase gneiss are found in the Gatineau zone, including biotite-garnet gneiss (1068-74, Table 19), biotite-hornblende gneiss (1064-74, Table 19), and a fine-grained biotite-calcic pyroxene gneiss (1073-74, Table 19), the latter forming thin layers in marble.

The above-noted association of marble, sillimanite gneiss, and quartzite evidently represents a sedimentary sequence which originally consisted of limestone, shale, and sandstone. In the zones to the west, where marble is less abundant, sillimanite gneiss and quartzite also become less abundant.

Garnet-biotite-hornblende gneisses of the western portion
of the Thorne zone

Along the western margin of the Thorne zone, in an area extending from Mecham to Barnes lakes on the south boundary, northerly to Grove lake and lac du Rang, various garnet-, biotite-, and hornblende-bearing gneisses and amphibolites are found interlayered with marble. Portions of this zone are covered by Maps 2A and 2B. The rocks are light to dark gray in colour and are characterized by the presence of one or more of garnet, biotite, and hornblende, and often all three are present. Calcic pyroxene, and less commonly orthopyroxene may be present. Sillimanite is rare. The dark minerals commonly make up 10 to 40 per cent of the rock, the remainder being mainly plagioclase. Quartz and white potassium feldspar may be present.

The interlayering of gneiss and marble is clearly shown in Map 2A; additional layers of marble, too narrow to map individually are commonly present. Interlayered marble and amphibolite, with layers about 6 meters thick, are exposed at co-ordinates (50.2, 19.7).

The character of the gneisses and amphibolites is well displayed at numerous points covered by Map 2A. Relatively fine-grained and homogeneous biotite-garnet-hornblende gneiss (G22-68, Table 19), containing some interlayers of biotite

amphibolite are found at (49.9, 20.8), and hornblende-biotite gneiss and amphibolite (G72-69, Table 19) and minor biotite-garnet gneiss are well exposed on a small cliff at (48.8, 21.35).

Immediately west of the area covered by Map 2A, beside a small lake (49, 22.6), a variety of gneisses is found within a relatively small area. These include biotite-garnet gneiss (573-69), biotite-garnet-hornblende gneiss (568-69), locally with cummingtonite (135-55), hornblende-biotite gneiss and amphibolite, hornblende-calcic pyroxene gneiss (569-69), and hornblende-orthopyroxene-biotite gneiss (138-55, Table 19). For the most part, mineral foliation, planar gneissosity, and layering in these rocks are all parallel, and the rocks may have initially formed a sequence of sedimentary strata.

Fine exposures of plagioclase gneiss and amphibolite are also found at Mecham lake. In the fields and woodland to the north-west of the lake, the dominant variety is a light-to-medium gray biotite gneiss (901-73) which locally contains minor hornblende or garnet. Layers and lenses of amphibolite are present. Also present is minor graphite gneiss and some white rocks that contain 30-40 per cent of quartz and minor biotite (903-73); sillimanite may be present in fairly large amounts, together with garnet and minor biotite (904-73). To the east, at the base of a prominent cliff of amphibolite, is found a sequence of gneisses, including biotite gneiss, garnet-biotite gneiss, hornblende-biotite gneiss, calcic pyroxene-hornblende gneiss, and layers of marble (some only 20 cm thick), which evidently overlies the rocks described above. The cliff itself, forming the upper part of the sequence,

consists of homogeneous hornblende-biotite gneiss or amphibolite (905-73, Table 19). A small amount of quartz-feldspar material in the form of veins is present.

These rocks also appear to represent a sequence of metamorphosed sedimentary strata. The cliff-forming amphibolite may be of volcanic origin.

The above rocks are evidently not representative of the Thorne zone as a whole. The eastern part of the zone, which was mapped by Baker (1956) contains a higher proportion of hornblende gneiss or amphibolite and marble than that found in the west, while garnet-bearing rocks are evidently less common.

Amphibolite, hornblende gneiss, and biotite gneiss of the
Calumet zone

The north-eastern part of Ile du Grand Calumet, which was mapped in detail by Shaw (1955) was subsequently examined by the writer in connection with a study of the calcite and dolomite marble found there. Associated with the marble are some noteworthy exposures of hornblende gneiss and amphibolite, and minor biotite gneiss which were briefly described by Shaw (1955). The following description, however, is taken almost entirely from the writer's own observations. Also presented below, is some recently found evidence for two ages of plagioclase gneiss in this part of the map-area.

Four distinctive varieties of hornblende-biotite-plagioclase gneiss or amphibolite are found within a fairly small area of the island. These are, briefly, as follows.

Where the southern boundary of the map-area meets the Ottawa River, a dark gray, relatively fine-grained amphibolite is well exposed. The rock is fairly homogeneous, and contains about 50 per cent of dark minerals, mainly hornblende, but also biotite and garnet (265-57, 266-57, 267-57, Table 19). Variation in mineral proportions locally give rise to layering, parallel to the mineral foliation; for example layers, about 5 cm thick, of more feldspathic rock are locally present. Nodules, containing garnet and calcic pyroxene, possibly concretions, are also present in some places. Cummingtonite is locally present in small amounts.

To the north-west, in the area covered by Map 2C, a body of amphibolite (2f) is exposed which resembles the amphibolite described above but is distinguished by the presence of a very well developed linear gneissic texture. Foliation and planar gneissic texture are only weakly developed. Both fine-grained (about $\frac{1}{2}$ mm) and coarse-grained (about 2 mm) varieties occur, and may be in sharp contact with each other. Locally the rock contains relatively large crystals of hornblende, or small calcite pods, containing biotite and quartz. The mineral assemblage in one specimen is given in Table 19 (873-72); this amphibolite also contains minor cummingtonite.

Toward the north-west, another body of amphibolite (2f') is exposed; this one is characterized by the presence of a conspicuous fine-layered structure, and by the presence of calcic pyroxene, scapolite, and calcite; the layering is the result of variations in mineral proportions. This rock possesses both linear and planar gneissic textures. Grain size

is variable, ranging, for hornblende, from $\frac{1}{2}$ mm to 3 mm. Near its contact with marble, the amphibolite is interlayered with marble on a small scale, the layers being about 1/3 meter thick; this may be sedimentary bedding. Representative mineral assemblages are listed in Table 19 (875-72, 887-72, 965-73).

Finally, a light gray hornblende-biotite gneiss (2f") is present and occurs as relatively homogeneous bodies. This rock also possesses a conspicuous linear gneissic texture, as well as a planar gneissosity. Isolated, angular fragments of amphibolite are locally found in the gneiss, which may be of igneous origin. Representative mineral assemblages are found in Table 19 (962-73, 964-73). The gneiss, with regard to composition, lies between the more common hornblende-biotite gneisses and amphibolite, and some of the granitic rocks of the area.

The above illustrates the variation that may be found locally in the map-area with regard to hornblende-biotite-plagioclase rocks, all of which may be classed as hornblende-biotite gneiss and amphibolite (2f). Such variation also exists elsewhere in the area, but in general, sufficient rock exposure and time were not available to map them separately. Although they are all metamorphic rocks, some are evidently of sedimentary origin, while others may be of volcanic or plutonic origin.

A very small amount of a fine-grained rock consisting of interlayered quartzite and biotite gneiss or schist (871-72, Table 19) was found at two places on Ile du Grand Calumet,

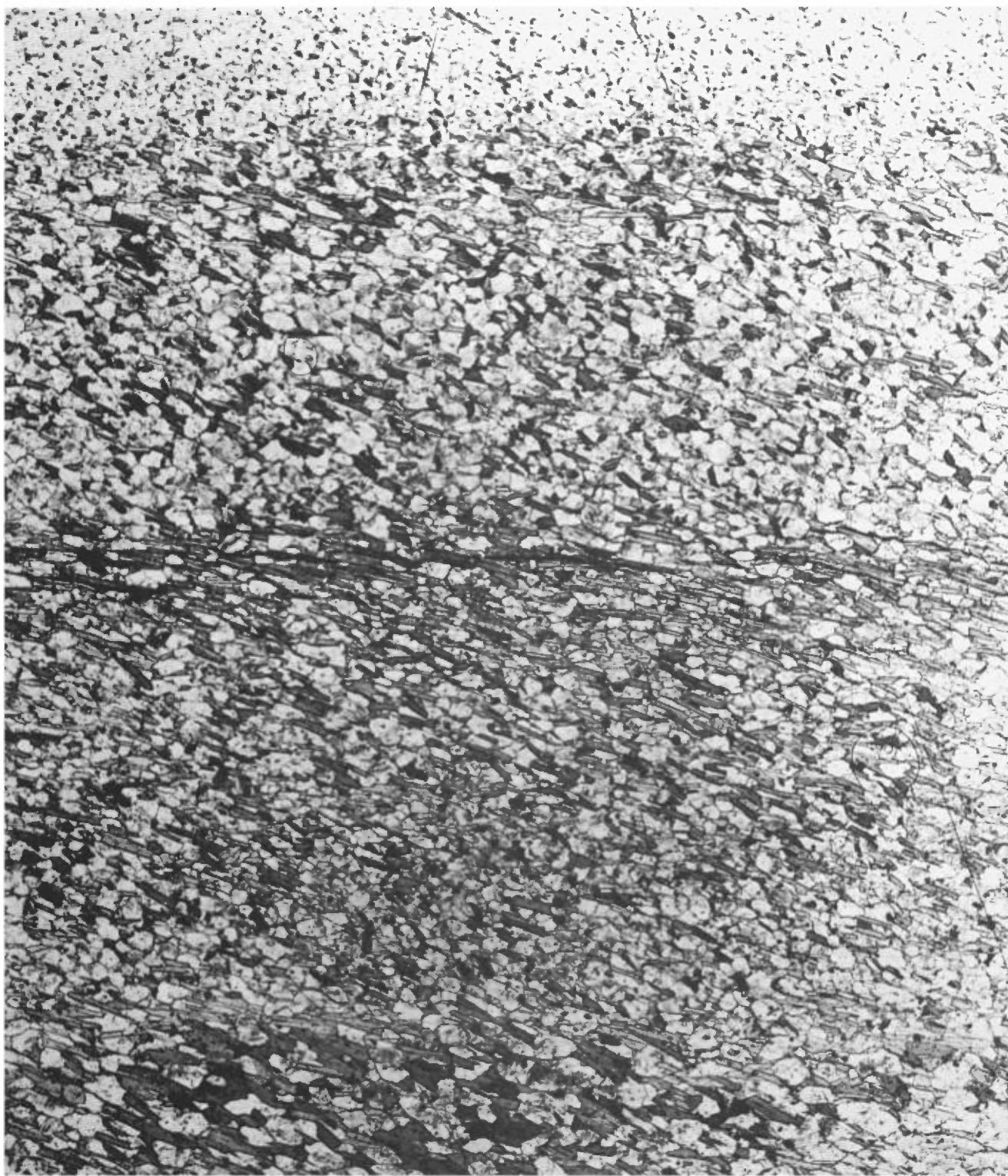


FIGURE 10 - Fine-grained biotite gneiss (871-72), showing gradation in biotite content that may be preserved graded bedding. Greatest edge of photograph is 15 mm long. Grand-Calumet Township.



FIGURE 11 - Two vertical sheets of amphibolite cutting folded biotite-garnet gneiss. A portion of the thicker sheet is shown at the top left corner; the thinner one, beneath the scale, is about 20 cm thick. Grand-Calumet township.

within the area covered by Map 2C. The grain size of these rocks is only about 0.1-0.2 mm, and about 0.5 mm for biotite. In some of the layers, which are only a few mm or a few cm thick, a gradation in the biotite content produces an effect that resembles graded bedding, and if this is in fact preserved graded bedding, the beds, which dip gently, are upright. Foliation, defined by biotite crystals, is at a slight angle to the plane of bedding (Fig. 10). The rock is cut by small tourmaline-bearing pegmatite dikes.

The small grain size, presumed graded bedding, and foliation at an angle to layering all distinguish the above rock from the common biotite gneisses of the area, and the rock may be younger in age. However an unconformity is evidently not present, for layering, or bedding, within the rock is parallel to layering in the adjacent marble.

At another locality in eastern Ile du Grand Calumet, (45.3, 38,0) (Map 1), folded biotite-garnet gneiss is cut by vertical sheets of amphibolite, as shown in Fig. 11. The gneiss is heterogeneous, while the amphibolite sheets are homogeneous, and lie parallel to and resemble the first variety of amphibolite, described above. Both gneiss and amphibolite are cut by narrow pegmatite dikes, which have been folded. The amphibolite sheets may be basaltic dikes which were emplaced into an older, folded sequence of rocks, the whole being subsequently subjected to metamorphism and deformation.

Minerals

Some information on the distribution and properties of the individual minerals of the plagioclase gneiss, amphibolite,

and quartzite of the map-area are listed below. The information is based on a microscopic examination of thin sections and polished sections cut from numerous rock specimens and on chemical analyses of numerous minerals.

The 220 specimens that were examined microscopically have been divided according to certain mineral associations, as follows; the number of specimens found to contain each association is given in parentheses.

biotite-garnet-sillimanite (13)

biotite-garnet (18)

biotite (12)

biotite-graphite (11)

hornblende (7)

hornblende-biotite (67)

hornblende-biotite-garnet (27)

hornblende-garnet (1)

calcic pyroxene (3)

calcic pyroxene-biotite (4)

calcic pyroxene-garnet (1)

calcic pyroxene-hornblende (17)

calcic pyroxene-hornblende-biotite (19)

calcic pyroxene-hornblende-garnet (2)

In addition, 9 specimens were found to contain orthopyroxene, with one or more of hornblende, biotite, garnet, and 9 specimens of quartzite were examined microscopically.

The sequence of minerals in the above listing, e.g. hornblende-biotite, is not an indication of the relative amounts of the minerals present, for these may vary greatly. The numbers in parentheses give an indication of the frequency of occurrence

of ferromagnesian minerals and sillimanite in plagioclase gneiss and amphibolite in the area as a whole.

Sillimanite

Sillimanite normally occurs in the association of biotite and garnet, and has not been found together with hornblende or calcic pyroxene. It always occurs as elongated crystals, which may form aggregates, never as fibres (fibrolite). The largest crystal observed is 2 mm long. Sillimanite is unevenly distributed in the rocks, and is normally concentrated along certain horizons, parallel to the foliation. Crystals may be aligned to produce a lineation. Sillimanite crystals locally occur as inclusions in garnet; elsewhere they show a preference for biotite.

Garnet

Garnet is widespread, and occurs in gneiss and amphibolite in which the dark minerals range from nearly zero to 70 per cent; it is also found in some occurrences of graphite gneiss and quartzite. It is usually dark red in colour, but in sillimanite-bearing gneiss, the colour is lighter, possibly because of a lower manganese content.

Garnet normally occurs as nearly equidimensional, irregular crystals, which rarely show crystal faces. Locally the crystals are lens-shaped, presumably the result of intense deformation. Normally the crystals are larger in size than those of the associated feldspar, biotite, and other minerals, and the size, expressed as the diameter of the largest crystal in a thin section or small volume of rock varies considerably

within the group of specimens examined microscopically, as shown in Fig. 12. In most rocks, the largest crystal has a diameter of 2-3 mm; any single rock will of course contain many smaller crystals as well. In garnet-biotite-sillimanite gneiss, garnet crystals are on the average larger than in amphibolite.

Although crystals of garnet commonly contain inclusions of quartz, plagioclase, biotite, and ilmenite, only rarely are the inclusions arranged to produce an internal foliation. Inclusions of plagioclase locally have a crystal form of garnet imposed on them. Locally, crystals rich in inclusions have a rim free of inclusions. In some amphibolite, garnet crystals are surrounded by grains of plagioclase, so that garnet-hornblende contacts are rarely found.

Representative chemical analyses of garnet from gneiss and amphibolite are listed in Table 21. The dominant component in all minerals that were analysed is the iron-aluminum garnet, almandine. The manganese and calcium content varies considerably, and is obviously not related to metamorphic grade; in sillimanite-bearing gneiss, these two components have relatively low concentrations.

Biotite

Biotite was found in 85 per cent of the rocks that were examined microscopically, but never in large amounts. It is surprisingly common in amphibolite. Biotite occurs as disc-shaped crystals with a diameter to height ratio of about 3, but locally the crystals are very thin, with a ratio larger than this. The crystals are usually arranged in parallel, or nearly so, to define a foliation.

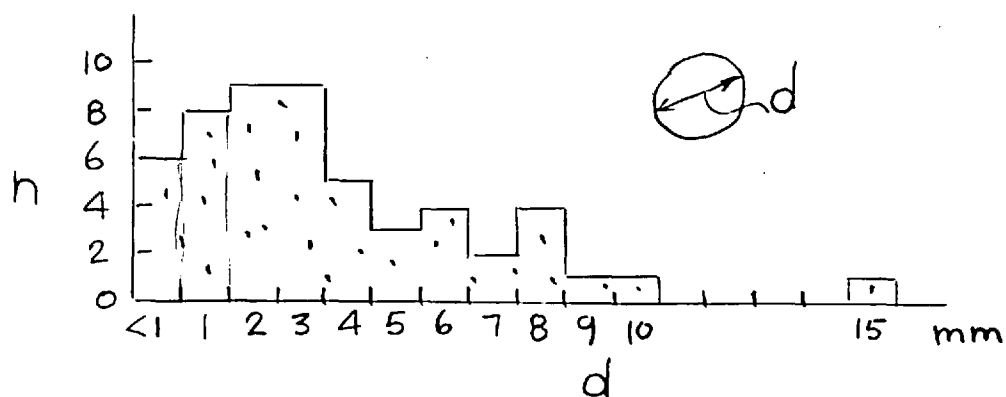


FIGURE 12 - Variation in the size of garnet crystals in plagioclase gneiss and amphibolite. Dimensions refer to the largest crystals observed in a small volume of rock, i.e. in a thin section.

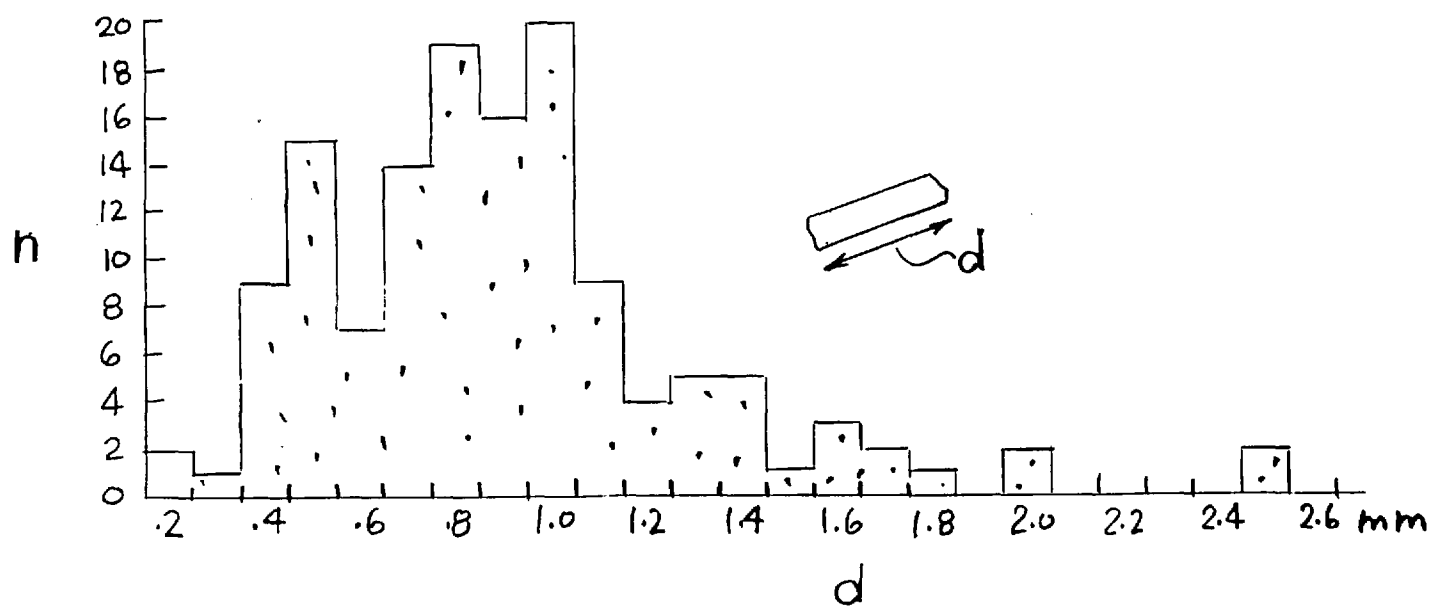


FIGURE 13 - Variation in the size of biotite crystals in plagioclase gneiss and amphibolite. Dimensions refer to the largest crystals observed in a small volume of rock, i.e. in a thin section.

The size of the biotite crystals, expressed as the diameter of the largest crystals among a group of several hundred crystals seen in a thin section, varies considerably among the rocks that were examined microscopically, as shown in Fig. 13. In most rocks, the largest crystals present have a diameter of between 0.7 and 1.1 mm, but the entire range extends from 0.2 to 2.5 mm. Since the size of biotite crystals in a rock is normally about the same as that of the major companion minerals (plagioclase, quartz, hornblende, pyroxene), the above data provide an indication of the encountered variation in rock grain size.

Representative analyses of biotite from some gneisses and amphibolites are listed in Table 21. The magnesium content in a group of several analyses, ranges from 5 to 12 per cent MgO; hence the mineral does not vary greatly with regard to the Mg/Fe ratio. Appreciable concentrations of titanium, sodium, and calcium are present; the aluminum content in sillimanite-bearing rocks is slightly above average.

In many rocks, biotite has partly altered to chlorite, and locally it is replaced by muscovite.

Hornblende

Hornblende is common in the light-to-medium gray gneisses, where it occurs in small amounts, and in the dark gray amphibolite, where it makes up about $\frac{1}{2}$ of the rock volume. Magnesium-rich calcium amphibole is present in some occurrences of quartzite.

Hornblende normally forms anhedral crystals which are nearly equidimensional in shape or approximate the shape of a

TABLE 22 - ANALYSES OF CALCIC PYROXENE AND
HORNBLLENDE FROM PLAGIOCLASE-CALCIC
PYROXENE-HORNBLLENDE GNEISS.

	Calcic Pyroxene			Hornblende		
	280-55	98-56	113-55	280-55	98-56	113-55
SiO ₂	52.9	51.6	51.4	44.2	42.5	43.2
TiO ₂	0.16	0.19	0.22	1.18	1.10	2.10
Al ₂ O ₃	2.01	1.73	1.39	11.37	11.84	10.77
Fe ₂ O ₃	2.64	1.99	2.52	6.72	5.82	4.37
FeO	6.03	8.76	10.48	9.34	13.07	15.59
MnO	0.31	0.27	0.34	0.21	0.20	0.24
MgO	12.69	11.24	11.40	12.43	9.59	8.73
CaO	22.05	21.90	21.66	10.17	10.12	10.00
Na ₂ O	0.55	0.33	0.36	2.05	1.37	1.65
K ₂ O	tr	0.01	0.03	0.98	1.69	1.06
[Fe ²⁺]	21.0	30.4	34.0	29.7	43.3	50.0

tr: less than 0.01 per cent

[Fe²⁺] : $\left[\text{Fe}^{2+} / (\text{Mg} + \text{Fe}^{2+}) \right] 100$

Analyses by Norman Suhr and Diane Garrett

three-axis ellipsoid. The latter crystals may produce a foliation or lineation, or both, depending on their arrangement in the rock. The orientation so produced is also a preferred crystallographic orientation.

Data are not available for the size of hornblende crystals, but these are similar to those given for biotite above.

Representative analyses of hornblende from gneisses and amphibolites that contain biotite or garnet or both are given in Table 21, while Table 22 lists three recently-obtained analyses of hornblende from hornblende-calcic pyroxene gneiss. The magnesium content generally ranges from 5 to 14 per cent MgO, which represents an intermediate Mg/Fe ratio. Hornblendes associated with calcic pyroxene (9 analyses available) appear to be, on the average, richer in magnesium than those that are associated with biotite and garnet. Some of the former are remarkably rich in ferric iron.

All of the analysed amphiboles are aluminous and all contain small amounts of alkalies. The manganese content is greater than in biotite but less than in garnet, and the titanium content is less than that in coexisting biotite. Further considerations of the sharing of elements by hornblende, biotite, and garnet in rocks of the map-area have been discussed elsewhere by the writer (1959).

Hornblende very locally occurs as patches in crystals of calcic pyroxene, where it contains tiny inclusions of unconfirmed quartz, and in these rocks has evidently formed from calcic pyroxene. Hornblende has locally altered to chlorite;

sphene and calcite may be by-products of this reaction.

Cummingtonite

Cummingtonite was found in only four rocks, two from the western part of the Thorne zone and two from the Calumet zone. It occurs, in very small amounts, together with hornblende, and in three of the rocks, garnet is also present. The crystals may show twinning, and often appear to have grown at the end of a hornblende crystal, maintaining to some extent, the crystallographic continuity.

Calcic pyroxene

Calcic pyroxene is less common than hornblende and biotite, and where found is generally accompanied by hornblende. The pyroxene to hornblende ratio varies widely; where pyroxene is relatively abundant the rock takes on a green colour, facilitating the identification of this mineral in the field.

Calcic pyroxene normally forms near-equidimensional grains, and rocks rich in pyroxene and plagioclase may be apparently devoid of a mineral foliation. If a gneissic texture is not discernable, the resulting rock is more appropriately referred to as granulite or granofels.

Three representative analyses of calcic pyroxene are listed in Table 22. Nine out of eleven analyses of this mineral yielded magnesium concentrations of between 11.2 and 12.7 per cent MgO; hence the Mg/Fe ratio does not vary greatly. Table 22 shows, however, that the magnesium and iron concentration in calcic pyroxene and hornblende change sympathetically. The data also show that calcic pyroxene tends to acquire a larger

share of manganese, and a smaller share of titanium, aluminum, and alkalies than the coexisting hornblende.

Calcic pyroxene is rarely found in an altered condition, having locally produced minor calcite and chlorite.

Orthopyroxene

Orthopyroxene was found in only 9 of the 220 specimens that were examined microscopically, where it occupies 1 to 10 per cent of the rock, and occurs as discrete, equidimensional grains. Some of the orthopyroxene-bearing rocks resemble the common biotite-garnet and hornblende-biotite gneisses or amphibolites, but some are special in that the associated plagioclase is greenish-gray in colour, a common feature of granulite-facies rocks. In one rock the $\text{Fe}/(\text{Fe} + \text{Mg})$ ratio was found to be about 0.4.

Cordierite

Cordierite was found by Albert Richard of Otter Lake on his farm north-west of the village, in what is here referred to as the Moore zone. The mineral, as seen in the field is bright blue, and forms about 10 per cent of a gneiss that contains, in addition, orthopyroxene and biotite (807-70, Table 19). Garnet may also be present. At this locality, (52.7, 29.5) outcroppings are not numerous, but an area a few hundred meters in diameter appears to be underlain by the cordierite gneiss. An estimate of the $\text{Mg}/(\text{Mg} + \text{Fe})$ ratio of the mineral by Hay (1965) gave a value of 0.83, which is the highest value he found in a study of cordierite from several localities in the Canadian Shield.

TABLE 23 - ANALYSES OF PLAGIOCLASE FROM CALCIC PYROXENE-HORNBLENDE GNEISS.

	161-55	176-55	306-55	98-56
*Fe ₂ O ₃	0.47	0.26	0.24	0.17
MnO	0.01	tr	0.01	tr
MgO	0.16	0.16	0.18	0.07
CaO	6.16	6.74	7.75	11.77
SrO	0.06	0.09	0.12	-
BaO	0.02	0.01	0.03	tr
Na ₂ O	7.05	7.73	7.70	5.14
K ₂ O	0.47	0.72	0.60	0.23
An	31.6	31.2	34.6	55.2
Ab	65.6	64.8	62.2	43.6
Or	2.8	4.0	3.2	1.3

*total iron expressed as Fe₂O₃

tr less than 0.01 per cent

- not determined

Analyst: Diane Garrett

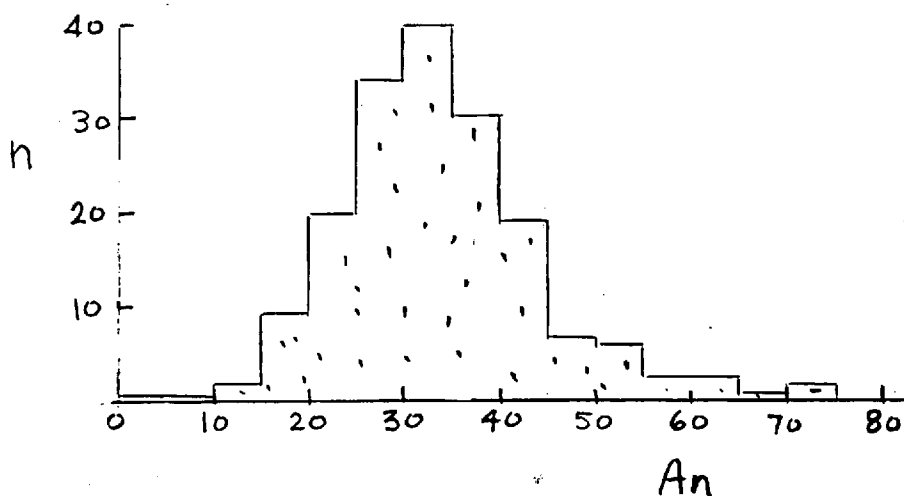


FIGURE 14 - Variation in the composition of plagioclase in plagioclase gneiss and amphibolite; n denotes number of specimens, An denotes mole per cent anorthite in plagioclase.

Unconfirmed cordierite was also found in a quartz-rich graphite gneiss at lac du Rang, together with sillimanite and biotite.

Plagioclase

Plagioclase is normally white but locally takes on a greenish gray colour, which is characteristic of high grade metamorphic rocks. It occurs as equidimensional, anhedral crystals, and the variation in the size obtained by these crystals in the various gneisses and amphibolites is indicated approximately by the data given above for biotite. The grains retain their equidimensional shape even when the associated biotite and hornblende crystals define a strong foliation or lineation, and judging by the orientation of twin lamellae, as seen in section, the crystallographic orientation of the plagioclase grains is nearly random.

Twinning is well developed in plagioclase crystals of most of rocks examined, and this is dominantly albite twinning. The width of the twin lamellae varies greatly. In some rocks these lamellae are slightly curved, presumably as a result of deformation.

Rarely, plagioclase crystals were found to contain lamellae of potassium feldspar, presumably the result of an exsolution reaction. Irregularly-shaped inclusions of potassium feldspar of less-certain origin, may be present. Plagioclase-quartz intergrowths (myrmekite) also occur locally.

The composition of plagioclase, in terms of the components albite (Ab) and anorthite (An) was estimated by the Michel-Lévy method, and was found to vary greatly, as shown in Fig. 14.

The range in plagioclase composition is about the same in rocks in which biotite dominates as in rocks in which hornblende and calcic pyroxene dominate, but the peak in the histogram for the former is at An_{25-30} and for the latter at An_{30-40} .

Chemical analyses of plagioclase from four hornblende-calcic pyroxene gneisses are listed in Table 23. The potassium content in these minerals ranges up to 4 mole per of the orthoclase (Or) component. Since the minerals separated from the rocks were very pure, the small amounts of iron and magnesium reported in the analyses are considered to be present in solid solution in the plagioclase crystals.

In only a few rocks was any evidence found for variation in the chemical composition of individual crystals, i.e. zoning. Where present, the zoning is normal, with crystals becoming progressively more sodic toward the margins.

In most of the rocks that were examined microscopically, plagioclase has altered, to a small extent, to white mica. This alteration may be very selective, affecting some grains or portions of grains more than others. Thus the centres of grains or certain twin lamellae are in some rocks the most altered portions of plagioclase crystals.

Scapolite

Scapolite is fairly common in calcic pyroxene-bearing gneiss, where it may form up to 20 to 30 per cent of the rock volume. It is rarely present in amphibolite, and was not found at all in the biotite and biotite-garnet gneisses, nor in graphite gneiss and quartzite. Where present, scapolite occurs

as discrete anhedral grains, which only rarely show any textural evidence of it having formed as an alteration of plagioclase. Scapolite itself may be altered to white mica.

Epidote

Epidote was found in only 8 of the rocks that were examined microscopically, mainly in calcic pyroxene-bearing gneiss. Usually it occurs as discrete, irregularly-shaped grains, which, apart from their irregular edges show no clear evidence for a secondary origin. Locally, however, it occurs as 'films' along grain boundaries, or as grains with many small inclusions of quartz, similar to grains of secondary amphibole, and at these places the epidote is almost certainly of secondary origin.

Allanite

Allanite was found, in small amounts, in some rocks, where it appears, in thin sections, as yellow-brown isolated anhedral grains that may show colour zoning. Radiating fractures may be present in the surrounding rock, and dark haloes may be present within hornblende or biotite where these are in contact with allanite.

Potassium feldspar

Potassium feldspar is present in nearly all of the biotite-sillimanite gneisses, and in most of the biotite, biotite-garnet, and graphite gneisses and in quartzite. The feldspar occurs as discrete, white anhedral grains, or it may form an intergrowth with plagioclase (perthite) in which the ratio of the two feldspars may be equal.

Muscovite

Muscovite was found in small amounts (less than 1 per cent) in only 8 biotite-bearing gneisses, and in none of the hornblende or calcic pyroxene-bearing rocks. In about half of the occurrences, it forms small crystals with 'frayed edges', interpreted as being of secondary origin, and in the remainder, it occurs as discrete, disc-shaped crystals that are presumably primary. In one rock, both of the above types of muscovite are present. In another, muscovite is concentrated on either side of a small fracture and is clearly of secondary origin.

Quartz

Apart from quartzite, where quartz forms 70-90 per cent or more of the rock, this mineral is an important constituent of the light gray and medium gray gneisses, and is also present in some of the darker rocks, which are dominated by hornblende and calcic pyroxene.

Quartz normally occurs as equi-dimensional anhedral grains. In quartzite, grain boundaries may be highly irregular. Rarely, quartz forms thin disc-shaped grains, parallel to the foliation. Individual grains are commonly made up of many, very nearly parallel crystals (mosaic structure), presumably an indication of strain.

Tourmaline

Tourmaline was found in nearly 1/3 of the specimens of biotite-graphite gneiss, only rarely in hornblende-biotite gneiss, and quartzite, and not at all in the other varieties. Where present, it occurs as a few widely separated, anhedral

grains. In thin sections, it is pleochroic from pale yellow to yellow or brown. Some crystals are zoned.

Sphene

Sphene was found in half of the calcic-pyroxene-bearing gneisses and hornblende gneisses, very rarely in hornblende-biotite-garnet gneiss and biotite gneiss, and not at all in the remaining rock types. It is almost invariably present in those rocks that contain calcic pyroxene and hornblende as the only ferromagnesium minerals; in the absence of calcic pyroxene, the titanium of the rock is more frequently tied up in ilmenite than in sphene. None of the orthopyroxene gneisses were found to contain sphene.

Sphene occurs as small equi-dimensional to somewhat lens-shaped crystals, or it may form rims about either ilmenite or magnetite.

Some chemical data on sphene from four specimens of calcic pyroxene-hornblende gneiss are given in Table 24. Notable concentrations of iron are present in the form of ferric iron, occupying the titanium position. Very small amounts of magnesium, manganese, and alkalies are present, and are probably occupying the calcium position.

Zircon

Zircon is a very common minor constituent in biotite-garnet-sillimanite, biotite-garnet, and biotite gneiss, but becomes progressively less common in rocks containing progressively greater amounts of hornblende and calcic pyroxene. It occurs as well-formed to poorly-formed tetragonal prisms, or

TABLE 24 - ANALYSES OF SPHENE FROM CALCIC
PYROXENE-HORNBLLENDE GNEISS.

	161-55	186-55	306-55	98-56	Ideal Sphene
TiO ₂	36.04	33.18	33.39	35.65	40.7
*Fe ₂ O ₃	2.23	0.93	1.60	1.09	-
MnO	0.14	0.02	0.08	0.07	-
MgO	0.23	0.20	0.16	0.16	-
CaO	27.30	29.83	28.07	27.20	28.6
Na ₂ O	0.08	0.10	0.08	0.08	-
K ₂ O	0.03	0.07	0.03	0.03	-

*total iron expressed as Fe₂O₃

Analyst: Diane Garrett

as nearly spherical grains, much smaller in size than the associated major minerals.

Apatite

Apatite is a very common minor constituent in the gneisses that were examined, except in the biotite-garnet and biotite-garnet-sillimanite gneisses, where it was found in less than half of the specimens, and in quartzite, where it is rarely present. It usually occurs as poorly-formed, short, hexagonal prisms, which rarely exceed 1 mm in length.

Graphite

Graphite is present in amounts up to 5 per cent in biotite-graphite gneiss, which is normally rich in quartz and may contain garnet and sillimanite, but never hornblende or calcic pyroxene. Elsewhere, within the gneisses, graphite is exceedingly rare; rocks that do contain this mineral are likely to occur near marble, or as inclusions in marble. Graphite was not found in rocks that were classed as quartzite, except where present as thin layers in marble.

Graphite occurs as thin, disc-shaped crystals, up to 1 mm in diameter, which are normally oriented in parallel to define, with biotite, a conspicuous foliation. Locally, crystals of graphite lie at large angles to the biotite foliation, suggesting that graphite was introduced to the rock following the crystallization of biotite.

Graphite from three specimens of biotite-graphite gneiss were analysed by Norman Suhr, and were found to contain 0.1 per cent of TiO_2 and small amounts of molybdenum and vanadium.

These three elements occur in smaller amounts in graphite from the associated marble.

Kornerupine

Kornerupine, a rare boron-bearing silicate, was found by the writer at one locality (59.0, 01.6), where it occurs together with sillimanite, garnet, biotite, and about 70 per cent of quartz in a rock here classed as quartzite. (1066-74, Table 20). It was also identified in specimens collected by students to the east of the above locality, near the highway. The well-known kornerupine locality in the adjacent area to the east (Girault, 1952) is only a few miles away.

At the locality for which co-ordinates are given above, kornerupine occurs as blue-gray prismatic crystals, up to 1 cm in length, forming nearly 20 per cent of a thin layer of quartzite. Tourmaline is also present.

Magnetite and Ilmenite

Magnetite or ilmenite or both occur in small amounts in most of the rocks under study, but they were not detected in biotite-graphite gneiss nor in quartzite. The minerals may be identified with the aid of a binocular microscope. Magnetite, being magnetic, is readily distinguishable from ilmenite, but when ilmenite is present in small amounts it may be difficult to identify. Information on magnetite and ilmenite is best obtained by use of an ore microscope, which was used to examine about 20 specimens of gneiss and amphibolite.

Magnetite and ilmenite usually occur as nearly equidimensional, rounded or somewhat flattened grains, devoid of

crystals faces, but ilmenite may occasionally form disc-shaped crystals. The non-equidimensional grains are usually arranged parallel to the foliation produced by silicate minerals. The grains are normally 0.3 to 0.5 mm in diameter, but may be larger.

Magnetite commonly contains lamellae of ilmenite. Three intersecting sets of lamellae may be present, and are evidently localized by crystallographic planes in magnetite. Ilmenite, which may show twinning, locally contains lamellae of magnetite; in places small magnetite grains are 'attached' to ilmenite, and may represent material that has exsolved from ilmenite.

Grains of both ilmenite and magnetite may be rimmed by sphene. Ilmenite has locally altered to material that is tentatively identified as rutile.

Pyrite, Pyrrhotite, Chalcopyrite, and Marcasite

Pyrite or pyrrhotite, or both minerals were identified in about 70 per cent of the rocks examined in detail; pyrite is more common than pyrrhotite. Although magnetic properties and hardness may often be used to distinguish between these minerals, they are best examined by use of an ore microscope.

Pyrite occurs as grains or clusters of grains which may show some crystal faces, or as vein-like masses, following grain boundaries between silicate minerals. Pyrrhotite forms nearly equi-dimensional, anhedral grains. Grains of pyrite and pyrrhotite are normally about 0.2 to 0.5 mm in diameter, but larger pods, a few mm in diameter, were very locally observed in amphibolite.

Chalcopyrite was identified in 1/3 of the specimens

that were examined in polished section, and is evidently not uncommon, (in minute amounts) in the gneisses and amphibolites. It occurs as small anhedral grains, about 0.1 mm in diameter, in contact with or enclosed by pyrrhotite.

Marcasite was identified by X-rays in one specimen of biotite-graphite gneiss.

Crystals of pyrite are almost invariably surrounded by a rim of hematite, and in places pyrite has entirely or almost entirely altered to hematite. The biotite-graphite gneiss always contains a very fine grained or amorphous material which is yellow, brown, or black in colour, and is usually concentrated along certain planes parallel to the foliation. An attempt to obtain an X-ray powder pattern of this material was unsuccessful. It is probably an iron hydroxide, and may be an alteration of pyrite.

Calcite

Calcite, as discrete grains about 1 mm in diameter, is found only occasionally in hornblende and biotite-bearing gneiss and in quartzite, and somewhat more frequently in calcic pyroxene-bearing gneiss. It forms up to 10 per cent of the rock volume, and is possibly of sedimentary origin.

Planar and linear features of gneiss and amphibolite

Two of the most striking attributes of the gneisses and amphibolites of the present study are a preferred orientation of crystals to give rise to a mineral foliation or lineation, and the clustering of crystals of a particular mineral to produce a planar or linear gneissic texture. These features

are of particular interest for the information they may provide concerning rock crystallization and deformation.

Some data on the orientation of crystals have been included in the above descriptions of individual minerals. The minerals that most commonly produce a mineral foliation are biotite, quartz, and hornblende, the foliation resulting from the parallel or near-parallel arrangement of crystals whose shape may be approximated by a disc (biotite), lens (quartz), and three-axis ellipsoid (hornblende). Other minerals that locally produce a foliation are graphite, garnet, calcic pyroxene, orthopyroxene, sphene, magnetite, and ilmenite. The mineral that most commonly produces a mineral lineation is hornblende, the lineation being defined by the parallel or near-parallel arrangement of the long axes of the three-axis ellipsoids, which are also the crystallographic c axes. Long prisms of sillimanite may also be aligned to produce a lineation. Rocks may possess a foliation, with no discernable lineation, or a lineation with no discernable foliation, or both together; where both are present, the lineation lies in the plane of foliation.

Gneissic texture, produced by the concentration of crystals of certain minerals into zones or 'segregations' is present in various degrees of development in nearly all of the gneisses and amphibolites of the map-area. The segregations may be lens-shaped or tabular to produce a planar gneissic texture, or they may be elongate to produce a linear gneissic texture. Where the segregations are lath-shaped, both a planar and linear gneissic texture may result.

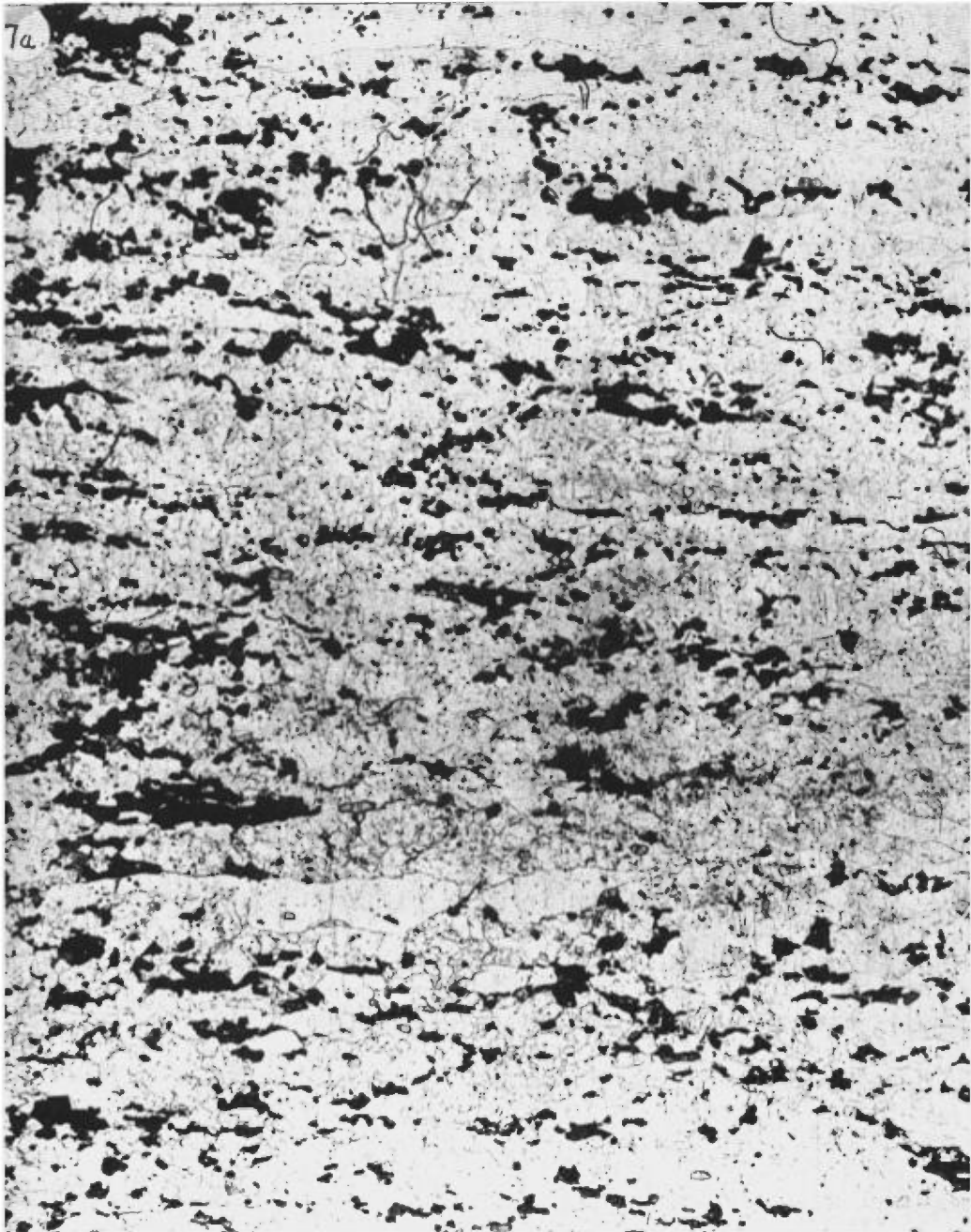


FIGURE 15 - Microscopic view of gneissic texture in hornblende gneiss (801-70). Greatest edge of photograph is 1.8 cm long.

The particular minerals that produce the segregations are usually the common minerals, hornblende, biotite, pyroxene, feldspar, and quartz. Planar gneissic texture is more common than linear gneissic texture. With few exceptions, the planar elements produced by mineral foliation and gneissic texture are parallel.

The shape and thickness of the mineral segregations varies greatly, as shown for example in Figs. 15 and 16. They may be small lens-shaped aggregates of grains of thickness equal to the diameter of a grain (one-grain layering), as shown in Fig. 15, or they may be several grain diameters thick as shown in Fig. 16. The shape of the segregations varies also; normally they are lens-shaped, but more continuous, layer-like segregations are also found.

Gneissic texture may be very weakly developed with only a slight tendency toward clustering, or it may be well developed, as in the above illustrations, and all intermediate stages are found. Representative examples of gneissic texture in the principal types of gneiss and amphibolite are illustrated in Fig. 17.

Small quartz-feldspar bodies.

Within the boundaries of a typical outcropping, which may measure a few meters or tens of meters across, plagioclase gneisses and amphibolites almost invariably contain some layers, veins, dikes, or irregularly shaped bodies composed mainly of quartz and white feldspar. These vary greatly in size. On the lower end of the spectrum, they grade into the small segregations of quartz and feldspar that form a part of the gneissic texture described above. With increasing size they grade into

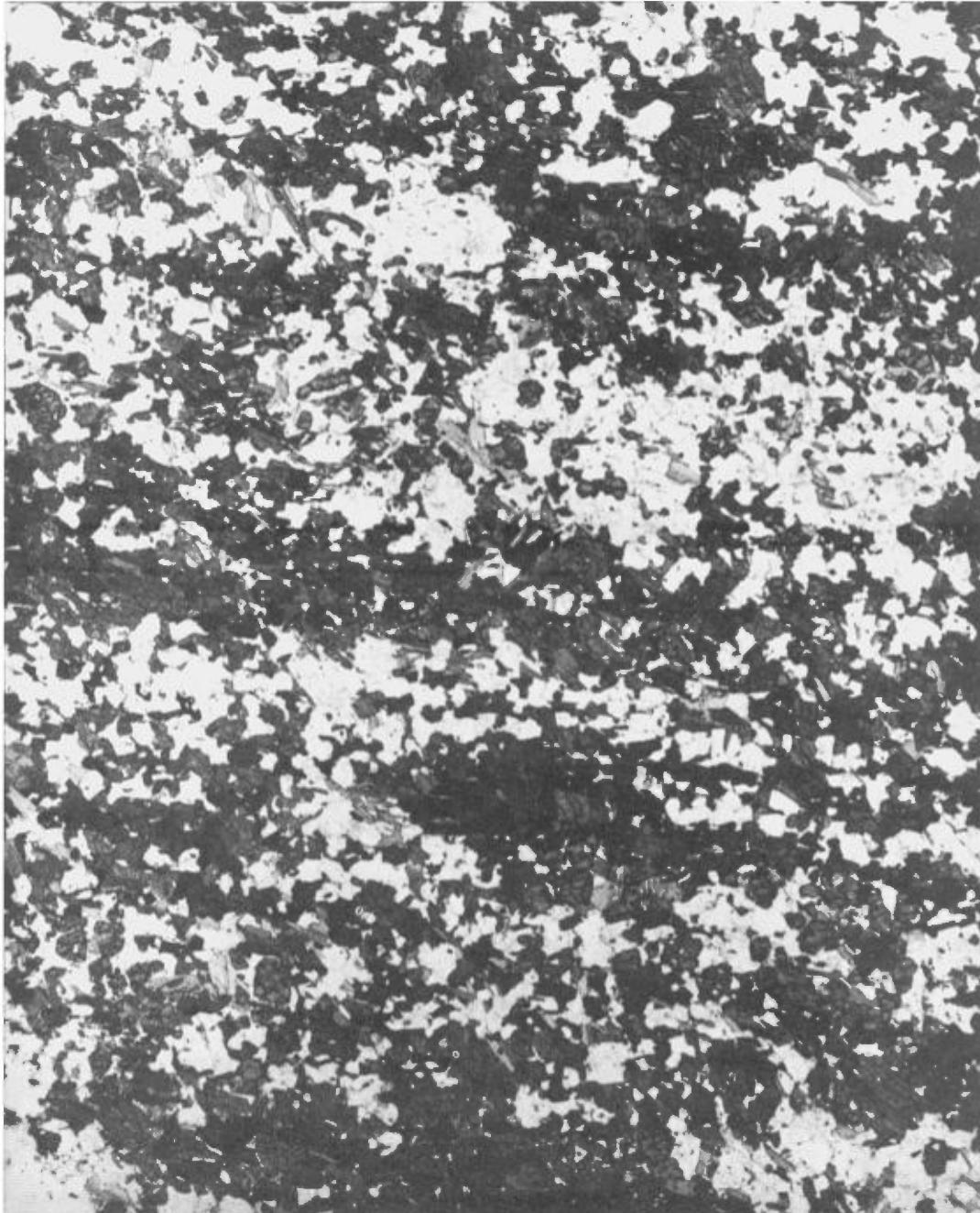


FIGURE 16 - Microscopic view of gneissic texture in hornblende-biotite-garnet gneiss (266-57). Greatest edge of photograph is 1.8 cm long.

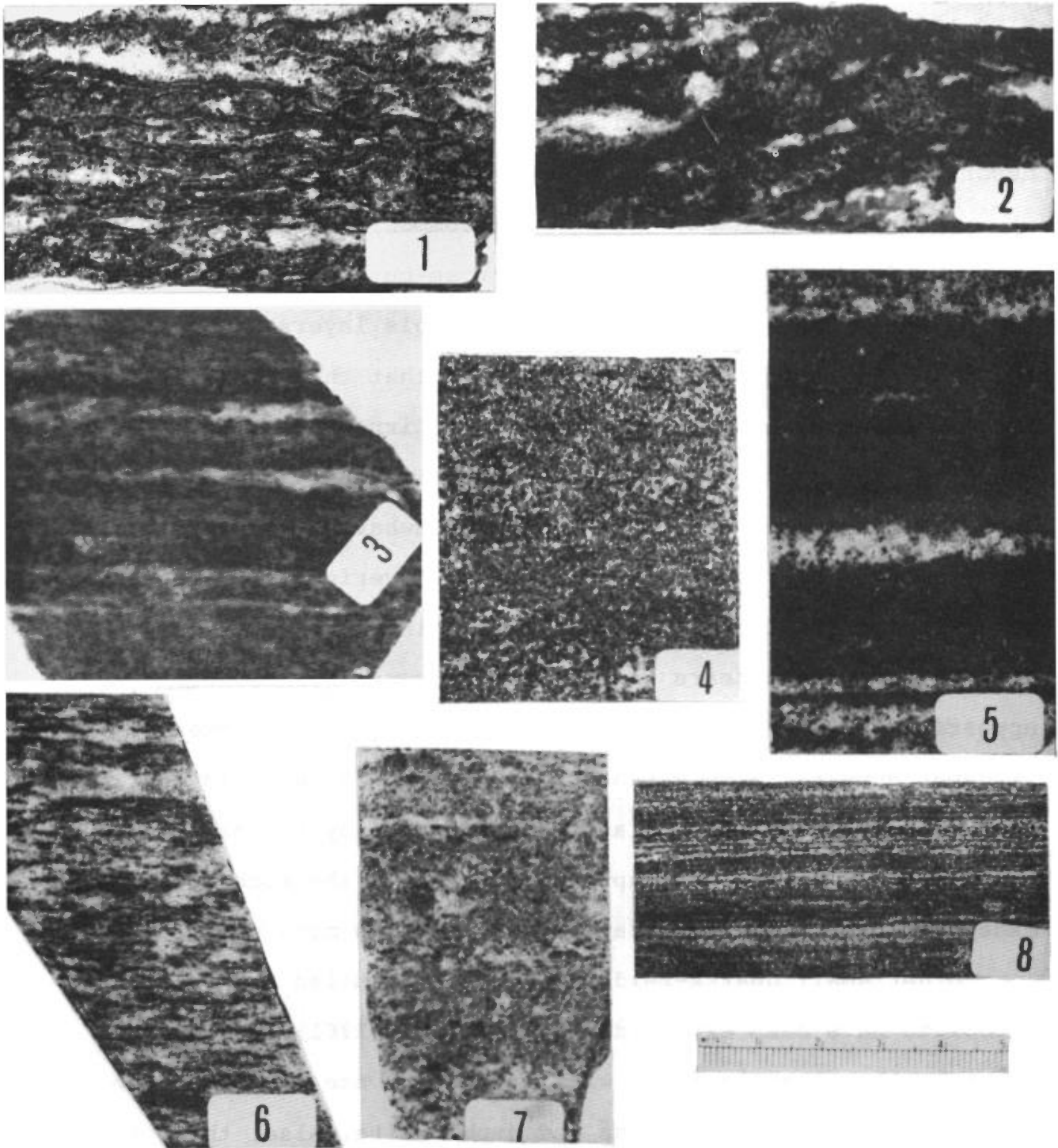


FIGURE 17 - Gneissic texture in 1) biotite-garnet sillimanite gneiss (735-70); 2) biotite-garnet gneiss (309-55); 3) biotite gneiss (901-73); 4) hornblende gneiss (682-70); 5) hornblende-biotite gneiss (71-55); 6) hornblende-biotite-garnet gneiss (G22-68); 7) calcic pyroxene gneiss (186-55); 8) hornblende-calcic pyroxene-biotite gneiss (887-72); mineral assemblages are listed in Table 19. Scale is 5 cm long.

common pegmatite, aplite, and granite dikes, which are grouped with the granitic and syenitic rocks, to be described below. At present the relatively small quartz-feldspar bodies, some of which may be true mineral segregations, will be briefly described.

The quartz-feldspar bodies most commonly occur as layers which may be conformable or cross-cutting with respect to the foliation. An example of conformable layers in amphibolite is shown in Fig. 18, which shows that the layers locally lens out and are in general more irregular than would be expected if the layering is sedimentary bedding. The dark portion of the rock is also somewhat layered.

The data of Table 25 show that the layering is produced by variation in mineral assemblage and mineral proportions. Calcic pyroxene appears in only some layers, hornblende appears in all, but in highly variable amounts, and potassium feldspar appears in only the thicker quartz-feldspar layers. The composition of plagioclase, as estimated by the Michel-Lévy method does not vary appreciably across the rock specimen, except in one of the dark layers, where it is more calcic.

Other small quartz-feldspar bodies in gneiss and amphibolite have been examined by the writer (1961), and in general, the minerals found within them are the same as those found in the enclosing gneiss and amphibolite. Also, the optical properties of the minerals in the quartz-feldspar rock and the enclosing rock are similar or identical, and if some differences exist in the composition of minerals, the differences are evidently not great. Hence the quartz-feldspar bodies

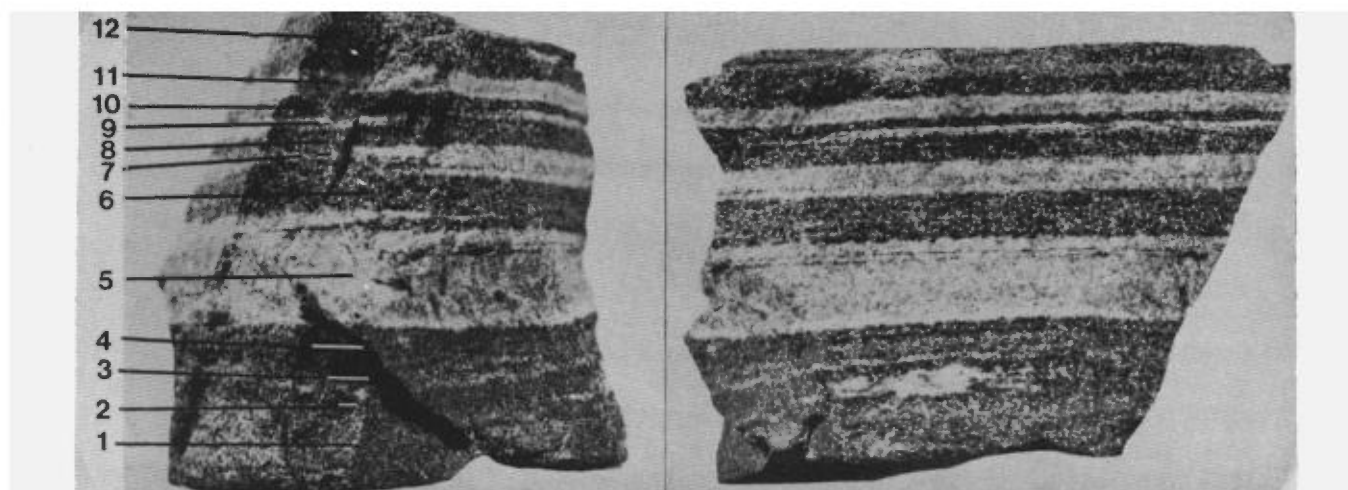


FIGURE 18 - Amphibolite with quartz-feldspar veins (283-56), showing two views of the specimen at 90 degrees to each other. Thickness and mineral content of layers 1 to 10 are given in Table 25.

TABLE 25 - MINERALS AND MINERAL PROPORTIONS (MODAL ANALYSES) OF LAYERED AMPHIBOLITE AND ASSOCIATED QUARTZ-FELDSPAR LAYERS, SHOWN IN FIG. 18. LAYERS 5, 7, 9, 11 ARE QUARTZ-FELDSPAR LAYERS.

Layer number:	1	2	3	4	5	6	7	8	9	10	11	12
plagioclase	54	35	43	51	44	43	60	43	54	38	53	36
K feldspar	t	-	-	-	25	-	2	-	t	-	-	-
quartz	-	-	18	-	26	8	36	8	46	3	45	5
biotite	t	t	t	4	1	t	t	t	t	t	1	t
hornblende	t	62	15	44	t	49	2	49	t	53	-	50
Ca pyroxene	42	3	22	-	-	-	-	-	-	5	-	7
sphene	4	-	t	t	t	-	-	-	-	t	-	t
zircon	-	-	-	-	t	-	-	-	t	t	t	-
allanite	-	-	-	-	t	-	-	-	t	t	t	-
apatite	t	t	t	t	-	t	-	t	-	t	t	t
magnetite	t	t	t	t	2	t	t	t	t	t	t	t
calcite	-	-	t	-	-	-	-	-	-	-	-	-
thickness mm.	6+	2½	4	7½	17	8½	1½	3½	2	3½	3½	6+

t less than 1 per cent

- absent

appear to be related to the particular gneiss or amphibolite in which they occur, and they may be the result of a rearrangement and segregation of minerals during metamorphism.

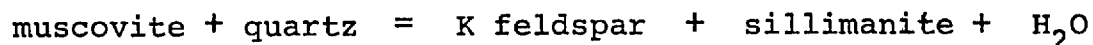
Metamorphism

The plagioclase gneisses, amphibolites, and quartzites described above are obviously metamorphic rocks that have experienced deformation and recrystallization at elevated temperatures and pressures. Minerals such as plagioclase, biotite, hornblende, and calcic pyroxene, which occur very commonly were evidently stable under the particular conditions of metamorphism, while others, such as chlorite and white mica are obviously of secondary origin and have crystallized at a later time and lower temperature. The status of epidote and muscovite is less certain; in some rocks these minerals appear to be secondary, but where evidence for a secondary origin is lacking, they must tentatively be regarded as primary. With regard to the feldspars, an exsolution reaction has evidently taken place in some rocks, presumably during cooling; hence where a very small amount of potassium feldspar is present in a rock, it will be regarded as possibly of secondary origin, and will be excluded from the primary assemblage.

An attempt will now be made to detect variations in metamorphic grade across the map-area by examining variations in the primary mineral assemblage. This will be done by examining the mineral assemblages in relation to four mineral-forming reactions, which may define isograds, or at least, delineate areas which have experienced a relatively high

or low grade of metamorphism.

The first reaction to be considered involves muscovite, quartz, potassium feldspar, sillimanite, and water, and when these minerals take on their simplified formulas, the reaction is as follows:



This reaction, which will be referred to as reaction number 2, has been investigated experimentally by Evans (1965) and is known to proceed to the right at a temperature of 630°C, when the water-vapour pressure is 3 kbars.

The association of all minerals of the above reaction was found in only one rock, and the position of this specimen on the metamorphic map (Fig. 8) is indicated by the symbol 2. Three specimens contain muscovite and quartz, but not all minerals of the reaction, and hence they represent the left-hand side of the reaction. These specimens, which are denoted 2-, might possibly define a low-grade region in the map-area. They are, however, widely scattered. Fourteen rocks were found to contain potassium feldspar plus sillimanite, but not all minerals of the reaction, and these represent the right-hand or high-temperature side. These rocks, which are denoted 2+, include most of the biotite-garnet-sillimanite gneisses, which are widespread across the map-area.

The second reaction for consideration is one that relates garnet, biotite, sillimanite, quartz, and potassium feldspar. If the formulas of these minerals are expressed in simplified form, both biotite and garnet containing only iron and magnesium as

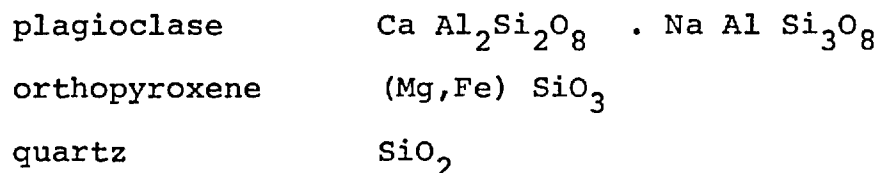
and amphibolites of the area, which are exceedingly common. Consequently the reaction may possibly be useful in locating zones of relatively high grade. However, only four rocks were found to contain all minerals of the reaction (designated 4 on the geological map) and only one was found to represent the right-hand side (designated 4+). These five specimens, although confined to the eastern half of the map-area are widespread.

Finally, a rather ill-defined reaction to produce orthopyroxene will be considered. Orthopyroxene, which is not commonly present in the gneisses and amphibolites of the area, is generally regarded as a relatively high-grade mineral, and within the map-area, may be a useful indicator of local high-grade metamorphic conditions. This mineral could conceivably be a product of the break-down of biotite, but potassium feldspar would be a by-product of the reaction, and potassium feldspar is absent from nearly all the orthopyroxene-bearing rocks that were examined microscopically. Hence it seems more likely that hornblende was responsible for the production of orthopyroxene.

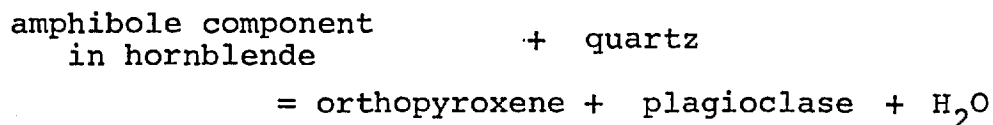
Different reactions may be proposed to produce orthopyroxene from hornblende. In the following, it is presumed that the contained calcium, sodium, and aluminum combined with silica to produce plagioclase, leaving the iron and magnesium for orthopyroxene. Some quartz would be required. The amphibole need not break down completely; only a portion of it referred to as an amphibole component, defined as follows, may be directly involved:

amphibole component: $\text{Ca Na (Mg,Fe)}_3 \text{Al}_3\text{Si}_7\text{O}_{22} (\text{OH})_2$

If the plagioclase, orthopyroxene, and quartz formulas are written:



the reaction is



This reaction, which is referred to as reaction 6, would also proceed over a range in temperature.

Rocks containing hornblende and quartz, representing the left-hand side of the above reaction are exceedingly common throughout the area, while those containing orthopyroxene, representing the reaction in progress are nine in number. The latter rocks, designated 6 on the metamorphic map, are widespread throughout the map area, and do not appear to define a single metamorphic zone.

The above analysis has been generally unsuccessful in delineating isograds, or in locating one or two regions of relatively high or low grade. If such regions exist, they must be numerous and small in size. Throughout most of the area, the isograd surfaces or the isothermal surfaces or both, as they existed at the peak of metamorphism may have been undulating, near-horizontal surfaces.

Origin

Some information on the origin of the plagioclase gneisses and amphibolites was presented above. In general, where the rocks are finely interlayered they are presumed to be of

sedimentary origin and where they occur as thick layers, the rock may be of sedimentary or of intrusive or extrusive igneous origin. At present attention will be briefly focused on the mineral and chemical composition of the rocks, and the information these might convey regarding the original character of the rocks.

With regard to the common plagioclase gneisses and amphibolites, all of which contain one or more of the minerals biotite, garnet, hornblende, and calcic pyroxene, a nearly continuous gradation appears to exist from light gray quartz-feldspar gneiss, with a very minor amount of ferromagnesian minerals, to dark gray gneiss or amphibolite, containing 80 or 90 per cent of hornblende. For hornblende and biotite-bearing gneisses, (free of sillimanite, garnet, and calcic pyroxene), the trend is shown as a-b-c in Fig. 19. However, the total information that is available concerning the mineral assemblages, mineral proportions, and composition of the minerals, as presented above, indicates that the rocks may not be regarded simply as one continuous 'series', but that they represent, in detail, a great variation in the proportion of the different elements present. Thus, in a group of rocks, all of which are composed of 60 per cent of plagioclase and 40 per cent of dark minerals, the kind and proportion of dark minerals comprising the 40 per cent may vary greatly. Consequently the proportions of calcium, iron, magnesium, potassium, etc. in the group of rocks will also vary.

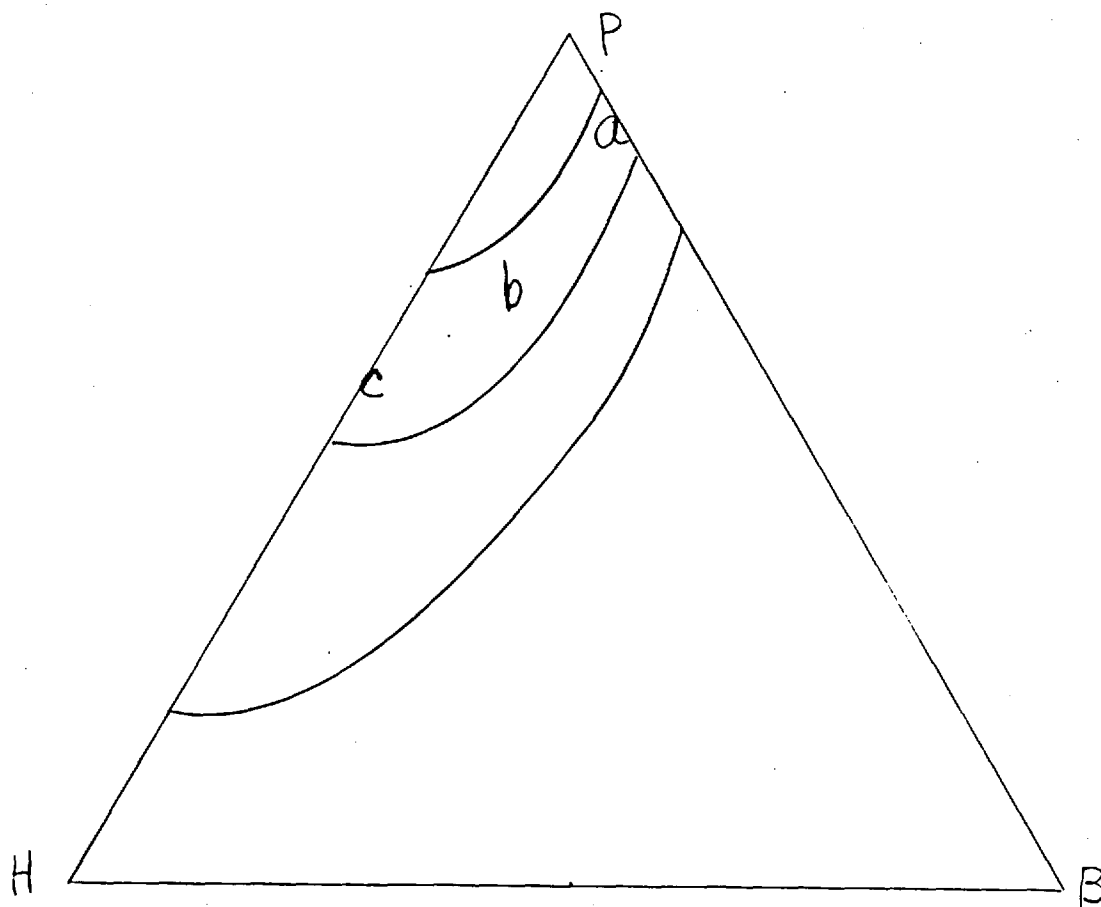


FIGURE 19 - Variation in the hornblende and biotite content of 67 gneisses and amphibolites that contain hornblende (H) and biotite (B) as the only ferromagnesian minerals, the remainder (P) consisting mainly of plagioclase. When estimated volume percentages of H, B and P are plotted in the diagram, 2/3 of the points fall in the zone abc, 1/3 fall in the two adjacent zones.

TABLE 26 - IRON, CALCIUM, POTASSIUM AND SODIUM CONTENT OF SOME PLAGIOCLASE GNEISSES AND AMPHIBOLITES.

	Specimen Number	Approx % dark minerals	Rock	FeO	CaO	K ₂ O	Na ₂ O
1.	904-73	2	sil>gar>bi gneiss	0.23	1.51	1.30	1.86
2.	901-73	10	bi gneiss	1.32	2.63	2.63	4.24
3.	G22-68	10	horn-bi-gar gneiss	2.81	2.53	0.92	3.74
4.	568-69	10	horn-bi-gar gneiss	2.33	1.97	0.98	4.46
5.	56A-55	30	bi>horn-gar gneiss	6.71	4.95	2.68	0.90
6.	905-73	40	horn>bi gneiss	9.16	7.70	0.98	3.28
7.	G72-69	40	horn>bi gneiss	9.80	7.56	1.69	3.34
8.	G96-69	50	horn>gar gneiss	9.87	9.94	0.95	2.93
9.	G106-69	40	horn>px amphibolite	7.82	10.37	0.43	3.08
10.	569-69	40	horn-px gneiss	7.02	11.58	0.74	2.87
11.	G85-69	70	horn>px>bi gneiss	8.04	13.50	1.55	1.63
12.	G94-69	90	horn>bi>px amphibolite	9.13	9.52	2.10	1.39

sil sillimanite
bi biotite
gar garnet
horn hornblende
px calcic pyroxene

Analyst: Diane Garrett

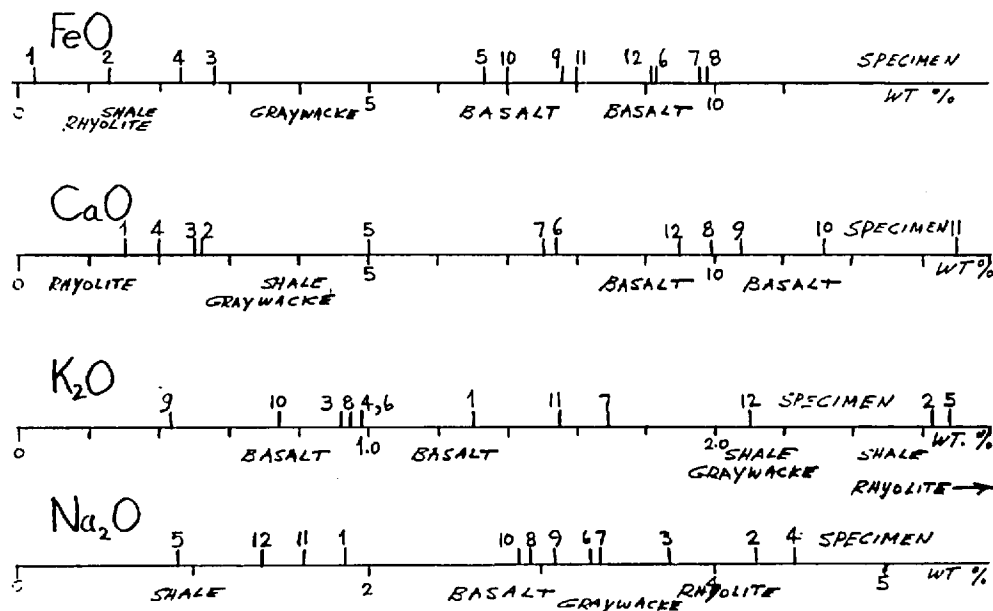


FIGURE 20 - Concentrations of certain element oxides in 12 specimens of plagioclase gneiss and amphibolite, compared with concentrations found in some common igneous and sedimentary rocks. Numbers 1 to 12 above the scale are specimen numbers.

Some preliminary data on the chemical composition of the plagioclase gneisses and amphibolites were obtained, and these are presented in Table 26. The 12 rocks that were analysed represent a range that extends from a sillimanite-bearing gneiss, almost free of ferromagnesian minerals (specimen 1) to a dark gray rock, with about 90 per cent of dark minerals, mainly hornblende (specimen 12). The variation that was found in the ferrous iron, calcium, potassium, and sodium content of the 12 rocks is illustrated in Fig. 20, which also shows the concentration of these elements commonly found in shale, graywacke, basalt, and rhyolite. The latter information was obtained from the compilations of Pettijohn (1949) and Barth (1962).

The first four specimens (1 to 4), which contain less than about 10 per cent of ferromagnesian minerals contain less than 3 per cent FeO, while the remaining specimens (5 to 12), which contain more than about 30 per cent of dark minerals, contain between 6 and 10 per cent of FeO (Fig. 20). Hence it may be possible to divide the rocks of the area into two groups, low-iron meta-shales and higher-iron metabasalt. This would separate rocks that fall at 'a' in Fig. 19 from those that fall at 'b' and 'c'. With regard to calcium content, the 12 rocks again appear to fall into two groups, (Fig. 20), but specimens 1 to 4 contain less calcium than is normally found in shale, and specimen 5 contains less calcium than is found in basalt. With regard to potassium, the scheme breaks down completely. Thus specimens 3 and 4 have far too little

potassium to make shale, and specimens 5 and 12 have more potassium than is found in basalt. The sodium concentrations are also anomalous, for the sodium content of the light gray gneisses is much greater than that of shale, and the sodium content of two dark gray rocks (11 and 12) is lower than that of basalt.

Thus the question of the original nature of the light gray gneisses remains unanswered. Although the concentrations of some elements are similar to those normally found in shale, the potassium content of some rocks at least, is too low and the sodium content is too high. This might have been deduced from the mineral content alone, for the rocks are poorer in muscovite (or its breakdown products, sillimanite and potassium feldspar) and richer in plagioclase than the common pelitic schists and gneisses. Also, the absence of sillimanite or its presence in only small amounts suggests that the aluminum content is lower than that of shale.

The problem was discussed in detail by Engel and Engel (1953), in connection with biotite-quartz-plagioclase gneisses that occur abundantly in the Northwest Adirondack Mountains. The authors considered various sedimentary materials, including graywacke, and also a possible addition or removal of material (metasomatism), to account for the high sodium - low potassium content of the gneiss, but could not arrive, with confidence, at a solution to the problem. The rocks of the present map-area are much more variable in composition than those from the Adirondacks referred to above, and all that

can be said with the data on hand, is that the rocks presumably formed by mixing together different kinds of sediments in different proportions.

With regard to the medium to dark gray gneisses, the concentrations of iron, calcium, and alkalies for some of the analysed specimens are similar to those found in basalt, and at least some of the amphibolites and hornblende gneisses are probably of basaltic or gabbroic origin. However, the rocks as a whole vary greatly in composition, and at least some of them, particularly those that are finely layered and those that contain calcite are very likely of sedimentary origin. The original rocks presumably were calcareous shales.

The biotite-graphite gneisses are evidently also high sodium-low potassium rocks, relative to shale, and apparently have also formed from some obscure sedimentary materials. The graphite may be of organic origin or it may have resulted from the reduction of carbon dioxide gas passing through the rocks.

There appears to be little doubt that the quartzites are metamorphosed sandstone. A small amount of clay-like and carbonate material in the sandstone could account for the local presence of sillimanite, garnet, phlogopite, amphibole, and pyroxene (Table 20). The small amount of feldspar present in some quartzites may be of detrital sedimentary origin.

MAFIC AND ULTRAMAFIC ROCKS (3)

A variety of mafic and ultramafic rocks, occurring mainly as sills, and small stocks were found within the surveyed terrain. The most common variety is a hornblende-plagioclase rock (3b) that varies greatly in texture, but commonly shows a coarse clustering of dark and light minerals, as shown in Fig. 21. This is clearly a metamorphic rock, which is however, in most places distinguishable from the hornblende gneiss and amphibolite described above. The term metagabbro was used for this rock, as a field term, and although its composition may not correspond exactly to that of gabbro, nor is it certain that the rock was initially a gabbro, the term is, for convenience, used in this report. Similar rock to the south has been referred to as gabbro and diorite by Sabourin (1965).

Most of the sills and small plutons of metagabbro within the map-area contain small portions of an ultramafic rock (3c), composed largely of pyroxene and amphibole and locally such rocks seem to occur alone, as small separate bodies. These rocks have also been metamorphosed to some extent.

Three types of mafic rocks, occurring mainly as dikes, are included in the present category. These are common diabase dikes (3a'), which have not been metamorphosed, some dikes or small plutons of gabbro which have been only slightly affected by metamorphism (3a), and narrow mafic dikes, presumably of igneous origin, which have been metamorphosed and completely recrystallized to fine-grained amphibolite.



FIGURE 21 - Typical metagabbro, composed mainly of plagioclase (white), hornblende (black), and calcic pyroxene (gray); a few large grains of calcic pyroxene rimmed by hornblende may be discernable. Distance across specimen is 6 cm.

Metagabbro (3b) and Ultramafic rock (3c)

Information on the metagabbro and ultramafic rock of the area is best conveyed by describing some of the larger individual bodies that are composed of one or both of these rock types. The bodies that are described below are all shown on the geological map (Map 1), and may be located by the co-ordinates given in parentheses.

The Picanoc metagabbro (59,31)

A body composed mainly of metagabbro, and a smaller amount of ultramafic rock was delineated in the northern part of the map-area, immediately west of the Picanoc river. In horizontal section, the body is elongate, trends north-west and is 4 miles long and half a mile wide. It extends for 1 mile into the Pontefract-Gillies area to the north (Kretz, 1957c) where it becomes somewhat wider before terminating.

The rocks to the west of the body are dominantly potassium feldspar gneisses, which appears to be folded about near-horizontal axes; the dominant dip, however, is moderately to the north-east. Local planar gneissic texture within the metagabbro along its western margin is similarly oriented. Rocks to the east of the body consist mainly of plagioclase gneiss and amphibolite in which the dominant dip direction is vertical or to the south-west; some south-westerly dips have also been observed within the metagabbro body along its eastern margin. Hence the body may be occupying the axial region of a synform. Whereas the north-western termination is rounded, in the south-east, the body appears to interfinger

with potassium feldspar gneiss. Hence the body may be elongate in shape, tapering and plunging gently to the south-east, which is the direction of plunge of linear gneissic texture within the body.

The dominant rock is metagabbro, consisting of hornblende and plagioclase in about equal proportions. As seen on the outcrop surface, the rock is usually homogeneous, but upon closer inspection, it normally shows a gneissic texture produced by the segregation of hornblende and of plagioclase. Although the grain size of the individual crystals is only 1 to 2 mm, aggregates of grains may vary greatly in size, depending on the extent to which the gneissic texture has developed. Thus the diameter of the segregations ranges from 2 or 3 mm to several mm. Moreover, the segregations of hornblende may be roughly equidimensional, or they may be lens-shaped or elongate to impart to the rock a planar or linear gneissic texture. The specimen shown Fig. 21 although not from this locality, is representative.

In addition to hornblende, which is the common variety, similar to that found in plagioclase gneiss and amphibolite, small amounts of calcic pyroxene may be present, often occupying the centres of clusters of hornblende grains. Discrete grains of orthopyroxene may also be present. Grains of the major minerals tend to be equidimensional, producing a mosaic texture. Plagioclase is relatively calcic, and in the two specimens of metagabbro listed in Table 27 (87-56, 388-55), was found to have compositions of An_{50} and An_{80} respectively.

Layers or pods of black ultramafic rock are found

TABLE 27 - MINERALS AND APPROXIMATE MINERAL PROPORTIONS IN FIVE BODIES
OF MAFIC AND ULTRAMAFIC ROCK.

	Picanoc				Litchfield				Lac du Rang			Thorne							Otter Lake							
													1	2	3	4	5	6	7							
	87-56	388-55	74-56	83-56	685-70	684-70	170-56	687-70	183-56	G109-69	G110-69	G100-69	913-73	927-73	912-73	910-73	909-73	81-55	926-73	701-70	698-70	G12-66A	240-55	700-70	699-70	239-55
m.o.	-	-	20	10	-	-	10	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	2	-
m.c.	-	-	20	50	-	-	-	-	-	-	2	-	20	-	30	20	-	30	20	20	-	10	30	10	20	30
olivine	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-
orthopyroxene	-	10	10	10	-	-	-	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	2	-
calcic pyroxene	10	20	-	-	-	-	10	-	-	-	-	20	2	-	2	10	50	2	30	-	10	-	10	10	-	30
hornblende	40	30	10	10	20	20	10	40	60	30	50	20	10	50	30	30	20	50	20	10	40	40	30	70	60	40
anthophyllite	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
biotite	.1	-	10	10	2	-	2	-	2	-	-	-	-	.1	-	-	-	-	-	2	.1	2	2	2	2	-
garnet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
epidote	-	-	-	-	.1	-	-	-	-	-	-	-	-	-	-	-	.1	-	-	-	-	-	-	-	-	-
plagioclase	40	40	10	.1	70	60	60	50	40	60	50	60	70	50	40	30	-	10	-	70	50	30	20	-	10	-
scapolite	-	-	-	-	-	10	-	.1	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	10	-	-
quartz	-	-	-	-	-	-	2	-	2	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
sphene	-	-	-	-	-	.1	-	-	-	-	-	.1	-	-	-	-	2	-	-	-	-	-	-	-	-	-
apatite	.1	-	2	2	.1	.1	.1	-	.1	-	.1	.1	-	.1	.1	10	2	.1	.1	.1	-	.1	-	-	.1	-
spinel	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-
magnetite	-	.1	.1	.1	-	2	2	*.1	-	2	-	2	*.1	2	*.1	-	-	2	.1	-	2	-	*.1	-	*.1	-
ilmenite	-	-	.1	.1	-	-	.1	-	2	2	-	-	.1	-	.1	2	-	2	2	-	-	-	-	-	-	-
pyrite	.1	-	.1	.1	.1	.1	.1	*.1	-	.1	-	.1	-	.1	.1	.1	.1	.2	.1	.1	.1	.1	.1	.1	.1	.1
pyrrhotite	-	-	.1	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.1	-	-	-	-	-	-	-
calcite	-	-	-	-	-	-	.1	-	-	-	-	-	-	.1	.1	.1	2	-	.1	-	-	-	-	-	-	-

*identification not confirmed

m.o. mafic intergrowth, mainly orthopyroxene

m.c. mafic intergrowth, mainly calcic pyroxene

Key: See Table 2

throughout the metagabbro body, and although the size and shape of these were not determined, some are at least several meters in dimension. They make up approximately 1/20 to 1/10 of the body as a whole, and appear to be slightly more abundant in the eastern portion.

The ultramafic rock, as seen in the field, is a black, homogeneous rock, completely devoid of gneissic texture or preferred mineral orientation. Thin plates, a cm or two in diameter, consisting of parallel crystals of red biotite may be present, and there are apparently oriented at random.

Under the microscope, the rock shows a complex texture, involving several minerals and mineral intergrowths. Two main types of fine-grained intergrowths are present. One of these occurs as rectangular-shaped grains, up to 3 mm across, that are composed mainly of pleochroic orthopyroxene, but contain throughout or in the central portion, a large number of very fine lamellae that appear to be hornblende. Also present are many tiny oriented plates of a reddish material, that may be iron oxide. Patches of hornblende may also be present. This intergrowth is referred to as mafic intergrowth, mainly orthopyroxene (abbreviated m.o.). The second type of intergrowth occurs as pale green grains that are similar in size and shape to those described above. They consist mainly of calcic pyroxene, and contain throughout or in the central portions, very many tiny lamellae of material that appears to be hornblende; patches of material, readily identifiable as hornblende, may also be present, and the entire grains are commonly

rimmed by hornblende. Tiny oriented plates of magnetite, and possibly another mineral, are commonly present, particularly in the central portions. The above intergrowth is referred to as mafic intergrowth, mainly calcic pyroxene (abbreviated m.c.).

In addition to the above intergrowths, discrete and more homogeneous grains of orthopyroxene and calcic pyroxene may also be present.

Olivine is found in some of the ultramafic rocks, and where plagioclase is present, a reaction evidently occurred between the two to produce a corona texture of the kind commonly observed in altered gabbroic rocks. Two mineral zones are produced by the reaction, the one touching olivine consists of orthopyroxene, and that touching plagioclase, of amphibole with inclusions of green spinel.

In addition to the above, green hornblende and red biotite are commonly present. Minerals found in small amounts include apatite, magnetite (containing lamellae of ilmenite), ilmenite, pyrite (rimmed by hematite), pyrrhotite, and chalcopyrite (in very small amounts, associated with pyrrhotite). The minerals of two representative samples of ultramafic rock from the Picanoc metagabbro are listed in Table 27 (74-56, 83-56). The small amount of plagioclase present in one of these has a composition of about An_{60} .

The Picanoc metagabbro body may have initially consisted of gabbro and smaller portions of pyroxenite. It was evidently involved in an episode of deformation and metamorphism, for the metagabbro possesses a metamorphic texture and was, evidently, completely recrystallized. The ultramafic

rock, however, appears to have been less affected by metamorphism, for the high-temperature pyroxenes have only partly altered to lower temperature pyroxene and to amphibole.

The Litchfield metagabbro (49,37)

In Litchfield township, in the western part of the area, large volumes of metagabbro occur together with amphibolite (2f) in what may be the southern extension of the Coulonge zone. The rock strata here trend northwesterly, and dip steeply or vertically. Hence the mass of metagabbro, which appears elongate in plan (Map 1), in three dimensions may be tabular or lens-shaped. As shown on the geological map, two or three bodies may be present, but these are probably interconnected.

In general, little difficulty was experienced in distinguishing metagabbro, similar to that found in the Picanoc body, from amphibolite or hornblende gneiss of unit 2. However, in portions of the Litchfield mass, gradations were found from one to the other, and in places an arbitrary decision was made concerning the assignment of the rocks to groups 2 or 3.

An example of a change along strike from amphibolite to metagabbro is found at co-ordinates (50.2, 36.8), Map 1. Elsewhere, amphibolite and possibly metagabbro as well, appear to change along strike to potassium feldspar gneiss. Hence the shape of the metagabbro body and its relationship to the surrounding rocks is not yet clearly established.

Typically, the metagabbro consists of plagioclase and

hornblende, with plagioclase making up 40 to 70 per cent of the rock. Some very striking gneissic textures are produced by the segregation of dark green hornblende into lens-shaped or rod-shaped aggregates. The rocks thus take on planar and linear gneissic textures. The aggregates are locally very coarse and at a few places (e.g. at 49.3, 37.7) were observed to contain cores of anthophyllite. Moreover, in places the rocks display a bewildering variation in the distribution of hornblende and plagioclase and in grain size, within short distances, as shown for example in Fig. 22. Thus locally the rock consists almost entirely of hornblende, and elsewhere of plagioclase. Dikes of nearly pure plagioclase (andesine), as shown in Fig. 22 are not common.

An examination of several rock specimens with the aid of a microscope has revealed the occasional presence of a mafic intergrowth, mainly calcic pyroxene, similar to that described above. Hornblende, mainly green but occasionally blue-green, is the dominant ferromagnesian mineral; black biotite is commonly present in small amounts, and rarely orthopyroxene. Brown anthophyllite or gedrite, nearly colorless in thin sections, occurs as clusters, rimmed by hornblende; small grains of orthopyroxene may be present in the clusters, and these may be relicts of the alteration of orthopyroxene to anthophyllite. Plagioclase usually occurs as nearly equidimensional grains, 1 to 2 mm in diameter, but in some rocks they may have a diameter of 1 cm. Locally plagioclase is seen as lath-shaped crystals, presumably the products of

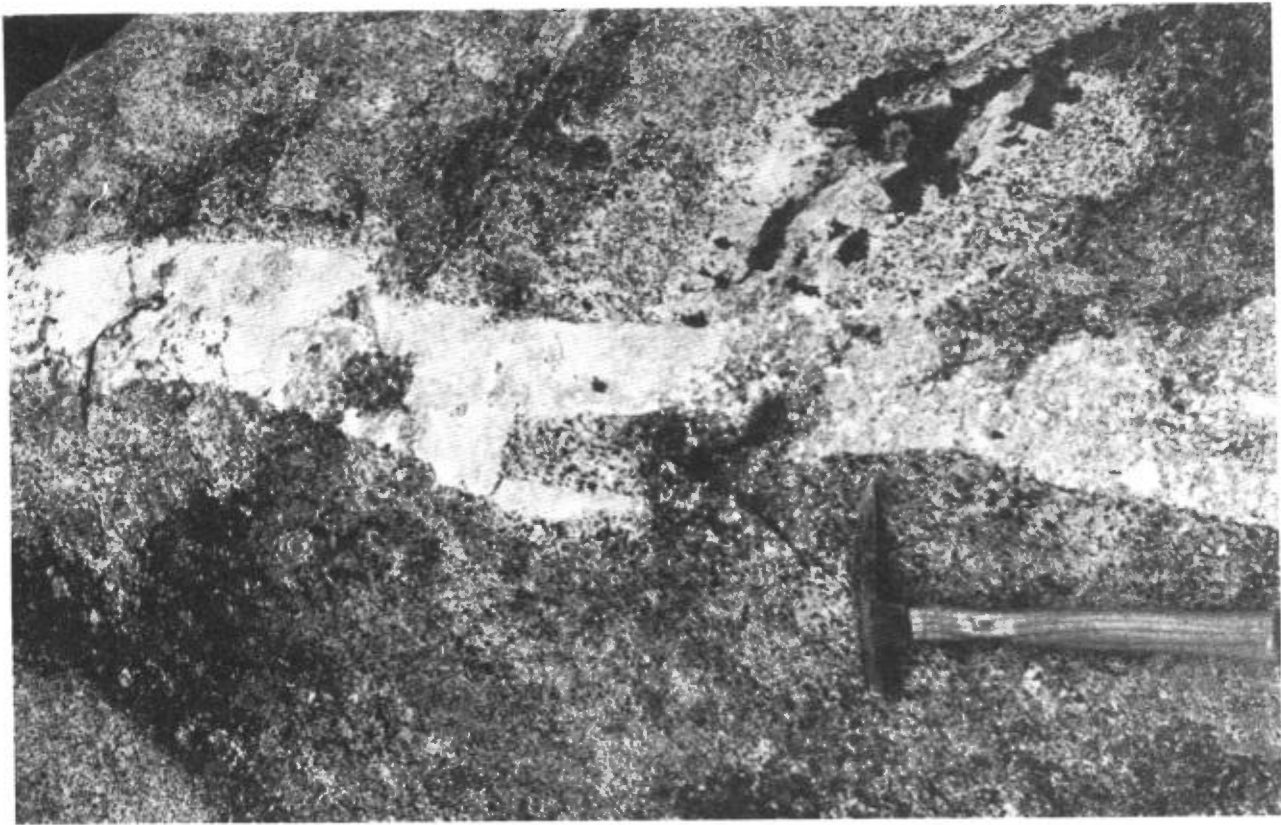


FIGURE 22 - Metagabbro of the Litchfield metagabbro body, showing an irregular distribution of black hornblende and white plagioclase (top right corner), and a cross-cutting dike composed almost entirely of plagioclase. North of Vinton (48.2, 36.5).

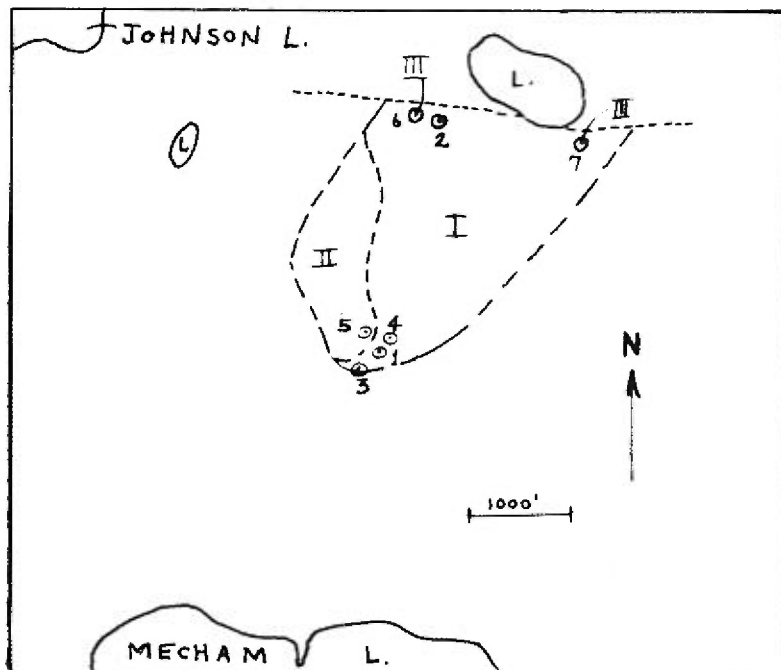


FIGURE 23 - The Thorne metagabbro body, showing portions I, II and III, and location of specimens listed in Table 27; bar is 1000 feet (305 m) long.

igneous crystallization. Estimates of the composition of plagioclase in five specimens produced values ranging from An₃₆ to An₄₅. Irregular grains of scapolite are locally present and have possibly formed by replacement of plagioclase. Other minerals present in small amounts include quartz, epidote (possibly secondary), sphene, apatite, magnetite, ilmenite, pyrite, and calcite. Representative mineral assemblages of the metagabbro are listed in Table 27.

The Litchfield metagabbro is obviously poorer in calcium and richer in silica than the Picanoc metagabbro. Calcic pyroxene is uncommon, plagioclase is richer in sodium, and quartz is locally present. Ultramafic rocks are apparently absent.

The Litchfield body is obviously a metamorphic rock, but relict igneous textures are locally present, and the rock mass may have been emplaced initially as sills of material of diorite composition. Alternatively, the rock, together with the associated amphibolite, may represent a sequence of volcanic rocks, the metagabbro having developed a more pronounced gneissic texture during metamorphism.

The lac du Rang metagabbro (51.5,18)

In the east central part of the map-area, west of lac du Rang, a clearly defined ridge-forming sill of metagabbro, about 600 feet thick, can be traced for a distance of 6 miles. The associated rocks are mainly plagioclase gneiss and amphibolite, which dip about 40 degrees to the east. The southern part of the sill, as shown in Map 2A, is

underlain by hornblende gneiss and overlain by marble.

The metagabbro resembles that of the Picanoc and Litchfield bodies, and shows a similar variation with regard to grain size and degree of development of gneissic texture. Hornblende and plagioclase are the main constituents. In the few specimens that were examined microscopically, the plagioclase, which shows both albite and pericline twinning varies little in composition from a mean value of An_{50} . Representative mineral assemblages are listed in Table 27.

The lac du Rang sill is considered to be a metamorphosed gabbro. Ultramafic rock or other evidence of magmatic differentiation were not found, but may emerge with further study.

The Thorne metagabbro (46.2, 21.7)

A small pluton, composed of metagabbro and ultramafic rock is exposed in Thorne township, in the south central part of the area (Maps 1, 2B). The pluton occupies the axial region of a synform, produced by folding of interlayered hornblende gneiss, biotite gneiss, and marble. The body may be an elongate mass, plunging northeasterly, parallel to the axis of the synform. The northern part of the body is evidently cut off by a fault.

Although the body of rock is only $\frac{1}{2}$ mile across, it shows much variation in mineral content and texture.

The portion shown by symbol I in Fig. 23 consists mainly of metagabbro, similar to that described above, except that calcic pyroxene is commonly present (specimens 1 to 4, Table 27); garnet is locally present and is erratically distributed,

or concentrated in parallel layers. Within zone I the 'coarseness' of the gneissic texture varies greatly, often within distances of only a few meters; in places medium and coarse-textured rocks are intermixed. The orientation of the gneissosity is also variable. A layering, possibly of igneous origin is locally present and is variable in attitude.

With the aid of a microscope, rocks of zone I are found to contain a mafic intergrowth, mainly calcic pyroxene, with tiny inclusions of ilmenite, and with rims of hornblende, similar to the mafic intergrowth found in the Picanoc metagabbro; discrete grains of calcic pyroxene are also present. Plagioclase crystals (An_{45}) show much variation in size; large crystals, containing many tiny inclusions, have evidently recrystallized in part, to produce a mosaic of smaller inclusion-free grains. Hornblende crystals, which in some rocks are pleochroic from pale green to red-green, are locally aligned with their c axes parallel to the linear gneissic texture. Garnet, where present, occurs as grains about 2 mm in diameter, and also as smaller grains scattered along hornblende-plagioclase grain boundaries; where garnet is present the rock is relatively rich in ilmenite and apatite. Discrete grains of calcite may be present.

Metagabbro of zone I appears to give way toward the west to a more mafic rock (II, Fig. 23), which is rich in calcic pyroxene and contains about 20 per cent of scapolite (specimen 5, Table 27). The presence of scapolite and sphene and the absence of magnetite and ilmenite produces a rock

that resembles some of the pyroxene-scapolite-sphene skarn rocks, described above. However, the ferromagnesian minerals are more abundant and darker (richer in iron) than those found in pyroxene-scapolite skarn. This rock may be an altered igneous rock.

Within zone I, small bodies of an ultramafic rock (III, Fig. 23), 8 meters or more in diameter, are found, and mineral assemblages of two of these (6 and 7) are listed in Table 27. The two rocks are highly mafic; one contains only about 10 per cent of plagioclase (An_{50}), as 'lath-shaped' crystals, and the other consists almost entirely of ferromagnesian minerals, including some olivine and spinel. Calcic pyroxene and amphibole in these rocks are light in colour and rich in magnesium. Minute amounts of chalcopyrite were found in both.

Rocks of the Thorne pluton resemble, to some extent, those of the Picanoc body, and the two may be related. The Thorne pluton was evidently emplaced prior to metamorphism, as an igneous body, for it was obviously affected by metamorphism and deformation. Further evidence for an igneous origin is found in the presence of brucite marble on its west contact, the brucite presumably being an alteration of the high-temperature mineral periclase. More information is needed on the scapolite-bearing rock in zone II and on the ultramafic bodies (III), in order to determine the relationship of these to the metagabbro, which forms most of the pluton.

The Otter Lake metagabbro (50.5,27)

In the central part of the map-area, 1 mile south-west of Otter Lake village, a body of metagabbro is partly exposed;

contacts with the surrounding rocks are covered.

The body consists mainly of metagabbro, which shows the characteristic variation with regard to development of gneissic texture. Patches of ultramafic rock, a few meters across, occur locally within the body, but it is not known if these are inclusions or if they have formed by some process of differentiation. The metagabbro itself shows much variation in mineral proportions, and all gradations appear to exist within the body as a whole, from rocks containing about 70 per cent of plagioclase to those devoid of plagioclase. In order to show this variation, 7 specimens were collected along a linear distance of 2000 feet on the south slope of the hill that marks the position of the body, and the approximate mineral proportions in the specimens are listed in Table 27.

Igneous textures are better preserved in the Otter Lake metagabbro than in the other bodies, described above. In some rocks, prismatic crystals (lath-shaped in section) of plagioclase are arranged in parallel to produce a foliation, presumably an igneous feature. Elsewhere, plagioclase forms large crystals, with inclusions of pyroxene and amphibole (poikilitic texture), also characteristic of some igneous rocks. A similar texture in another rock, where scapolite occupies the place of plagioclase, suggests that the scapolite has replaced plagioclase. Various ferromagnesian minerals are present, as listed in Table 27. Calcic pyroxene has locally altered to hornblende. Biotite occurs as platy aggregates,

similar to those found in the Picanoc metagabbro. Calcic pyroxene was evidently present in the original igneous rock, and it has recrystallized to some extent during metamorphism; hornblende and biotite appear to be metamorphic minerals.

The Otter Lake pluton resembles the Thorne pluton but differs from it slightly with regard to the ferromagnesian minerals present. The Otter Lake body contains more biotite, and is richer in potassium, which may be viewed in relation to the proximity of the body to potassium feldspar gneisses.

Other bodies of metagabbro and ultramafic rock

The northern portion of a body of metagabbro is exposed along the southern boundary of the map-area, in Grand-Calumet township (45.0, 38.1). The rock was described by Shaw (1955) and was also examined by the writer. The rock shows a remarkable variation in grain size, from fine (less than 1 mm) to coarse (about 1 cm), in degree of development of gneissic texture, and in the degree of development of a mineral foliation. Despite these variations, most of the body has a fairly uniform composition, consisting of plagioclase (about An₄₀), with smaller amounts of hornblende and calcic pyroxene, and minor quartz, biotite, magnetite, ilmenite, and pyrite. Igneous texture is well preserved locally, where prismatic crystals of complexly twinned plagioclase are arranged in parallel. Bodies of ultramafic rock are also present, and this rock contains about 20 per cent plagioclase, and larger amounts of hornblende and some mafic intergrowths (both varieties, as described above) and biotite. The body resembles the Otter Lake pluton.

A tabular body of metagabbro is exposed south of Vinton (46.8, 38.3) and is of interest for the small deposit of magnetite-rich rock found near its contact with amphibolite. The metagabbro consists of hornblende and plagioclase, in about equal amounts, with minor quartz and ilmenite, and very minor magnetite, pyrite, and chalcopyrite. Most of the body possesses conspicuous planar and linear gneissic textures, as well as a mineral foliation and lineation produced by hornblende crystals. Plagioclase occurs as scattered large crystals, presumably a relict igneous feature, and a mosaic of smaller grains of metamorphic origin. A faint layering, possibly an igneous layering is locally visible.

Two bodies, possibly interconnected, of mafic and ultramafic rock occur north of Moore lake (55.5, 30.0). The southern body appears to contain a high proportion of ultramafic rock. One sample of metagabbro obtained from this body is comparatively rich in calcic pyroxene, and lacks gneissic texture and mineral foliation. Zoned plagioclase crystals are present and appear to be partly replaced by red biotite, the latter forming plate-like aggregates similar to those found in the Picanoc metagabbro, to the north. A sample of ultramafic rock from the same place contains 10 per cent of plagioclase (An₆₀) calcic pyroxene, hornblende, and about 30 per cent orthopyroxene. Randomly oriented platy clusters of red biotite are also present in this rock, and locally attain a diameter of 3 cm. In both rocks, calcic pyroxene has evidently altered to some extent to hornblende.

In the south-eastern corner of the area, near lac Bernard (45.7, 1.7), a small body of ultramafic rock was discovered by the writer. The size and shape of this body are known only approximately. The rock consists of calcic pyroxene, hornblende, and biotite, in the ratio 6:3:1, and also contains minor feldspar, epidote, sphene, apatite, and pyrite. Hornblende appears to have formed by alteration of pyroxene. The rock differs from the ultramafic rocks to the west in its coarser grain size (about 1 cm) and in the absence of mafic intergrowths.

On the eastern border of the area, three bodies of a rock which is almost entirely composed of hornblende were outlined by the writer and were mapped as ultramafic rock. The rock is black and is associated with hornblende gneiss, to which it resembles, except for a higher hornblende content. Hornblende forms 70 to 100 per cent of the rock; other minerals present include plagioclase and biotite, and the secondary minerals epidote and white mica. Grain size is normally about 1 mm but is locally larger. At most places, crystals of hornblende define a mineral foliation and lineation.

A body of metagabbro and ultramafic rock was located by the writer south-west of Venosta (51.2, 5.1). The ultramafic rock here is noteworthy for its olivine content, which amounts to about 30 per cent. The remainder of the rock consists mainly of pyroxene, together with some plagioclase and spinel. Some spectacular corona textures have developed at the contacts

between olivine and plagioclase crystals.

A few additional bodies of mafic and ultramafic rock are present in the map-area, but these closely resemble one or another of those described above. Also, mention should be made of the occurrence of rock very similar to that referred to above as metagabbro, as thin layers, lenses, and pods, a few cm to a few meters across, in amphibolite. Bodies of this kind are found, for example, in the Kazabazua River sub-area (50.25, 19.65). These small bodies appear to have formed by the recrystallization of amphibolite.

Dike Rocks

Amphibolite dikes

Cross-cutting sheets of amphibolite, a meter or so thick, were locally found in the various gneisses of the area. Some of these may be igneous dike rocks that have been metamorphosed while others may be gneiss or amphibolite that has been mobilized and intruded into opening fractures. In places they appear to represent only one aspect of a complex intermixing of rock types, and no separate map symbol was assigned to them.

However, a few bodies of unquestionable igneous origin were found and two localities are described below. At co-ordinates (46.1, 30.1) a few tabular sheets of amphibolite are found in a body of potassium feldspar gneiss. One of these is 0.7 meters thick and has sharp straight contacts, one of which has a 'step' similar to those found on the contacts of diabase and pegmatite dikes that have formed by dilation of en echelon fractures. Hence there is little doubt that the bodies were

initially mafic dikes of igneous origin. The dikes cut the gneissic texture in the enclosing gneiss, and although they show no evidence of deformation, a faint gneissic texture has developed within them, parallel to that in the adjacent gneiss. The dike rock is fine-grained amphibolite, possessing a well-formed metamorphic-mosaic texture. The dikes cut masses of pegmatite in the enclosing rock but themselves are cut by pink pegmatite dikes.

It is suggested that the dikes were emplaced toward the end of the main episode of metamorphism, deformation, and pegmatite development, before metamorphic temperature declined, and while some mobile pegmatite-forming matter was still available.

A similar dike from a locality north of Sinclair lake (49.3, 7.4) was described by Baker (1956). This dike also possesses a foliation parallel to that in the adjacent rock, which is biotite-garnet gneiss, but it has obviously been deformed and folded. The dike is also cut by pegmatite dikes. It contains some mica, and Baker suggested that it was originally a lamprophyre dike.

Gabbro and slightly altered gabbro (3a)

A few dikes or small bodies of unknown shape composed of gabbro and slightly altered gabbro were found at a few localities. In some of these, progressive stages in the transformation of gabbro to amphibolite or gneiss may be observed. Some of the bodies resemble diabase dikes, to be described below, but on microscopic examination, prismatic plagioclase crystals are seen to be bent and partly recrystallised to a

fine-grained aggregate. Also, pyroxene is much altered to hornblende.

An example of altered gabbro is found in the Kazabazua River sub-area, at co-ordinates (49.62, 21.55), where a dike-like body, at least 240 meters long and 30 meters wide, consists of a fine-grained homogeneous mafic rock. Two samples, 5 meters apart, were collected from the southern end of the dike. One of these (G 35-68, Table 28) possesses a sub-ophitic texture, but the presence of irregular surfaces on the long prismatic plagioclase crystals, and the presence of hornblende rims about pyroxene crystals suggests that the rock was somewhat affected by metamorphism. The second sample (G 36-68) shows a more advanced stage in the destruction of the sub-ophitic texture, and in this rock, both orthopyroxene and calcic pyroxene have completely altered to hornblende.

Another example of altered gabbro is also found in the Kazabuzua River sub-area, at co-ordinates (48.66, 20.87) where a small mass, approximately 75 meters across may be part of a dike or small pluton. The texture of the rock body is highly variable. Portions of it, represented by specimen G 53-68, Table 28, are homogenous, with no signs of a gneissic texture or preferred orientation of minerals. The contained plagioclase crystals show some tendency toward a prismatic shape and calcic pyroxene appears as relicts of the alteration of pyroxene to hornblende. Other portions of the rock body, represented by specimen G 54-68A, Table 28, possess a pronounced gneissic texture, and contain large amounts of hornblende

TABLE 28 - GABBRO AND ALTERED GABBRO.

	G35-68	G36-68	G53-68	G54-68A
orthopyroxene	2	-	-	-
Ca pyroxene	10	-	10	.1
hornblende	10	30	30	50
biotite	10	2	.1	.1
garnet	-	-	-	2
plagioclase	60	60	60	50
quartz	2	2	-	-
other	2	2	2	2

Key: See Table 2

TABLE 29 - MINERAL PROPORTIONS* IN DIABASE DIKES.

	634-70 Olivine Diabase	1037-74 Diabase	576-69 Quartz Diabase
olivine	<1	-	-
pigeonite	-	2	<1
augite	43	38	22
plagioclase	43	50	58
potassium feldspar	-	1	3
quartz	-	1	3
apatite	<1	<1	<1
opaque minerals	7(1)	5(2)	6(3)
hydrous minerals	6(4)	3(5)	7(6)

*modal analysis, 1000 points

< less than

- not detected

- (1) mainly magnetite
- (2) mainly magnetite, also maghemite (alteration of magnetite) and ilmenite, and very minor chalcopyrite and bornite
- (3) mainly maghemite (alteration of magnetite), also magnetite and ilmenite, and very minor chalcopyrite and bornite
- (4) chlorite, apparently an alteration of olivine
- (5) mica, chlorite, apparently mainly an alteration of augite
- (6) amphibole, mica, chlorite, apparently mainly an alteration of augite

Location: 634-70 south-east of Vinton (45.6, 35.0)
 1037-74 south-west of Venosta (49.7, 2.2)
 576-69 south-east of Otter Lake Village (49.0, 22.5)

and little or no pyroxene. The plagioclase is more sodic, and garnet may be present. Thus, portions of the original gabbro body were altered, through metamorphism, to hornblende gneiss.

Diabase dikes (3a')

Approximately 100 diabase dikes, similar to those found in other portions of the Canadian Shield, were located within the map-area. A large dike, in the south-east corner, was mapped by Baker (1956), who followed it for 3000 feet and reported a thickness that locally exceeds 300 feet. Another, in the north central part of the area, west of Petit Lac Cayamant, forms a slight ridge which is visible on the air photograph. This dike can be traced for 3000 feet and has a thickness of about 200 feet. Most dikes of the area, whose thickness can be determined, are 100 to 200 feet thick. Individual dikes probably extend for several miles, but lack of exposure prevents one from following them on the ground. Smaller dikes, ranging in thickness down to 6 cm are also present, usually near larger dikes; many small branching dikes are well exposed north of Vinton, at (49.3, 37.4).

The few dikes that can be traced for some distance horizontally, and others which have one or both contacts partly exposed, trend easterly or slightly south of east, and dip nearly vertically. Small dikes may have different orientations. In many places, where contacts are not exposed, it is difficult to obtain information on the thickness and trend of the dyke, and except for some of the larger dikes, the map symbol used

is not intended to convey this information.

Baker (1956) noted that diabase dikes in the eastern 1/3 of the area do not appear to be concentrated in any part of the area, and this appears to be true for the map-area as a whole. However in Grand-Calumet township, which was mapped in detail by Shaw (1955) and in the Kazabazua River sub-area, which was mapped in detail by the writer, only one diabase dike was found in each, while areas of similar size elsewhere, examined in less detail, contain several dikes. The dikes may be nearly randomly distributed, rather than uniformly distributed, which would account for a slightly greater concentration in some places than in others. The dikes do not appear to form swarms, as they do in some parts of the shield, unless all the dikes of the area are regarded as a swarm.

Easterly-trending and vertically-dipping fractures are locally found in the country rocks, and it seems likely that the diabase dikes were localized by tension fractures. The sinuous nature of the contacts of some dikes was cited by Baker (1956) as evidence for the emplacement of dikes along tension fractures. A dike east of Johnson lake (46.6, 22.2) is found in a zone that is presumed to be a fault.

The diabase is black, massive rock, with a brownish weathered surface. Along the margins of the dikes, the rock is fine grained, but the larger, central portions are medium grained. Very narrow dikes are very fine grained and are usually porphyritic.

Samples from 15 relatively large dikes, scattered across

the area from west to east, were examined microscopically, and most of these were found to contain abundant plagioclase and augite, and very minor quartz. Some variation exist in the proportions of these three minerals, but dike 1037-74, Table 29, may be regarded as typical. Olivine was found in only one dike (634-70, Table 29), a relatively small dike, 12 feet thick. A few dikes were found to contain relatively large amounts of quartz and potassium feldspar (up to 3 per cent of each), and dike 576-79, Table 29, is representative of these.

Further information on the rocks is provided by the following brief description of the contained minerals.

Olivine, in the single dike found to contain this mineral, occurs in very small amount, as small grains enclosed by aggregates of green chlorite. It appears to have largely altered to chlorite, and if so, the original amount present was about 2 per cent. Olivine was not present in the sample collected at the margin of the dike, but aggregates, composed largely of carbonate appear to form pseudomorphs of olivine.

Augite is the dominant dark mineral in all dikes, and occurs as nearly-equidimensional to rectangular grains, as shown in Fig. 24. In thin sections, crystals are pale gray, commonly twinned, and may be slightly zoned. The optic axial angle (2V) is invariably about 40 degrees, which is characteristic of sub-calcic augite. The mineral is commonly altered to a fine-grained brownish material, here referred to as brown chlorite. The brown chlorite is usually concentrated in the

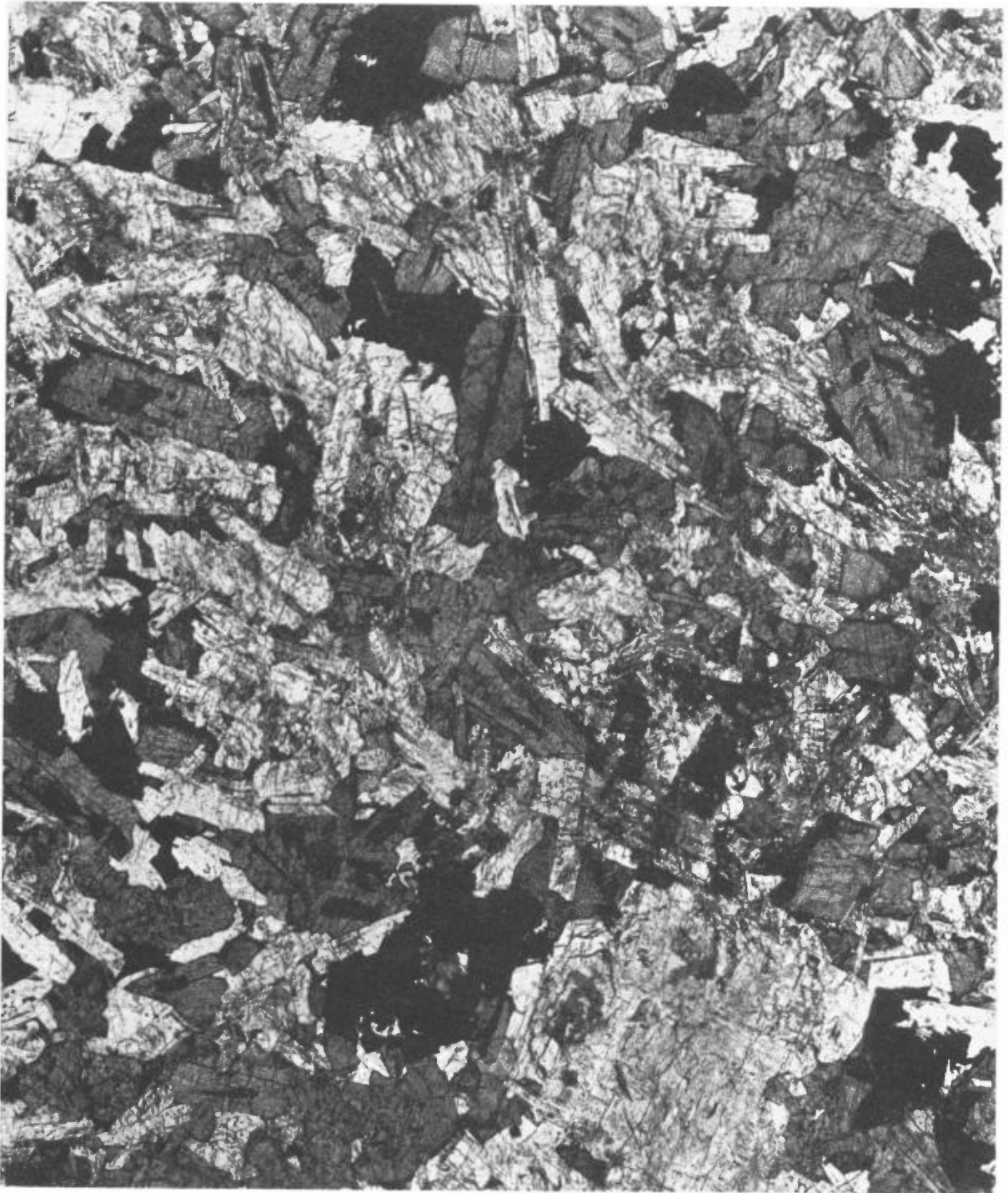


FIGURE 24 - Microscopic view of typical diabase, showing crystals of plagioclase (white), augite (gray), and magnetite, and alteration of magnetite (black). Width of photograph is 18 mm. The specimen is from dike 576-69 (Table 29), in the central part of the map-area (49.0, 22.5).

central portions of augite crystals, as shown in Fig. 24.

Pigeonite was detected in nine of the 15 dikes that were examined microscopically, where it occurs as irregularly-shaped patches within crystals of augite, usually within the central regions of these crystals. The colour of the mineral is identical to that of augite, and the optic axes are nearly coincidental with those of augite, but the pigeonite can usually be detected by its slightly lower birefringence, and by its small optic axial angle (2V) which is about 10 degrees. In one dike, pigeonite was present to about 2 or 3 per cent in the central region, but was absent from the margins, which suggests that relatively slow cooling may be essential for its formation. Brown chlorite, described above as an alteration of augite may be concentrated along the boundary between augite and pigeonite, and may be an alteration of both minerals.

Plagioclase occurs as roughly equi-dimensional or, more commonly, as prismatic crystals, as shown in Fig. 24. These may be partly enclosed by grains of pyroxene to produce a subophitic texture. The crystals normally show a complex pattern of twinning (Carlsbad, albite, pericline twinning), and faint zoning, normal or oscillatory. The composition, as estimated by the Michel Lévy method is about An_{60} ; in one rock, relatively rich in quartz and potassium feldspar, the composition is An_{44} . Plagioclase is commonly slightly altered to white mica.

In some rocks, quartz and potassium feldspar are present in nearly equal amounts. They form small 'interstitial' masses

in which the two minerals are truly intergrown, or quartz may be segregated in a small pod, surrounded by potassium feldspar. In other rocks, either quartz or potassium feldspar may dominate, occurring as discrete 'interstitial' grains. In some rocks, the two minerals appear to be absent.

A small amount of apatite is normally present, and forms long slender crystals.

Various fine-grained hydrous minerals are present. Brown hornblende (pleochroic in shades of brown) occurs as rims about crystals of augite, or as discrete grains, which are usually touching augite, and this mineral is apparently an alteration of augite. Green mica (dark brown to black in hand specimens, green in thin flakes, pleochroic from pale yellow to green in thin sections) occurs as nearly equidimensional grains, up to 2 mm in diameter. It is not obviously a secondary mineral. Green chlorite, as fine-grained aggregates, appears to be an alteration of brown amphibole or green mica, and very locally, olivine. The very fine grained brownish material, referred to as brown chlorite, has formed from pyroxene.

Several opaque minerals are present. Magnetite forms skeletal crystals, about 1 mm in diameter, that may make up nearly 4 per cent of the rock. It is usually partly or completely altered to maghemite, and varying stages in the alteration process may be seen in adjacent crystals. Grains of maghemite may contain lamellae of ilmenite, which exsolved from the original magnetite and were unaffected by the magnetite to maghemite alteration. Ilmenite is usually less abundant than

magnetite, and forms small, discrete, anhedral grains and small swarms made of rounded ilmenite grains, and also as lamellae in maghemite, as noted above. Neither pyrite nor pyrrhotite were found in the rocks that were examined, but very small amounts of chalcopyrite may be present, occurring as irregularly-shaped grains, up to 0.1 mm across, that may or may not be associated with magnetite and ilmenite. A minute amount of bornite was found in two rocks, where it is associated with chalcopyrite.

The diabase dike south-east of Otter Lake village (49.0, 22.5), which is illustrated in Fig. 24 contains all of the above minerals except olivine.

Although chemical data are not available, it is evident from the above description that some variation exists in the chemical composition of diabase within the map-area. Thus the observed variation in the content of quartz and potassium feldspar is likely to be a reflection of variations in the potassium and silica content of the rock. Further study may determine if these variations have regional or temporal significance.

PINK POTASSIUM FELDSPAR GNEISS (4)

A large part of the surveyed area is underlain by a rock that is here referred to as potassium feldspar gneiss. The most common variety is a gray to pink biotite gneiss that contains many parallel veins of pink quartz-feldspar material, and is referred to as veined gneiss (4a). Less common is a rock composed almost entirely of quartz and feldspar, which will be referred to as quartz-feldspar granulite (4b), and a relatively fine-grained and homogeneous rock composed of quartz, plagioclase, potassium feldspar, and biotite or hornblende (4c). These rocks, as a group, are characterized by the presence of potassium feldspar, which is generally more abundant than in the plagioclase gneisses and amphibolites (2), described above. Some of them resemble the granitic rocks, to be described below, but differ from them in mineral content or in texture.

Potassium feldspar gneisses are found to some extent within the five zones in which marble, plagioclase gneiss, amphibolite, and quartzite are concentrated (Fig. 3), but they occur much more abundantly in the regions that separate these zones, where they are found together with bodies of pink granitic and syenitic rocks, which are also relatively rich in potassium feldspar.

Veined gneiss (4a)

A belt of rock, composed predominantly of veined gneiss, is found in the south central part of the area, and will be referred to as the Otter Lake belt (Fig. 3). The veined gneiss here is gray to pink in colour and is composed of biotite, quartz,

plagioclase, and potassium feldspar; garnet is locally also present, and less commonly hornblende or sillimanite. As seen on the scale of an outcropping or a hand specimen, the most striking attribute of the rock is the very irregular distribution of potassium feldspar, which may be concentrated in scattered large crystals, in thin layers, one to a few mm thick, or in discontinuous parallel veins, a few mm to a few cm thick. The layers and veins normally consist of potassium feldspar, plagioclase, and quartz, in about equal proportions, with very minor biotite, and these could be referred to as pegmatite. Usually the layers and lenses all lie parallel to mineral foliation produced by biotite, but some layers may lie at small angles to the foliation.

An example of veined gneiss from the Otter Lake belt is shown in Fig. 25. The bottom part of this specimen, including layers 10, 11, and 12, shows the characteristic development of thin layers, and somewhat thicker, discontinuous lenses or veins, while the top half shows a higher concentration of potassium feldspar-bearing veins and layers. Also present are some zones very rich in biotite (4 and 9), and at the bottom of the specimen, a layer of amphibolite. The heterogeneity of the specimen is further illustrated in Fig. 26, which shows the variation in mineral proportions across the specimen from top to bottom, obtained by modal analysis. These data show that most of the specimen could be regarded as consisting of darker portions, relatively rich in biotite, and lighter portions, relatively rich in potassium feldspar. Indeed, the greatest

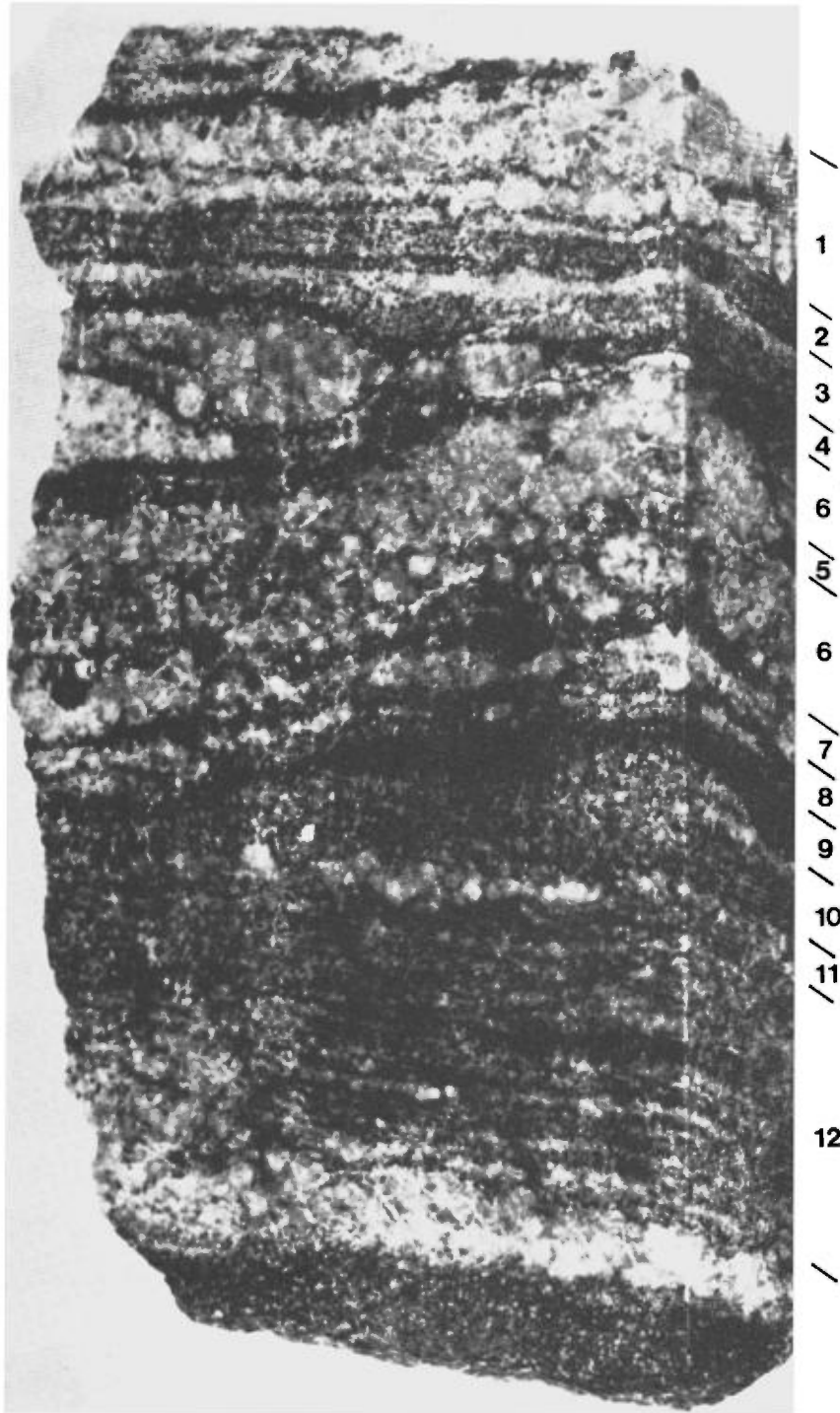


FIGURE 25 - A specimen of veined gneiss (290-55) from the Otter Lake belt. Height of specimen is 15 cm. Mineral proportions in different parts of the rock specimen are given in Fig. 26.

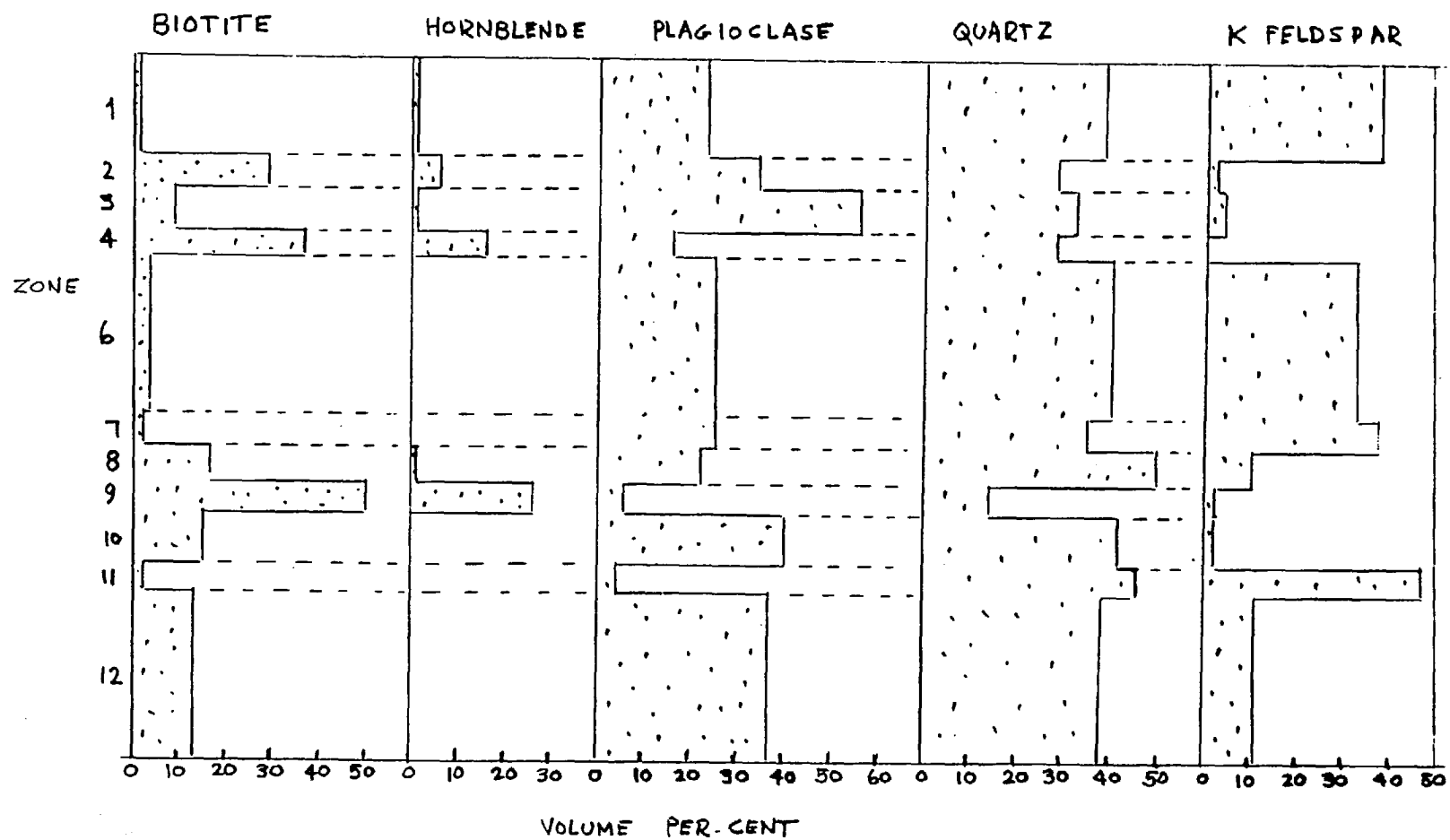


FIGURE 26 - Variation in mineral content in a specimen of veined gneiss (290-55), shown in Fig. 25.

variation in the specimen, apart from the local presence of hornblende, is in the abundance of biotite and potassium feldspar; the concentrations of quartz and plagioclase show less variation. Consequently biotite and potassium feldspar bear an inverse relationship to each other, as shown in Fig. 27.

In general, in the Otter Lake belt, the darker portions of the veined gneiss resemble biotite-plagioclase gneiss of unit 2, described above, and Sabourin (1965) suggested that similar rock to the south formed by the injection and permeation of quartz-feldspar material into plagioclase gneiss. This represents one attractive interpretation of the rocks under study, but the term 'injection gneiss', used by Sabourin, has been avoided to allow for other interpretations.

The mineral assemblages and approximate mineral proportions in several additional specimens of veined gneiss from the Otter Lake belt are listed in Table 30. Fine exposures of veined gneiss are found west of Ladysmith (45.8, 24.1), southeast of Otter Lake Village (49.5, 23.1), (48.8, 24.0), and east of the Village (51.5, 21.9), and also in the Kazabazua River sub-area (fig. 2).

Within the Otter Lake belt, layers of gray plagioclase gneiss and amphibolite, indistinguishable from the rocks of unit 2 described above, are found from place to place, and appear to be broadly interlayered with veined gneiss. The layers range in thickness from a few meters to several hundred meters, and two relatively large bodies of such rock have been outlined on the geological map (Map 1). Along the eastern margin of the belt, the veined gneiss is, for the most part, in sharp

TABLE 30 - POTASSIUM FELDSPAR GNEISS.

	4a											4b					4c																
Belt:	Otter Lake											Vinton					Other					Vinton			Otter Lake		Other						
	1018-74	2-55	21-55	40-55	314-55	550-69	G33-68	G124-69	918-73	943-73	310-55	643-70	672-70	676-70	934-73	G7-67	G1-67	273-55	306-56	747-70	785-70	879-72	641-70	638-70	635-70	976-74	994-74A	994-74B	264-55B	714-70	1017-74		
sillimanite	.1	-	-	.1	-	.1	.1	-	-	2	-	-	-	-	-	10	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	
garnet	2	2	-	2	2	2	-	-	2	2	-	-	-	-	-	-	-	-	.1	.1	2	-	-	-	-	-	-	.1	2	-	-	-	
biotite	10	10	2	2	10	2	20	10	10	10	10	10	10	10	2	10	-	10	10	10	2	20	2	2	2	.1	2	.1	2	.1	.1	.1	
hornblende	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	20	-	-	-	-	-	2	-	-	-	-	-	-	-	2	10	2	
Ca pyroxene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
plagioclase	50	30	40	40	30	40	40	50	30	30	40	40	30	50	30	20	40	40	40	40	20	30	2	50	50	30	60	50	40	40	30	40	
K feldspar	20	30	30	20	30	30	20	10	30	30	20	20	30	10	40	20	40	30	20	20	30	70	2	2	10	30	10	20	30	30	30	20	20
quartz	20	30	30	30	30	30	20	20	30	30	20	30	30	30	30	30	-	30	30	40	30	-	40	40	30	30	30	30	30	30	30	20	20
muscovite	.1	-	.1	.1	-	-	2	.1	2	-	-	-	-	-	-	2	-	-	-	2	-	-	.1	.1	.1	-	-	-	-	-	-	-	-
epidote	-	-	-	-	-	-	-	-	-	-	.1	-	.1	-	-	-	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
allanite	-	-	-	-	-	-	-	-	-	-	.1	-	-	-	-	-	2	-	-	-	-	.1	-	-	-	-	-	-	-	.1	2	2	
sphene	-	-	-	-	-	-	-	-	-	-	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.1	2	2	
zircon	.1	.1	-	.1	.1	.1	.1	.1	.1	.1	.1	.1	-	.1	.1	.1	.1	.1	.1	.1	.1	-	-	-	-	-	-	.1	-	-	.1	.1	
apatite	.1	.1	.1	.1	.1	*.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	-	-	.1	*	.1	.1	.1	-	-	-	.1	.1	.1	
magnetite	.1	-	-	.1	-	.1	.1	.1	.1	.1	.1	-	.1	.1	2	-	-	.1	-	*	.1	.2	.1	.1	.1	.1	2	.1	.1	2	2	.1	
ilmenite	-	-	-	-	.1	-	-	-	-	-	.1	-	-	-	-	-	-	-	-	.1	-	-	-	-	-	-	-	-	-	-	-	.1	
pyrite	.1	.1	.1	.1	-	-	-	-	-	-	.1	-	-	-	-	-	-	-	-	.1	-	.1	-	.1	.1	-	-	-	-	-	-	.1	
calcite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	.1	-	-	-	-	-	-	-	.1

*identification not confirmed

Key: See Table 2

4a veined gneiss

4b quartz-feldspar granulite

4c potassium feldspar-biotite gneiss,
potassium feldspar-hornblende gneiss

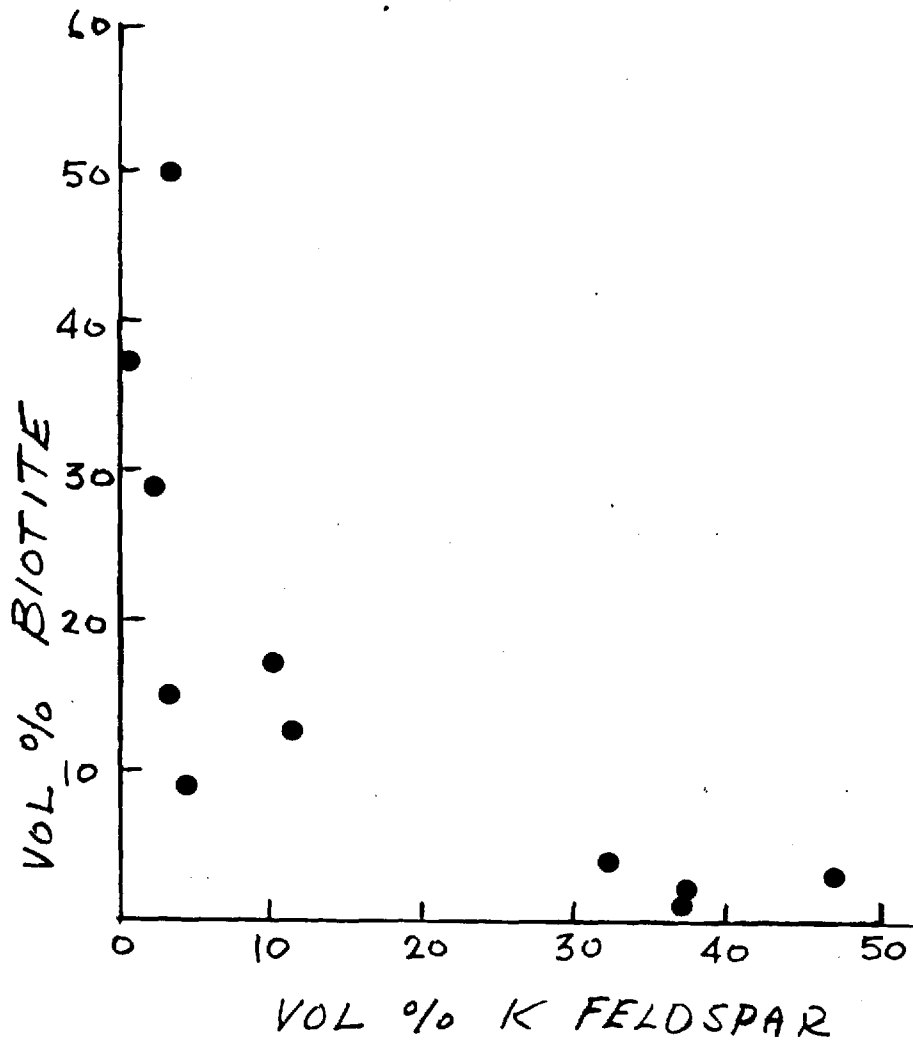


FIGURE 27 - Inverse relationship between biotite and potassium feldspar content of different portions of a specimen of veined gneiss (290-55); data from Fig. 26.

TABLE 3.1 - AMPHIBOLITE LAYERS IN VEINED GNEISS.

	562-69	434-55	39-55	53-55
garnet	10	10	1	1
biotite	1	2	2	10
hornblende	70	60	60	60
plagioclase	10	10	20	20
quartz	2	10	10	10
magnetite	.1	10	.1	1
other	.1	.1	.1	.1

Key: See Table 2

contact with plagioclase gneiss and amphibolite of the adjacent Thorne zone and appears to underlie them, but at co-ordinates (54, 19.5) plagioclase gneiss and amphibolite evidently pass gradationally along strike into veined gneiss. Gradations from amphibolite to veined gneiss have also been observed on a smaller scale, within a distance of 30 meters. These observations suggest that the veined gneisses are metasomatic rocks, in the sense that quartz-feldspar material was introduced, and according to this interpretation, the layers of plagioclase gneiss and amphibolite within the belt may be regarded as unaffected remnants.

Another type of rock found within the belt is a black, hornblende-rich amphibolite, that contains 60 to 70 per cent of hornblende and other minerals, as listed in Table 31. The rock occurs as isolated layers or lenses, commonly about 1 meter thick, lying conformably within veined gneiss. In places these bodies have been folded or stretched and disjointed. The rocks are distinctive in their high hornblende content, together with modest amounts of quartz, and they may have been gabbroic dikes and sills that have been altered by metamorphism.

Also, a very common companion of veined gneiss is pink pegmatite (5c) in the form of large sills, dikes, and irregularly-shaped bodies, up to several meters across. These will be described below under the heading of granitic rocks.

Toward the north, the veined gneiss of the Otter Lake belt becomes more and more intermixed and interlayered with

amphibolite and pink leucogranite, and the belt becomes less clearly defined. Much of the rock in the north central part of the map-area, designated by the map symbol M consists of veined gneiss, similar to that found farther south.

In the eastern part of the map-area, a north-trending belt of rock separates the Gatineau zone to the east from the Thorne zone to the west. It may be continuous with the Otter Lake belt described above, but will be referred to as the Danford Lake belt. Apart from some bodies of granitic rock, the rocks of the belt have been referred to as 'granitic injection complex' by Baker (1956), who described them as follows:

" The granitic injection complex has the form of a sheet or layer which forms a central belt in extending from the southern to the northern margin of the area. The complex is composed of rocks of the Grenville series which have been permeated, injected, and intruded by younger pink granite, granite gneiss, pegmatite, and some quartz veins. Hornblende gneiss, sillimanite-garnet-biotite gneiss, and biotite-quartz-feldspar paragneiss are the chief Grenville-type rocks present in the complex. However, crystalline limestone, quartzite, and skarns are also present. Besides being composed of varieties of Grenville-type rocks and granite, granite gneiss, and pegmatite, the complex contains several distinctive rocks which are believed to have originated as a result of mixing and interaction of some of the Grenville series with the intrusive granites. Ordinary injection gneiss

or migmatite, composed of layers and seams of pink granite and pegmatite which alternate with layers and seams of Grenville-type gneiss are extremely common. Migmatitic mixtures of granite and hornblende gneiss are typical, but the most common is injected sillimanite-garnet-biotite gneiss and biotite-quartz-feldspar gneiss. Migmatites composed of the latter have a characteristic banded appearance, due to the alternating layers of coarser grained pink granite or pegmatite with the fine-grained gray biotite-quartz-feldspar gneiss."

Thus the zone described above apparently contains large portions of veined gneiss similar to that found in the Otter Lake belt, together with other rock types. Two specimens of veined gneiss from this belt are listed in Table 30 (747-70 and 758-70). Rocks of this zone may be examined in a road cut at Danford Lake Village (55.4, 8.9) where specimen 747-70 was obtained, and on a cliff face southwest of Venosta (50.5, 5.5).

Veined gneiss also occurs abundantly in the south-western part of the area, in a north-westerly trending belt that will be referred to as the Vinton belt. This also appears to be connected to the Otter Lake belt, joining it in the south, in the area mapped by Sabourin (1965).

The veined gneiss of the Vinton belt varies in character from place to place, and in general resembles that of the Otter Lake belt, described above. However, garnet is very rarely present, and the rock appears to be, on the average, richer

in potassium feldspar, so that the rock as a whole is pink in colour, and the contrast between dark and light portions is not so great.

The most common kind of veined gneiss in the Vinton belt is a pink rock, consisting of 1 mm grains of quartz, potassium feldspar, and plagioclase in about equal proportions, together with a few per cent of biotite. The biotite crystals, together with lens-shaped quartz crystals are arranged in parallel to produce a foliation. This rock contains numerous quartz-feldspar veins a few mm or a few cm thick, lying parallel to the foliation, and also, to a small extent, in other directions. In many places these have been folded.

Representative mineral assemblages from the Vinton belt are listed in Table 30. The veined gneiss is well exposed along Highway 148 at Vinton and to the south-east of the Village. A peculiar variety of veined gneiss, consisting of amphibolite with large crystals and aggregates of potassium feldspar (Gl-67, Table 30) is exposed on the southern boundary of the area (45.0, 36.1).

The Vinton belt contains a smaller amount of intermixed plagioclase gneiss and amphibolite than does the Otter Lake belt. However a conspicuous band of steeply dipping and isoclinally folded amphibolite and garnet-bearing gneisses is found at (45.4, 36.0) and can be traced in a north-westerly direction for $1\frac{1}{2}$ miles. In addition, layers and lenses of amphibolite, a meter or so thick are fairly common and are well exposed along the highway between Vinton and the south boundary. These are, on the average, not as rich in hornblende as those of the Otter

Lake belt, and garnet is absent. Some show pinch-and-swell and boudinage structures, with inter-boudin spaces filled with pegmatite and quartz. Where in contact with veined gneiss, the hornblende of some amphibolite bodies has completely altered to biotite. The amphibolite contains veins of gray pegmatite and in places has been invaded by pink pegmatite. Pink pegmatite dikes, lenses, and irregularly-shaped bodies, one to a few meters across are also commonly found. Some of these possess a foliation, defined by the parallel arrangement of lens-shaped quartz grains. Some are relatively rich in magnetite or tourmaline.

Veined gneiss, similar to that found in the Otter Lake and Vinton belts is present at numerous other places within the map-area, as is indicated on the geological map. Although it occurs most abundantly outside of the gray gneiss-marble zones, it is important to note that it is also found within these zones. Thus it occurs interlayered with gneiss and amphibolite well within the Thorne and Moore zones, and at numerous places within the Coulonge zone, in association with marble, plagioclase gneiss, amphibolite, and pink granitic and syenitic rocks. Within the Gatineau and Calumet zones, typical veined gneiss is rare or absent, but some biotite and hornblende gneiss in these zones contain parallel veins of pink granitic rock, producing a rock that resembles veined gneiss. Some specimens from these zones are listed in Table 30. Veined gneiss also occurs interlayered with pink granitic rock in the Bell Mount Complex, to be described below.

Quartz-feldspar granulite (4b)

Within the Vinton belt, and near the southern boundary of the map-area (45.7, 35.2), a rock composed almost entirely of quartz and feldspar, with very minor biotite and magnetite underlies a fairly large part of the belt and is referred to as quartz-feldspar granulite. The rock is even-grained, at about 1 mm, and foliated as a result of the parallel arrangement of biotite crystals and lens-shaped quartz grains. But because of the small amount of biotite present, the foliation is difficult to detect in the field. A very faint gneissic texture may be present, resulting from slight variation in grain size or mineral proportions, and the layered aspect of the rock is brought out by occasional schlieren of biotite and lenses of amphibolite. Narrow pink quartz-feldspar dikes, with gradational contacts are commonly present at wide intervals; they are 1 mm to a few cm thick and contain the same minerals as the granulite. Quartz may be concentrated in the central part of the dikes.

Representative mineral proportions for the granulite are listed in Table 30, which shows that some of the granulite contains only small amounts of potassium feldspar. However, because of its association with veined gneiss, it was grouped with the potassium feldspar gneisses rather than the plagioclase gneisses. The associated quartz-feldspar veins invariably contain appreciable amounts of potassium feldspar.

A similar rock occurs locally in the Otter Lake belt, for example north-west of Sparling lake (47.8, 26.9) where it possesses a more conspicuous layered structure, and garnet is

present in some layers. The two specimens listed in Table 30 are from this locality. Other occurrences are indicated on the geological map.

Potassium feldspar-biotite gneiss

and potassium feldspar-hornblende gneiss (4c)

Within this group are placed a variety of pink rocks that have a grain size of about 1 mm, contain about 10 to 30 per cent of potassium feldspar, and a few per cent of dark minerals, mainly biotite or hornblende, or both, and locally calcic pyroxene. They normally display a mineral foliation and a gneissic texture, and apart from the presence of pink potassium feldspar, they resemble the plagioclase gneisses described above. With a more pronounced development of a gneissic texture they grade into veined gneiss, with which they are associated.

A clearly-defined body of potassium feldspar-hornblende gneiss is found north-west of Greer Mount(46, 30) where the rock (1017-74, Table 30) is homogeneous, finely gneissic, and possesses a pronounced near-horizontal lineation, marked by the parallel arrangement of elongate hornblende grains. The rock body contains some hornblende-plagioclase gneiss, in the form of thin layers and lenses, and large dikes of pink leucogranite and pyroxene-bearing pegmatite. The body is surrounded by leucogranite of the Bell Mount Complex.

Similar rock is found elsewhere in the area, for example north of Hughes lake (specimen 264-55B, Table 30) and in Huddersfield township, at the portal of the Yates adit (specimen 714-70, Table 30).

The origin of the quartz-feldspar granulite is obscure, but the potassium feldspar-biotite and potassium feldspar-hornblende gneisses may be plagioclase gneisses (2) to which potassium feldspar has been added by metasomatism.

Minerals

Additional information on the minerals of the potassium feldspar gneisses, especially the veined gneisses, will be presented below. The information is based on a microscopic examination of 90 specimens and on some chemical analyses of the contained minerals.

Sillimanite is moderately common in the veined gneisses, but less so than is suggested by the listing of minerals in Table 30. It occurs much as it does in plagioclase gneisses, and tends to form clusters of crystals concentrated on certain horizons parallel to the foliation and gneissic texture. For example, in one rock from the Vinton belt it occurs as clusters of thousands of prismatic crystals, each 0.02 mm in length, most of which are aligned to produce a mineral lineation, but some of which swirl off in other directions. In a rock from the Otter Lake zone, sillimanite forms slender prismatic crystals, up to 4 mm long, occurring individually or in clusters, with a weak inclination to parallelism. Sillimanite crystals may show a preferred association with biotite or muscovite, or they may be enclosed by garnet. Locally it is altered to a muscovite-like mineral.

Garnet forms equidimensional, or sometimes lens-shaped crystals, devoid of crystal faces. In 14 out of 20 garnet-bearing

veined gneisses that were examined microscopically, the diameter of the largest crystals in a small volume of rock was found to lie between 2 and 3 mm, while the entire range extends from 0.6 to 10 mm. Hence the size of the garnet crystals is, on the average, the same as in the plagioclase gneisses. Inclusions are not common, and where present consist of quartz, feldspar, and rarely biotite or sillimanite. In some rocks garnet crystals have been fractured at a high angle to the foliation, in others parallel to the foliation.

Representative analyses of garnet from veined gneiss are listed in Table 32. Compared with garnet from plagioclase gneiss and amphibolite, garnet from veined gneiss is slightly richer in the iron component (almandine) and poorer in the magnesium component (pyrope). Garnet occurring together with sillimanite, whether in plagioclase gneiss or potassium feldspar gneiss, is relatively low in calcium and manganese.

Biotite occurs as disc-shaped crystals that are normally arranged nearly in parallel, to define a foliation. In half of 57 rocks that were examined with regard to the size of the crystals, the diameter of the largest crystals in a small volume of rock was found to fall in the range of 0.6 to 0.9 mm, while the entire range extends from 0.3 to 2.0 mm. Hence the size of the biotite crystals is similar to that in plagioclase gneiss.

Representative analyses of biotite from veined gneiss are listed in Table 32. The analyses are similar to those obtained for biotite from plagioclase gneiss, except that the range in iron content appears to extend a little higher in biotites from

TABLE 3 2 - ANALYSES OF MINERALS FROM VEINED GNEISS.

Garnet				Biotite'				Potassium Feldspar					
	2-55B	550-69	314-55		306-56	40-55	550-69	2-55B		2-55B	40-55	273-55	550-69
*FeO	34.56	40.14	38.60	TiO ₂	1.73	5.81	4.16	3.72	**Fe ₂ O ₃	0.141	0.168	0.098	0.074
MnO	4.93	0.83	0.72	*FeO	18.79	23.49	24.48	29.99	CaO	0.065	0.109	0.067	0.066
MgO	1.81	2.47	3.38	MnO	0.28	0.06	0.04	0.23	SrO	0.025	0.028	0.026	0.035
CaO	4.01	1.26	1.61	MgO	11.96	8.45	6.73	5.00	BaO	0.256	0.249	0.173	0.267
				CaO	0.05	0.26	0.07	0.26	Na ₂ O	1.43	1.56	1.58	1.59
[Fe]	72.1	85.4	81.4	Na ₂ O	0.18	0.19	0.15	0.13	K ₂ O	14.29	14.41	14.40	14.32
[Mn]	10.4	1.8	1.5	K ₂ O	9.12	8.45	9.06	8.17					
[Mg]	6.7	9.4	12.7						Or	86.5	85.4	85.4	85.3
[Ca]	10.7	3.4	4.3						Ab	13.1	14.0	14.2	14.4
									An	0.33	0.54	0.33	0.33

* total iron expressed as FeO

**total iron expressed as Fe₂O₃

[Fe] = [Fe/(Fe+Mn+Mg+Ca)] 100; similarly for others

Analyst: Diane Garrett

veined gneiss. This is reflected in the colour of the mineral, which tends to be slightly darker, as seen in thin sections. Appreciable amounts of garnet accompany three of the four biotites listed in Table 32, and these are also relatively rich in iron.

Biotite in veined gneiss is commonly partly altered to chlorite, or to muscovite, chlorite, and rutile. Alteration of this kind is even more common in the quartz-feldspar veins that form a part of the veined gneiss.

Hornblende, where present in veined gneiss and potassium feldspar-hornblende gneiss, resembles that found in plagioclase gneiss and amphibolite, but in some rocks, the normal shades of green, as seen in thin sections, have a bluish tint, suggesting that the mineral may be relatively rich in sodium. In one specimen of potassium feldspar-hornblende gneiss, which also contains calcic pyroxene, the hornblende has evidently formed from pyroxene.

Plagioclase occurs as equidimensional grains, usually about 1 mm in diameter, which in some rocks show little twinning, and occasionally, very slight zoning. Irregularly-shaped inclusions of potassium feldspar are commonly present, and plagioclase crystals, where in contact with potassium feldspar, may be rimmed by albite. In most of the specimens that were examined, the plagioclase composition was estimated, by the Michel-Lévy method, to be approximately $An_{20} \pm 6$, but in a few rocks it was found to be approximately An_{30} . Plagioclase is commonly slightly altered to white mica or white mica plus carbonate.

Potassium feldspar occurs as equidimensional grains that

vary greatly in size; locally individual crystals in veined gneiss attain a diameter of 2 or 3 cm. Microcline-type twinning is usually well developed, and lamellae or irregularly-shaped inclusions of albite are common.

Chemical analyses of potassium feldspar from four specimens of veined gneiss are listed in Table 32. A high level of purity was obtained for the mineral separates, and all of the elements listed are considered to be present in solid solution. The minerals contain an appreciable concentration of iron, which may be responsible for the pink colour. Compared with potassium feldspar from marble (Table 9), the iron content is slightly higher and the calcium content is lower. The potassium feldspars from veined gneiss are remarkably uniform with regard to their sodium and potassium content.

Quartz normally occurs as lens-shaped or roughly-formed disc-shaped grains, up to 5 mm in diameter. These are arranged in parallel and often end-on-end to produce a foliation and gneissic texture. In some rocks, quartz is the dominant foliation-forming mineral. Quartz normally shows mosaic structure (undulatory extinction), presumably evidence of strain.

Muscovite was found in about one-third of the specimens of potassium feldspar gneiss that were examined microscopically, and is more common in these rocks than in plagioclase gneiss. It is also present in some of the small quartz-feldspar veins that are present in the veined gneisses and in the quartz-feldspar granulites.

Muscovite where present is usually unevenly distributed in

the rocks, and never occurs in large amounts. In some rocks it forms small (0.1 to 0.3 mm) irregularly shaped, shred-like grains, presumably of secondary origin, while in others it occurs as well-formed disc-shaped crystals, 2 mm across, presumably primary. In some rocks both of these are present. Locally it occurs as large (2 mm) highly irregular grains, that may have partly broken down by reaction. The expected reaction products are potassium feldspar and sillimanite, but no sillimanite is present in the rock.

The question of whether muscovite is primary or secondary is important to the discussion of metamorphism, to follow. Using the shape of the crystals as a criterion, muscovite in the first, third, and fourth specimens of veined gneiss (Table 30) and in the first and second specimens of quartz-feldspar granulite are considered to be secondary, the remaining primary.

Sphene, epidote, and allanite are rarely present in the potassium feldspar gneisses; the latter may form zoned crystals, 1 to 2 mm long. Zircon occurs commonly, as small rounded prismatic grains up to 0.6 mm long. Apatite and magnetite are very common, but ilmenite is rare. Small crystals of pyrite, rimmed by hematite appear to be more common in the Otter Lake veined gneisses than in those of the Vinton belt.

Metamorphism

The potassium feldspar gneisses will now be examined in relation to mineral reactions number 2 and 3, which were used in an evaluation of metamorphic grade of the plagioclase gneisses, amphibolites, and quartzites of unit 2. The reactions are as follows:

Reaction 2: muscovite + quartz = K feldspar + sillimanite + H₂O

Reaction 3: biotite + sillimanite + quartz

garnet + K feldspar + H₂O

All minerals of these reactions, as found in the potassium feldspar gneisses are obviously primary, with the exception of muscovite, which in some rocks appears to be of secondary origin. As noted above, if muscovite forms discrete disc-shaped crystals, it is regarded as primary, if irregular shred-like crystals are present, they are regarded as secondary.

Within the group of potassium feldspar gneisses that was examined microscopically, all of which contain potassium feldspar and quartz, six specimens were found to represent the left-hand side of reaction 2; two specimens contain all the minerals of 2 and represent the reaction in progress, and 8 specimens were found to represent the right hand side of reaction 2. These are denoted 2-, 2, and 2+ on the metamorphic map (Fig. 8). With regard to reaction 3, two specimens were found to represent the left hand side of the reaction; 8 specimens represent the reaction in progress, and 14 represent the right hand side. These are denoted 3-, 3, and 3+ on the metamorphic map.

The 8 specimens that contain all of the minerals of reaction 3, and are denoted 3, do not contain muscovite, and they are therefore the same 8 specimens that represent the right-hand side of reaction 2 and are denoted 2+. Also, the two muscovite-bearing rocks denoted 2 are the same two specimens that represented the left-hand side of reaction 3, denoted 3-. Thus reaction 3 evidently takes place at a higher temperature

(or range of temperature) than reaction 2. If so, garnet-bearing, sillimanite-free gneisses (3+) should not contain muscovite, which would simultaneously create assemblage 2-. Only two or the fourteen specimens in group 3+ were found to contain muscovite (306-56, 1001-74), but in these rocks, the muscovite occurs as both primary and secondary muscovite. Presumably all of the muscovite in these two rocks is secondary, and they are retained in group 3+ and removed from group 2-.

The remaining four specimens in group 2-, together with the two specimens in 2, equal six specimens that represent relatively low grade metamorphic conditions. Three of these are from the Vinton belt, and three are from a very small area in the Otter Lake belt (in the Kazabazua River sub-area). Nearly all of the 26 specimens assigned to (2+, 3) and to 3+ fall within the Otter Lake belt, the remainder, in other portions of the area. These results strengthen the conclusion that emerged from the rocks of units 1 and 2, namely that the rocks of the Ottawa Valley lowlands are on the average at a slightly lower grade of metamorphism than those of the highlands.

Origin

The above information on the potassium feldspar gneisses and their minerals indicates that the veined gneisses have much in common with biotite-garnet-sillimanite, biotite-garnet, and biotite gneisses of unit 2. The main difference lies in their slightly higher content of potassium feldspar, and in the pink colour of this mineral. Thus the veined gneisses may have existed initially as plagioclase gneisses, similar to those of unit

2, to which $KAlSi_3O_8$ and possibly minor other constituents were added metasomatically, according to processes described by Ramberg (1952). The various plagioclase gneisses that occur within the belts of predominantly potassium feldspar gneiss, would, according to this interpretation, be regarded as remnants, unaffected by metasomatism. The origin of the quartz-feldspar granulites is obscure, but the potassium feldspar-biotite and potassium feldspar-hornblende gneisses may have existed as plagioclase gneisses and also amphibolites, to which $KAlSi_3O_8$ was added more uniformly, without the formation of quartz-feldspar veins. The alternative interpretation is that the potassium feldspar gneisses originally consisted of a sequence of sedimentary rocks, relatively rich in potassium.

GRANITIC, SYENITIC, DIORITIC ROCKS, ANORTHOSITE (5)

Granitic and syenitic rocks are widespread in the map-area, and are subdivided on the basis of homogeneity, colour, and mineral content. Smaller amounts of dioritic rock are present, and very minor anorthosite. The rocks are, for the most part, gneissic, and they are, typically, interlayered and intermixed with other rock types, described above, or with each other; large homogeneous plutons of granitic, syenitic, or dioritic rocks are not present.

Rocks are said to be homogeneous when, on the scale of a few meters, the rock shows relatively little variation from place to place with regard to the minerals present, their proportions, and mean grain size; on a smaller scale, clustering of crystals may be present in the form of gneissic texture.

Rocks are said to be heterogeneous when, on the scale of a few meters, they show marked heterogeneity in the form of layers or patches in which dark minerals are relatively more abundant, or the grain size is relatively coarse or fine.

The heterogeneous rocks have been subdivided to some extent on whether they are gray or pink. In portions of the area, gray and pink pegmatite are readily distinguishable, the former apparently being older than the latter, but elsewhere gradations are found from gray to pink, and the colour may have little importance.

The principal basis for subdividing the rocks is the mineral content, namely 1) the degree of 'saturation' with regard to silica i.e. a) quartz abundantly present, b) quartz scarcely present or absent, and c) quartz absent and nepheline present); 2) the ratio of alkali feldspar to plagioclase feldspar; 3) the amount of dark mineral present.

The scheme employed, and the terminology used is shown in Fig. 28, which also shows the approximate range in composition of some rock bodies of the area.

Heterogeneous gray leucogranite and
pegmatite (5a), and granite and
granodiorite (5b)

It is scarcely possible to find an outcropping of plagioclase gneiss or amphibolite within the map-area that does not contain some gray quartz-feldspar material in the form of dikes, veins, or irregularly-shaped masses. When this material exceeds about 10 per cent of the total rock, as seen in an outcrop area, its presence is recorded by use of the symbol 5a or 5b, depending

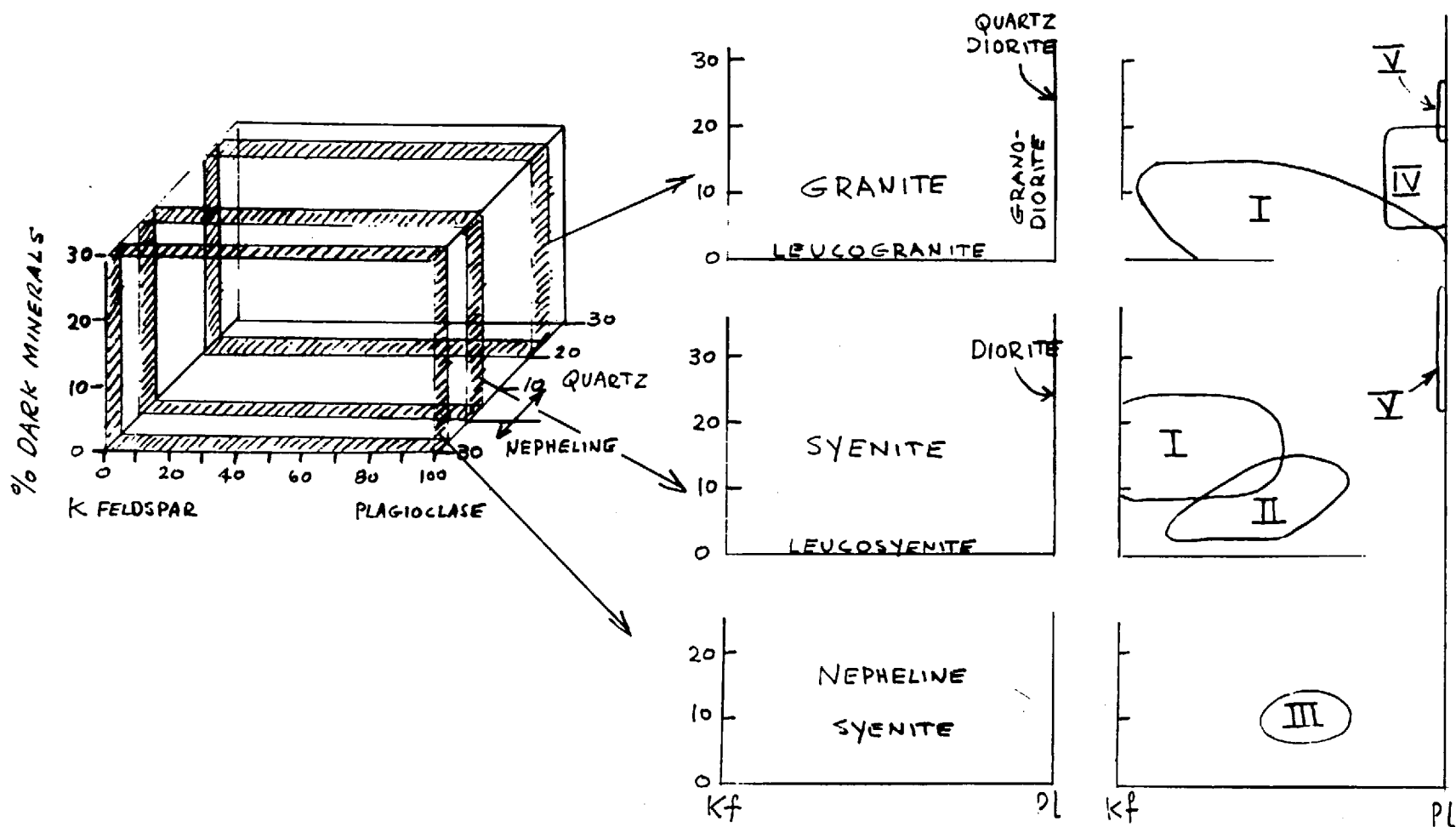


FIGURE 28 - Subdivision of granitic, syenitic, and dioritic rocks, based on mineral content, showing the fields occupied by some of the rock bodies of the map-area: I, Bell Mount Complex; II, Stag syenite; III, Cawood nepheline syenite; IV Lafontaine granodiorite; V Danford diorite and quartz diorite.

on whether dark minerals are nearly absent (5a) or present to a few per cent (5b). This subdivision is somewhat arbitrary for the amount of dark mineral present may vary within short distances. The texture of the rock is also variable, and terms such as pegmatite, aplite, and granite may be applied locally. Thus the rocks of the present category are highly variable with regard to both mineral content and texture; the term granitic rock will be used to refer to all of them.

Although gray granitic rock is found mainly in plagioclase gneiss and amphibolite, it also occurs as dikes and irregularly-shaped bodies in marble, and to a small extent, in mafic and ultramafic rocks.

Within plagioclase gneiss and amphibolite (2), the gray granitic bodies frequently occur as layers lying parallel to the foliation and gneissic texture. The layers range in thickness from a few mm to several meters, but are commonly a few cm or tens of cm thick. Cross-cutting tabular or vein-like sheets of granitic rock are also common, and these may cut those lying parallel to the foliation. Irregularly-shaped bodies, apparently isolated, are also found, and in places the rock outcropping shows an exceedingly complex intermixture of gneiss or amphibolite and granitic rock. Where the granitic rock increases in amount it may form an irregular network, surrounding apparently isolated blocks of gneiss or amphibolite.

In places where interlayered hornblende gneiss and gray granitic rock have been folded, the rock may be cut by apparently underformed dikes of pegmatite, and where minor displacement has taken place along small faults, the faults may be

'filled' with quartz-feldspar material. Evidently not all of the gray granitic rock is of the same age.

The gray granitic rock, as found in plagioclase gneiss and amphibolite consists of quartz, alkali feldspar, and plagioclase, with smaller amounts of one or more of the minerals biotite, hornblende, garnet, and rarely calcic pyroxene or magnetite. The ratio of alkali feldspar (potassium feldspar or a potassium feldspar plus albite intergrowth) to plagioclase feldspar is commonly about 1:1 but varies greatly; relatively small bodies tend to contain relatively more plagioclase. Small amounts of apatite, zircon, allanite, tourmaline, sphene may be present, and the secondary minerals muscovite (in shred-like crystals), white mica, chlorite, epidote, and carbonate. Grain size varies greatly, even within individual bodies. A foliation may be present, defined by the parallel arrangement of lens-shaped grains of quartz, or by biotite, and in some conformable layers that have been folded, a lineation has been observed, parallel to the fold axes. Examples of gray granitic bodies in hornblende-biotite gneiss may be examined on a cliff in the Kazabazua River sub-area (Map 2A) at (48.4, 21.35).

Dike-like bodies of gray granitic rock in metagabbro (3b) are not distinguishable from those described above.

At several places within the map-area, particularly in the Kazabazua River sub-area, calcite rich marble contains layers of gray granitic rock ranging in thickness from a few cm to a few tens of cm. These generally lie parallel to the layering within the marble, and may be folded. The mineral

content is similar to that of the relatively small bodies of granitic rock in plagioclase gneiss and amphibolite, described above. Examples are found at (49.05, 19.3).

Larger bodies of gray granitic rock in marble are found locally, for example near (48.7, 20.0), where irregularly shaped bodies of such rock, a few meters to a few tens of meters across are embedded within a folded layer of marble. Locally marble appears to have invaded granitic rock. The proportion of granitic rock to marble varies from place to place, but the overall proportion in the axial region of the fold may be close to 1:1; the limbs of the fold contain only a small proportion of granitic rock. The minerals present include biotite, quartz, and feldspar, with much variation from place to place in the alkali feldspar to plagioclase ratio. The grain diameter is normally about 1 mm, but ranges from fine to coarse; alternating layers of slightly differing grain size show up in some places. The rock locally possesses a pronounced lineation, defined by elongate aggregates of biotite grains. The granitic bodies in marble here and elsewhere may be disjointed fragments of pre-existing relatively thick and continuous layers of rock.

Bodies of gray granitic rock, large enough to show up on the geological map, were located at a few places. In Huddersfield township (55.0, 33.5), an elongated area is underlain by white to gray biotite granite, with smaller amounts of intermixed plagioclase gneiss (biotite gneiss, biotite-garnet gneiss, hornblende-biotite gneiss) occurring mainly as layers, and also some green pyroxene skarn and hornblende-rich rock, occurring as inclusions. In one specimen obtained from this body, the

quartz: potassium feldspar: albite ratio was found to be, approximately 20:50:30; the two feldspars occur as discrete grains. Foliation and gneissic texture are present but are not conspicuous.

North of Moore lake, an area is underlain by white to gray biotite granite and pegmatite, with smaller amount of intermixed plagioclase gneiss, including biotite gneiss and biotite-garnet gneiss. In Cawood township, two small bodies of dominantly gray granitic rock occur at (49.8, 16.5) and (48.5, 15.0). The northern body consists mainly of biotite-hornblende granodiorite, which at least locally has a cataclastic texture (bent and broken biotite and plagioclase grains). The southern body is relatively coarse-grained, and consists of biotite granite, with local garnet. These bodies contain some intermixed plagioclase gneiss.

Heterogeneous pink leucogranite and
pegmatite (5c), granite (5d),
and syenite (5e).

Bell Mount Complex

The Bell Mount Complex, in the western half of the map-area, is a north-westerly trending body of rock composed mainly of heterogeneous pink granitic and syenitic rocks. The body is highly variable on two accounts: firstly, the granitic and syenitic rocks themselves are highly variable with regard to mineral content and texture, and secondly, the proportion and kind of gneisses, amphibolites, and other rocks intermixed with the granitic and syenitic rocks vary from place to place within the body. The contacts of the complex are not

sharp, but are broad zones across which the proportion of granitic and syenitic rocks, relative to other rock types, decreases outwards.

The granitic-syenitic part of the complex consists mainly of leucogranite and pegmatite (5c), with smaller amounts of hornblende granite, calcic pyroxene granite, and biotite granite (5d), and calcic pyroxene syenite (5e). These rocks are pink in colour and consist mainly of alkali feldspar and plagioclase, with variable amounts of quartz, biotite, hornblende, and calcic pyroxene. Although biotite is commonly present in small amounts, the dominant ferromagnesian minerals are green pyroxene and black hornblende. The ratio of plagioclase feldspar to alkali feldspar varies across the whole range, from rocks in which all the feldspar is plagioclase to those in which all the feldspar is alkali feldspar. Representative mineral assemblages are listed in Table 33, while Fig. 28 summarizes the variation that was found in the major mineral content.

The feldspar minerals, as seen with the aid of a microscope, consist of grains of plagioclase of composition close to An₂₀, and grains that are made up of a fine lamellar intergrowth of potassium feldspar and albite. The pink colour of the feldspar minerals appears to be accentuated by very fine grained reddish material, probably hematite, found along grain-boundaries and fractures, and scattered throughout the feldspar crystals.

Calcic pyroxene, as seen in thin-sections is gray green to green, and very slightly pleochroic. Hornblende is pleochroic

TABLE 33 - THE BELL MOUNT COMPLEX.

	Leucogranite							Granite						Syenite						
	971-73	982-74	1000-74	973-73	795-70	792-70	980-74	972-73	1009-74	90-55	166-55	790-70	800-70	51-55	149-55	26-56	789-70	1010-74	974-73	32-56
biotite	-	-	.1	.1	2	2	2	2	.1	.1	2	2	.1	.1	.1	.1	.1	-	.1	.1
hornblende	-	-	-	-	-	-	2	2	10	10	10	10	.1	2	2	2	2	.1	2	-
Ca pyroxene	-	-	-	-	-	-	-	-	-	-	-	-	2	10	10	10	10	10	20	40
plagioclase	60	70	30	40	20	70	30	40	50	20	10	40	20	10	20	2	10	10	40	-
alkali feldspar	20	2	40	30	50	-	30	20	20	60	70	20	60	60	60	80	70	80	40	60
quartz	20	30	30	30	20	30	30	30	20	10	10	20	10	10	.1	.1	2	2	2	.1
allanite	-	.1	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
sphene	-	-	-	-	.1	-	.1	.1	.1	-	-	-	2	2	2	2	.1	.1	.1	2
zircon	-	.1	.1	-	.1	.1	.1	.1	-	.1	-	.1	-	.1	-	-	-	-	-	-
apatite	-	-	.1	-	.1	-	*.1	.1	.1	.1	.1	*.1	*.1	.1	.1	.1	.1	-	.1	-
magnetite	-	.1	.1	.1	.1	-	.1	.1	-	-	-	*.1	*.1	2	-	-	-	.1	-	-
pyrite	.1	-	-	-	.1	-	-	-	.1	-	-	-	-	2	.1	-	.1	.1	-	-
epidote	-	-	-	-	.1	-	2	.1	-	-	.1	-	-	-	-	.1	-	-	-	-
muscovite	.1	.1	.1	.1	-	.1	.1	.1	-	-	-	.1	-	.1	-	.1	-	-	-	-
chlorite	-	-	.1	-	2	.1	-	-	-	-	.1	-	.1	2	-	.1	.1	-	-	-
white mica	-	-	.1	-	.1	.1	-	-	-	-	.1	-	-	.1	-	.1	-	-	-	-
calcite	-	-	-	-	.1	-	-	.1	-	-	.1	.1	.1	.1	-	.1	.1	.1	.1	.1
hematite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.1	.1	-	-	-	-

*identification not confirmed

Key: See Table 2

from pale green to slightly bluish green. The colour of pyroxene and amphibole indicates the presence of some sodium. Amphibole occurs as discrete grains and as rims about pyroxene; the rims may contain tiny inclusions of quartz. Biotite is light-coloured and evidently rich in magnesium relative to iron.

Among the minor minerals, allanite is commonly present, especially in leucogranite, where it occurs as widely-spaced crystals, from which fractures radiate into the surrounding feldspar. Epidote is fairly common, occurring as pleochroic crystals or aggregates of crystals, and also as fine-grained gray material associated with plagioclase. Other minerals that are locally present include sphene, tourmaline, zircon, apatite, magnetite, pyrite, pyrrhotite, calcite, muscovite, chlorite, and white mica.

The most notable textural feature of the granitic and syenitic rocks of the Bell Mount Complex is the great variation in the distribution of dark minerals and of quartz. This heterogeneity, as seen in rock outcroppings, may create a crude gneissic texture or an irregular pattern, or it may create a layered structure, resembling bedding, as shown in Fig. 29. Great variation is also found in the grain size, which is uneven but is mainly 2 to 3 mm for quartz, feldspar, and ferromagnesian minerals; frequently layers, lenses, or irregular masses of rock that are finer grained or coarser grained, are present thus producing a heterogeneity with regard to grain size. Concerning the orientation of crystals, a mineral foliation is commonly present, produced by the parallel arrangement of lens-shaped quartz grains, as shown in Fig. 30, which is a



FIGURE 29 - Layered structure, resembling bedding, in pyroxene granite on the Bell Mount Complex, near Greer Mount.



FIGURE 30 - Microscopic view of leucogranite (973-73) of the Bell Mount Complex, showing parallel arrangement of lens-shaped quartz grains.

representative microscopic view of leucogranite. Biotite, hornblende, and sphene may also show a preferred orientation of minerals.

A notable feature of the granitic and syenitic rocks of the Bell Mount Complex is the common presence of secondary minerals, which indicates that secondary alteration or retrograde metamorphism has been more effective within the complex than elsewhere within the map-area. This may result in the presence of as many as 17 minerals in a small volume of rock. Two stages of alteration may be recognized. During the first stage, pyroxene was partly altered to amphibole and quartz, which form rims about the pyroxene crystals, and at this time shred-like crystals of muscovite and large irregularly shaped grains of epidote also crystallized, while biotite altered to chlorite. The second stage produced very fine grained minerals. Feldspar altered to white mica, some plagioclase altered to albite, epidote, and calcite, pyroxene altered to epidote and chlorite, while magnetite and pyrite altered to hematite. Advanced stages of alteration are found locally and some of these occur near known or suspected faults.

The additional rock types that are commonly present and are intermixed with the granitic and syenitic rocks are chiefly amphibolite (2f), veined gneiss (4a), potassium feldspar-biotite gneiss (4c), and smaller amounts of biotite gneiss (2c), green pyroxene skarn and pyroxene-scapolite skarn (1g), metagabbro (3b), and rarely biotite-garnet-sillimanite gneiss (2a) and marble (1a). These rocks, as examined in the field and under the microscope are similar or identical to those which form



FIGURE 31 - Interlayered pink leucogranite and dark amphibolite of the Bell Mount Complex, at Bell Mount.

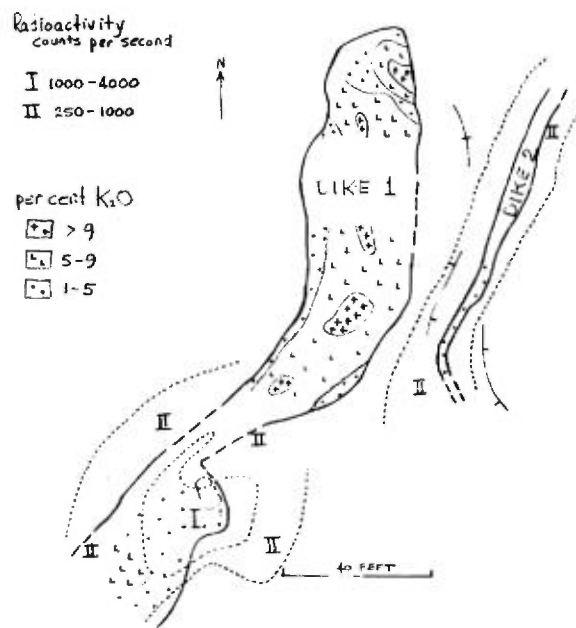


FIGURE 32 - Variation in radioactivity and potash content in two pegmatite dikes in steeply-dipping amphibolite, south of Vinton (46.7, 38.5). Data obtained by Calvin Pride, University of Ottawa.

large bodies of rock outside of the complex, as described earlier in this report. The intermixing of the additional rocks with granite or syenite usually takes the form of an interlayering of rock types. Thus amphibolite and veined gneiss are commonly found interlayered with granite or syenite, the layers usually being a meter to a few tens of meters thick. An example of interlayered amphibolite and pink leucogranite is found at Bell Mount, as shown in Fig. 31. The layers are often somewhat irregular and discontinuous. Elsewhere amphibolite occurs as slabs or rounded inclusions in granite or syenite; these range in size from a fraction of a meter to 100 meters and are commonly cut by pink pegmatite dikes.

Rocks of the Bell Mount Complex may be readily examined in the vicinity of Lawless lake, for example at (46.3, 31.5), (45.7, 32.5), (46.8, 30.2) and also at Bell Mount (50.6, 30.5), where the proportion of the additional rock types is relatively great.

Other occurrences

A body of rock similar to that described above but much smaller in size is found near Murray lake (56, 25).

On Ile du Grand Calumet, in the vicinity of (47.7, 43.2), Shaw (1955) mapped a body of leucogranite, granite pegmatite, pyroxene granite, pyroxene syenite, and associated pyroxene-calcite-fluorite veins. The pyroxene syenite locally contains fluorite, and the pyroxene is reported to be aegirine augite. A small amount of amphibolite is intermixed with these rocks, but apparently no potassium feldspar gneisses.

Two bodies composed mainly of pink leucogranite and pegmatite

were located by Baker (1956) in the eastern part of the map-area, at (52, 05) and (49.6, 03). The southern body was examined by the writer and was found to consist mainly of very heterogeneous pink leucogranite, with grain size locally as large as several cm. Features characteristic of pegmatite, such as quartz-alkali feldspar intergrowths and quartz 'cores' were not found. Hornblende gneiss and biotite gneiss occur as interlayers and inclusions, some of which show a well-developed mineral lineation. Inter-layered leucogranite and white marble is exposed along the northern margin. Immediately to the north, at Carson lake (50.3, 02.7) a cliff-forming mass of pink pegmatite rests on marble. This rock contains quartz-alkali feldspar intergrowths quartz 'cores', and minor tourmaline, hornblende, magnetite, allanite, and zircon, and is typical pegmatite. A similar body is found where the highway crosses the eastern boundary of the map-area.

Pink granitic rock is very common, as layers and dikes, within the terrain that is composed mainly of potassium feldspar gneiss. In outcroppings of veined gneiss, all gradations may be seen from small quartz-feldspar veins to larger layers and dikes, several meters across. Quartz-feldspar intergrowths are not common, and many of these bodies could be referred to as either pegmatite or leucogranite. The ratio of alkali feldspar to plagioclase is variable; small amounts of biotite and garnet may be present, and locally sillimanite.

Within the Coulange zone, and in portions of the area mapped as mixed rocks (M), heterogeneous pink granitic and syenitic

rock are found interlayered with amphibolite, veined gneiss, and other gneisses, and as cross-cutting dikes. Locally in the Coulonge zone, amphibolite and pink syenite are interlayered on a scale of a few cm or tens of cm.

Notable occurrences of pink pegmatite are found on either side of the Ottawa River, in the area south of Vinton, where pegmatite dikes of various size cut amphibolite. Two dikes at (46.7, 38.5) were mapped by Calvin Pride and are shown in Fig. 32. The pegmatite here consists of potassium feldspar, albite, quartz, and minor biotite, tourmaline, and magnetite. Quartz-feldspar intergrowths are locally present. According to Calvin Pride, the larger dike is zoned, with higher concentrations of potassium in the central portion as shown in Fig. 32. Radioactivity is concentrated at one place in the larger dike, near an inclusion of amphibolite, where the pegmatite is red in colour. The mineral producing the radioactivity was not identified. Near the pegmatite, the amphibolite appears to have been somewhat affected by the emplacement of the dike, for the contained hornblende has been partly altered to epidote, and biotite is more abundant than elsewhere. Other dikes in the same outcrop area contain notable amounts of tourmaline.

Another large pegmatite dike is well exposed on the opposite side of the river, on Ile du Grand Calumet, at (45.6, 38.0). The dike was mapped and described by Shaw (1955) and by Richard Savard. The body consists of feldspar and quartz, and small amounts of allanite, biotite, chlorite, tourmaline, magnetite, pyrite, and a radioactive mineral. Locally,

near its walls, the dike is fine grained and shows a peculiar concentric layered structure, consisting of alternating layers, a few mm thick, rich in alkali feldspar and in plagioclase and iron oxide.

All of the pink granitic and syenitic rocks described above may be broadly contemporaneous. The rocks, as found in the Bell Mount Complex normally possess a foliation and have evidently experienced considerable deformation and metamorphism; some dikes are obviously folded. Elsewhere, for example south of Vinton, pink pegmatite dikes have evidently not experienced a large amount of deformation and these may be somewhat younger in age. Some of the pink granitic and syenitic rock may be metasomatic in the sense that they have replaced pre-existing rock, and some may be intrusive in as much as the country rocks provided space for them. The importance of igneous processes in the origin of the rocks will be briefly considered on a later page.

Homogeneous gray or pink granite and
granodiorite (5f), diorite (5g),
syenite (5h), nepheline syenite (5i),
and anorthosite (5j)

Lafontaine Complex (mainly granodiorite, 2f)

In the south west corner of the map-area (45.5, 44), a portion of a relatively homogeneous body of pale pink granitic rock has been mapped and described by Shaw (1955), who named it the Lafontaine tonalite Complex. The body consists mainly of tonalite or granodiorite, made up of plagioclase An_{25} , with smaller amounts of quartz, 5 to 20 per cent of biotite,

with or without hornblende, and 0 to 20 per cent of potassium feldspar. Minor minerals include magnetite, apatite, zircon, sphene, calcite, and chlorite. As seen in a typical outcropping, the rock is nearly homogeneous, shows a slight foliation (produced by biotite) and some development of gneissic texture. The rock is more gneissic in the margins of the complex, where it is locally interlayered with a diorite gneiss, containing about 50 per cent of dark minerals. Shaw (1955) suggested that the granodiorite was injected as a large pod-like sill, together with numerous thinner sheets.

Isabel Complex (mainly granite, 5f)

In the eastern part of the map-area, near the southern border (45.6, 05.8), a body of 'granite, granite gneiss, and pegmatite' was located by Baker (1956), and is here referred to as the Isabel Complex. The available information on this body, as obtained by Baker and the writer indicates that it consists mainly of homogeneous pink granite, which contains about 5 per cent of biotite (with or without hornblende), roughly equal amounts of plagioclase and potassium feldspar, and 1 to 20 per cent of quartz. Small amounts of zircon, apatite, magnetite, and sphene are also present. Thus, depending on the quartz content, the rock may be referred to as granite or syenite. In some outcroppings the grain size is less than 1 mm and in others it is about 3 mm, with potassium feldspar crystals up to 6 mm. Some samples that were collected show a faint gneissic texture but no foliation. Locally swarms of tabular or rounded inclusions of amphibolite are present

within a remarkably homogeneous granitic rock, suggesting that the rock may be of magmatic origin. Other rocks associated with the granite are amphibolite and potassium feldspar gneiss, both of which occur abundantly in the terrain that surrounds the complex.

Danford diorite and quartz diorite (5g)

In the eastern part of the map-area, within the eastern half of the Thorne zone, Baker (1956) observed and described rocks of quartz diorite and diorite composition, and outlined fairly large areas as being underlain by 'quartz diorite and related facies' and by a 'diorite injection complex'. These rock masses were said to consist, for the most part, of an intermixture of dioritic rock and Grenville-type hornblende and biotite gneisses.

Although quartz diorite and diorite, as described by Baker can be readily recognized in the field, the writer could not confirm the reported abundance of these rocks relative to hornblende gneiss or amphibolite, identical to rock that, farther west, was assigned to unit 2 (plagioclase gneiss and amphibolite). Hence the areas originally mapped as 'quartz diorite and related facies' and 'diorite injection complex' are shown on the present map (Map 1) as 'predominantly plagioclase gneiss and amphibolite', and the presence of dioritic rocks is indicated by use of a symbol.

The quartz diorite and diorite, as described by Baker (1956) and observed by the writer is a sandy weathering, relatively homogeneous rock that consists of plagioclase and variable amounts of garnet, biotite, hornblende, orthopyroxene,

TABLE 34 - DIORITIC AND SYENITIC ROCKS.

	a				b						c		
					I		II		III				
	1022-74	1023-74	1029-74	1030-74	777-70	1050-74	826-70	1040-74	821-70	1044-74	1045-74	1104-74	1145-74
garnet	2	2	20	10	-	-	-	.1	-	-	-	-	-
biotite	10	2	.1	2	2	10	10	10	2	2	2	2	-
hornblende	-	-	10	10	-	-	.1	-	10	2	2	10	10
orthopyroxene	10	2	2	2	-	-	-	-	-	-	-	-	-
plagioclase	70	70	60	70	20	50	30	50	40	30	30	40	40
alkali feldspar	2	.1	-	-	70	20	60	40	40	70	60	20	40
nepheline	-	-	-	-	-	-	*	-	-	-	-	20	10
quartz	10	20	.1	2	2	-	.1	-	-	-	10	-	-
sphene	-	-	-	-	2	2	2	.1	2	2	.1	2	-
zircon	-	-	-	-	.1	.1	-	-	-	-	.1	-	-
apatite	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	-
magnetite	-	*	2	2	2	2	2	2	2	2	2	2	2
ilmenite	2	.1	-	2	-	-	-	-	-	*	.1	-	-
pyrite	-	-	-	.1	.1	.1	.1	-	.1	.1	.1	.1	.1
calcite	-	-	-	-	-	-	-	-	2	-	-	.1	2

*identification not confirmed

Key: See Table 2

a Danford diorite and quartz diorite

b Stag syenite

c Cawood nepheline syenite

and quartz (Table 34). The rocks are even-grained, at 2 to 3 mm, and usually gneissic. A foliation, defined by the parallel arrangement of biotite and hornblende grains and quartz lenses is usually apparent. The composition of plagioclase in quartz diorite is An_{30-40} and in diorite, An_{40-45} . Some varieties rich in quartz and alkali feldspar are also present.

The type locality for quartz diorite may be chosen as O'Brien mountain (53.3, 14.0) where this rock is interlayered or intermixed with faintly-layered hornblende gneiss. The first two specimens listed in Table 34 are from this locality. Other reported occurrences of quartz diorite include an area north of Sinclair lake (49, 0.95), east of Trooper lake (51, 10.5), and south-west of Cawood (48.5, 13.7).

The type locality for diorite is an outcropping north of Danford Lake village (58.0, 11.2), which was described in detail by Baker (1956). At this place diorite forms sill-like bodies in hornblende gneiss or amphibolite and locally contains slab-like inclusions of amphibolite. Hence the intrusive nature of the diorite appears to be well established. Garnet is present in both rock types and in places is very unevenly distributed. Baker suggested that the emplacement of the diorite has transformed hornblende gneiss to hornblende-garnet gneiss. The third and fourth specimens listed in Table 34 are from this locality.

Although the quartz diorite and diorite are evidently of igneous origin, the rocks have obviously been affected by metamorphism. The contained orthopyroxene occurs as discrete

grains, unlike the mafic intergrowths found in ultramafic rocks (3c), and very similar to those occurring locally in the plagioclase gneiss and amphibolite (2h). Hence these rocks may also be considered in relation to the orthopyroxene-forming reaction, and provide some additional data points for the metamorphic map (Fig. 8).

Stag syenite-diorite-amphibolite bodies (mainly syenite, 5h)

Three small bodies of mixed rock, which contain as one component a homogeneous pink syenite, were mapped in the Gatineau zone, in the eastern part of the map-area. These are referred to, from north to south as Stag I (49.8, 1.5), Stag II (49.2, 02.3), and Stag III (47.5, 02.0). The first two were mapped by Baker (1956) and included in his group 'granite, granite gneiss, and pegmatite', and the third was not shown on his map.

Stag I consists of an intermixture of syenite, a dark rock that will be referred to as diorite, and amphibolite. The syenite consists mainly of alkali feldspar and plagioclase in variable proportions, and minor biotite. Grain size is about 1 mm. The rock appears nearly homogeneous when viewed on an outcrop surface, but its most striking feature is a conspicuous lineation, defined by elongate aggregates of biotite grains. The diorite, which is somewhat coarser than the syenite contains about 10 per cent of each of biotite, hornblende, and calcic pyroxene, the remainder being plagioclase. The amphibolite, which is fine to coarse grained consists of hornblende and plagioclase in about equal proportions. These three rocks are irregularly intermixed,



FIGURE 33 - Intermixed syenite and amphibolite in the Stag III pluton, viewed nearly parallel to the mineral lineation.

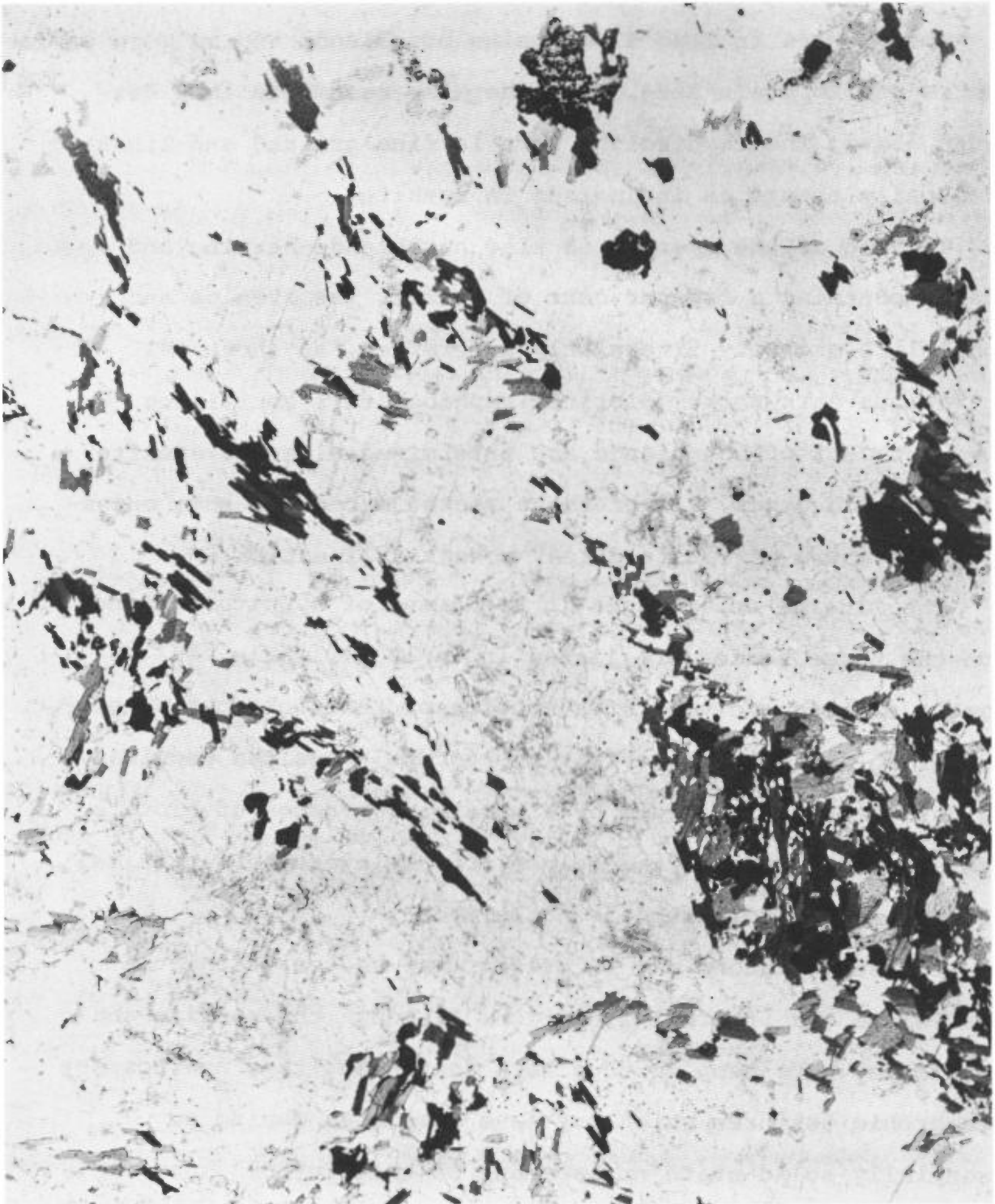


FIGURE 34 - Microscopic view of syenite (1040-74) from the Stag II pluton. Section is cut perpendicular to gneissic lineation, and shows clusters of biotite crystals (gray to black) in feldspar (white). 12X.

and are cut by quartz-bearing granite and pegmatite dikes.

The syenite in Stag II contains hornblende and is more variable with regard to grain size, but otherwise resembles that described above. The amphibolite here is fine grained and lineated and locally occurs as inclusions in syenite.

In Stag III the syenite is also hornblende-bearing and locally contains a few per cent of quartz. The syenite and amphibolite are very irregularly intermixed, as shown Fig. 33

Various dark rocks (diorite, amphibolite), containing 30 to 80 per cent of hornblende, are intermixed with the syenite and with each other. All of these rocks, excepting some cross-cutting granite pegmatite dikes, possess a lineation.

The mineral assemblages in specimens of syenite obtained from the three bodies are listed in Table 34, while Fig. 34 shows a microscopic view of a section of the rock, cut perpendicular to the lineation. This photograph shows the peculiar gneissic texture, produced by elongate aggregates of biotite crystals; the crystals themselves are not everywhere parallel and evidently a foliation is not present.

The Stag plutons may be cylindrical bodies, elongated parallel to the internal lineation. Although the syenite and diorite may have been igneous rock initially, they now possess metamorphic textures which may have developed during an essentially solid-state emplacement of the plutons.

Syenitic rock similar to that described above has been observed at only a few other places within the map-area. A body of hornblende-biotite syenite, with nearly 80 per cent of potassium feldspar was found in the northern margin of

the area, at (59.4, 37.3). A syenite dike at (45.6, 11.7) was described by Baker (1956), who noted that although the dike is apparently undeformed, it possesses a foliation parallel to that in the surrounding plagioclase gneiss. The syenite resembles that found in the Stag plutons, and is also cut by quartz-bearing pegmatite.

Cawood nepheline syenite (5i)

A body of nepheline syenite, measuring about 1 mile across was located by the writer in the eastern part of the area, north of Cawood, at (51.5, 12.5). The surrounding rock is marble, but contacts with this rock are not exposed. Most of the body consists of fairly homogeneous, gneissic rock, which contains 5 to 20 per cent of biotite and hornblende and about 10 per cent of nepheline. Grain size is 2 to 3 mm. The weathered surface shows the characteristic pitted surface, resulting from the rapid weathering of nepheline. Layers of a more mafic rock are locally present, as well as some nepheline-bearing pegmatite bodies.

The mineral proportions in two specimens from the pluton are listed in Table 34. The rock may be readily examined on a prominent south-facing cliff, near the above-given co-ordinates.

The Cawood pluton lines up well with the elongated zone of nepheline syenite occurrences in the Bancroft area, and may be regarded as a north-easterly extension of this zone.

Anorthosite (5j)

A few small bodies of anorthosite were located by Baker (1956) within the belt of potassium feldspar gneiss that traverses the eastern part of the area, for example at

co-ordinates (53.2, 06.8), (50.7, 05.7), and (48.6, 06.2). The size of the bodies is smaller than is indicated on Map 1.

These rocks, which were not examined by the writer, were reported to consist of plagioclase (An₅₅) with very minor hornblende, calcic pyroxene, and local scapolite, biotite, sphene, and allanite. The rock is massive, but locally gneissic and layered; grain size is 1 to 2 mm. The minerals show extensive alteration to white mica, epidote, calcite, and chlorite. The rock is cut by pink granite and pegmatite dikes.

Baker suggested that the anorthosite might be of igneous or metasomatic origin.

Origin

The origin of the granitic, syenitic, and dioritic rocks described above will be considered very briefly in relation to the following three models:

1. emplacement and crystallization of a body of silicate melt, and later metamorphism and deformation of the solid rock,
2. local accumulation and crystallization of mobile rock-forming material in dilating zones, the material being transported in solution, by diffusion, or by another mechanism,
3. partial or complete replacement of pre-existing rock by mobile rock-forming material, bringing about the crystallization of potassium feldspar and other minerals (metasomatism).

The relatively homogeneous rocks are thought to have passed through a magmatic stage, as indicated by model 1. The Danford diorite and quartz diorite were evidently emplaced as sills prior to their metamorphism. The granitic rocks of the Lafontaine and Isabel complexes and the syenitic and dioritic rocks of the Stag plutons may also be magmatic rocks that have been affected by metamorphism. Some of these bodies may have become mobilized in the solid state, and displaced to higher levels during a period of orogeny.

The compositionally and texturally heterogeneous granitic and syenitic rocks are thought to have formed according to models 2 and 3. Thus the granitic and syenitic rocks of the Bell Mount Complex may be largely metasomatic rocks, representing a more advanced stage of metasomatism than that shown by the potassium feldspar gneisses. Many of the pervasive gray and pink pegmatite bodies may be accounted for by model 2.

An understanding of the origin of all of the granitic, syenitic, and dioritic rocks is as yet far from complete, but the above data and models provide convenient starting points for further study.

ORDOVICIAN SEDIMENTARY ROCKS (6)

Paleozoic rock, within the map-area, is confined to a small area on Ile du Grand Calumet, at (47.3, 45), where flat-lying sandstone and arkosic conglomerate (6a) and dolomite (6b) are poorly exposed.

According to Shaw (1955), who mapped these rocks, the base of the section consists of a bed of conglomerate, not more than a few feet thick. The conglomerate consists of pebbles of quartz alone or quartz and feldspar, up to 2 cm in diameter, within a matrix of sand. This is overlain by poorly bedded dolomite, which is a very fine grained, buff-weathering rock that is gray in colour and locally contains pods and lenses of calcite and euhedral dolomite. R.V. Best has identified fragments of brachiopods, crinoids, bryozoa, and ostracods within these rocks, which indicates an age not older than mid-Ordovician.

Similar rock on the western tip of Ile des Allumettes, 22 miles to the west, was provisionally assigned to the Oxford Formation (Beekmantown Sub-Epoch of the Ordovician period) by Alice E. Wilson (1946), and later mapped as such by Katz (1969). Thus the Ordovician rocks within the map-area are evidently members of the Oxford Formation.

STRUCTURAL GEOLOGY

All rocks of the map-area, with the exception of the Ordovician sedimentary rocks, diabase dikes, and possibly some small gabbroic and granitic bodies were obviously deformed; signs of deformation appear mainly in the form of small-to-large

scale folds but also in the form of mineral foliation and lineation and gneissic texture. Faults are also present, some of which were evidently instrumental in forming the Ottawa graben. The known and presumed large-scale folds and faults within the map-area are shown in the structural map (Map 3).

I Rock Deformation

Introduction

Both planar and linear structural elements are present in the deformed rocks of the map-area, as noted above in the descriptions of the individual rock units. For the purpose of deciphering the structural history of the rocks, the most important planar elements are those varieties of layering that may be interpreted as bedding. Such layering, as exemplified by interlayered marble and gneiss or different kind of biotite and garnet gneiss, was found at numerous places within the map-area. At these places, the planar elements defined by mineral foliation and gneissic texture are almost invariably parallel to the layering. Where rocks of presumed sedimentary or volcanic origin are encountered, devoid of bedding, the existing mineral foliation or planar gneissic texture will be utilized in the structural analysis, keeping in mind the possibility that the original bedding may have had some other orientation.

Some importance will also be given to linear structural elements, particularly to mineral lineations and linear gneissic textures but also to the axes of minor folds. Within the map-area, lineations appear to be useful indicators of the nature of the deformation and the orientation of the major folds axes.

The trend of planar and linear structural elements within the map-area is shown on the structural map (Map 3), which also shows the dominant marble-rich horizons. In general, the planar elements in or near layers of marble may, with a relatively high level of confidence, be regarded as bedding.

Very little interpretation has gone into the preparation of the structural map, for nearly all trend lines are based on several to many field measurements. Where strike and dip measurements showed much local variation, the area was left blank. Each lineation symbol is based on one to a few field measurements.

The map-area has been divided into three structural zones, as indicated in the inset map of Map 3. In the Eastern zone, the dominant planar trend is north to northeast, and the lineations show much variation. In the Western zone, the dominant planar trend is north-west, and the lineations are dominantly to the south-east. The Central zone, which separates the other two zones, shows much variation in the orientation of planar elements, and possesses some characteristics of each of the adjacent zones.

The Eastern zone

The Eastern Zone occupies the eastern half of the map-area

and consists of large volumes of marble, together with plagioclase gneiss and amphibolite, potassium feldspar gneiss, and minor granitic and syenitic rocks.

Major folds

The eastern part of this zone, north of the Low fault (Map 3) is dominated by a large synform and an adjacent anti-form. These folds, which were mapped by Baker (1956), will be referred to as the Kazabazua folds. Their axial planes appear to be roughly vertical, and their axes appear to plunge about 60 degrees to the north-east.

West of the Kazabazua folds, the orientation of the planar elements becomes more uniform, for the strike maintains a value of about 20 degrees east of north, and the dip decreases and becomes fixed at about 20 to 30 degrees easterly. The rocks here apparently form isoclinal folds, with axial planes that dip to the east and axes that plunge gently to the north-east.

In a portion of Cawood township, in the vicinity of co-ordinates (50, 15) much variation is found in the attitude of planar elements, and this may be a contorted axial region of a major fold, possibly the south-westerly extension of the Kazabazua synform.

In the southern part of the Eastern zone, between the Low and Johnson faults, a similar variation in structure is found from east to west. In the extreme south-east corner of the map-area, three rather open folds, two synforms and one antiform appear to have developed in rock which consists mainly of marble.

The axial planes of these folds appear to parallel those of the Kazabazua folds, but the axes have a somewhat shallower plunge, at about 40 degrees north-east.

To the west of these folds, the potassium feldspar gneisses show considerable variation in attitude, including some easterly, near vertical trends, which may indicate local isoclinal folding in this region. Observations of this kind have suggested to Baker (1956) that the contact between the potassium feldspar gneisses and the marble to the east may be an unconformity or a fault. Alternatively, the anomalous trends may have resulted from the emplacement of the Isabel Complex.

Moving westward, into the vicinity of Sinclair lake (47, 09) and beyond, a consistent north-easterly trend is observed in the underlying plagioclase gneiss, amphibolite, and marble, with dips that are moderately steep, changing from dominantly south-east to dominantly north-west. Hence an antiform structure, with a near-horizontal axis may be present in this region.

To the west, a contorted zone is encountered, which may be the further extension of the Kazabazua synform, and to the west of this, isoclinal or near-isoclinal folds are present, with axial planes that appear to dip steeply to the east and axes that plunge 15 degrees north-easterly.

Along the southern margin of the map-area, south of the Johnson fault, at least two synforms and two antiforms are present. The axial planes, all of which are vertical or easterly dipping, appear to become progressively inclined as one moves westward; the axes plunge gently to the north-east. The nature

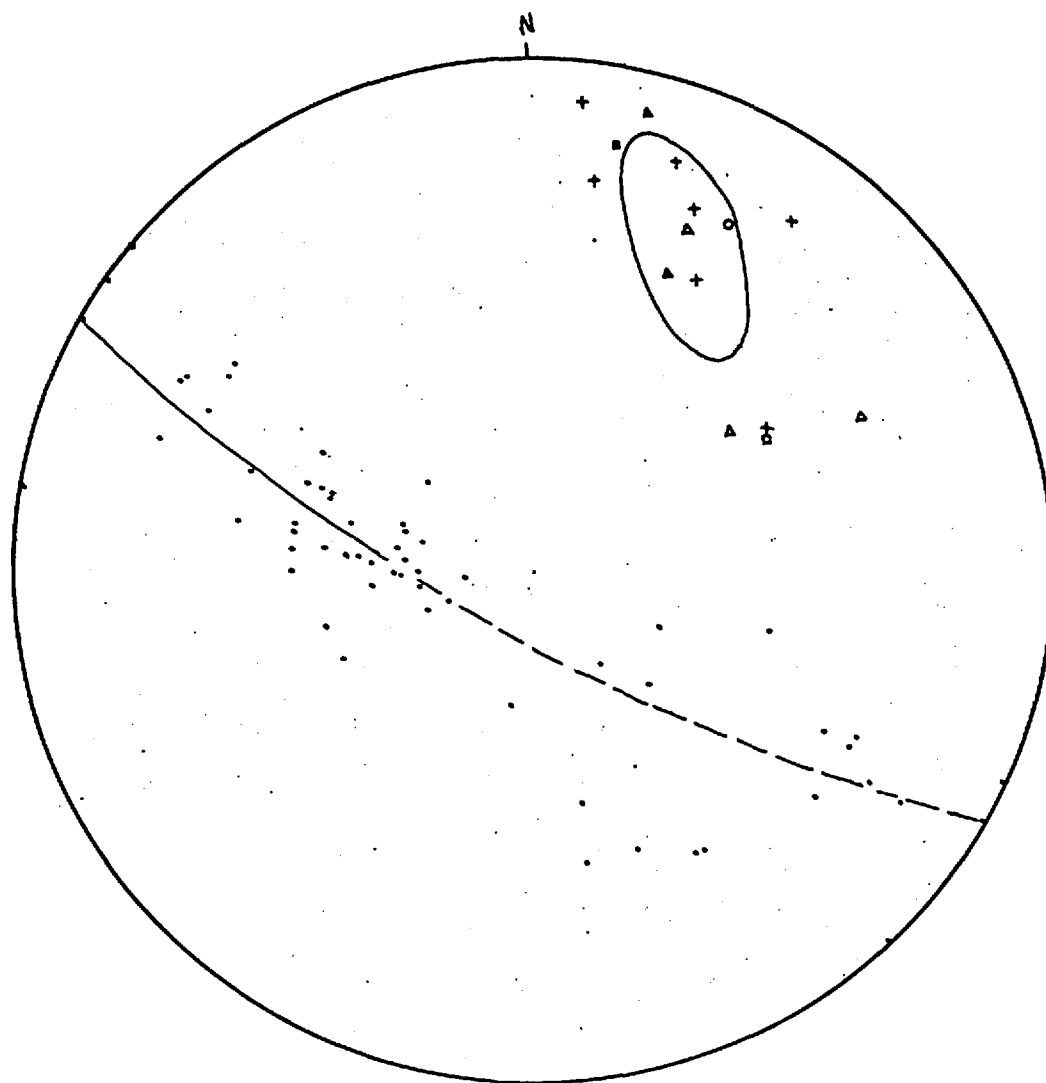
of the synform east of Ladysmith has been examined in some detail, as shown on Map 2B.

The existence of some of the folds described above has been established with confidence, while others are somewhat conjectural. Thus in the southern half of the Kazabazua River sub-area (Map 2A), there is little doubt that the variation in strike and dip is the result of the presence of northeasterly plunging folds, one of which is shown. This is confirmed by observing in Fig. 35 that the poles to the planar elements define a girdle, whose axis plunges gently northeasterly.

In the northern part of the sub-area, all planar elements dip gently to the east, as shown in Fig. 36, and the presence of isoclinal folding is largely a matter of interpretation. The inferred continuation of the two dominant layers of marble to produce a synform, as shown on Map 3, is speculative:

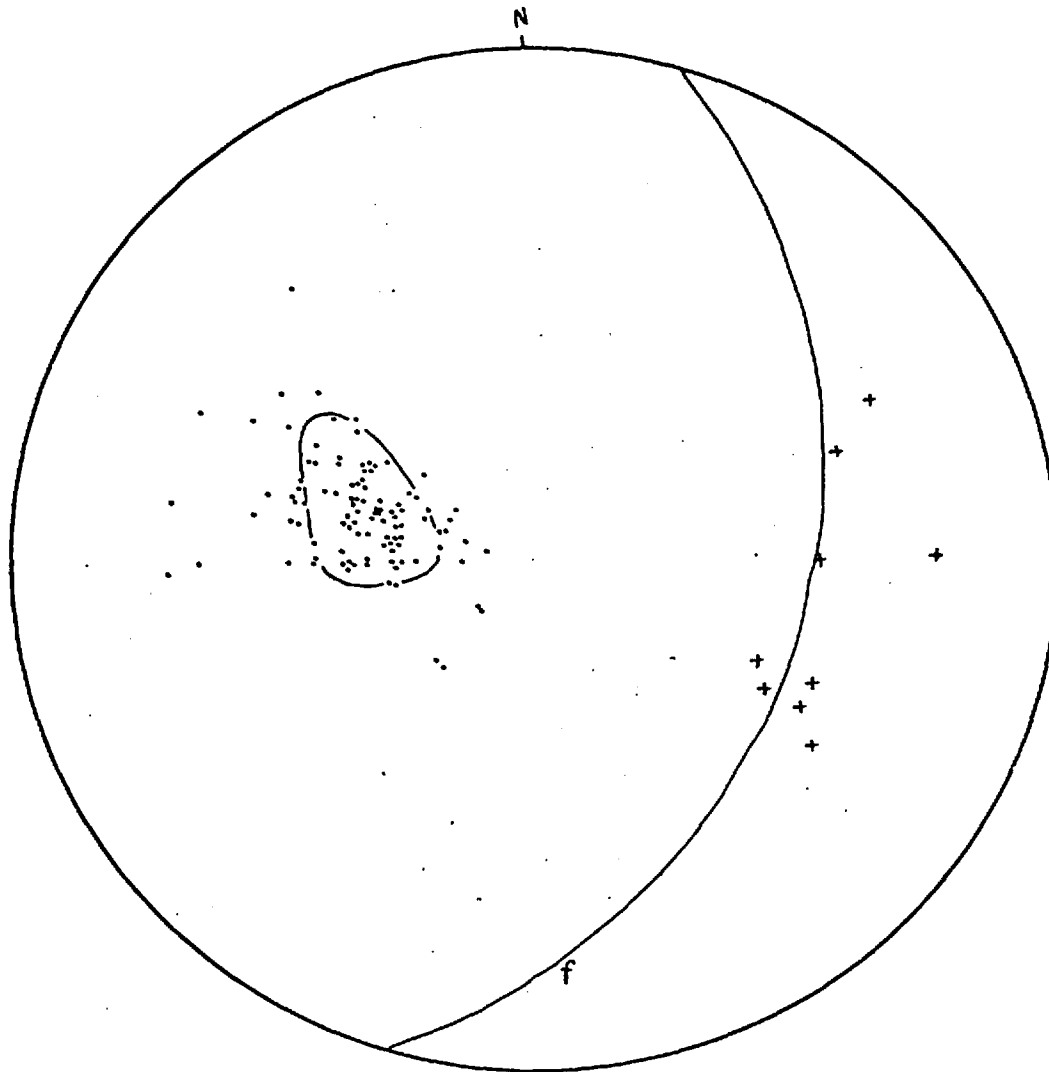
The presence of two major near-isoclinal folds along the western margin of the Eastern zone, one at (48, 24) and the other at (58, 23), as shown on Map 3 is deduced largely on the basis of converging structural trends, and appears to be fairly well established.

Thus considerable variation is found within the Eastern zone with regard to the shape and orientation of major folds. In general, the folds become more closed toward the west, and the axial planes turn from north-east to north, accompanied by a change in dip from vertical to gently east. Also the orientation of the fold axes changes from fairly steep in the east to gently plunging in the western part of the zone. Despite these variations, all of the large-scale folds described above



- Poles to layering, planar gneissosity, mineral foliation
- + Mineral lineation
- ◻ Fold axis, plagioclase gneiss
- △ Fold axis, quartz-feldspar layer in marble
- Variation in fold axes (12 measurements), quartz-feldspar layers in marble at co-ordinates 48.57, 20.42
- ◊ Girdle axis

FIGURE 35 - Stereographic projection of planar and linear elements in the southern part of the Kazabazua River sub-area.



- Poles to layering, planar gneissosity, mineral foliation
- Variation in poles to layering, planar gneissosity, mineral foliation (17 measurements) in an area 240 x 900 m at co-ordinates 49.8, 20.8
- + Mineral lineation
- f Mean of planar features

FIGURE 36 - Stereographic projection of planar and linear elements in the northern part of the Kazabazua River sub-area.

are regarded as being roughly contemporaneous, and will be referred to as north-east folds.

Evidence for a later period of folding within the Eastern zone is found east of Lac Petit Cayamant (59, 19) where the easterly dipping planar elements appear to be gently folded about east to south-east axes. Other possible folds of similar form are found in the Kazabazua River sub-area (50, 19) and along the northern limb of the Kazabazua synform (54, 10). These folds will be referred to as south-east folds.

Minor folds

Numerous minor folds, i.e. folds which are observed in individual rock outcroppings were found in the rocks of the Eastern zone, and the orientation of the axes of most of these is shown on Map 3. Much variation exists in the orientation of the axial planes, which vary from vertical to gently dipping, and in the degree of closure which ranges from open to tightly closed.

Locally, the axes of minor folds parallel those of the major folds, as shown for example in the southern half of the Kazabazua River sub-area, where the axes of minor folds, including folded quartz-feldspar layers in marble which may not represent bedding, lie roughly parallel to the major fold axes, as illustrated in Fig. 35.

The minor folds in marble along the eastern margin of the map-area show an especially wide range in orientation with the bearing of the axes falling in all four quadrants, and the plunge ranging from horizontal to vertical. The folds at one

locality are shown in Fig. 37(a) which indicates that south plunging isoclinal folds were subsequently folded about north-easterly plunging axes.

An example of irregularly-shaped folds, with variation in the shape and orientation of axial planes, involving interlayered marble and gneiss, is shown in Fig. 37(b). Intensely folded quartz-feldspar layers in marble are shown in Fig. 38, attesting to the intense strain that the marble has locally experienced.

Minor folds are also present in the gneisses and amphibolites of the Eastern zone, but these are more consistent in orientation, plunging mainly to the northeast, parallel to the major fold axes. Quartz-feldspar veins are also commonly folded, as shown in fig. 37(c), which illustrates that some veins were emplaced prior to deformation and others subsequently.

Isolated blocks of gneiss or amphibolite in marble and boudinage structures involving silicate rock in marble are common in the present map-area, as in other marble-bearing metamorphic terrains, and the impression obtained from an examination of these features is that the marble behaved in a relatively plastic manner during deformation. Hence not a great deal of importance can be assigned to the orientation of individual minor folds in marble, and the general variability in fold axes may be attributed to irregularity in the movement that has taken place within the marble bodies, causing early-formed folds to rotate to some extent during deformation. However the presence of isoclinal folding in the eastern part of the Eastern zone does indicate that at least locally, deformation was more intense than would be expected

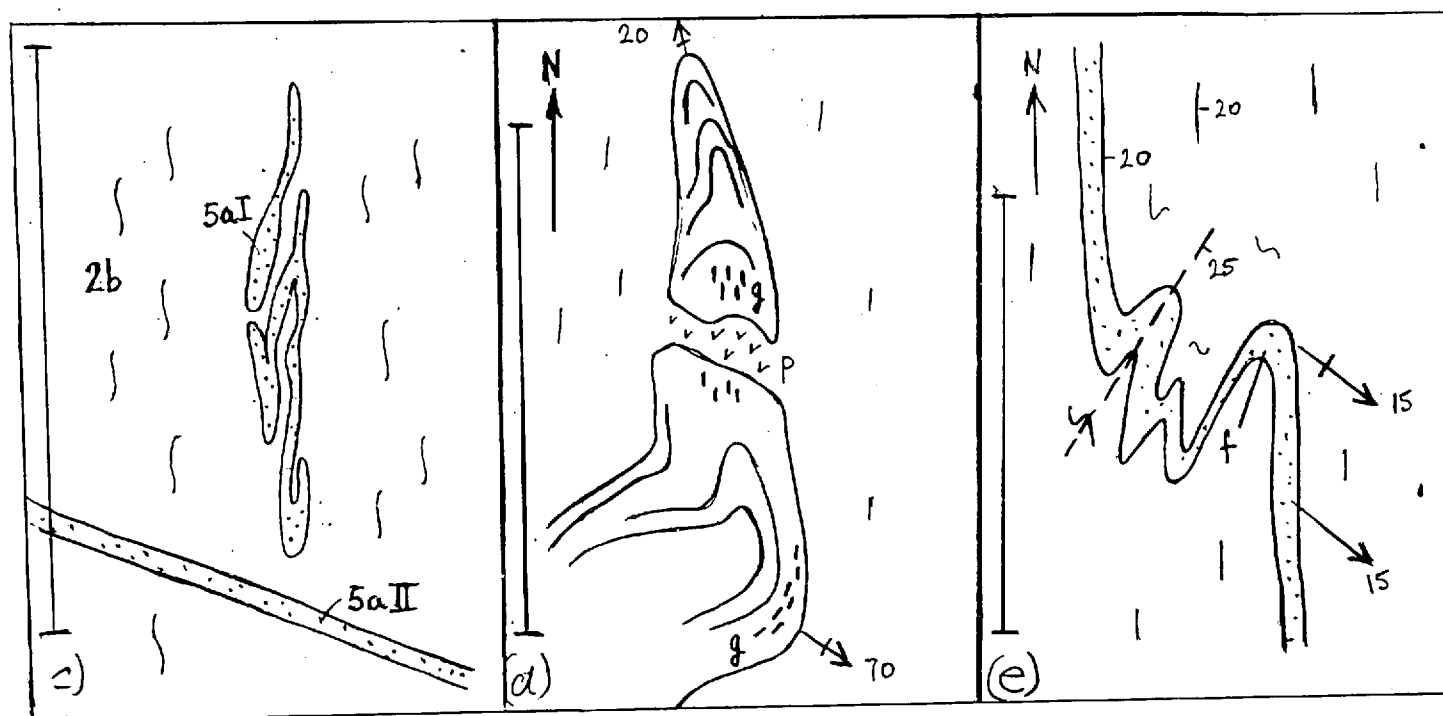
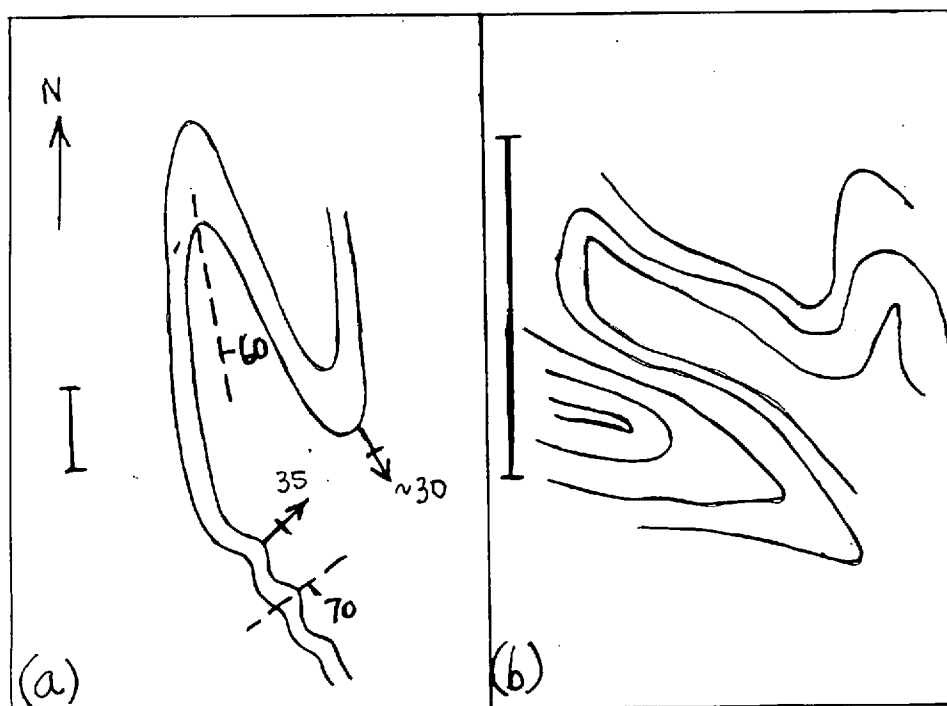


FIGURE 37 - Minor folds:

- a) sketch of near-isoclinal folds in marble, and local small open folds, presumably younger in age, south of Kazabazua (53.4, 01.6);
- b) minor folds with variably-oriented axial planes, in interlayered calcite marble and silicate-rich marble, northeast of Ladysmith (47.4, 17.2);
- c) isoclinally-folded white quartz-feldspar veins (5aI) in garnet-biotite gneiss (2b), and later cross-cutting white quartz-feldspar vein (5aII), at road cut, north of Kazabuzua (58.0, 0.1.5);
- d) isoclinally-folded hornblende gneiss and hornblende-garnet gneiss surrounded by biotite gneiss and pegmatite, deformed by a southeasterly plunging secondary fold. Note boundinage-like structure, with pegmatite (p) filling inter-boudin spaces, and note orientation of planar gneissosity at g. The section is nearly horizontal, and oblique to the major fold axis. Location, south of Vinton (46.7, 36.5);
- e) locally folded amphibole layer in veined gneiss, showing orientation of fold axes, axial planes, and mineral lineation within amphibolite. Axial plane foliation has developed only locally, near the inner contact of the amphibolite (at f), not elsewhere in the amphibolite nor in the veined gneiss. Location, south of Sparling lake (46.6, 26.2). Bar in Figs. a to e is approximately 1 metre long.

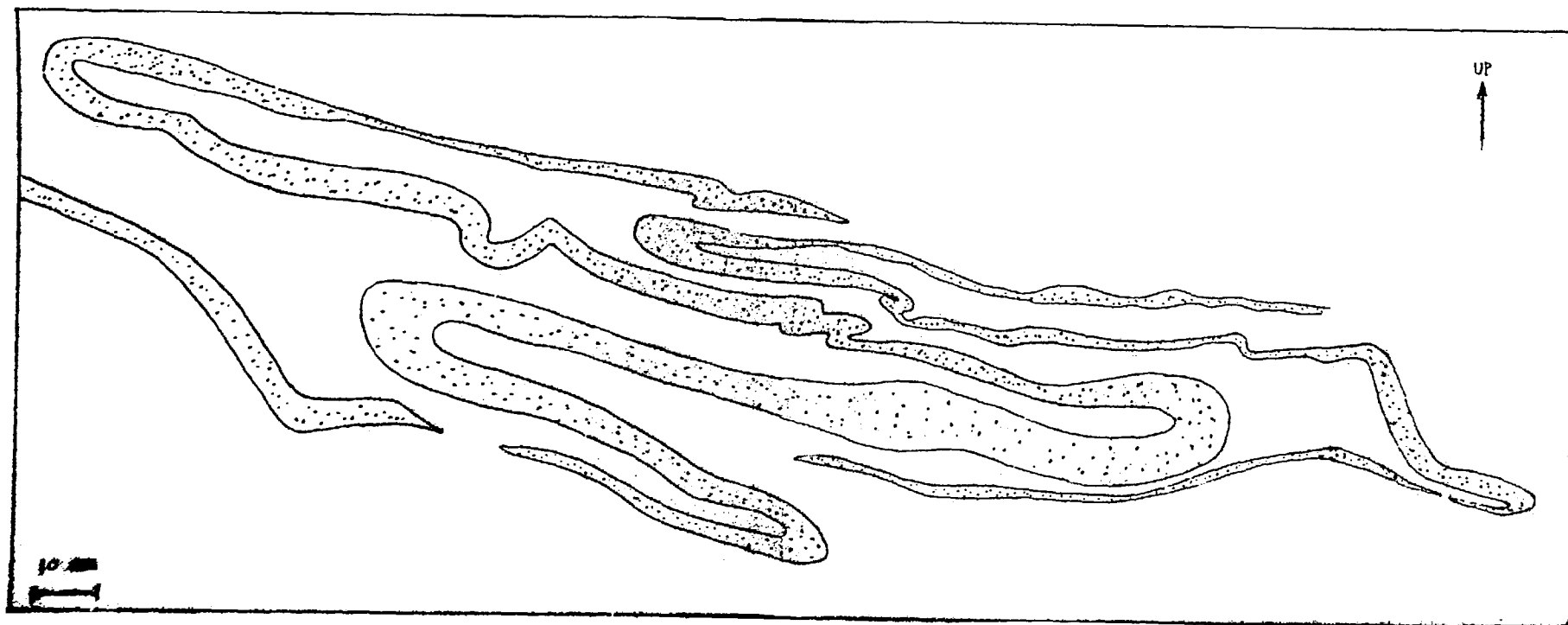


FIGURE 38 - Vertical section of folded quartz-feldspar layers in marble, looking north 60° east; bar is 1 metre long. Location, southeast of Otter Lake village (50.4, 23.5).

to result from the rather open folding indicated by the major folds. It is suggested therefore that the rocks may have been folded, possibly isoclinally, prior to the deformation that produced the north-east folds, but this is not conclusive.

Lineations

Linear elements produced by mineral lineations and linear gneissic texture in the Eastern structural zone generally have bearings that fall in the north-east or south-east quadrants, and plunge gently to moderately, but possess a considerable variation, as shown on Map 3. Some of these lie parallel to axes of northeast folds, or nearly so, as shown in Fig. 35, while others, that plunge easterly or southeasterly may be related to the south-east folds described above.

Two of the three Stag plutons, which consist largely of syenite, have strong north-easterly plunging lineations, while the third, together with the Cawood nepheline syenite have strong south-easterly plunging lineations.

Thus most, but not all of the lineations, can be related to the dominant north-east folds and the weakly developed south-east folds.

The Western Zone

The Western structural zone, shown on Map 3 consists of marble, plagioclase gneiss and amphibolite, potassium feldspar gneiss, and a higher proportion of granitic and syenitic rocks than does the Eastern zone. It is characterized by planar elements (layering, gneissosity, foliation) that strike northwest and dip at moderate to steep angles toward

the north-east or the south-west. The linear elements (mineral lineation, gneissic lineation) with few exceptions plunge to the south-east at angles ranging from zero to 50 degrees. These lineations are locally very well developed, and are more uniform in orientation than similar lineations in the Eastern zone.

Major folds

One conspicuous major fold is found in the Western zone, in rocks of the Bell Mount Complex and the adjacent gneisses. The nature of the axial region of this fold, as seen west of Hickey lake (56, 39) seems to indicate that the fold plunges about 30 degrees to the south-east, but on the limbs of the fold, planar elements are seen to dip both toward and away from the presumed location of the axial plane. Hence the fold appears to be a complex synform-like structure, possibly with a curved axis.

In large portions of the Western zone, the planar elements of the gneisses and granitic rocks are observed to strike consistently north-west but to change in dip from north-east to south-west, the changes occurring within distances of a few tens to a few hundreds of meters. These structures, as found in Huddersfield township (58, 33) and north of Vinton (49, 36) appear to be folds with near-horizontal north-westerly trending axes, and near-vertical axial planes.

A few large flexures are evidently present in the Western zone, for example on the Western margin of the map-area (56, 44) and south-east of Vinton (46, 35). The axes of these flexures appear to plunge gently to the south-east.

In the south-west corner of the map-area, in Grand-

Calumet township, where some northeasterly trending planar structures are found, the structural picture is still somewhat obscure. The reason for this may be that many of the planar elements, for instance those produced by layers of diopside skarn in marble and by gneissosity in amphibolite may bear no relation to original bedding; indeed, some of the amphibolite may be metamorphosed intrusive dikes, similar to those illustrated in Fig. 11. Also, the emplacement of the Lafontaine pluton may have produced local distortions. Thus, despite detailed mapping by Shaw (1955) and the writer, no clearly defined major folds have emerged. Shaw postulated the presence of a northeasterly trending major fold, with an axial plane passing through the centre of the Lafontaine Complex, and a fold on either side. If information could be obtained to demonstrate that the two major marble zones shown on Map 3 are continuous, Shaw's central fold would appear to be an antiform with an axial plane that strikes northeast, and an axis that presumably plunges southeast, parallel to the dominant lineation. If this picture is correct, the Lafontaine pluton would form the core of the antiform.

Thus the dominant major structures in the Western zone are evidently folds and flexures, with axes that bear southeast and range in plunge from zero to about 30 degrees. These resemble the southeast folds of the Eastern zone, but are in general more tightly folded; they will also be referred to as southeast folds.

Minor folds

Numerous minor folds were observed throughout the Western zone, and the axes of many of them are shown on Map 3. Most of the

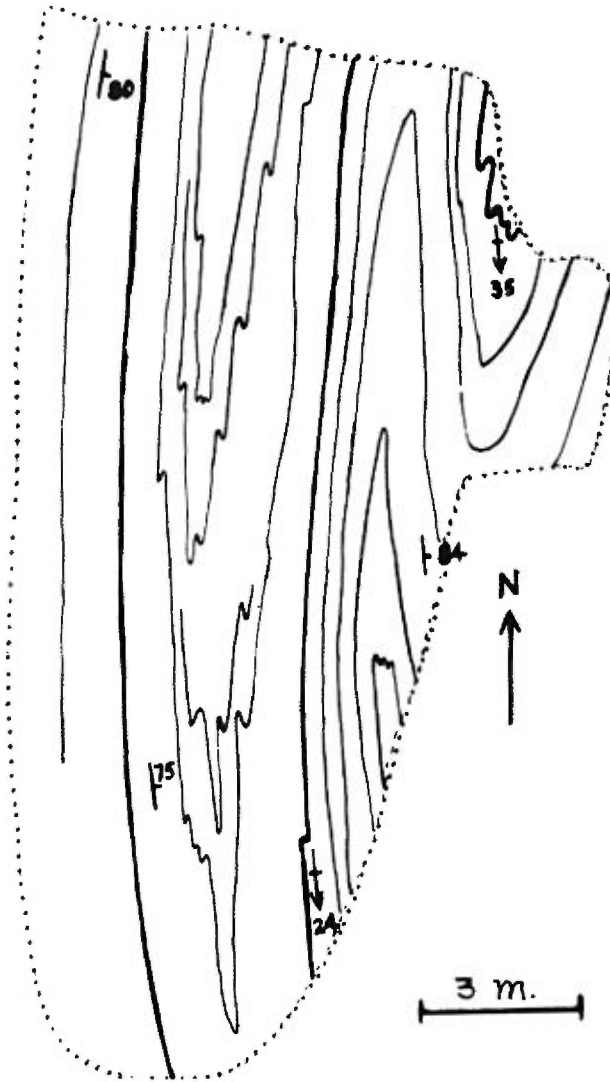


FIGURE 39 - Map of isoclinally folded marble; light lines represent bedding planes, heavy lines represent silicate layers, mainly disjointed. Bar is 10 feet (3 meters) long. Location, Grand-Calumet township (45.9,41.0).

Figure 40 - Folded quartz-feldspar layers in amphibolite, Grand-Calumet township. Photograph by E.W. Hearn.



folds, including folded quartz-feldspar veins, plunge gently to the south-east.

Many of the folds that were observed in the marble of Grand-Calumet township resemble those of the Eastern zone with regard to variations in attitude. An example of isoclinally folded marble in which bedding is preserved is shown in Fig. 39; the axes plunge about 30 degrees to the south, at a fairly large angle to the dominant mineral lineation in the vicinity. This fold may have formed prior to the dominant south-east lineation.

An example of minor folds involving quartz-feldspar veins in amphibolite, also from Grand-Calumet township is shown in Fig. 40. The axes of these folds lie parallel to a well-developed mineral lineation in the enclosing amphibolite, and in the absence of folded bedding, they provide ample evidence that the amphibolite has experienced a large magnitude of strain.

Intense minor folding has also been observed in a zone of garnet-bearing gneiss and amphibolite that is located south-east of Vinton (between 45.4, 36.0 and 46.7, 36.5), and is bordered by veined gneiss. Many of the folds in this zone are isoclinal, with shallow-plunging axes and one of these, shown in Fig. 37(d) was disjointed to form a boudinage structure, and then folded slightly about a steep easterly plunging axis. Further examples of folding and boudinage structures from this zone are shown in Figs. 41 and 42. Isoclinally-folded hornblende-biotite-garnet gneiss and amphibolite is shown in Fig. 41; a portion of the fold was evidently disjointed and displaced, the interspace being filled with relatively plastic biotite-

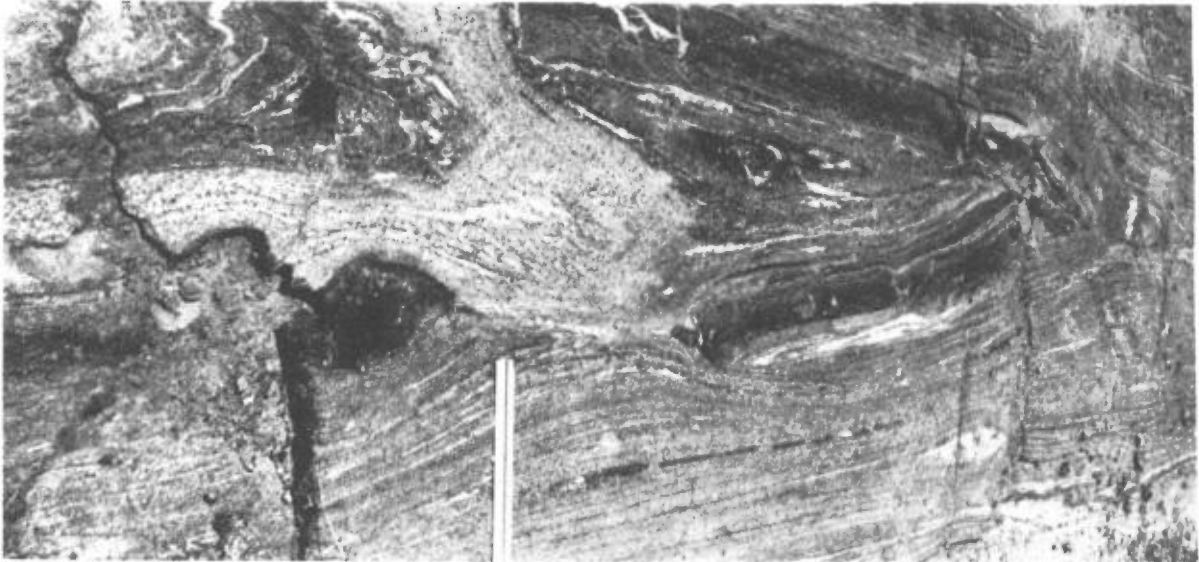


FIGURE 41 - Isoclinally folded hornblende-biotite-garnet gneiss (gray), amphibolite (dark gray), and biotite-garnet gneiss (light gray). Scale is 1 foot (30 cm) long. Southeast of Vinton (46.7, 36.5).

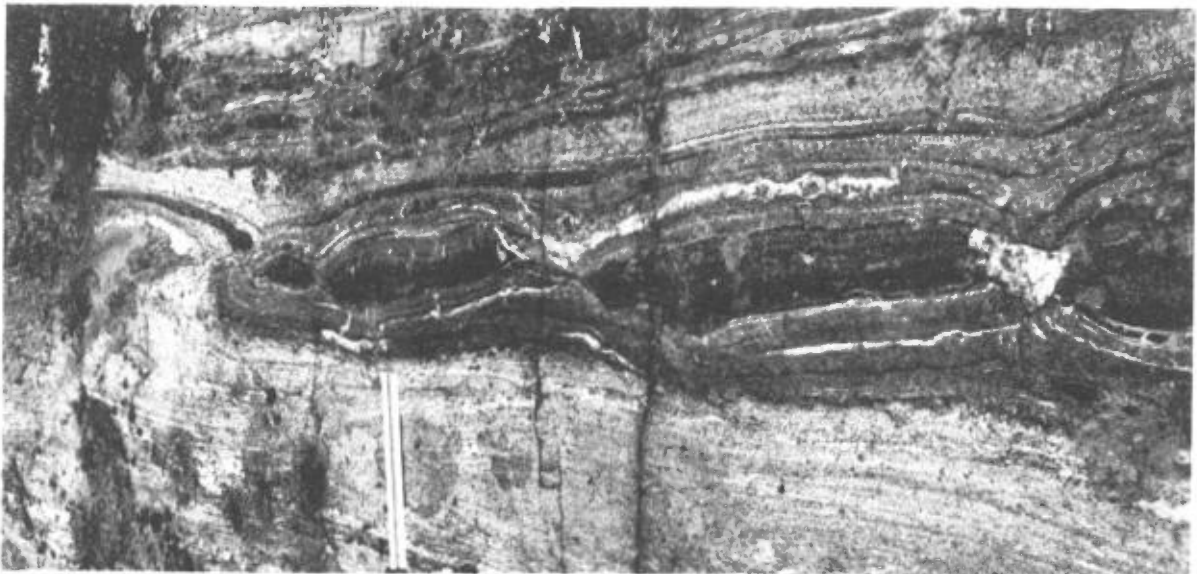


FIGURE 42 - Isoclinally folded biotite gneiss, with a core of amphibolite, which has been disjoined to produce boudinage structure. Scale is 1 foot (30 cm long). Southeast of Vinton (46.7, 36.5).

garnet gneiss. Deformation of this kind can obviously give rise to considerable variation in the shape and orientation of fold-like structures. The structure shown in Fig. 42 appears to be an isoclinal fold in biotite gneiss, with a core of amphibolite, the whole having been further compressed, causing the amphibolite to become disjointed to produce a boudinage structure.

The veined gneiss adjacent to the intensely deformed zone described above, shows signs of rather open minor folding about nearly horizontal south-east trending axes. The planar elements that are folded here are quartz-feldspar veins, which are considered to have been introduced during a period of metamorphism and metasomatism; the original layering or bedding is no longer visible. The minor folds in the veined gneiss are considered to have formed together with the major south-east folds, while those that are present in the garnet gneiss-amphibolite zone may have formed at an earlier time.

Lineations

In the Western zone, mineral lineations and linear gneissic textures almost invariably bear south-easterly and plunge at small to moderate angles to the south-east. Locally the lineation is nearly horizontal or plunges gently to the north-west. A few anomalous north to north-east lineations were observed, for example in the rocks north of Fort-Coulonge (54, 44).

Some of the amphibolites and granitic rocks in Grand-Calumet township show a very well developed lineation (Maps 2c, 3) with a plunge angle that varies from place

to place but on the average is relatively steep. Well-developed lineations are also present in amphibolite and potassium feldspar gneiss north of the Ottawa River, between Vinton and Greer Mount (Maps 1, 2B, 3), but here the lineations are nearly horizontal. In general, the orientation of the lineations is roughly parallel to that of the inferred axes of the major southeast folds, and thus folding and the development of lineation are considered to be contemporaneous. Apart from the few widely divergent lineations, the observed variation could conceivably result from variations in local strain occurring during a single period of deformation.

The Central zone

The key to the relationship between the northeast folds of the Eastern zone and the southeast folds of the Western zone may possibly be found at the junction of the two zones. The junction, however, is not a line or a plane, but a zone 2 to 6 miles wide, characterized by a great variation in strike and dip of planar structures. This zone (Map 3) consists of plagioclase gneiss and amphibolite, potassium feldspar gneiss, and granitic-syenitic rocks, and will be referred to as the Central zone. Its boundaries are marked by two lines (actually planes of unknown dip) beyond which the pronounced trends in the Eastern and Western zones can no longer be clearly recognized. Locally, however, within the Central zone, north-west to north-east trends are discernable, as shown in Map 3.

The attitude of planar elements in most of the Central zone, excluding the narrow portion, along the southern margin of the map-area, is shown in Fig. 43, where the

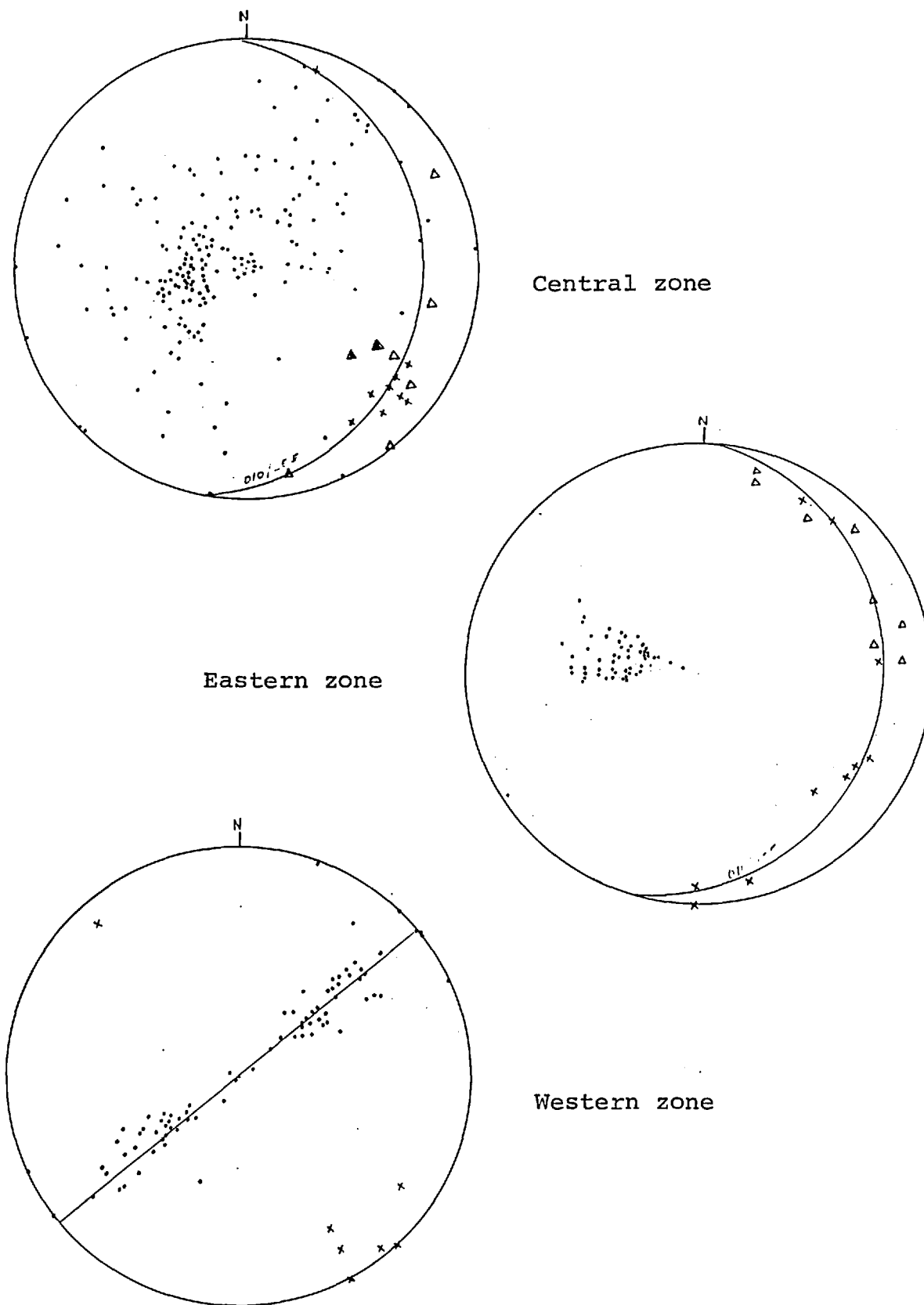


FIGURE 43 - Stereographic plot of planar and linear elements
• poles to planar features
x lineations
Δ small-fold axes

planes are plotted as small circles in a lower-hemisphere stereonet. The great variability in attitude of planar elements is shown in this figure by the scattered distribution of points. The orientation of planar elements along the western margin of the Eastern zone, where a pronounced north to northeast trend is present, is also shown; these points are clustered about a mean orientation of $010 / 25$ east. The orientation of planar elements along the eastern margin of the Western zone, shows a pronounced northwest trend; the points define a vertical girdle, as expected, for the rocks appear to be folded about nearly horizontal northwesterly trending axes. It is apparent from Fig. 43 that some of the planar elements in the Central zone are parallel to those in the Eastern zone while others are parallel to those in the Western zone, but many lie at highly divergent angles. It is clear, however, that north-easterly striking planar elements, with dips that are vertical or moderate to the north-west are relatively rare, for the corresponding area on the stereonet is nearly vacant.

Lineations are also plotted in Fig. 43. In the eastern margin of the Western zone, as in the zone as a whole, the lineations show little variation, and the points are clustered. In the western margin of the Eastern zone, lineations show greater variation, but because they are confined to the foliation plane, they fall near the great circle which represents the mean planar element. Now the lineations in the Central zone, with few exceptions, are

parallel to those in the Western zone, as shown in Fig. 43. Thus with regard to mineral lineations and linear gneissic textures, the Central zone resembles more closely the Western than the Eastern zone.

Only eight measurements of minor fold axes were obtained from that part of the Central zone that is presently under study, and five of these cluster with the southeasterly lineations, well away from the northeasterly axes which occur in the Eastern zone. Thus all linear elements, including fold axes of minor folds more closely resemble those of the Western than the Eastern zone.

Further information on the transition from the Eastern to Western zones is given on Map 2B which covers the southern, relatively narrow part of the Central zone. Here one may observe in the potassium feldspar gneisses west of Ladysmith, a gradual change from a northerly strike to a north-westerly strike, accompanied by a steepening of dip. Meanwhile the variously oriented linear elements of the Eastern zone become resolved into a single south-easterly lineation, which is characteristic of the Western zone. The nature of locally-developed south-easterly plunging minor folds in northerly striking rocks on the hill south of Sparling lake is shown in Fig. 37(e).

Secondary Planar Elements

At a few localities a weakly developed mineral foliation or gneissic texture was found oblique to a well-developed foliation and planar gneissic texture. The few measurements available, as shown in Maps 1 and 3 strike north-east, but it is uncertain at present if these have regional

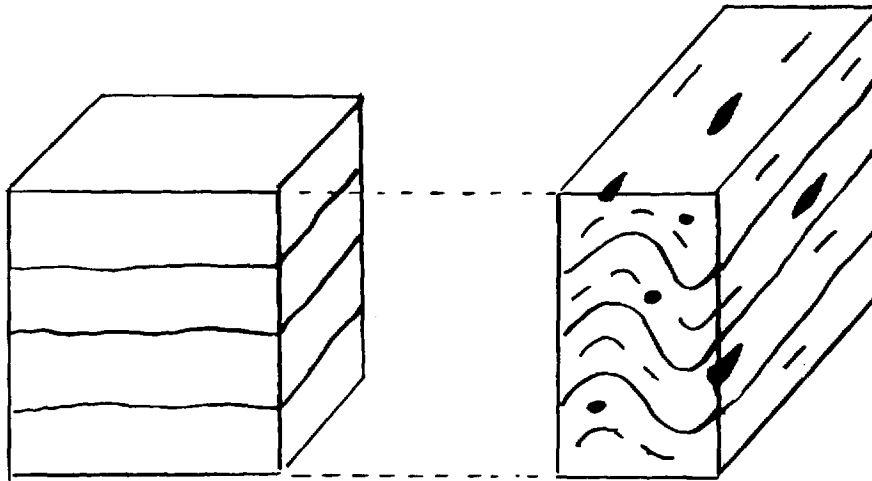


FIGURE 44 - Postulated strain in a body of rock, to produce folds, planar elements (mineral foliation, planar gneissosity) and linear elements (mineral lineation, linear gneissosity), the latter parallel to fold axes.

significance.

Deformational History

The above information indicates that much of the rock of the map-area has been deformed or strained and that the magnitude of strain at least locally was sufficiently great to produce isoclinally-folded planar elements. Mineral lineations and linear gneissic textures, which are for the most part shallow plunging, were evidently produced at the time of the most recent major deformation, possibly as the result of a pattern of strain similar to that shown in Fig. 44. The mineral foliation and planar gneissic texture presumably also formed at this time, but the orientation of these elements, which in general is parallel to layering, may have been controlled by the strain itself or by a pre-existing foliation that was oriented parallel to the layering.

Evidence was cited above, in connection with plagioclase gneiss and amphibolite, for an early period of deformation, followed by the emplacement of mafic dikes, followed by a later period of deformation and metamorphism. Also, some evidence for an early period of folding, preceding that which produced the major north-east and south-east folds was found in the minor folds of the Eastern and Western zones. It seems likely therefore that the rocks of both zones experienced an episode of deformation and possibly of low-grade metamorphism prior to that which produced the North-east and South-east folds. On the other hand, no complex interference patterns were found, for instance in the shape of the marble layers, and few conspicuous refolded folds were

found among the minor and major folds of the map-area.

The cause for the two contrasting structural trends within the map-area and surrounding portions of the Grenville province is not yet adequately understood. In the north-central part of the map-area, younger south-east folds appear to be imposed on older north-east folds. If the south-east folds to the west are of the same age, then the Western zone may represent a late period of deformation. The Central zone would then represent an area wherein the south-east folds are partially superimposed on the earlier north-east folds, thus accounting for some of the variation in attitude of planar elements found within this zone. A greater amount of granitic-syenitic rock is found in the Western than in the Eastern zone, and most of this may have developed during the South-east period of deformation.

II Fractures, Faults, Mylonites, Breccias

Fractures

The dominant fractures or joints in the map-area strike easterly and dip nearly vertically, parallel or nearly parallel to the diabase dikes. Fracture sets were also observed in various other directions.

Faults

A number of easterly to south-easterly trending faults pass through the map-area. The faults shown on the structural

map (Map 3) include those that have been located with confidence and others inferred to be present, as shown separately on Map 1.

The Coulonge fault

The presence of a major fault north of Fort-Coulonge was deduced by Marshal Kay (1942), who referred to it as the Coulonge fault. This fault presumably produced the conspicuous escarpment northwest of Fort-Colounge, which marks the border between the Ottawa valley lowlands and the Laurentien highlands. Because the valley here is floored by flat-lying Paleozoic strata, which are absent from the highlands, Marshal Kay (1942, p. 612) concluded that the south side of the fault was displaced downward relative to the north side by at least 1000 feet. Thus the rocks of the valley, at the time of metamorphism and deformation, may have rested at a higher level than those of the highlands, which might account for the apparently slightly lower grade of metamorphism in the lowlands, on Ile du Grand Calumet.

The Coulonge fault evidently played a part in forming the gorge of Coulonge chute, where evidence for faulting was reported by Retty (1932), and is found in the form of breccia, slickensides, and differences in attitude of layering on either side of the gorge. Eastward from here, Marshal Kay (1942, p. 613) suggested that the fault follows along the Vinton escarpment, but according to the writer's interpretation, the Coulonge fault continues beneath the pronounced valley formed by the Serpentine river and Litchfield lake, and another fault (the Vinton fault)

is responsible for the Vinton escarpment (Map 3). Some spectacular fault breccias consisting of angular fragments of granitic rock, up to 1/3 meter in diameter were found at three places in the Serpentine river valley, at places indicated on Map 1; the matrix of the breccias consists of fractured and displaced grains of feldspar and grains of quartz that show evidence of internal strain. Also present are white mica, carbonate, and chlorite. Some of the large angular fragments have slickensided surfaces.

A conspicuous valley, at an angle to the structural trend, lies south of Litchfield lake, and this is presumed to be the site of a branch of the Coulonge fault, as shown on Map 3.

The Vinton fault

Only meager evidence is available for the Vinton fault, and its location as shown on Map 3 is speculative. A major fault is presumed to separate the Ottawa valley lowlands from the highlands north of Vinton, and a branch of this fault may be responsible for the Vinton escarpment, as shown on Map 3. The presumed Vinton fault may intersect the Coulonge fault in Coulonge chute and it may underlie the valley to the northwest. Presumably, the vertical displacement on the Coulonge fault decreases to the east while that on the Vinton fault increases to the east.

The Low fault

A conspicuous topographic lineament, in the form of a valley and a small escarpment, extends from the eastern border of the map-area to the area north-west of Leslie lake, a distance of some 30 miles. This is presumed to be

the locus of an important fault, here referred to as the Low fault (fig. 18). The fault was first recognized by Baker (1956) in the eastern part of the map-area, where a right-hand offset of 1 to 2 miles was indicated by geological mapping. To the west, further evidence for the existence of the Low fault was found by the writer in the Kazabazua River sub-area (Map 2A), where the lithology and structure of the rocks north and south of the presumed location of the fault are different. Also, some rocks near the lineament were found to be much altered to secondary minerals.

By analogy with the Coulonge fault, the Low fault may also have produced some vertical displacement, the south side moving down relative to the north, but the displacement may not have been as great. The right-hand offset in the eastern end of the fault could be produced by the south block moving down or to the west relative to the north block.

The Johnson fault

A conspicuous east-west linear valley which contains Johnson and Sparling lakes evidently forms the locus of a fault, here referred to as the Johnson fault. Evidence for faulting, in the form of highly altered rock was found at a few places along the lineament, for example south of Sparling lake where some highly altered and crushed rock was found, in which some small faults are visible.

Further evidence for faulting is found in the discontinuity of lithology and structure north-east of Lady-smith, and the apparent displacement of the western boundary of the Eastern structural zone, as seen west

of Ladysmith. Judging by the displacement, the horizontal component of movement on the Johnson fault is small.

The Thorne fault

Evidence for the Thorne fault, through Ladysmith, exists mainly in the form of a prominent east-west lineament, and also in an apparent displacement in lithology east of Ladysmith and in the presence locally within the lineament of highly altered rock. This fault may possibly be a continuation of the Coulonge fault.

The Hickey fault

Fault breccia was found at one place near Hickey lake, in the north-west part of the map-area (Map 1), within an east-west lineament, and a relatively small east-west fault is considered to be present here.

Northerly-trending faults

Evidence for northerly-trending faults was found at a few localities.

In the north central part of the area, near Lauréat, numerous fault planes are exposed in a road cut; the faults strike 30 degrees east of north and have a variable dip, the average of which is nearly vertical. Slickensided surfaces indicate vertical movement. Mylonites are also present, and the site may be on an old shear zone, along which some relatively recent movement has taken place.

Evidence for a fault zone is found north of Kazabazua, where near-vertical fault planes strike about 20 degrees east of north, and some fragmented rocks, containing many quartz veins are exposed. The presumed fault evidently

produced a right-hand displacement of a zone of plagioclase gneisses, as shown on Map 3.

The Otter, Grove, and Picanoc Lineaments

The Otter Lake - Lac Petit Cayamant valley, the Grove Lake valley, and the Picanoc valley were described earlier in this report, where attention was drawn to the remarkable lineaments that are created by these three valleys, as shown on Maps 1 and 3. Further study is needed to determine whether or not these are fault-controlled lineaments.

Mylonites

Mylonitic silicate rock and marble were found at several places throughout the map-area, and appear to be of only local development; no through-going mylonitic zones appear to be present. Where found, the mylonitic zones are generally only a few cm thick and lie parallel to the dominant layering and foliation.

Mylonitic granitic rock is well exposed in a road cut north of Kazabazua (58.0, 01.5); the mylonite zone here is nearly horizontal.

Mylonitic marble occurs at numerous places, for example in the Kazabazua River sub-area (49.8, 21.0) where it forms thin zones in normal marble. The zones are darker in colour as a result of the dispersal of graphite and the small grain size of the calcite. Larger crystals (cataclasts) of dolomite may be present.

The mylonites presumably formed during the closing of the most recent major period of deformation.

The Coulonge breccia

A peculiar rock consisting of nearly spherical fragments

of syenite in a calcite-bearing matrix was found at a few localities in the Coulonge valley, and is here referred to as the Coulonge breccia. It may be readily examined on a cliff in lot 15, range V of Mansfield township (53.8, 41.5), which will be regarded as the type locality.

At the type locality the breccia is a conformable, tabular or lens-shaped body which is underlain by heterogeneous syenite and overlain by interlayered hornblende gneiss and syenite. The body is about 15 meters thick and dips moderately to the south-east.

The underlying rock is a heterogeneous pyroxene syenite, which contains veinlets of green pyroxene and some irregular masses of coarse-grained calcite. The amount of calcite increase upwards, and immediately below the breccia is a 2-meter zone in which grains, pods, and veinlets of calcite are abundantly present.

The breccia itself consists of near-spherical fragments of syenite, 1 cm to 1 meter in diameter, in a matrix composed mainly of calcite, potassium feldspar, and black amphibolite. In typical breccia, as shown in Fig. 45, the proportion of fragments to matrix is approximately 3:7.

The mineral content and texture of the syenite fragments varies considerably, and adjacent fragments may be quite different from each other. Minerals that have been identified within the fragments include potassium feldspar, dark green calcic pyroxene, black amphibole, biotite, sphene, calcite, apatite, and pyrite. Some fragments are distinctly zoned; for example the rims



FIGURE 45 - The Coulange breccia: round fragments of syenite in a calcite-rich matrix.

may contain a greater content of ferromagnesian minerals than the cores. Some fragments were observed to have striated surfaces.

The minerals of the matrix are the same as those found in the fragments, with the exception of biotite. The matrix is fairly homogeneous, and the crystals appear to be randomly oriented.

Overlying the breccia is a layer of syenite, about $\frac{1}{2}$ meter thick, which contains pods and veins of calcite, and is similar to the rock immediately below the breccia. Overlying this is interlayered hornblende gneiss and syenite. The upper contact of the breccia, as seen at one place, is a sharp contact which is somewhat striated, the striae plunging about 30 degrees to the east. The striations on the fragments immediately below this plane are variable in orientation, but tend to lie within a plane parallel to the contact plane. The matrix here is mylonitic.

Similar rock was found at a few other localities, as shown on the geological map (Map 1), including the gorge of the Coulonge chute. On a hill 1 mile north-west of the chute, irregular and apparently isolated bodies of breccia are found in syenite.

The Coulonge breccia may be a metamorphosed fault breccia. According to this interpretation, the matrix of the original fault breccia was partially replaced by calcite, and the fragments were rounded, presumably by replacement, which also produced zoning in some fragments. Later movement in the breccia zone produced mylonitization

of the matrix, and striations on the surfaces of some fragments. This later movement may have occurred while movement on the Coulonge fault was in progress.

PLEISTOCENE AND RECENT GEOLOGY

The map-area is covered by a blanket of unconsolidated material, through which the underlying bedrock protrudes at innumerable places. The material consists of till, and in the lower-lying regions, of stratified drift, including clay, silt, sand, and gravel. The distribution of relatively thick and continuous deposits of unconsolidated material is shown on the geological map (Map 1). All of these deposits are of Late Pleistocene and Recent age.

Summary of Late Pleistocene and recent events in the Ottawa Valley and adjacent regions

The last major sheet of ice to cover Eastern North America advanced as far south as the latitude of present-day New York City, from which it began to recede about 20 000 years ago. Approximately 12 000 years ago, the ice front had reached the latitude of present-day Montréal and Ottawa, whereupon the Champlain Sea invaded the St. Lawrence and Ottawa valleys. During the next thousand years, the ice front migrated northward across the map-area and adjacent areas, receding at about 100 meters per year. Toward the end of this period, the large glacial lake which occupied the Great Lakes basin to the west began to spill into the Ottawa valley and into the Champlain Sea.

In the Ottawa valley the highest shore line of the

Champlain Sea coincided approximately with the present-day 650-foot contour, and hence this sea extended up the Gatineau and Coulange valleys, and may have occupied some of the smaller valleys in the highlands. However, soon after its invasion, the sea began to withdraw, and at about 9 000 years ago, when the ice front was about 140 miles (220 km) north of the map-area, it had withdrawn completely from the Ottawa valley. Hence the Champlain Sea covered the floor of the lower Ottawa valley for 3 000 years; higher ground was submerged for shorter periods of time.

The time interval from about 9 000 years ago to the present was marked by a decelerating rise of the land mass, and the withdrawal of the sea from the St. Lawrence valley. During the first few hundred years of this period, the St. Lawrence river became the major outlet to the Great Lakes, causing the Ottawa River to decrease in size.

Further information may be obtained from the compilation of Prest (1970) from which the above summary was prepared.

Ice-flow direction

The orientation of observed glacial striations in the map-area is shown on Map 4. In the highlands, the striations bear southerly, and in the Ottawa valley, south-easterly. These and similar observations in adjacent areas by Sabourin (1965) and Gadd (1962b) indicate a southerly flow of basal ice, with some deflection down the Ottawa valley.

Glacial Till (7d)

The hills in the highlands are covered by a veneer of till, which evidently extends beneath some of the deposits of stratified drift that occur in the valleys. Where rock exposures are numerous, the thickness of the till appears to range up to 1 or 2 meters, but on some of the hills, where rock exposures are scarce or absent, the thickness may be considerably greater. Thus relatively thick deposits of till are evidently present northwest of Danford lake (58,13; Baker, 1956), south of Ellen lake (58,28), west of Moore lake (53.5,29), south of McCuaig lake (49.5,27), and south of Litchfield lake (48,33), at places indicated on Map 4. The deposit northwest of Danford lake forms a number of northeasterly trending ridges, which are visible on topographic maps and air photographs. Many of the relatively thick deposits of till occur on northern slopes of hills, which may be favorable places for the accumulation of ground moraine.

Within the highlands, the till consists of a mixture of fragments ranging in size from clay size to 1/3 meter, with occasional fragments 1 meter or more in diameter. Fragments of cobble to boulder size may be angular but often are somewhat rounded. These fragments consist of various rock types, mainly gneisses and granitic rocks, but also amphibolite; locally the latter is weathered and disintegrates upon removal. The till is characterized by a lack of bedding, but indistinct horizontal fractures are locally present. Exposures of till may be examined in road cuts south of Ladysmith (45,23.5),

west of Sparling lake (47.5,27.5), and along the Picanoc road north of the Otter lake village.

In the Ottawa valley, till similar to that described above occurs locally, for example on the high ridge of Ile du Grand Calumet (45,40). However more commonly it takes the form of coarse rubble that was evidently derived from normal till by the removal of the fine material.

Glacial erratics, up to several meters in diameter, are fairly common, both in the highlands and lowlands. Locally, for example west of Murray lake (in the vicinity of 57.2,25.5) they appear to be particularly abundant.

Stratified Drift (7a,b,c,d,e).

The largest deposits of clay (7a), silt (7b), sand (7c), and gravel (7d) are found in the Ottawa and Gatineau valleys, at elevations below 650 feet above sea level. Extensive deposits of silt, sand, and gravel are also found in the smaller valleys in the highlands, at elevations up to 750 feet, and small deposits are locally found as high as 800 feet above sea level. In addition, some ridges of coarse sand (7e), presumed to be eskers, occur in the highlands.

Information on the distribution of stratified drift within the map-area is presented in the geological map (Map 1) and on Map 4. The following eight deposits will be briefly described:

Ottawa valley

1. Calumet ridge deposits
2. Coulonge terrace deposits
3. Lawless lake deposits
4. Calumet sand

5. Fort-Coulonge sand and silt.

Gatineau valley

6. Venosta clay

7. Kazabazua sand

Smaller valleys in highlands

8. Otter Lake sand, silt, gravel.

The location of these deposits is shown, by the designated numbers, on Map 4.

1. Calumet ridge deposits

The Calumet ridge deposits at co-ordinates (45.3, 40.8) and at an elevation of about 500 feet above sea level consist mainly of interbedded sand and gravel, and contain in addition, some thin, discontinuous beds of silt and clay. In a gravel pit at the co-ordinates given above, inter-bedded and cross-bedded sand and gravel are found, as well as a 1-meter thick bed of silty clay which contains a faulted horizon, a few cm thick, that is very rich in marine shells (Table 35). Within the lenses and layers of gravel, pebbles and cobbles consist mainly of Paleozoic sedimentary rock, suggesting a westerly source. Considerable slumping has evidently occurred within these deposits.

The very large sand and gravel deposits at Campbell's Bay, immediately south of the map-area, on the edge of the valley, are located at approximately the same elevation, and also contain fossils (Table 35). However the clasts here consist almost entirely of Precambrian gneiss and granitic rock, suggesting a northerly source.

The origin of the Calumet ridge and similar deposits is not fully understood. Some may be ice-marginal

TABLE 35 - MARINE FOSSILS FROM THE MAP-AREA
AND ADJACENT AREAS, OTTAWA AND
GATINEAU VALLEYS.

<u>Location</u>	<u>Elevation</u> (feet above sea level)	<u>Note</u>
Ottawa Valley		
1. Ile-du-Grand Calument (45.3,40.8)	500	Horizon rich in <u>Macoma sp.</u> in 1 meter thick bed of silty clay within sand and gravel.
2. Fort Coulonge	370 $\pm$	Goldring (1920-21), Antevs (1939); no further information given
3. Campbell's Bay gravel pit (Highway 148, 0.4 mi/0.6 km west of intersection with 301; immediately south of map area)	500	Single specimen of <u>Macoma sp.</u> in growth position in fine sand within sand and gravel, minor clay. Other specimens of <u>Macoma sp.</u> in vicinity.
4. La Passe, Renfrew county, Ontario (3 mi/4.8 km west of map area)	475	Location 3, Wagner (1970). <u>Portlandia arctica</u>
Gatineau Valley		
1. Venosta	570	Antevs (1939). No further information given.
2. Brennan (2 $\frac{1}{2}$ mi/4 km east of map area)	380 $\pm$	Antevs (1939). <u>Portlandia</u> <u>arctica</u> and <u>Macoma sp.</u> (one specimen only)
3. Martindale (3 mi/ 4.8 km east of map area)	578	Location 1a, Romanelli (1976). <u>Macoma balthica</u> . Age 11,900 $\pm$ 160 B.P. (GSC 1772, Lowdon and Blake, 1973).
4. Farrellton (4 mi/ 6.4 km south-east of map area)	545	Location 4, Romanelli (1976). <u>Macoma sp.</u>

deposits (Antevs, 1925; Rust, 1976) that were subsequently re-worked by streams during the period when the Champlain Sea shoreline stood near the present-day 500-foot contour.

2. Coulouge terrace deposits

The Coulouge terrace deposits are located in the lower Coulouge valley and cover a part of the north-eastern margin of the Ottawa valley, extending south-east as far as Vinton. The Ottawa, Coulouge, and Serpentine rivers have cut channels and gulleys into these deposits, and have created a number of terraces, as shown on Map 1.

The lowest exposed member of the succession is massive gray clay, at least several meters thick, which is apparently lacking in fossils and locally contains concretions. The clay is exposed in gulleys of the Serpentine river, at elevations of about 370 feet, and is referred to as the Serpentine clay. It may be correlative with the Mottled clay of the Ottawa-Hull area to the south-east, for which Gadd (1962a) proposed a fresh-water origin. Clay is also found north of Fort-Coulouge (for example, at 52.3, 44.8), at an elevation of 400 feet, and these may be other exposures of the Serpentine clay.

The Serpentine clay is overlain by a succession of interbedded silt and sand, about 200 feet (60 meters) thick, which has been partly removed by erosion. This succession contains at least one horizon of clay, which is exposed east of the Coulouge chute (52.5, 40) at an elevation of about 550 feet. Discontinuous beds of gravel are also present, particularly in the margin of the deposits, representing the margin of the basis

of sedimentation. A small deposit of marl south of Coulonge chute was described by Retty (1932) and Waddington (1950).

Retty (1932) suggested that the Coulonge terrace deposits consist of outwash material transported from the north by the ancestral Coulonge river, and laid down in the Champlain sea. The Serpentine clay was presumably deposited in relatively deep water, which may account for the lack of fossils. The deposits may originally have extended much farther to the south and east. The terraces, which are evidently river terraces, were cut after the Champlain Sea had withdrawn, and while the Ottawa and lower Coulonge rivers were flowing at elevation up to 200 feet above their present levels.

3. Lawless Lake deposits

The Lawless Lake gravel, sand, and clay forms a relatively small deposit, perched on the edge of the Ottawa valley (46,32) at an elevation of about 550 feet. Within a horizontal distance of $2\frac{1}{2}$ miles (4 km) a gradation can be observed from gravel and sand in the north to clay in the south. At one locality in the north, at an elevation of about 600 feet, bedded and cross-bedded sand, with lenses of gravel is overlain by very coarse gravel, which may be a beach deposit.

The gravel, sand, and clay may have formed as a delta-like deposit of outwash material brought down from the north along the valley now occupied by Leslie lake.

4. Calumet sand

Much of the northern part of the Ile du Grand Calumet

is covered by a sheet of sand, the surface of which forms the Calumet sand plain, at an elevation of 370 feet above sea level. The deposit, which is shown in the vertical cross-section of Fig. 46, is at least a few meters thick, and is thought to be relatively young alluvial sand, laid down by the Ottawa River.

5. Fort Coulonge sand and silt

A poorly-exposed deposit of sand and silt lies below the plain south of Fort-Coulonge; some gravel is probably also present. Retty (1932) reported that a log was found in these deposits at a depth of 3 meters, which indicates that the material is a post-Champlain Sea alluvial deposit. Additional deposits of sand, silt, and gravel lying adjacent to the present-day Ottawa River and forming small islands within it are also very young fluvial deposits; some of these are shown in cross-section of Fig. 46.

6. Venosta clay

Stratified drift in that portion of the Gatineau valley that is covered by the map-area consists mainly of clay and sand.

An extensive deposit of gray, massive to faintly stratified clay occurs in the south-eastern part of the map-area, south of Venosta, at elevations between 450 to 550 feet above sea level. Hence the clay, which is referred to as the Venosta clay, is at least 100 feet (30 meters) thick. It is well exposed at the covered bridge over Stag creek (49.4,01.2), at an elevation of

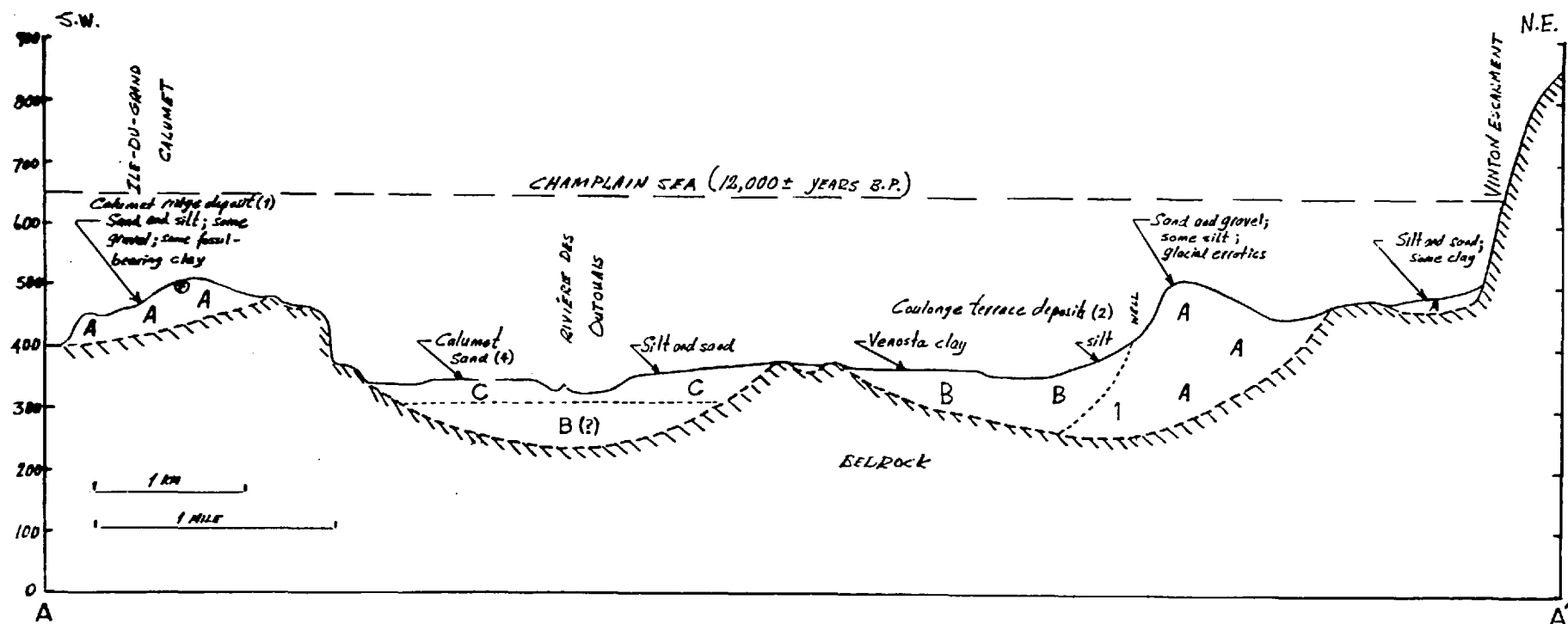


FIGURE 46 - Vertical section A-A' (Map 4) through stratified drift deposits in a portion of the Ottawa valley showing presumed ice-marginal deposits (A), Champlain Sea clay and silt (B), and post-Champlain Sea alluvial deposits (C).

about 450 feet. The clay may be of marine origin, for Antevs (1939) has found marine fossils near Venosta, presumably within the clay (Table 35).

Similar clay, possibly correlative with the Venosta clay is found in the north-eastern corners of the map-area, also below an elevation of 550 feet.

7. Kazabazua sand

A large deposit of sand overlies the Venosta clay and the surface of this deposit forms the Kazabazua sand plain, at an elevation of about 600 to 630 feet above sea level. Thus the sand deposit has a thickness of about 50 to 80 feet (15 to 24 meters).

The sand is fine to coarse in texture and is remarkably pure. However, along the margin of the plain, it is locally seen to be interbedded with gravel. The surface of the plain is, for the most part, flat, but locally it forms a rolling or hummocky topography. A group of conspicuous near-parallel ridges, trending 50 degrees east of north, occurs south of Kazabazua (54,03), as shown on Map 4 and Fig. 47. The ridges, which consist of faintly bedded sand, are up to 40 feet (12 m) high and 150 feet (46 m) wide along the base, and are thought to be transverse sand dunes.

Information on the age of the Kazabazua sand is provided by a radiocarbon date of 9910 ± 200 years before the present, obtained by Lowdon and Blake (1968) for material from a peat bog, 2.2 miles (3.5 km) west of Kazabazua. Thus the deposit is approximately 10 000 years old, or older.

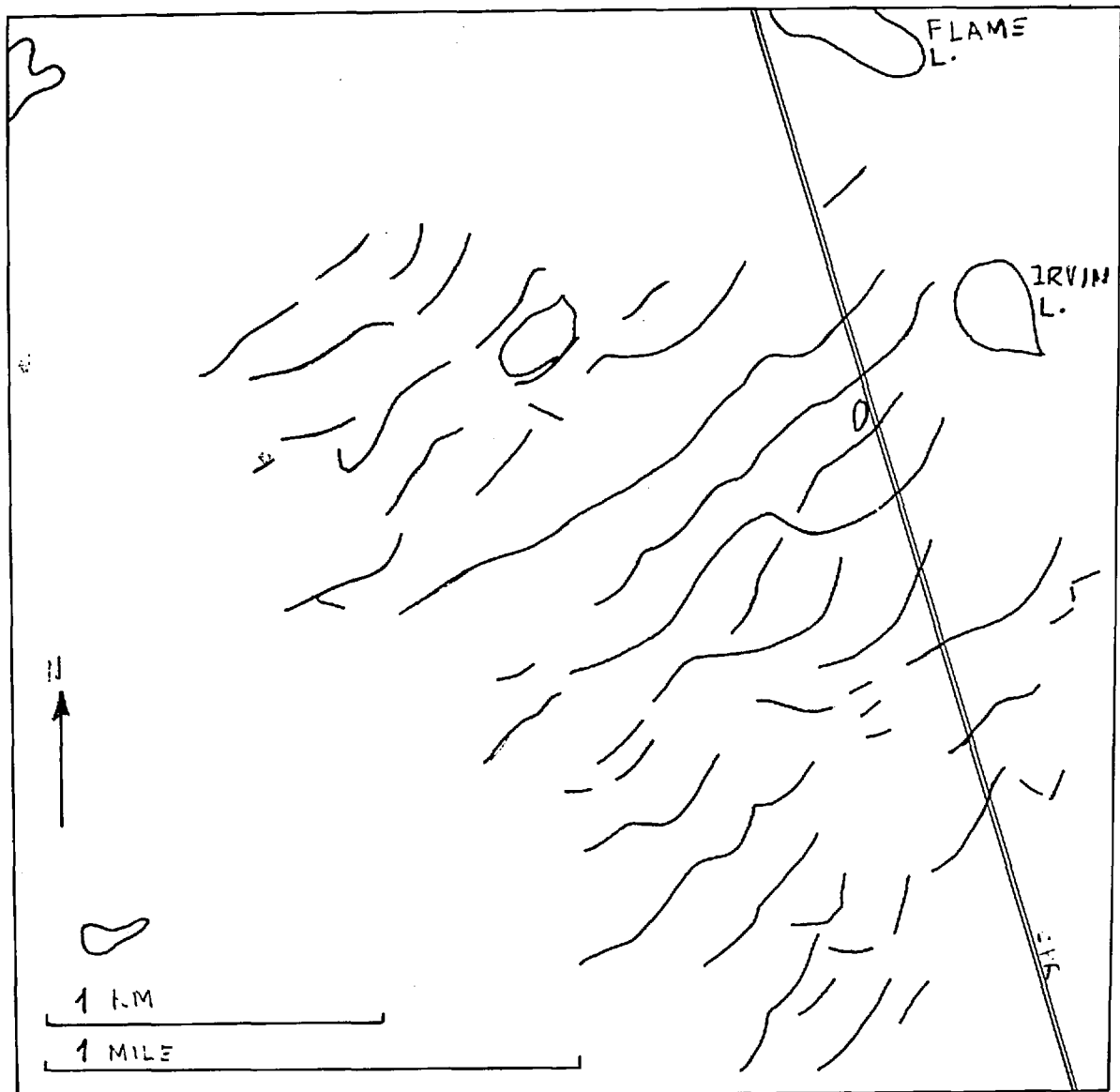


FIGURE 47 - Kazabazua sand dunes, showing ridge lines and location of railway tracks (CPR) (Air photo Q69801-244).

8. Otter lake sand, silt, gravel

Some of the smaller valleys in the highlands are floored by deposits of silt, sand, and gravel; the largest of these occur in the Otter lake - Lac Petit Cayamant valley and in the Grove lake valley, as shown in Fig. 46. Where exposed, the material is seen to consist principally of interbedded sand and gravel, which may show cross-bedding and slump structures. Most of these deposits are regarded as river-transported and river-deposited outwash material. However, narrow arms of the Champlain Sea may have invaded some of the smaller valleys from the east and from the south (Map 4) and, although no fossils were found, some of the lower-lying drift may be deltaic in origin.

The surface of most of the stratified drift deposits within the smaller valleys forms plains and terraces, at the elevations of between 650 and 760 feet elevation, but these are locally broken by rolling or hummocky topography. A remarkable example of hummocky topography is found at (49,17) and is shown in Fig. 48; this may be an ice-margin kame deposit. Elsewhere distinct kettle-like depressions occur, for example in the bend of the Picanoc river (54,26), which may be places where blocks of ice were buried by outwash material.

A conspicuous ridge or ridge system, composed of coarse gravel, extends from Lac Petit Cayamant on the north border to McCuaig lake, near Otter Lake village, and this is presumed to be an esker. The coarse gravel is exposed where the Picanoc road cuts through the ridge (52,26),

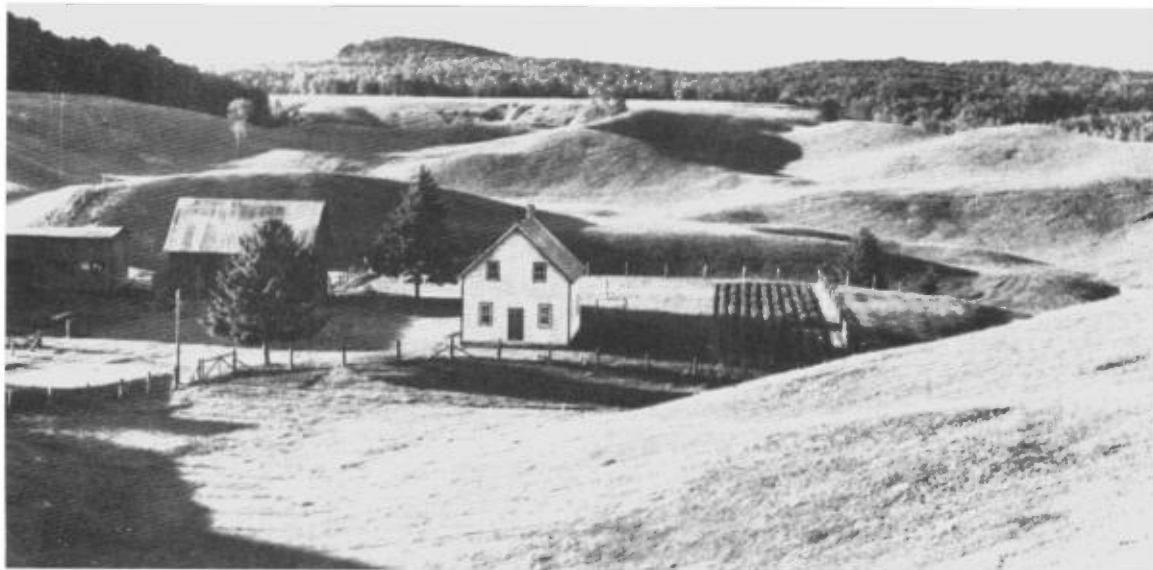


FIGURE 48 - Hummocky topography, Cawood township (48.5, 17).



FIGURE 49 - Coarse gravel (scale is 17.5 cm long), presumed esker at Otter lake (52.5, 25).

and on the east side of Otter lake (52.5,25), and at these places it consists of a heterogeneous mixture of fragments ranging from sand size to 1 meter in diameter, as shown in Fig. 49. Bedding was not recognized with confidence, but locally the gravel ridge is flanked by bedded sand.

Summary

The withdrawal of ice from the Ottawa valley was evidently followed by a period of rapid deposition of outwash material derived from the north and west, and deposited in the Champlain Sea. The Calumet ridge, Coulonge terrace, and Lawless lake deposits form remnants of these outwash deposits. The withdrawal of the Champlain Sea was followed by a period of rapid erosion, caused mainly by the large ancestral Ottawa River. The Coulonge terraces were evidently cut at this time. As the river decreased in size, deposition occurred locally to form the Calumet sand plain and the Fort-Coulonge deposits. Local deposition and erosion have continued to the present.

In the Gatineau valley, the Venosta clay and the overlying Kazabazua sand were evidently deposited in the Gatineau arm of the Champlain Sea. The material was brought down from the north and north-west by glacial streams, as proposed by Antevs (1939), and as the land rose, these deposits were partially eroded by the Gatineau river and its tributaries.

Outwash silt, sand, and gravel was also deposited in the smaller valleys in the highlands, some of which

may have been occupied by narrow arms of the Champlain Sea.

Preliminary Studies on Clay and Sand

Six chemical analyses of clay from the vicinity of Fort-Coulonge are presented in Table 36. The samples were obtained by Dr. Le Guerrier and analysed by the Québec Department of Mines in 1948. Sample 1 was evidently obtained from the occurrence of clay of Fort-Coulonge (elevation about 400 feet) which was described above as a possible north-western extension of the Serpentine clay, at the base of the Coulonge terrace deposits, and samples 2 and 3 were evidently taken from the same formation to the west, near Davidson. Samples 4, 5 and 6 were obtained east of Coulonge chute (elevation about 500 feet) from a higher and presumably younger clay horizon.

The analyses shows that the lower and upper clays do not differ noticeably in chemical composition. However, a comparison of these clays with the 'Leda clay' near Ottawa 60 miles (100 km) to the east, as represented by samples 7, 8, 9 (Table 36) reveals that the clays at Fort-Coulonge are slightly richer in SiO_2 and poorer in Al_2O_3 , MgO , K_2O than those at Ottawa. This may be the result of a higher content of quartz and a lower content of illite-like minerals and chlorite, minerals which are present at Ottawa (Gillott, 1971) and in other glacial clays of eastern North America (Allen and Johns, 1960).

A comparism of glacial clays at Fort-Coulonge and Ottawa with average shale (samples 10 and 11, table 36) shows the clays to be richer in MgO and Na_2O , possibly as a result of a relatively high content of chlorite, amphibole,

TABLE 36 - CHEMICAL ANALYSES OF CLAY

	1	2	3	4	5	6	7	8	9	10	11
SiO ₂	58.4	57.0	66.2	59.1	61.5	56.9	52.3	53.4	48.1	58.9	50.7
TiO ₂	1.0	1.6	0.9	0.9	0.9	1.0	-	-	-	0.8	0.8
Al ₂ O ₃	16.5	14.9	13.7	15.8	15.1	17.0	19.3	17.8	24.1	16.7	15.1
Fe ₂ O ₃	4.2	5.4	3.0	3.7	2.2	3.7	7.9	7.4	8.1	2.8	4.4
FeO	3.0	2.6	1.6	3.0	3.0	3.3				3.7	2.1
MnO	0.13	0.12	0.05	0.12	0.12	0.13	-	-	-	0.09	0.08
MgO	4.0	4.7	2.6	3.8	3.0	4.3	4.8	4.2	4.6	2.6	3.3
CaO	3.7	4.0	3.6	3.9	3.6	3.9	3.4	5.2	3.5	2.2	7.2
Na ₂ O	3.2	2.9	3.3	3.4	3.1	2.8	3.3	2.7	3.2	1.6	0.8
K ₂ O	3.2	3.2	2.4	3.0	2.7	3.1	3.8	3.6	3.4	3.6	3.5
P ₂ O ₅	0.32	0.48	0.38	0.27	0.27	0.31	0.15	0.17	0.08	0.16	0.10
BaO	0.37	0.07	0.11	0.63	0.59	0.40	-	-	-		
CO ₂	-	-	-	-	-	-	0.91	2.6	1.0	1.3	6.1
LOI	<u>2.4</u>	<u>3.0</u>	<u>1.9</u>	<u>2.7</u>	<u>3.9</u>	<u>3.4</u>	<u>5.2</u>	<u>6.2</u>	<u>5.8</u>	5.0	5.0
	100.3	99.9	99.7	100.3	100.1	100.1	100.1	103.3	101.9		

Note: In 7,8,9, total iron is expressed as FeO

In 10,11, LOI = 5.0 = H₂O

- indicates no data available

1. Sample T9, lots 16-23, Range II, Mansfield twp.
2. Sample T14, lots 44-46, Range II, Mansfield twp.
3. Sample T15, lots 44-46, Range II, Mansfield twp.
4. Sample T11, } lots 6-8, Range IV, Mansfield twp.
5. Sample T12, } Samples 1 to 6 analysed by Qué. Dept. Mines in 1948
6. Sample T13, } for Dr. Le Guerrier of Campbell's Bay.
7. Sample A Ottawa Sewage Plant, depth 45 feet (Gillott, 1971)
8. Sample C Walkley and Russell Rd, Ottawa, depth 33 feet (Gillott, 1971)
9. Sample D C.F.S. Gloucester, Ontario, depth 16½ feet (Gillott, 1971)
10. Average shale (mainly from geosynclines) (Wedepohl, 1969)
11. Average shale (mainly from platforms) (Wedepohl, 1969)

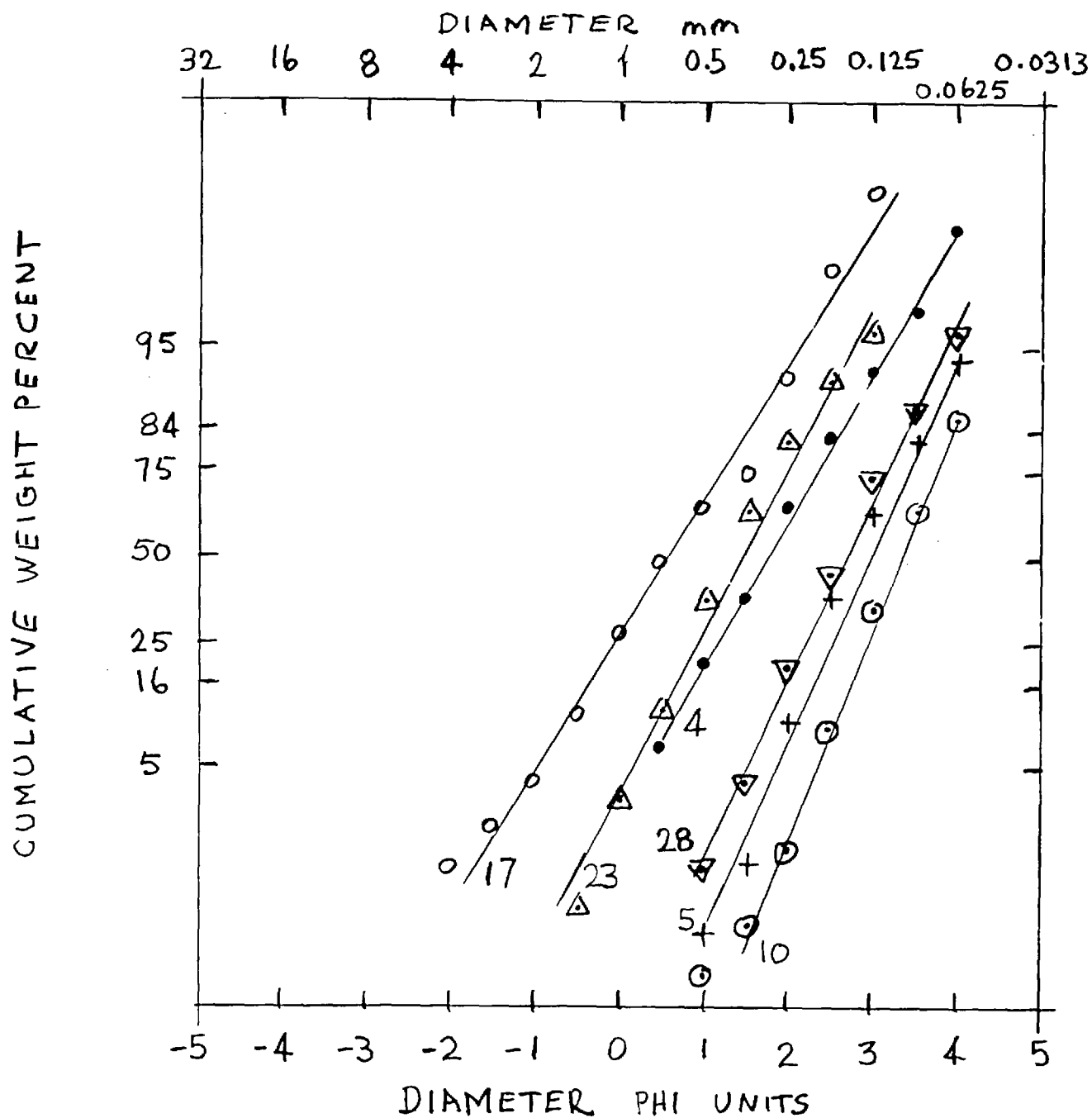


FIGURE 50 - Grain-size analyses of sand; sample locations shown on Map 4.

and feldspar.

A study was made of the particle-size distribution in samples of sand from the map-area, and some of the results are presented in Fig. 50. All of the samples are from beds or lenses of apparently homogeneous sand, some of which are associated with finer or coarser material (silt, sand, gravel). One of the samples (4) is from the Ottawa valley, three (17,23,28) are from the Gatineau valley, and two (5,10) are from the smaller valleys in the highlands. Sample locations are shown Map 4.

Within the group of six samples, the mean size ranges from nearly 1 mm (very coarse sand) to about 0.1 mm (very fine sand). The three coarser samples (17,23,4) were evidently derived from outwash material carried into the Champlain Sea. Two of the three finer samples (5,10) are from higher elevations, and may be purely alluvial, or lacustrine, while the third (28) is from a sand dune on the Kazabazua sand plain. Although considerable variation exists in the mean size, the variation within each sample, as expressed by the slope of the lines in Fig. 50 does not vary greatly.

Further studies on the chemical and mineral composition, texture, and minor structures of the great variety of clay, silt, sand, and gravel deposits in the map-area may resolve some of the problems that exist concerning the origin of these deposits and the mechanisms of transport and deposition that operated during glacial and post-glacial time.

MINERAL DEPOSITS

Minerals within the boundaries of the map-area, that have attracted some attention in the past, from the view point of mineral exploration, development, and mining, are asbestos, garnet, mica, graphite, molybdenite, iron, and uranium-thorium minerals. Exploratory work has been carried out on a number of deposits, and small amounts of mica and molybdenite were mined several decades ago. No minerals or metals are being mined at present, but because much of the bedrock is drift-covered, the possibility exists that mineral deposits are present but have not yet been discovered. .

Asbestos

Three occurrences of veins of fibrous asbestos are listed in Table 37. All of these occurrences are in nodules of serpentine skarn, enclosed by common calcite-dolomite marble. The veins and the host rock were described above under the heading of serpentine skarn. Only very small amounts of asbestos were observed at these localities. Asbestos has also been reported from Thorne, range VII, lot 2, Alleyn, range II, lot 4, and Cawood, range II, lot 27.

Garnet

An occurrence of garnet-bearing skarn, containing about 60 to 80 per cent of andradite garnet is indicated in Table 37, and is described above under the heading of pyroxene-garnet skarn (specimen 304-55, Table 13, Table 16). The skarn occurs as two easterly-dipping layers, about 3 meters thick, which appear to have a horizontal continuity of several hundred meters.

Mica

From 1886 to about 1920, Canada was the chief phlogopite-producing country in the world (Hoadley, 1960), and during the early part of this period, much of the mica came from Ontario and Québec, including portions of the map-area. The mica deposits of the map-area were described by de Schmidt (1912) and Spence (1929); the latter report lists 17 mica occurrences within the boundaries of the present map-area. Not all of these were examined by the writer; some are listed in Table 37.

The principal host rock for the mica is skarn, mainly green pyroxene skarn and pink calcite skarn but also other varieties. The nature of the mica, as found in these

TABLE 37 - MINERAL OCCURRENCES

<u>Township</u>	<u>Range</u>	<u>Lot</u>	<u>Approximate Co-ordinates</u>	<u>Name</u>	<u>Host Rock</u>
<u>Asbestos (ASB)</u>					
Cawood	I	51	49.2, 18.4	-	serpentine skarn in marble
Cawood	I	21	49.8, 13.1	-	"
Low	VII	44,45	48.4, 0.1	-	"
<u>Garnet (GRT)</u>					
Leslie	IV, V	12	53.2, 21.9	-	pyroxene-garnet skarn
<u>Mica (MICA)</u>					
Cawood	V	43	52.1, 17.6	Cawood Mine	green pyroxene skarn and pink calcite skarn
Cawood	III	49	50.8, 18.6	Zimmerling prospect	pink calcite skarn
Thorne	East	32,33	47.3, 23.3	-	pink calcite skarn
Thorne	VI	3	45.8, 19.8	-	amphibole skarn, pegmatite
Huddersfield	IV	20	57.4, 33.3	-	pyroxene-scapolite skarn
Low	A	30	49.5, 07.2	-	green pyroxene skarn
<u>Graphite (2d)</u>					
Cawood			51.4, 16.9	-	biotite-graphite gneiss
Thorne			45.7, 21.3	-	"
Clapham			53.8, 28.1	-	"
<u>Molybdenite (Mo)</u>					
Clapham	II	7	55.4, 20.4	-	green pyroxene skarn
Aldfield	VI	54	45.7, 19.4	-	pyroxene-scapolite skarn at marble-pegmatite contact
Litchfield	IX	28	47.8, 29.6	Crawford prospect	shear zone in granitic rock
Litchfield	X	21,22	50.0 31.8	Leslie Lake skarn	pink calcite skarn, and green pyroxene skarn
<u>Iron (Fe)</u>					
Litchfield	V	12	46.9, 38.3	Vinton prospect	metagabbro
Leslie	III	11	51.3, 21.8	-	sand and silt

rocks has been described above under the heading of skarn. Large crystals of black phlogopite, amber coloured in thin flakes, up to 6 to 8 inches in diameter are not uncommon in these rocks.

Mica was mined principally from small open pits. Some underground workings exist at the Cawood mine (Table 37) but these are now largely inaccessible.

Graphite

Graphite-bearing gneiss, which occurs at numerous places throughout the map-area, some of which are listed in Table 37, forms a potential source of graphite. This rock contains up to 2 or 3 per cent of graphite, together with other minerals as listed in Table 19. The gneiss occurs as layers a few cm to several tens of meters thick, as described above under the heading of plagioclase gneiss and amphibolite.

Molybdenite

Molybdenite occurs at a few localities within the map-area. Prospecting for this mineral was active during the first world war, and in 1917 about one ton of ore was shipped from the Clapham deposit (Table 37), which was reported to contain 0.13 per cent MoO_2 (Ingham, 1943). The workings here and elsewhere consist of open pits.

The principal host rock is skarn, mainly green pyroxene skarn, pyroxene-scapolite skarn, and pink calcite skarn, as described above under the heading of skarn. Within these rocks, molybdenite occurs as scattered crystals, normally 2 to 3 cm across, but locally, for example at Leslie lake (Table 37) they are rarely 8 cm across. Molybdenite

is also found in sheared granitic rocks, together with pyrite.

Iron

An iron-rich rock is poorly exposed in a small open pit west of Vinton (Table 37) where the dominant rock is metagabbro and amphibolite. A specimen of the rock was found to contain about 40 per cent of each of magnetite and ilmenite, as grains about 1 mm in diameter, together with magnesium-rich amphibolite and biotite, and minor pyrite and green spinel.

In Leslie township (Table 37), a near-surface layer of brick-red soil, about 1 meter thick contains layers of limonite nodules. The layer is underlain by white sand and silt. An analysis of a sample of the soil together with nodules, gave 48.8 per cent total iron.

Uranium-thorium minerals

Uranium and thorium-bearing minerals occur at numerous localities within the map-area, particularly in Huddersfield and Grand-Calumet townships. A considerable amount of prospecting and exploratory work in the form of trenching and diamond drilling was carried out in 1954 and 1955. Information on these deposits may be obtained in a report by Shaw (1958), from which the summary in Table 38 was prepared.

The main host rock for the uranium and thorium minerals is skarn, particularly green pyroxene skarn, pyroxene-scapolite skarn, and pink calcite skarn. Such skarns which are fluorite-bearing, as found on the Yates property, appear to be especially favourable host rocks for radioactive minerals, and many of the skarns listed in Table 38

TABLE 38 - PRINCIPAL OCCURRENCES OF URANIUM-THORIUM MINERALS (DATA FROM SHAW, 1958).

<u>Township</u>	<u>Range</u>	<u>Lots</u>	<u>Approximate Co-ordinates</u>	<u>Name of Property</u>	<u>Host Rock</u>	<u>Radioactive minerals identified</u>
Huddersfield	I	29-31	54.5, 35	Consolidated Halliwell	pyroxene granite	uranothorite
Huddersfield	V	21-22	57.7, 33.7	Huddersfield Uranium and Minerals	green pyroxene skarn, pyroxene- scapolite skarn, pink calcite skarn	thorianite, urano- thorite, urano- phane
Huddersfield	III	27	55.8, 34.5	Pool	granitic rock	uranophane
Huddersfield	V IV	25 26	57.3, 34.5	Soma-Duverny	green pyroxene skarn, pyroxene- scapolite skarn, pink calcite skarn, humite marble	uranoan thorianite
Huddersfield	IV V V	18,20 16,17 19,20	57.7, 32.7	Yates	green pyroxene skarn, pyroxene- scapolite skarn, pink calcite skarn	uranothorite, thorianite, uranophane
Grand Calumet	VIII	31,32	46.7, 44.8	Calumet Contact	pink calcite skarn	uranothorite
Grand Calumet	VI VII	31,32 28-31	47, 43	Calumet Uranium	pink calcite skarn	uranothorite, uranoan thorianite
Grand Calumet	V	4, 5	45.6, 38	Dun Raven	pegmatite	—

contain fluorite. Pink pegmatite dikes may also be locally radioactive, as shown for example in Fig. 32. In many pegmatite dikes which are locally radioactive to about 3 times the background intensity, the radioactivity appears to be due to allanite.

In skarn and in pegmatite, uranium-thorium minerals are typically distributed in an erratic manner, making it difficult to obtain a representative sample. The concentrations of uranium (U_3O_8) and thorium (ThO_2) reported by Shaw (1958) are generally low. For example, one of the zones of the Calumet Uranium property was estimated to contain 490 000 tons of ore averaging 0.05 per cent U_3O_8 and 0.15 per cent ThO_2 . To the present time, no radioactive minerals have been mined from the several prospects that occur within the map-area.

PROBLEMS OF GRENVILLE GEOLOGY

The Fort-Coulonge-Otter Lake-Kazabazua area may be viewed as a small part of the Grenville Province of the Canadian Precambrian Shield, and in this perspective we shall now briefly examine some of the results of the present study in relation to major problems of Grenville geology. The problems centre about the age and origin of the stratified rocks, their metamorphism, metasomatism, and deformation, and the origin of the more homogeneous plutonic rocks with which they are associated. Background information may be found in several compilations and discussions, by Dresser and Denis (1944), Engel and Engel (1953), Osborne (1956), Osborne and Morin (1962), Hewitt (1956,1962), and Wynne-Edwards (1972).

The problem of the nature and distribution of the Grenville group, which has troubled geologists for more than 100 years, is clearly displayed in the map-area. The group, as found in Grenville township and inferred to extend into the Bancroft area, consists of marble, with varying proportions of quartzite, garnet-sillimanite gneiss, metavolcanic rocks, and amphibolite. Thus, in the present map-area, the rocks of the Gatineau zone may be tentatively correlated with the rocks at Grenville, 120 km to the east. However as one moves westward across the map-area, through the Thorne and Moore zones, and into the Coulonge and Calumet zones, a variety of plagioclase gneisses and amphibolites are encountered, which may or may not be associated with marble. Should all of these rocks be

assigned to the Grenville group? To further complicate matters, evidence exists to indicate that some gneisses and amphibolites, and possibly marbles as well, have been altered by metasomatism to produce potassium feldspar gneisses, migmatites, and granitic and syenitic rocks, and if interpretations are correct, such rocks should also be present in the Grenville Group. The importance of granitization (in the broadest sense) was emphasized by Hewitt (1956) and Osborne (1956), who were well aware of the difficulty of recognizing members of the Grenville Group in certain portions of the Grenville Province. In a simplified view, which presumes that marble is diagnostic of the group, and supposes that metasomatism was inoperative or affected only the base of the section, the north-western limit of the group may be drawn through the central part of the map-area, as shown in Fig. 51, and the Calumet and Coulange zones, or portions thereof might be regarded as infolded pendants. According to this interpretation, which is taken by Bourne (1970), Wynne-Edwards (1972), and Baer (1976), the Grenville group is more or less restricted to area 2, shown in Fig. 51, and the gneissic to the west are thought to be older rocks, unconformably underlying the Grenville Group. In the writer's view, the problem of defining the Grenville Group and determining its distribution in the map-area has not yet been solved in a satisfactory manner.

Structurally, the map-area may be compared with the Bancroft area to the south-west, for the Eastern structural zone is somewhat similar to the Hastings basin, and the

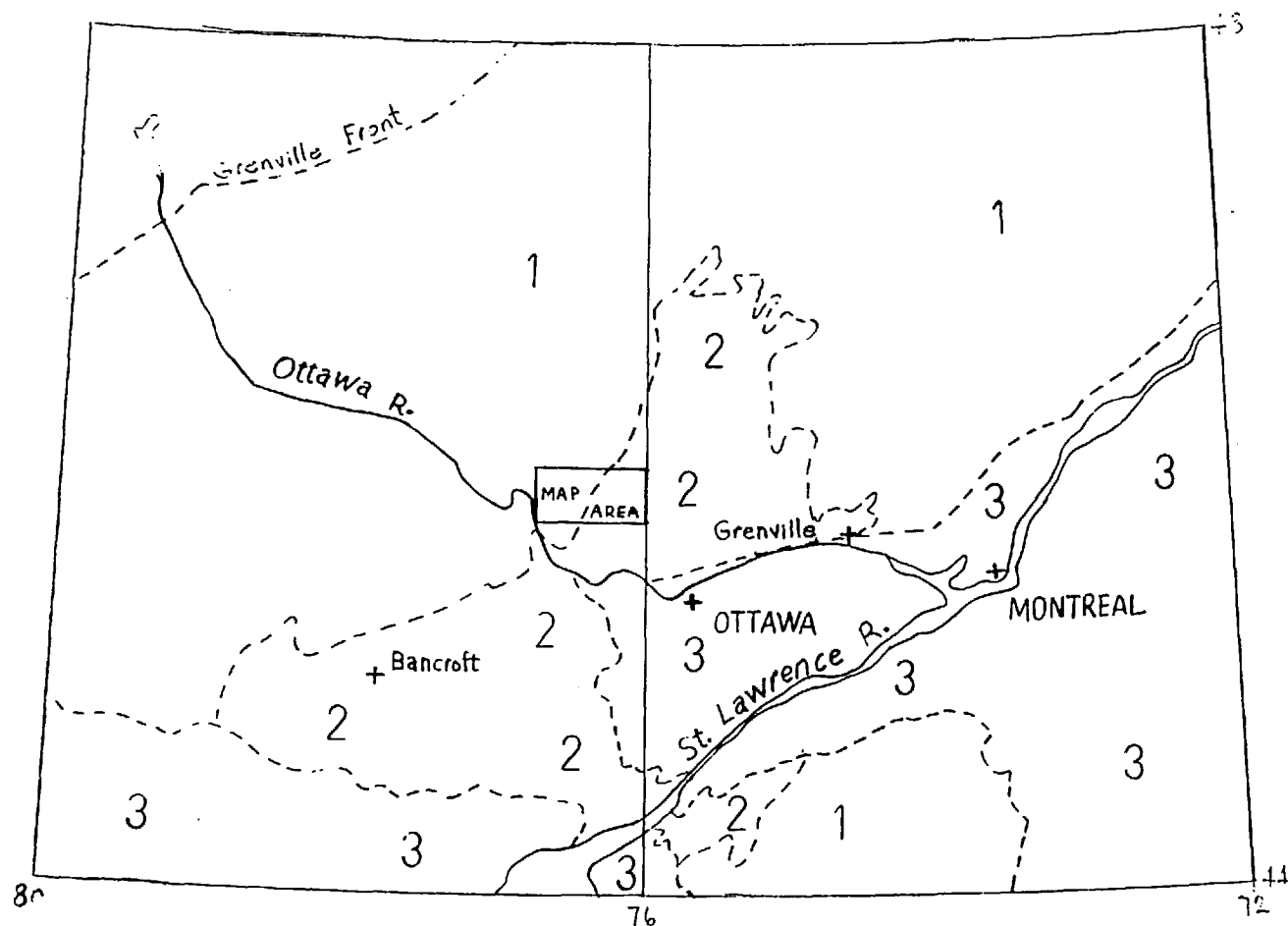


FIGURE 51 - Map showing the distribution of 1) areas underlain principally by Archean and/or Proterozoic gneisses, 2) area underlain principally by Proterozoic (Helikian) metasedimentary rocks, and 3) area underlain principally by Paleozoic sedimentary rocks, as shown on the geological map of Canada (Douglas, 1970). Area 2 corresponds approximately with the area defined by Baer (1976) as being underlain principally by rocks of the Grenville Group.

Western structural zone to the Haliburton-Hastings highlands. The Eastern zone is characterized by folds of variable plunge, that are overturned to the north-west, and similar structures occur in the Hastings basin, as described by Hewitt (1962), Best(1966), and Divi and Fyson (1973). Folds of this kind are evidently common in the Grenville Province as a whole (Wynne-Edwards,1972). The south-east plunging lineations of the Western structural zone have their counterpart in the Haliburton-Hastings highlands, where however, the trend of planar features is more variable than in the Western zone. Some similarities also exist with portions of the Adirondack area to the south, where Buddington (1956) found folds overturned toward relatively rigid rock bodies. In the present map-area, the Western zone would, by this interpretation, constitute the relatively rigid block. The crucial question is the age of principal structures in the Western zone relative to the age of those in the Eastern zone, and this question has not yet been answered with confidence. More work is in progress in an attempt to solve this problem.

Although anorthosite bodies are virtually absent from the map-area, a variety of ultramafic, gabbroic, dioritic, granitic, and syenitic rocks are present, as in other portions of the Grenville province, and the origin and relative age of these rocks is not fully understood. The gabbroic rocks, if more was known about them, might form useful time markers, and the study of these rocks in conjunction with structural studies, may more clearly

separate different periods of deformation. Thus some of the metagabbro bodies of the map-area show relict igneous textures, which are absent from the associated amphibolites, presumably also of igneous origin, indicating that the metagabbro bodies may have been emplaced between two periods of deformation. With regard to granitic and syenitic rocks, the interpretations of the present study are in agreement with those of Hewitt (1956), who suggested that both magmatism and metasomatism were important processes leading to the development of these rocks in portions of the Grenville Province in Ontario. Thus the relatively large and very heterogeneous bodies of granitic-syenitic rock are regarded as products of metasomatism, some of the more homogeneous bodies may be magmatic, and the multitude of small quartzo-feldspathic veins that are found throughout the area may be products of the rearrangement of matter during regional metamorphism and regional metasomatism. The source of most of the granitic-syenitic material of the map-area and other portions of the Grenville Province is likely to be found in portions of the crust that underlie the Grenville Group. This material may presumably rise as bodies of silicate melt, as bodies of solid rock in a plastic state (Wegmann, 1935; Eskola, 1949; Hewitt, 1956), or as more dispersed material, which is capable of slowly penetrating rock, to produce granitization and other kinds of metasomatism.

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APPENDIX

The location of rock specimens referred to in this report is shown in Figure 52, pages 308-309.

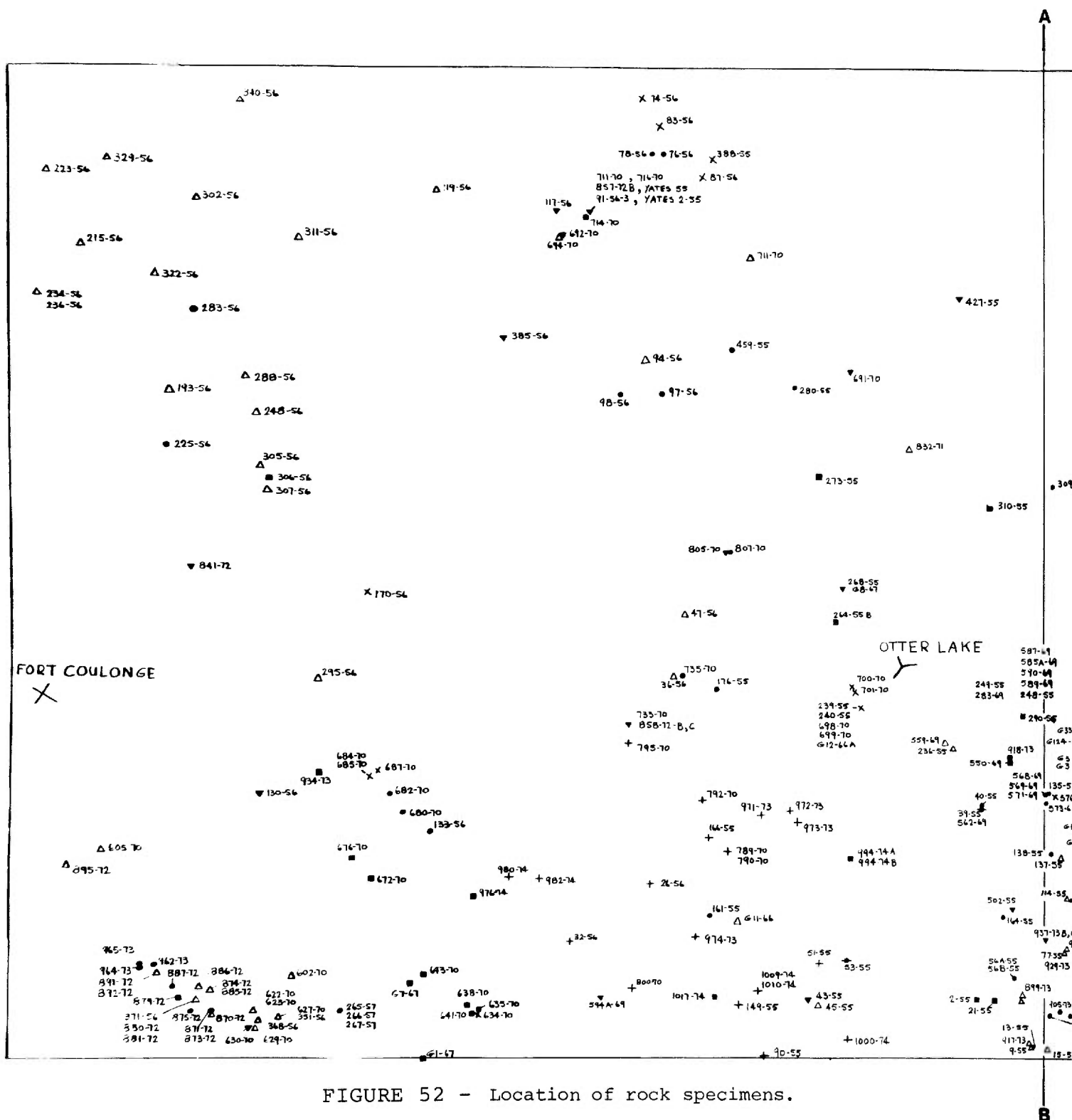
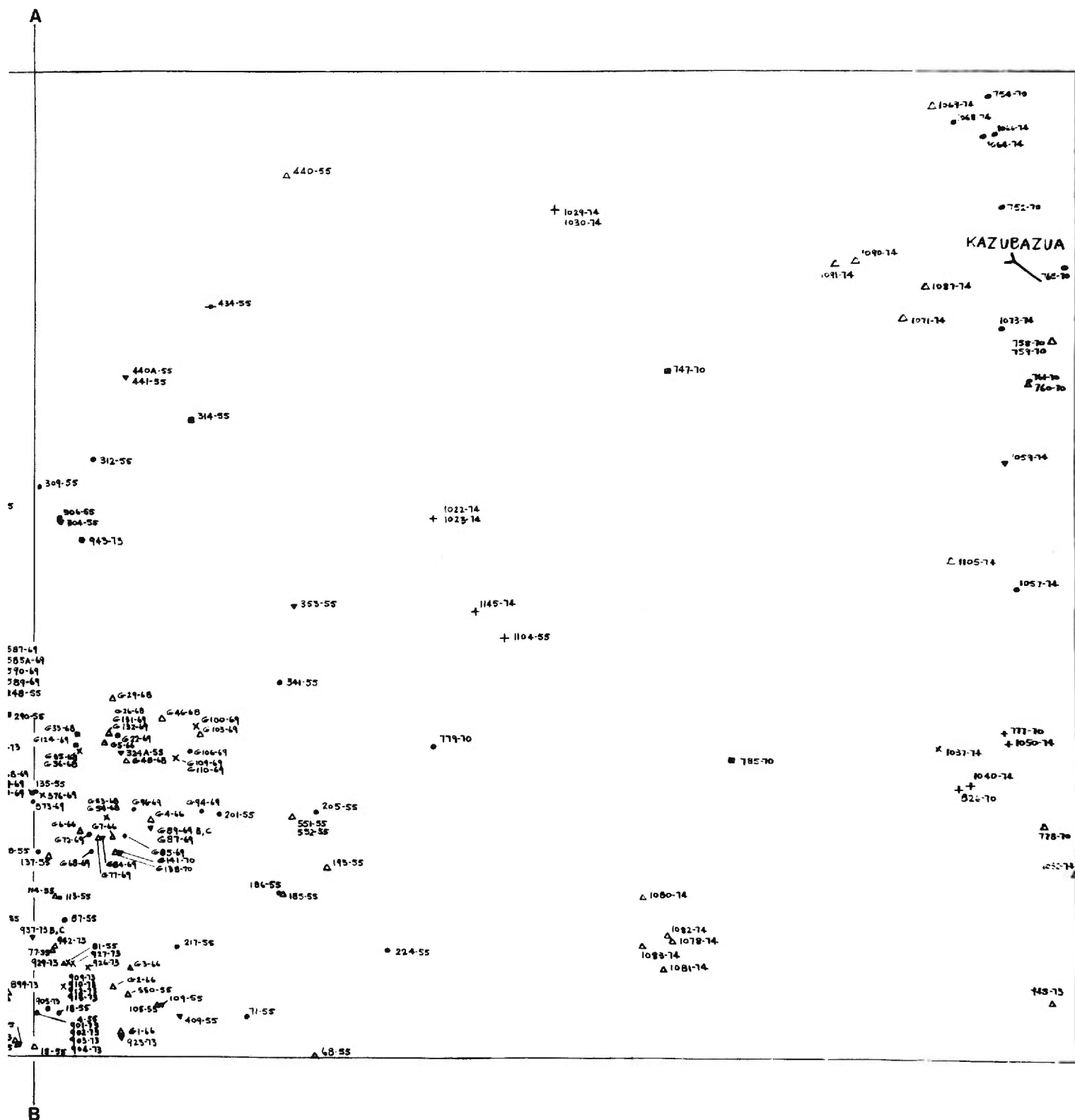


FIGURE 52 - Location of rock specimens.

- + Granitic, syenitic, dioritic rocks
- Potassium feldspar gneiss
- Amphibolite inclusions in potassium feldspar gneiss



- x Mafic and ultramafic rocks
- Plagioclase gneiss, amphibolite, quartzite
- ▼ Skarn
- △ Marble

