

# TH 0678

GEOLOGY OF A PORTION OF MCKENZIE TOWNSHIP

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TH 0678

The geology of a portion of  
McKenzie township,  
Chibougamau district,  
Québec

A dissertation submitted to the Faculty of Philosophy  
Of the Johns Hopkins University in conformity  
With the requirements for the degree of  
Doctor of Philosophy

By

Gilles O. Allard

Baltimore  
October 1956

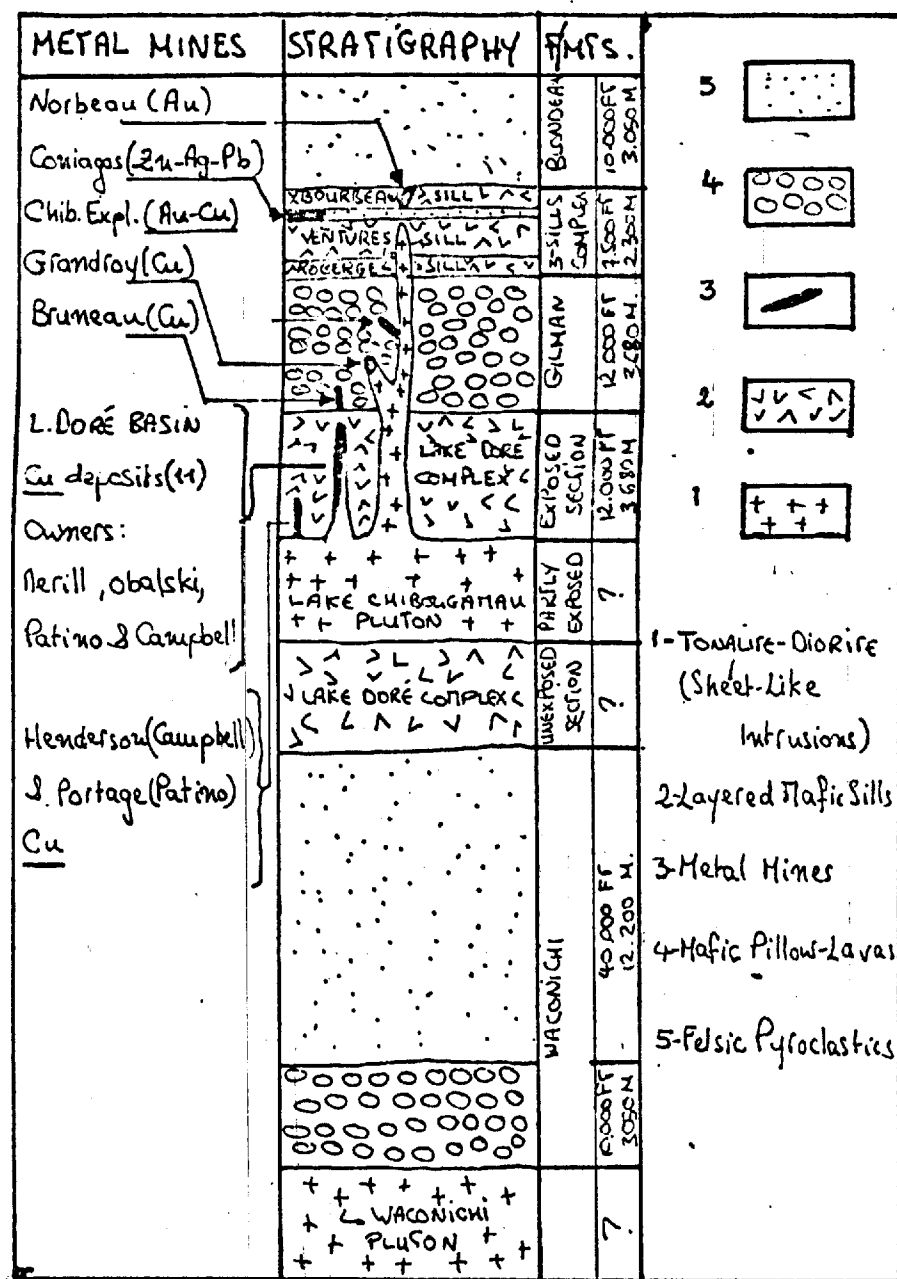
A. E. ORLEY

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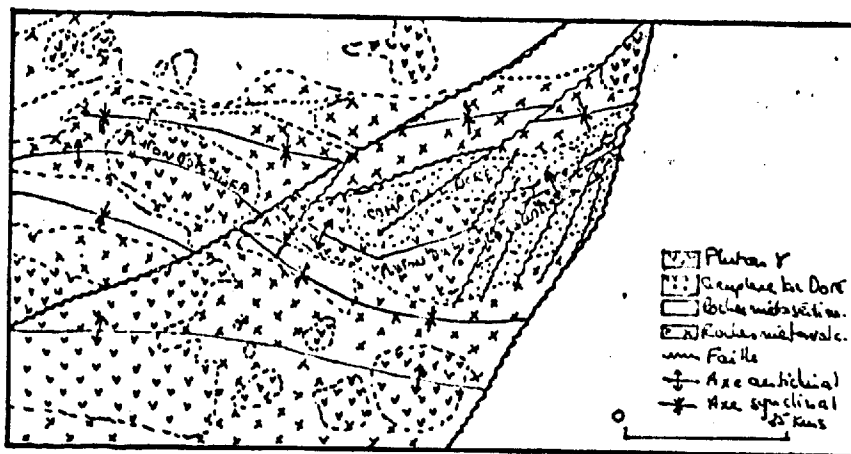
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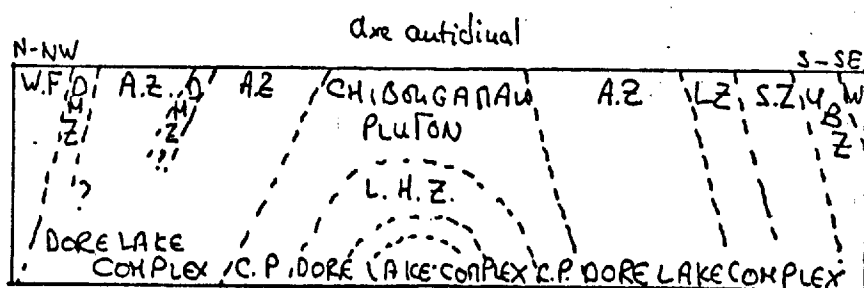


Stratigraphie de l'ARCHÉEN et Modèle métallogénique idéalise, avant l'acquisition kévoriennne

(C. Duquette, 1970 in 24<sup>e</sup> Congrès int. Montréal, 1972)



Carte géologique simplifiée de la région de Chibougamau



Coupe idéalisée du complexe du lac Doré à l'est de l'île de Portage  
 la coupe a environ 19 kms. de long

- WF = Formation de Wocowich
- DIZ = Zone à dumite riche en magnétite
- AZ = Zone quartzitique
- LZ = Zone lithée
- SZ = Zone à amphibole sodique
- UBZ = Zone de contact supérieurs. (upper border zone)

UPPER BORDER CONE 1200'	Gabbro						
GRANOPHYRE SODIQUE ZONE 2800'	Granophyre sodique						
	Niveau P <sub>3</sub> - Pyroxénite - Niveau muraux de gabbro 500' - 1400'						X
	Niveau A <sub>2</sub> - Anorthosite GABBROÏQUE Gabbro anorthositique 1200' - 1400'						X
ZONE LIÉE 1600' - 3200'	Niveau P <sub>2</sub> - Pyroxénite - Gabbro - lits d'oxyde massifs 30-75'						X
	Niveau A <sub>1</sub> - Anorth. GABBROÏQUE - Gabbro anorthositique 20' - 150'						X
	Niveau P <sub>1</sub> - Pyroxénite - Gabbro - lits d'oxyde massifs.						X
	GABBRO - Oxydes disséminés						X
	GABBRO						X
ZONE ANORTHOSIQUE 8000' - 12000'	GABBRO Anorthositique						tr
	ANORTHOSITE Gabbroïque						tr
	ANORTHOSITE						tr
CONTACT DE L'INTRUSION	Intrusion par le complexe tonalitique de lac Clibourgamae.						

Séquence stratigraphique générale du Lac Oue (centre sud) D'après fig. 18 24° cart. 71. Montréal.

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INTRODUCTION

The interest of the mining industry in the Chibougamau area was first aroused in 1870 when James Richardson geologically explored the area and discovered sulphide-bearing zones.

Geological mapping and prospecting were done intermittently, with a burst of activity between 1930 and 1936. Following the construction of the highway, a program of detailed mapping was initiated by the Department of Mines in 1949.

The author spent the summer of 1952 with Dr R.B. Graham investigating the active mining properties of the area and continuing the detailed mapping initiated by Graham in Obalski township. During the summers of 1953 and 1954, he mapped the south portion of the southeast quarter of McKenzie township. At the same time, Dr J.R. Smith was mapping the southwest quarter of the township and the north half of the southeast quarter.

ACKNOWLEDGMENTS

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Some of the laboratory work was done at the Geophysical Laboratory of the Carnegie Institution, Washington, D.C. Special thanks are due to Hatten S. Yoder, Felix Chayes, R. Boyd, and J.R. Smith. Dr Yoder helped the author with X-Ray determinations and Dr Chayes instructed on the theory and practice of point count analysis.

Finally, the writer is indebted to his wife Bern without whose aid and encouragement this research could not have been completed.

#### LOCATION AND ACCESS

The Chibougamau area (Fig. 1) lies in the eastern part of Abitibi-east County, about 320 miles north of Montreal and 250 miles northeast of the Rouyn-Noranda mining district.

The St. Felicien-Chibougamau highway, built by the Quebec

Department of Mines in 1948 and 1949, provides easy access. A good motor road connects this highway with Campbell Chibougamau Mines, only 3 miles south of the area under consideration. Aerial transportation is available from numerous private companies.

#### TOPOGRAPHY

The map-area lies north of the height of land between St. Lawrence River and James Bay. Its relief of 250 to 400 feet is greater than the average near this drainage divide.

The map-area is crossed by east-trending ridges separated by lowlands and small lakes. Most of it lies in the Dore Lake hilly belt along the north shore of Dore Lake. Abundant rock outcrops occur on the ridges. The belt is not a continuous ridge, but is made up of a series of short ridge-like hills separated by tracts of lowlands. The highest hill, located just south of Little Gilman Lake, is capped by a fire ranger's observation tower.

Gouin Peninsula is a narrow band of land separating Dore Lake from Chibougamau Lake. From the Obalski-McKenzie township line northward for 1200 feet, the Peninsula is very flat and covered by a deep sheet of glacial gravel. Diamond drilling indicated over 150 feet of drift. Further north, Gouin Peninsula becomes a ridge that rises steeply on the Chibougamau Lake side with a more gradual slope on the Dore Lake side.

#### DRAINAGE

The map-area drains northward into James Bay, but by a very circuitous route. Lake Chibougamau is about 1230 feet above sea level.

It drains through two outlets into Dore Lake which is 12 feet lower. Dore Lake and Gilman Lake flow southwestward into Chibougamau River and through numerous lakes which are enlarged portions of this river. The waters of Chibougamau River discharge into James Bay via Waswanipi and Nottaway Rivers.

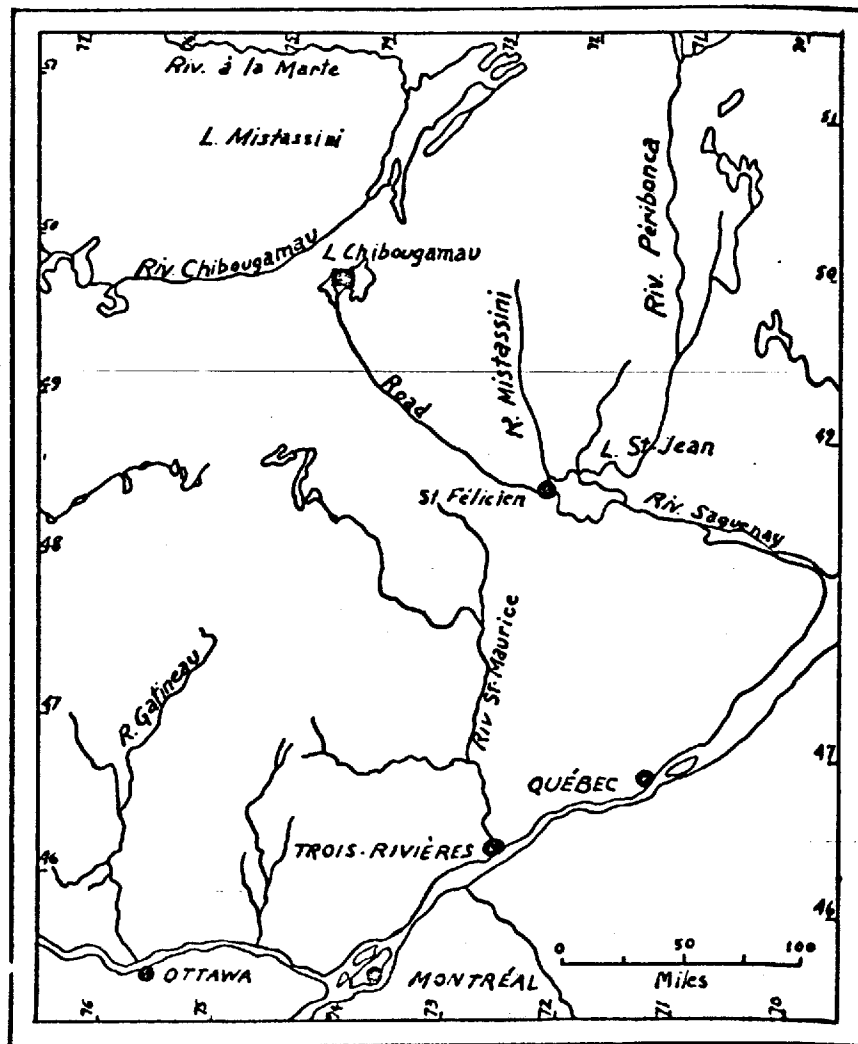
#### GLACIAL GEOLOGY

Pleistocene ice-sheets greatly modified the surface. Glacial striae are numerous and trend from 210 degrees to 220 degrees (azimuth). The best striae are found along wave-beaten lake shores and on ridge tops.

The southwestward movement of the ice-sheet, combined with the structure of the area markedly affected the regional topography. The ice sheet left a thick blanket of boulder till, sand, and gravel over most of the area. A little east of Machin Point, a drill hole (60 degrees) penetrated over 200 feet of drift before it reached bedrock. In that vicinity, a number of drill holes have gone through highly altered and weathered anorthosite with a deep red color, full of vugs and cavities, somewhat similar to laterites. This may indicate an area from which the preglacial weathered bedrock was not removed by the ice. This is rarely observed in glaciated countries and could mean that the ice-sheet removed little of the bedrock although the possibility of a deep depression in the original pre-glaciation surface should be considered.

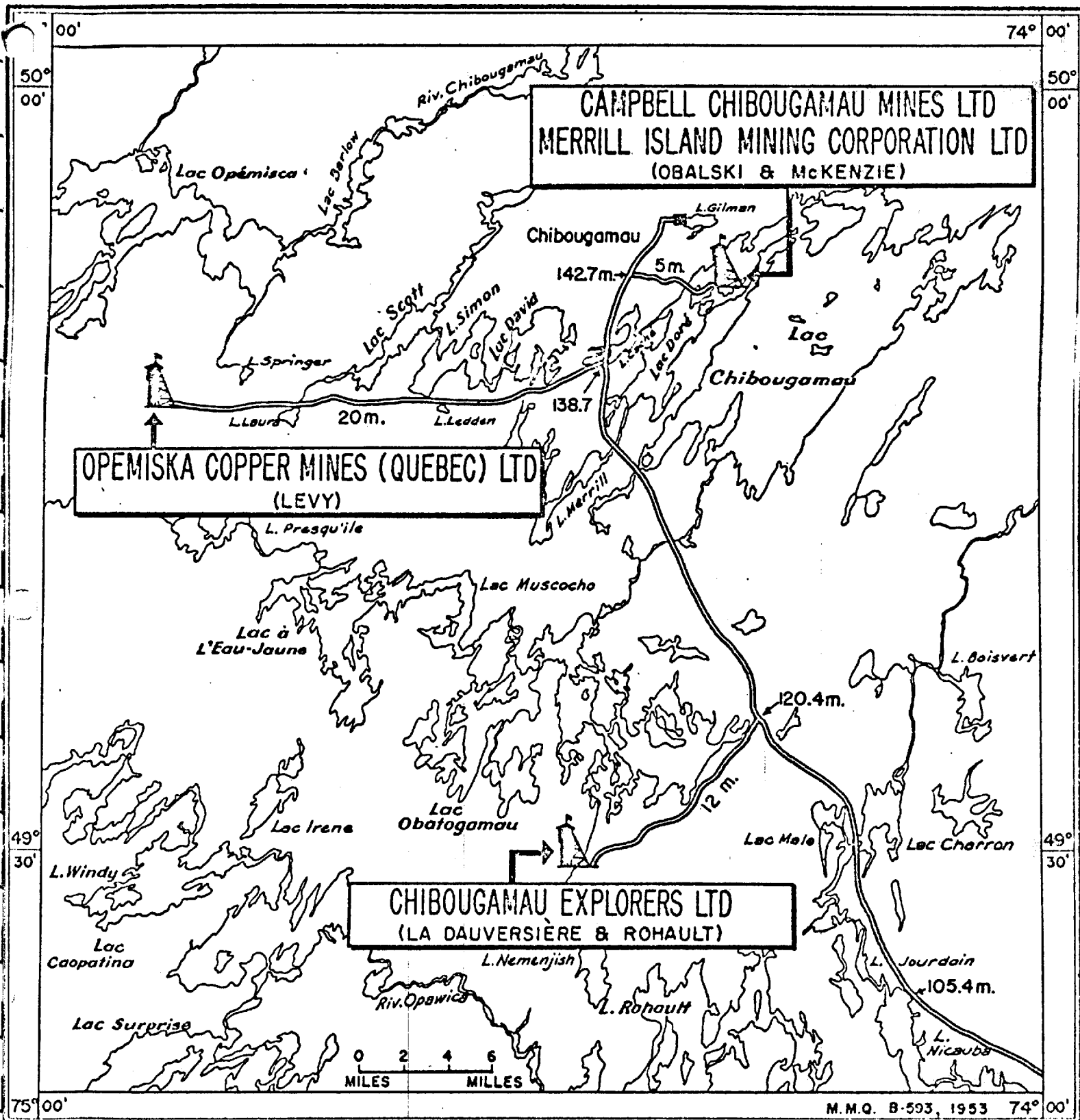
Most ridges have a steep rocky north face and a gentle south slope covered with bouldery gravel. No eskers were found in the map-area.

Coulin Peninsula probably represents a marginal recessional



INDEX MAP SHOWING LOCATION OF THE  
CHIBOUGAMAU AREA (BLACK RECTANGLE)

Figure 1



M-M-38

INDEX MAP OF THE PRINCIPAL METALLIC MINES IN CHIBOUGAMAU REGION

Figure 2

moraine between two ice lobes which covered Doré and Chibougamau Lakes respectively.

The plain on which Chibougamau village is located has a featureless flat surface, except where it is gullied by David Creek and its tributaries. It is underlain by stratified fine-to medium-grained sand that was deposited in a Pleistocene Lake.

#### PREVIOUS GEOLOGICAL WORK

The area was explored by Richardson as early as 1870. In 1884, the Bignell-Low Mistassini expedition passed through the region. In 1892 and 1905, A.P. Low returned and further explored the vicinity of Chibougamau Lake. All these expeditions followed the waterways and no general mapping was attempted. Because of pressure to build a railway into the area, the Quebec Government decided to have an unbiased and authoritative report on the mineral resources and economic possibilities of the area. Accordingly, the Chibougamau Commission was appointed in 1910 and their report was published in 1911. They concentrated their work on the mineral occurrences and did little geological mapping.

Hetty (1930) mapped McKenzie township in 1929 for the Quebec Department of Mines at a scale of one mile to the inch. In 1927, 1930 and 1934, Hawsley (1927) and Norman (1935) mapped at the same scale an area west of Chibougamau Lake, including the area covered by Hetty. During the following years, Norman extended the mapping to the west.

In 1950, following construction of the highway, Graham (1951)

started mapping Obalski township at a scale of 1000 feet to the inch. In 1951, J.R. Smith proceeded to map the southern portion of McKenzie township, and J.R. Smith and the writer completed this project at a scale of 500 feet to the inch by the end of 1954.

#### FIELD METHODS

The area was photographed from the air in 1953 at a scale of 1000 feet to the inch and enlargements provided at 500 feet to the inch. However, the heavy forest cover (Fig. 3) limits the use of the photographs. On the other hand, most of the map-area has been covered by geophysical surveys and the cut-lines provided excellent control on which to plot the geology. The base lines were tied in to old surveyed lines and to the topography. Most traverses were chained unless chainage was still readable on the original pickets. In the portion of the map-area where cut-lines were not available, traverses were run on compass and chained. Traverses were spaced 250 and 300 feet apart, except where no lines were available. In the latter case, 400- or 500-foot spacing was used depending on the topography, availability of rock outcrops, and horizon markers.

To understand some of the difficulties encountered in the mapping, a few words about the nature of the terrain are in order. Most of the area is covered with glacial drift. Rock exposures without drift cover are plentiful but small. Moreover, they are generally concealed by a heavy blanket of moss. To observe the bedrock, one has to seek cliffs where the rock is already exposed or else strip the moss cover from driftless rocky exposures. The

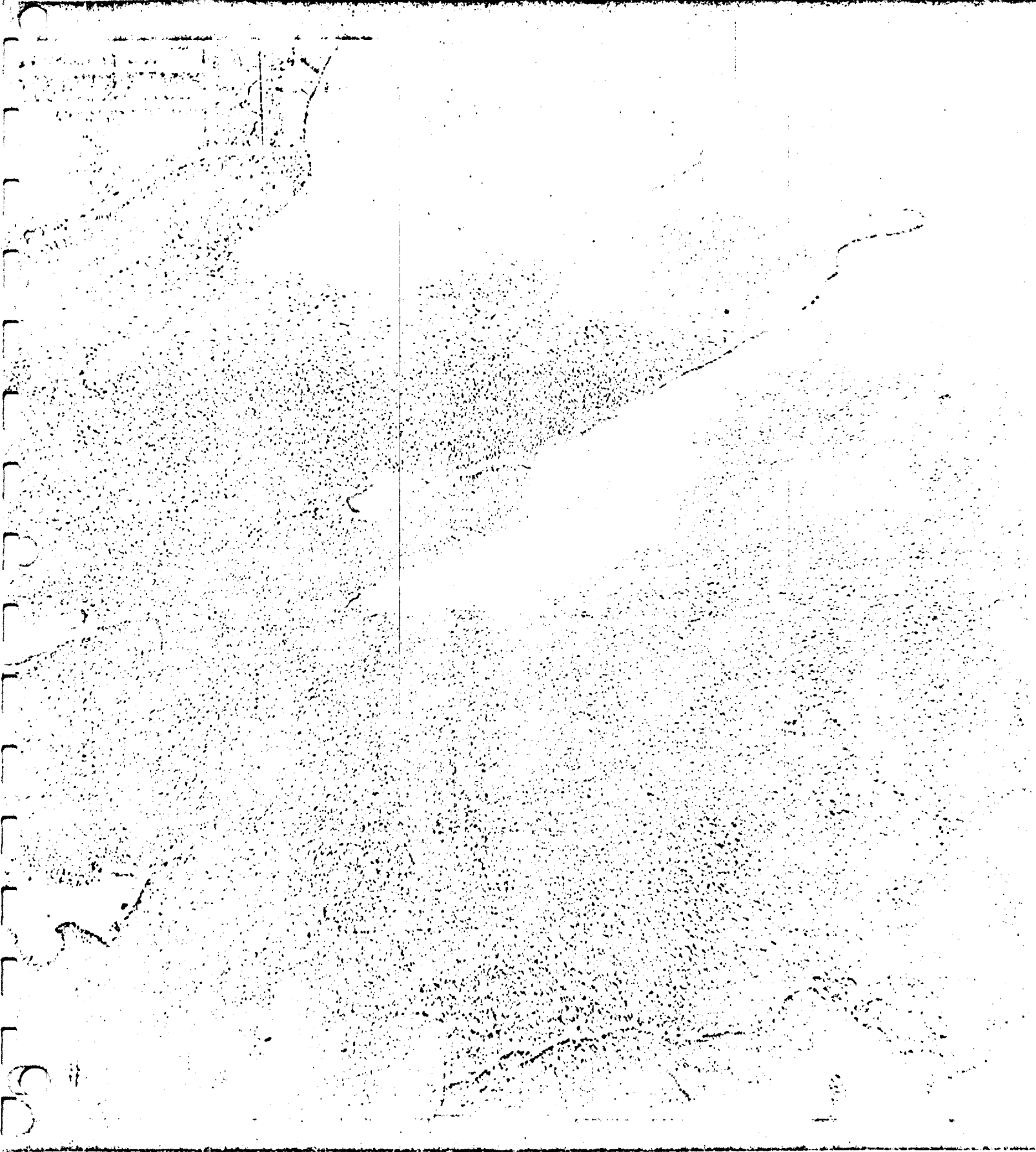


Figure 3. Aerial photograph (scale 1000': 1") of part of the map-area showing the dense forest cover which blankets the area.

latter method involves a great deal of manual work, especially in heavily timbered areas. The wet moss acts like an etching reagent and the texture and structures of the rock are beautifully exhibited when the moss is rolled off (Fig. 4)



Figure 4

Exposure of porphyritic metabasalt showing the texture after the moss has been rolled off.

Scale is 6" long.

Scale rests on the chilled bottom portion of the flow to the right.

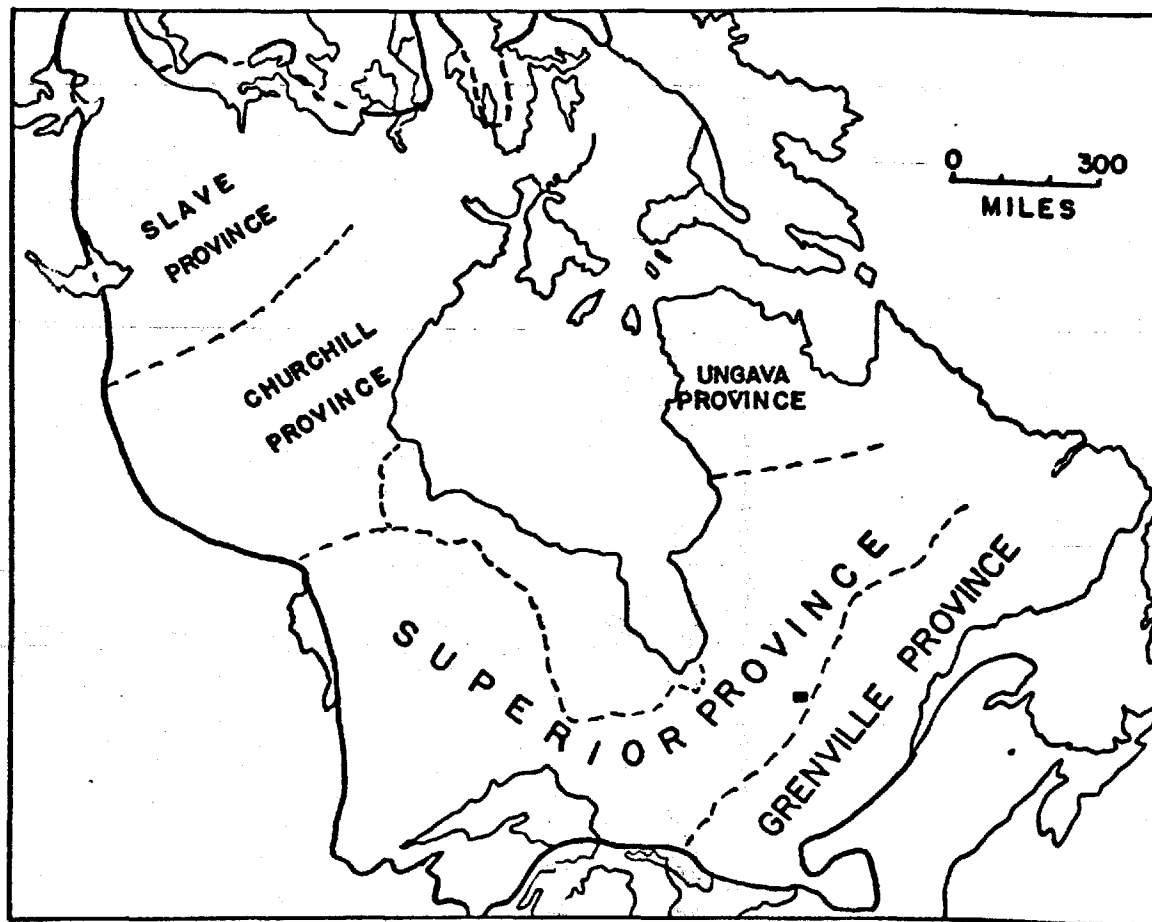
In many places, especially where hydrothermal alteration has been intense, the etched and weathered surface is the best clue to the identification of the original rock. The structure and textures of the rock, and the outlines of the original minerals, are well displayed on such surfaces, but on a fresh surface one only observes a fine mat of chlorite, sericite, carbonate and other hydrothermal products which blur the original structures and textures.

REGIONAL GEOLOGY

An understanding of the geology of this restricted area requires some knowledge of the geology of the whole Chibougamau district.

Gill's (1948) nomenclature of the different sub-provinces of the Canadian Shield is used (Fig. 5). The Chibougamau district lies in the easternmost portion of the Superior province. What is now called the Superior province includes the Timiskaming sub-province and other sub-provinces in the western part. M.S. Wilson introduced the concept of sub-provinces (1913) and applied the geosynclinal theory to rocks of the Canadian Shield: he interpreted the central belt of Laurentian banded gneisses, extending from the north shore of Lake Huron to Lake Mistassini, as the core of a Precambrian mountain chain which stood as a geanticlinal belt between geosynclines formed by the Abitibi group and the Grenville series.

The division in sub-provinces was done to help in the correlation of similar rocks found over such wide areas that outcrop correlation was impossible. Local names were used for each sub-province. However, the outcrop situation and the size of the sub-province made correlation an impossible task in many instances. This led to a terminology which expressed lithologic similarity without equivalence in time. The terms used-- Keewatin-type, Timiskaming-type, and Grenville-type -- have a time-stratigraphic significance in the type localities but have been used broadly by most geologists as purely lithological terms



MAIN DIVISIONS OF THE CANADIAN SHIELD  
(BLACK SQUARE = CHIBOUGAMAU AREA) (GILL, 1949)

Figure 5

carrying no time connotation. This is the usage followed here, and the terms *Acewater-type* or *Timiskaming-type* could be put on rocks found in any province in Canada or anywhere else in the world for that matter without signifying anything about equivalence in time.

The nature of the boundary itself between the Grenville and the Superior provinces has not yet been settled. A conclusion adopted by many is that the boundary is a fault zone. The names "*Huron-Mistassini fault zone*" (J.T. Wilson 1949) or "*Huron-Mistassini thrust*" (J.T. Wilson 1949a) or "*Grenville front*" (Derry et al. 1950) have been used.

Norman (1936) believed that the provincial boundary was a structural feature resulting from "mountain building" of the Grenville orthogneisses and paragneisses in Late Precambrian time. Folding of the Archean rocks of the Timiskaming sub-province about east-trending axes antedated and was truncated by this boundary.

Gill and Wilson have expanded on Norman's theory: they divided the Canadian Shield into provinces characterized by distinct structural trends. They refer to the Grenville sub-province as the Grenville Province. The limits of the Timiskaming sub-province have been expanded and it is a Province.

Gill (1948, p.29; 1949, pp66-67) considers that the Grenville Province marks the site of a Late Precambrian mountain belt which has a trend followed farther to the southeast by the Paleozoic mountain systems. His reasons include

- a) truncation of the eastern-trending structures of the Superior province by the northeast-trending structures of the Grenville sub-province.

b) radioactive dating of the Grenville rocks.

He subscribes to Norman's hypothesis that the rocks of the Grenville sub-province have been raised relative to those of the Superior Province by thrusting.

Regarding the Grenville front, Johnston said (1954)

"the two sub-provinces are in fault contact along a zone of northeast-striking, east-dipping faults, with displacement of the Grenville, or southeast side, upward. The amount of displacement at these faults ranks them with the major tectonic features of the earth's crust".

Recently, Garland (personal communication from F.F. Osborne) suggested that the so-called Grenville front in Quebec is the northwest edge of a zone of injection which corresponds to a gravity low.

The Superior Province is typically underlain by belts of volcanic rocks intruded by basic and ultrabasic sills and by granite and dioritic batholiths and stocks. In the Chibougamau district, Norman (1936) found that the salic masses occupy the anticlinal positions whereas the volcanic rocks and intrusive sills are in tightly folded synclines.

The volcanic sequences comprise basalts, andesites, rhyolites and pyroclastics, all metamorphosed to the greenschist facies. The area mapped by the writer includes the basal portion of a thick succession of flows that form the southern limb of a syncline whose axis is invaded by numerous basic and ultrabasic sills. The sills have been mapped for a length of 60 miles. Some of them show pronounced differentiation, and D. Derry (1939) states:

"the intrusive series seems to be something of the same type as the well known Bushveld Complex of Transvaal" (p.127).

One of the major salic masses mentioned above is the Chibougamau

Lake batholith. This mass is surrounded by anorthosite and gabbro, thought to represent members of an original flat-lying thick sill arched up by the intrusion of the Chibougamau Lake batholith. The anorthosite and gabbro were intruded in a flat-lying structure within the lavas.

North of the area studied, a few patches of flat-lying sedimentary rocks (Huronian?) overlie steeply dipping volcanic and ultrabasic rocks.

#### GENERAL GEOLOGY

The area mapped by the writer is indicated on Plate 2. It can be divided into two parts: an area to the north underlain by volcanic rocks, and an area to the south underlain by plutonic rocks which comprise the various members of the Dore Lake Complex.

All the consolidated rocks of the area are of Precambrian age. The volcanic group, presumably the oldest group of the area, has been assigned to the Keewatin by many workers but it is called here the Keewatin-type series. The term Keewatin was originally applied by A.C. Lawson in 1885 to a series of hornblende schists, diabases, diorites, chloritic schists, and volcanic agglomerates in the Lake of the Woods region. Lawson found this assemblage highly folded, metamorphosed, and cut by bodies of granite; and he, therefore, coined the term Keewatin to differentiate these rocks from the Huronian, generally less metamorphosed, and younger than the granite. When detailed studies of northern Ontario and Quebec were done, it was natural to use the term Keewatin when referring to this pre-Huronian assemblage, in spite of the fact that gaps which cannot be bridged

by correlation exist between northern Ontario, Lake of the Woods, and Lake Superior. Due to the lack of precise correlation, the term Keewatin has been replaced by Keewatin-type, which implies a predominantly volcanic assemblage, lithologically similar to the original Keewatin-type section.

These volcanic rocks crop out in the northern portion of the map-area and are described in greater detail below. The southern part of the map-area is underlain by rocks of the Dore Lake Complex: metaorthosite, metagabbro, a transition member between metaorthosite and metagabbro, and other minor facies including metapyroxenite, magnetite-rich metapyroxenite, magnetite-rich diorite, pegmatitic diorite, and granophyre.

All the rocks, except a few members of the Dore Lake Complex, have been metamorphosed to the greenschist facies. Practically no original minerals remain intact except for the magnetite and ilmenite in some layers of the Dore Lake Complex. The metamorphic assemblages vary depending on the original composition, the grain size, and the location with respect to nearby faults and igneous intrusives.

The area is transected by three sets of fractures, a major northeasterly-trending set, parallel to the Grenville front, and a southeasterly-trending set which is very important economically. The third set strikes slightly east of north and is still very poorly known. The southeast-striking set is made up of shear zones of variable width along which chalcopyrite, sphalerite, and siderite veins are localized. Mining is in progress along five of these southeast-trending mineralized shear zones. Hydrothermal alteration and

intense shearing are characteristics of these fractures. Carbonatization and development of chloritoid are the main types of hydrothermal alteration, but silicification, chloritization, and sericitization are also very common.

#### STATEMENT OF THE PROBLEMS

The detailed mapping of this area focuses attention on the following problems:

- a) the original nature and shape of the Dore Lake group of rocks (especially the Dore Lake Complex).
- b) the relations between the various members of the Dore Lake Complex .
- c) the regional structure, its origin and history, and relation to ore location and ore finding.
- d) the nature and characteristics of the hydrothermal alteration, with special attention to the chloritoid problem.
- e) a comparison between Keewatin and Recent or Tertiary volcanism and volcanic rocks.
- f) the metamorphism and metamorphic processes as studied in this area.

The area mapped in detail is too limited to provide a complete solution to all these problems. However, they are discussed here because any comments and contributions are apt to help others in unraveling this complex picture.

#### KEEWATIN-TYPE VOLCANIC ROCKS

The northern part of the map-area is underlain by volcanic rocks of the Keewatin-type. The extrusives, shortly after their formation, constituted a thick volcanic series comparable in most

respects to the large Recent and Tertiary Lava plateaus. As seen on Plate 2, this volcanic assemblage extended at least 64 miles without any major discontinuity, and it could have been much more extensive because it is terminated to the east at the Groville front. Westward, lack of detailed mapping makes it difficult to extend the volcanic rocks further than Opemisca township, west of the Opemisca batholith (Plate 2) but further work may show an extension westward of many miles.

As previously stated, this volcanic series has been folded into a syncline (Plate 2). The areas mapped by J.R. Smith, R.S. Graham and the writer are all on the south limb of this syncline. The thickness of the volcanic series, together with the interleaved basic sills, ranges from 19,000 feet to 22,000 feet. In a 19,000 foot section measured from Antoinette Lake to Half Moon Lake, 14,000 feet are volcanic rocks and the remainder is basic sills. A section south of the west end of Larone Lake shows that 16,000 feet out 22,000 are volcanic rocks, and similar figures apply to a section drawn on the McKenzie-Roy township line which is the eastern boundary of the map-area.

The top (north) of the section also shows shreds of pyroclastic rocks that have been preserved in spite of the intrusion of numerous gabbro, pyroxenite, peridotite, and dunite sills and plugs. Some of these pyroclastic remnants attain a thickness of 1,300 feet and should be added to the total thickness of the volcanic series. These pyroclastics probably represent the waning stages of the volcanic activity.

The base of the volcanic series has not been observed. In

the field, exposures of the lower part of the series invariably end against a fault zone or are intruded by rocks of the Dore Lake Complex. Hence the original thickness of the volcanic sequence may have been greater.

Some faults are nearly parallel to the strike of the volcanic rocks, but much of the movement was strike-slip and there is little evidence indicating thickening or repetition of the volcanic group.

Such a large thickness of volcanic rocks is not unknown but rather uncommon. In the Yellowknife district (Northwest Territories of Canada), Henderson and Brown (1952) report

"22,000 feet of nearly vertical flows is exposed between Negus Point and the granodiorite to the northwest".

In the Olympic Peninsula of Washington State, Park (1946) mentions

"at least 30,000 feet of argillites, greywackes, volcanic rocks and limestones of early-middle Eocene age".

In the Noranda area (northern Quebec), Wilson (1941) estimated the total thickness of the volcanic rocks at 25,425 feet. In the Keweenaw Peninsula of Michigan, Wright and Cornwall (1954) state that

"the total thickness of 17,000 feet includes about 350 separate flows and approximately 20 thin beds of sedimentary rocks. Nearly all the flows are less than 150 feet thick and about half of them are less than 20 feet thick".

#### Methods of approach

When the name Archean was proposed by J.D. Dana for the Precambrian and was later redefined by the United States Geological Survey to include only early Precambrian formations, most geologists thought that the Archean was composed of crystalline schists and gneisses of igneous origin "radically different in character" from later rocks. The detailed mapping done in Chibougamau supports the

contention of many modern geologists that Archean geology is very similar to post-Cambrian geology and can easily be unraveled provided enough data are available to warrant a thorough comparison with younger better known rocks.

The volcanic rocks were mapped in detail, about 60 thin sections were studied, density measurements done on a group of representative specimens, and fusion techniques (Mathews 1951) used in an effort to study the variations between the rocks at the base and those at the top of the series. In doing the fusion work, the author also intended to test the feasibility of this method in working out the original nature of Archean volcanic sequences.

#### Nomenclature

Mapping of this type of rock always involves problems in nomenclature. The original rocks have been metamorphosed to the greenschist facies, and original minerals (except magnetite and part of the ilmenite) are no longer present. Various criteria can be set up as bases of classification. For example, textures, composition of the plagioclase, color, and other schemes have been used. The majority of geologists have called these rocks andesites, basalts, and rhyolites, or basic, intermediate, and acid volcanic rocks. The first names are misleading because the rock has been metamorphosed to the greenschist or amphibolite facies and should be called metabasalt, metaandesite, or metarhyolite to indicate both the original nature of the rock and the fact that it has been metamorphosed. The division into basic, intermediate, and acid is even worse because the terms are partly chemical and not geological. Moreover, they do not convey the idea of comparing the Archean volcanics with

Tertiary and Recent equivalents. Since the latter are better known, the criteria which serve to differentiate rock varieties in unmetamorphosed terrains should be tested and modified for the purpose of mapping Archean rocks.

Regarding the area in which we are interested, previous workers have called the volcanic rocks by different names. The Chibougamau Commission (1911) in their report states

"The Keewatin formation of the Chibougamau region is made up principally of consolidated lavas, ranging in the prevailing species from rocks of very basic types to others of intermediate composition" (p. 163).

Reilly (1930, p.58) said:

"Andesite constitutes sixty per cent of the Keewatin. ... rhyolite amounts to twenty per cent of the Keewatin" (translation by the writer from the French edition)

Mawdsley and Norman (1935, p.12) reported that

"highly altered flows of intermediate composition, probably andesites, predominate in the volcanic assemblage. They are typical greenstones".

#### Distribution

The Keewatin-type volcanic rocks underlie the northern part of the map-area and extend northward for three miles. The south boundary is the Lac Sauvage fault zone. A narrow wedge of volcanics also appears on the north shore of Goulin Peninsula, close to the Iby-McKenzie township line (Plate 1). This band is only 1000 feet wide and 3500 feet long, but its extension to the east has not been accurately determined, although it is known to be present across most of Portage Island (D. Horcroft, pers. communication).

### Characteristic features

The Keewatin-type volcanic rocks vary from metabasalt at the base to altered pyroclastics at the top. Some rocks of unknown origin are present to the north of the area mapped by the writer; they are thought to be metasediments and possibly metarhyolites. A few thin sections were examined, but not enough for a complete analysis.

### Massive and pillowed flows

The volcanic rocks were extruded on a flat surface as shown by the regularity of the flow contacts. Flow junctions strike slightly north of east in a uniform regular manner. The dip varies between 80 degrees north and 80 degrees south. Since the actual surface is a cross-section across the whole sequence, one can study the relation of the massive flows with regular flow contacts to belts of pillowed flows laid down under water. The belts of pillowed flows are elongated parallel to the strike and are of limited width. This means that shallow depressions formed on the surface of the flows in which water accumulated. These were obliterated by the next incoming rush of lava. Or it could be that adjacent volcanoes poured out lava flows toward one another and blocked rivers to create large water bodies.

The volcanic rocks at the base of the series were of original basaltic composition. Going upward in the stratigraphic sequence, the lava became more andesitic, and the final outbursts of volcanic activity gave rise to rhyolite and pyroclastic rocks.

Most of the flows are massive, and show only minor alteration of the original structures and textures. At the base, about 80 per cent

of the flows are massive; the remaining 20 per cent have well developed pillow structure. North of the Grandines road, pillowed flows are more abundant. The mineralogical alteration has, however, been profound in both kinds.

The massive flows of metabasalt are monotonously uniform. They weather to a greyish green or dark green color. They generally give smooth rounded glaciated surfaces. Only a few flows could be measured from top to bottom, but the thickness of individual flows appear to vary from 15 to 110 feet. From the observed grain size of some flows, greater thicknesses are suspected, but lack of outcrops commonly prevent exact measurement of individual flows. The massive flows are very uniform in appearance and mineralogy. They are much coarser than the pillowed flows, some range up to one quarter of an inch in average grain size. Amygdaloidal layers are abundant and it is common in the field to go from a massive coarse-grained greenstone with typical intergranular texture through a zone exhibiting increasing amounts of amygdules, and finally four or five feet of a slaggy flow top. Some of the flow tops are fragmental.

The massive portions of the flows resist erosion much better than the flow tops and amygdaloidal portions. This explains the great abundance of rounded humps in the field, underlain by massive metabasalt flows, and the relative lack of well exposed flow tops and amygdaloidal layers. For this reason, workers in Precambrian terranes, when doing mile-to-the-inch mapping, have great difficulty in determining whether isolated outcrops are the centers of flows

or are intrusive sills of similar composition. The detailed work done by the writer shows a consistent pattern repeated in many places: the center of the outcrop corresponds to the center of the flow and the flow tops and amygdaloidal parts underlie the intervening draws.

Stripping of the mass along small step-like cliffs usually reveal either amygdaloidal-rich lava or the intricate patterns due to differential weathering of the slaggy flow tops.

The amygdaloidal horizons are generally very pitted and rock-marked on the weathered surface because the most common amygdale-filling is calcite. Chlorite and quartz are also found in amygdules.

Thin sections of rocks that appear massive and coarse-grained commonly reveal tiny amygdules indicating the extrusive nature of the material.

Filled lavas are much finer grained than their massive counterparts. They are also paler in color, being medium to pale green. The pillows range from a few inches to fifteen feet in length, and average about two feet long. Each pillow has a very fine-grained rim, half an inch to one inch thick, slightly darker or paler green in color than the rest of the pillow. It is very common to have a band two to six inches wide of amygdules or variolites (amygdules are more common) against this rim of altered original glass. The amygdules become rarer proceeding inward toward the center of the pillow, and disappear completely in the larger ones (Fig. 6).

The most common pillows are the mattress and balloon-type (Shrock, 1948, p. 364). Only the balloon-shaped ones are useful in

determining the tops of the flows. The pillows are never connected one to the other; they are separated by glassy rims and interstitial material. Both matrix and pillow are heavily chloritized and carbonized. In two places, in or a little above the center of the pillow, a large cavity filled with quartz was noticed. Similar features were reported by Auger (quoted in Strock 1948, p. 361) and Henderson and Brown (1952). Because they are rare in this area they have been little used to indicate top from bottom.

The significance of pillow lavas is hardly debated any more. Pillow structure is a feature of lavas that have flowed into water. Henderson (1953) has summarized the problem and arguments so well that it is not necessary to review it here. Henderson (1953, p.27)

concluded

"pillows were deposited one on top of the other as globules of lava with tough but flexible glassy skin and with still plastic interior".

As mentioned earlier, it is possible that lakes formed in depressions on top of flows or by the damming of rivers. Another possibility is that they formed in calderas, as suggested by Hickey (1948)

"pillow-structure is a feature of lavas that have flowed into standing water, and the examples from the interior of Mull indicate the repeated occurrence of lakes formed during periods of quiescence within a vast crater. The floor of this wide crater, or caldera, sank repeatedly. This is indicated the great thickness of the pillow-lava assemblage".

In the Chibougamau district, calderas could be determined only if the level of erosion was such as to expose the ancient volcanic necks and the caldera walls. Such features have not been found and the true nature of the basin of deposition for the pillow lavas remains

an unsolved problem. However, the linearity and width of the pillow-lava belts favours extrusion into shallow lakes not connected with calderas.

The lavas were erupted quietly and intermittently. They are very rarely interbedded with ash. The few flow contacts observed show no sign of weathering or soil accumulation between flows. This indicates rapid outpouring of the lava sequence.

When compared to the basalts of other areas such as the Inner Hebrides (called Plateau Lavas by Richey), the Columbia River basalt (Waters) or the Catoclin greenstone (Reed 1955), it is remarkable that no columnar structures were observed in any of the flows. It is possible that poor exposures and unfavorable orientation of the outcrop surface caused this apparent lack of columns, but it would be surprising that so many observations would not have yielded any signs of columns anywhere. This situation is not unique however. For example, out of 17,000 feet of lavas in the Michigan area (Bright and Cornwall, 1954), only two flows showed good columnar jointing. The situation in Chibougamau is in harmony with the thinness of the flows. Only flows over 50 feet thick commonly develop good columns.

The absence or presence of columnar jointing is dependent upon the viscosity of the lava, the temperature, the rate of cooling, the homogeneity of the lava (Janss 1920). According to Janss, homogeneity of the lava is very important and would not be attained in shallow surface flows much disturbed by movement. Moreover, in a thin flow, cooling will be too rapid to permit development of

columnar jointing. Some of the flows mapped in this area are thick enough (over 100 feet) that one would expect columns to be developed. They also show great homogeneity in the field and in thin sections.

#### Flow tops

More than 50 flow tops were observed in the metabasalts. In over 25 cases, the exposures were good enough to indicate the direction of the flow top. Typically, a flow top is gradational into the amygdaloidal part of the flow, and is only a few feet thick. Some ambiguities exist in the literature as to the terms for flow tops. Richey (1948, p. 40) describing flow tops similar to those in the Chibougamau district says:

"the middle tier is surmounted by a layer of slag. The gas cavities (vesicles) of the slags are filled with minerals, forming amygdules".

Should we then call these flow tops "slaggy flow tops"? Or should we follow Macdonald (1949, p. 59) and call them "pumiceous flow tops"? Since slag better expresses the nature of the material, the term used here will be slaggy flow tops and slaggy fragmental flow tops. Fig. 7 illustrates a weathered surface of scoriaceous flow top in contact with the massive bottom of the next flow. Figure 8 is taken on a piece of drill core of scoriaceous flow top. Fig. 9 and 10 are taken on a polished surface of a hand specimen of flow top. Fig. 11 is taken on a thin section of a scoriaceous flow top.

The distinctive weathered surface is usually quite dark, rusty green, and full of holes and pits of all shapes and dimensions, accompanied here and there by ribs of whitish silica that resists

weathering better than the carbonate and chlorite filling the amygdalites.

The abundant vesicles indicate that the magma had a high volatile content. Slaggy fragmental flow tops appear to have been formed when the lava was in movement. Fragments of the partly consolidated lava rind on top of the flows were broken as the flow advanced and were caught in the fast-freezing top. Most fragments are amygdaloidal and some attain eighteen inches in length. They commonly show a very fine-grained chilled border and sometimes slight banding parallel to their borders.

Flow tops which were used in determining the stratigraphic tops are indicated on the map (Plate 10).

#### Porphyritic flows

Flows with phenocrysts studded uniformly through the flow were not observed in the metabasalts. However, at six different localities, indicated on the map (Plate 1), layers from 9 inches to 4 feet thick are studded with plagioclase phenocrysts (fig. 4, 12, and 13). Each of these outcrops showed the basal portions of the phenocryst-bearing flow and the top of the adjacent lower flow.

The plagioclase phenocrysts vary from  $\frac{1}{4}$  of an inch to 2 inches. On the weathered surface, they stand out as white humps in a smooth fine-grained green matrix. The layered nature of the phenocrysts-bearing bands and their close proximity to the base of the flow indicates that the intratelluric phenocrysts settled in the still liquid lava after extrusion. In one flow, the phenocrysts are euhedral and rhomb-shaped. Fig. 14 is a photograph of a thin section of a porphyritic flow.

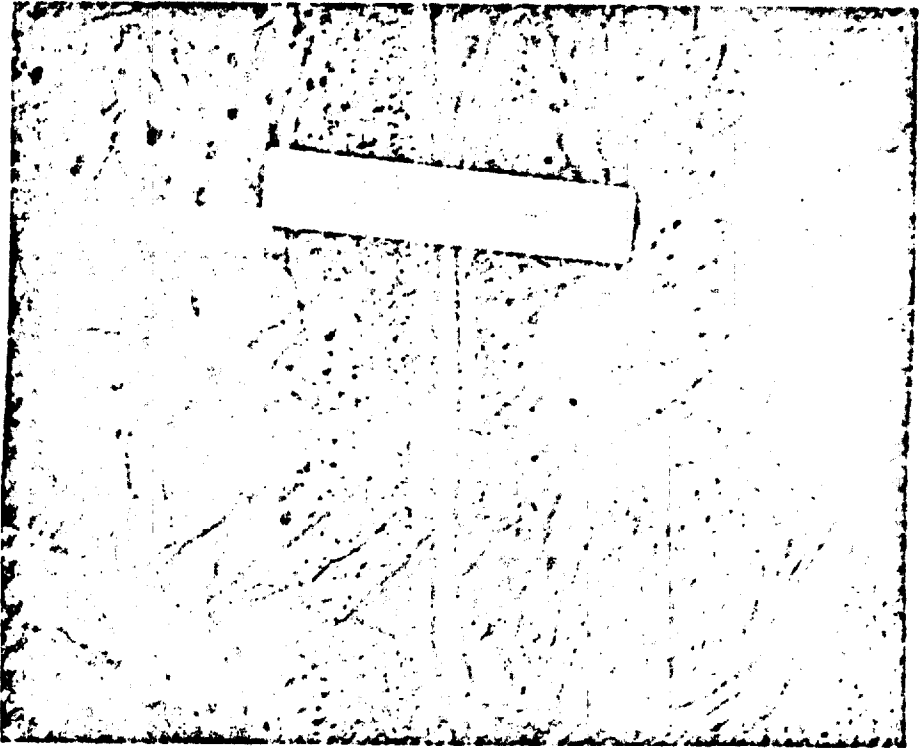


Fig. 6 Pillows with fine-grained rims and a decreasing amount of amygdules toward their center. Scale is 6 inches long.



Fig. 7 Scoriaceous flow top (bottom) in contact with the bottom of the next flow. Scale indicated by boot.



Fig. 8 Piece of drill core showing a scoriaceous flow top. Dark crystals are chloritoid grains. From a drill hole underneath Little Gilman Lake, across the Lac Sauvage fault zone. (3x)

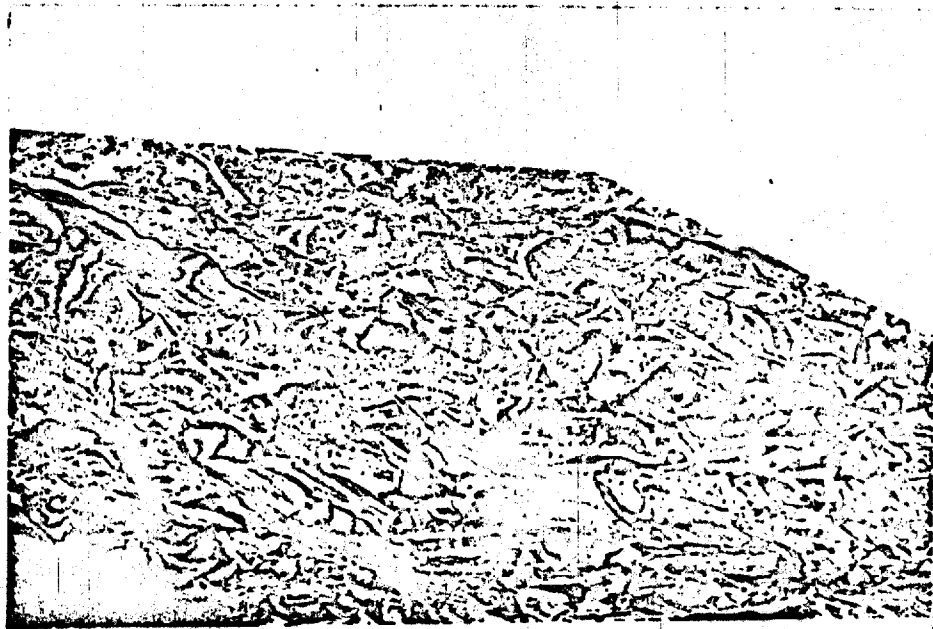


Fig. 9 Hand specimen of a scoriaceous flow top. Note the excellent preservation of texture in spite of folding and metamorphism. (natural size)



Fig. 10 Polished surface of a hand specimen of scoriaceous flow top. Note the large amygdaloidal fragment at the bottom of the photograph. (Natural size)



Fig. 11 Thin section of a scoriaceous flow top. The white patches are made up of calcite, quartz, chlorite. The dark broken fragments are devitrified glass particles now made up of nearly isotropic brown material which has not been identified. (6x)



Fig. 12 Outcrop of porphyritic metabasalt.  
The white humps are plagioclase phenocrysts.  
The tape in the corner is 2" across.

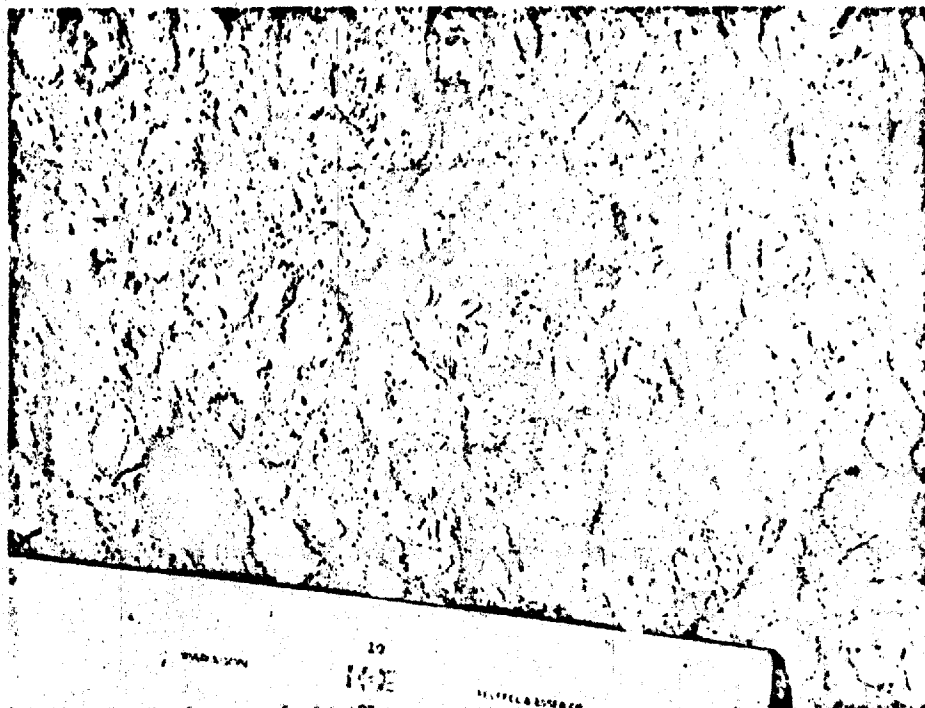


Fig. 13 Outcrop of porphyritic metabasalt.  
Scale is 6 inches long.

Metaandesite (?)

The metabasalt flows are succeeded to the north, and in places appear to be interfingered with, a much more feldspathic paler rock (Table 1) called here metaandesite. This type of volcanic rock is found about 1000 feet south of the Grandines road and northward. The long slope south of this road is so heavily moss-and-brush covered that only few small outcrops were available. They are much better in Smith's area to the north. The rock weathers greenish white to white in marked contrast to the green and dark green surfaces of the metabasalts. On fresh surfaces, the rock is fine grained to aphanitic, in places porphyritic (outcrop along the Grandines road) and pale greenish grey to white. Further north, pale grey white rhyolite(?) makes its appearance, and finally gives way to feldspathic pyroclastics. The surface of these feldspathic rocks is usually blocky, and small angular specimens can be picked up easily. This contrasts with the metabasalts which give rounded polished outcrops very hard to sample.

The change in specific gravity from a maximum of 3.02 for the metabasalts (average around 2.90) to a minimum of 2.64 for the rocks further north (average around 2.75) is indicative of a progressive change in original and actual composition. As noted in Table 1, this change in density is reflected in the modal analyses of the rock by a very marked decrease in the amount of magnetite, leucocene, epidote and actinolite, and a gradual increase in the amount of albite.

J.R. Smith mapped the pyroclastics to the north. The author saw them only during a field trip under his guidance. Smith's description (1954) of the pyroclastics reads as follows:

- 34 -

"much of the clastic rock is closely similar in appearance and composition to the feldspathic lavas, weathering to chalky buff to white colors and consisting predominantly of clouded sodic plagioclase. Such feldspathic clastic rock is in many places thinly to thickly bedded, and contains recognizable clastic fragments of feldspathic and andesitic rocks. Massive, homogeneous, evenly fine-grained feldspathic rock of dubious origin is included with the clastic rocks of the northern part of the area on the accompanying map; such rock may be in part of intrusive or extrusive origin. Where the clastic rocks are thinly bedded, the grain size commonly varies from coarse to aphanitic from bed to bed, and although the composition is generally feldspathic, some beds and sequence of beds are richer in chlorite and other mafic constituents. Laminae of cherty appearance, varying in color from white to black, are common, and a thick sequence of true cherts occurs in the north-central part of the area (see map). The recognizable rock fragments in the clastic rocks are almost exclusively similar to the feldspathic lavas, and especially in the southern part of the area, to metaandesitic lava. For this reason, the clastic rocks are thought to be largely of pyroclastic origin, although the thinly bedded types were probably deposited in water".

### Petrography

The volcanic rocks of the map-area are metamorphosed to the greenschist facies. Field geologists call these rocks green schists or greenstones. The latter term is preferred because of the preponderance of massive, unfoliated rocks encountered in the field. The massive portions of the flows still show the original textures and structures, and, for reasons mentioned below, the author believes that very little has been added or lost during the metamorphism of these rocks.

Along flow tops, or shear zones, the rock is commonly schistose and could be called a chlorite schist, or carbonate-chlorite (sometimes chloritoid is present) schist. The introduction of carbonate, ankerite and/or siderite, modifies the color of the rock. For a while, this misled the author in the field naming of

some of these rocks. The introduction of submicroscopic grains of carbonate throughout the rock gives it a much paler color. The carbonate-bearing solutions were very tenuous and spread out on each side of the channelways in massive rocks. The carbonate replaces the original constituent of the rocks, especially plagioclase, and forms a mat of very tiny grains which are not recognizable as such in the hand specimen. They give a pale brownish color to the rock.

The chlorite and/or carbonate schists are very fine-grained and cannot be positively identified as volcanic in origin unless they contain amygdules or have the typical intergranular texture of basalts. Chlorite is thoroughly redistributed in these rocks, and no modal analyses were done on this type of altered rock since it is extremely variable, and does not represent the original composition.

The point counter method developed by Chayes (1949) proved to be useful in modal analysis of the coarse-grained metavolcanic rocks. The number of points counted on each section and the results are indicated on Table 1. The reproducibility and accuracy of some of these modal analyses is not as good as the analysis of a coarse-grained fresh granite. It has to be done at medium and high-power and one analysis may take from 4 to 6 hours, especially where both chlorite and actinolite are present. However, the fact that 4 analyses of rock with similar field relations and appearance gave the following amounts of albite (41, 39.4, 39.3, 36 per cent) seem to indicate a fair reproducibility. The amount of albite is probably always a little high because of the presence of tiny sericite, calcite, chlorite, and magnetite inclusions in the albite. Ore, chlorite, and epidote estimates are close to the actual values. Actinolite

TABLE 1a

MODES OF METABASALTS

Specimen No.	53-52	53-292	53-293	54-30	54-72	54-160	54-259	54-249	54-267
Albite	41	39.1	39.2	36	31.9	57.4	45.8	53.32	59.2
Actinolite	none	18.2	35.4	23	40.7	.16	16.8	none	none
Chlorite	32.8	12	13.6	10.3	7.8	30.2	12	32.7	36
Epidote	7.9	11.7	2.2	6.9	9.2	.11	5.6	none	none
Opaque	6.7	10.8	.11	15	.8	2.5	10.3	.06	.5
Isucoxane	5.9	8.2	6.7	8	.8	6.6	6.2	7	4.6
Calcite	3.9	none	none	none	none	—	3	6.5	none
Quartz	1.6	none	2.8	none	none	.21	.25	.35	none
Number points	2173	1539	1794	1664	1668	1850	1938	1714	1813
Reproducibility	good	fair	very good	good	fair	fair	very good	poor	fair
Specific gravity	2.68	2.93	2.87	2.9	2.92	2.69	2.92	—	2.71
Index of artificial glasses formed by fusion & quenching	1.594	1.604	1.595	1.595	1.601	1.542	1.593	1.546	1.552

TABLE 1b

## CALCULATED CHEMICAL ANALYSES ( FROM MODES )

Specimen No.	53-52	53-292	53-293	54-30	54-72	54-160	54-259	54-249	54-207
SiO <sub>2</sub>	41	42	54.5	42.2	52	49.5	44	48.8	50.5
Al <sub>2</sub> O <sub>3</sub>	15.2	11.7	9.8	9.9	9.9	15.9	10.3	16	17
Fe <sub>2</sub> O <sub>3</sub>	9.4	13.7	.5	19.4	1.8	3.2	12.7	.08	.6
FeO	11.4	10.8	9.8	7	9	9	10.8	8.4	9.2
MgO	6.4	4.6	8.1	5.2	7.4	6.3	4.6	7	7.4
CaO	6	7.5	7.1	7.2	10.5	2.4	7.1	6.2	1.6
Na <sub>2</sub> O	3.7	3.8	4.1	3.6	3.4	6.4	4.6	6.1	6.5
TiO <sub>2</sub>	2.9	3.7	3.3	3.7	3.8	3.4	2.9	3.2	2.4
H <sub>2</sub> O	3.8	1.9	2.6	1.8	2	3.8	1.8	4.2	4.4
F <sub>2</sub> O	—	—	—	—	—	—	—	—	—
Total	99.7	99.7	99.8	100	99.8	99.9	99.8	99.9	99.7

is difficult to count because of the porphyroblastic nature of this mineral with long ragged ends projecting into the adjacent plagioclase grains.

Plagioclase was determined on the U-Stage using maximum extinction angles (Rittman method)  $\perp$  (010) and extinction angle  $\perp$  to (001) and (010). The An content (mole per cent) is probably not more accurate than 4 per cent. Precise index work would be required to get better results, but the presence of ubiquitous inclusions of sericite and chlorite in the plagioclase makes this method next to impossible.

Optical properties of actinolite and epidote were also determined using the U-Stage and Winchell's curves (1927, p.443 and 449).

The textures of the metavolcanic rocks are remarkably uniform. Intergranular and glomeroporphyritic are the most common textures. Porphyritic flows (single crystals) without clotted phenocrysts were encountered in a few places as indicated in the field description. Microporphyritic textures are rare. The term intergranular implies that the space between plagioclase laths are occupied by grains of pyroxene and olivine and small grains of magnetite and ilmenite. This cannot always be proven in those altered flows; perhaps in some flows the interstices between plagioclase laths were filled with glass. This would give an intersertal texture, but since this problem can seldom be resolved, the term intergranular is used throughout this work.

A remarkable textural feature is pictured in Fig. 15 where a chilled zone around an amygdale is preserved in spite of complete metamorphism. The amygdale is filled with chlorite and the aureole

around it contains ore minerals and fine-grained plagioclase, much smaller than the plagioclase laths in the rest of the rock. Identical textures (chilling around amygdules) are common in unmetamorphosed Tertiary and Recent pillow basalts.

The grain size of these rocks, not including the porphyritic ones, varies between 4 mm x .7 mm for the microphenocrysts of specimen 53-207 to very small grains in the order of .03 mm. In some flows more than 90 per cent of the albite is in long laths, 4 or 5 times as long as wide. In other flows (e.g. spec. 53-52 and 53-292), most of the albite grains are equant euhedral to subhedral grains.

#### Microscope work

The massive metabasalts are made up of albite, chlorite, actinolite, epidote, opaque (magnetite, ilmenite, pyrite), leucoxene, calcite and minor quartz.

Albite ( $Al_0$  to  $Al_6$ ) occurs in long lath-shaped grains randomly distributed in the rock (Fig. 17). In a number of cases, the larger grains or microphenocrysts are grouped together producing a typical glomeroporphyritic texture (Fig. 15 and 16). The albite is twinned following the albite, Carlsbad, and albite-Carlsbad laws. In general, the twinning lamellae are wide, only two or three are present in each grain. This follows the observations of many authors (Donnay 1940). Many grains which appear to be untwinned on the flat stage reveal a composition plane when tipped on the U-stage around the north-south axis. There are untwinned grains, but they are rare.

Chlorite, sericite, carbonate, magnetite, and small epidote grains are disseminated throughout the albite in submicroscopic grains. A feature peculiar to the equant grains is the presence of a square core

of chlorite. This chlorite is apparently the alteration of original glass or magnetite grains which are commonly noted occupying a similar position in the equant grains of fresh Tertiary and recent basalts. In the large lath-shaped grains, tiny inclusions of chlorite define a vague zoning which is also common in fresh volcanic rocks where small magnetite grains, or glass inclusions, or both, follow the zoning boundaries of the plagioclase.

In the light-colored rocks to the north of the metabasalts, the albite is generally much finer-grained. It still has the predominant lath shape but it appears to have a larger length to width ratio than in the coarse metabasalts. The texture is still intergranular but the glomeroporphyritic texture was not noted, and a plumose arrangement of the albite laths is common (Fig. 18).

Actinolite is commonly present in the metabasalts of the area, especially in the coarse-grained darker flows close to the base of the volcanic series. It is pale green and weakly pleochroic (very similar to chlorite in ordinary light) with  $c/\lambda$  typically 16-17°. The following pleochroism formula would apply with minor variations to all the metabasalts studied:

X: colorless to very pale yellow

Y: pale greenish yellow

Z: pale bluish green

Actinolite occurs either as small individual grains between plagioclase laths or as large poikiloblastic grains enclosing many grains of albite and opaque. Small individual pyroxene grains in optical continuity were observed in the core of the actinolite grains in only two thin sections. Small individual grains of actinolite are



Fig. 14 Thin section of a typical porphyritic metabasalt. The phenocrysts of labradorite are gone to albite with a lot of tiny sericite flecks. The matrix is a very fine-grained mixture of albite laths and chlorite with the typical intergranular texture of basalts. (6x)



Fig. 15 Typical metabasalt. Note the glomeroporphyritic texture and the chilled rim around the chlorite-filled amygdale. Note the irregular patches of chlorite in the matrix which may be pseudomorphing chlorophacite. (9.5 x)

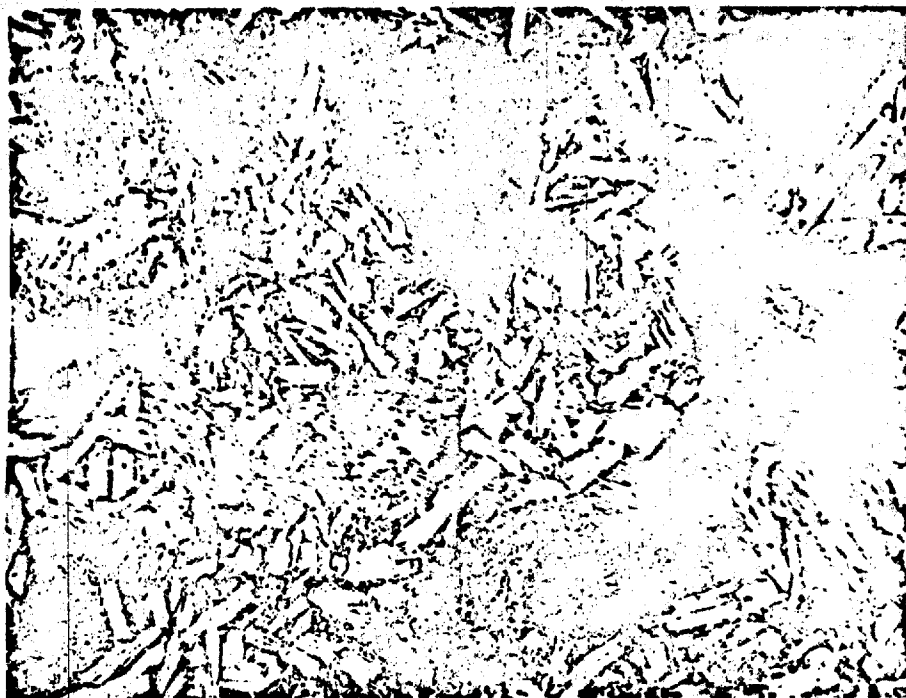


Fig. 16 Typical metabasalt with well developed glomeroporphyritic texture. Note the irregularly-shaped patch of chlorite (C) possibly derived from chlorophaeite. (24 x)

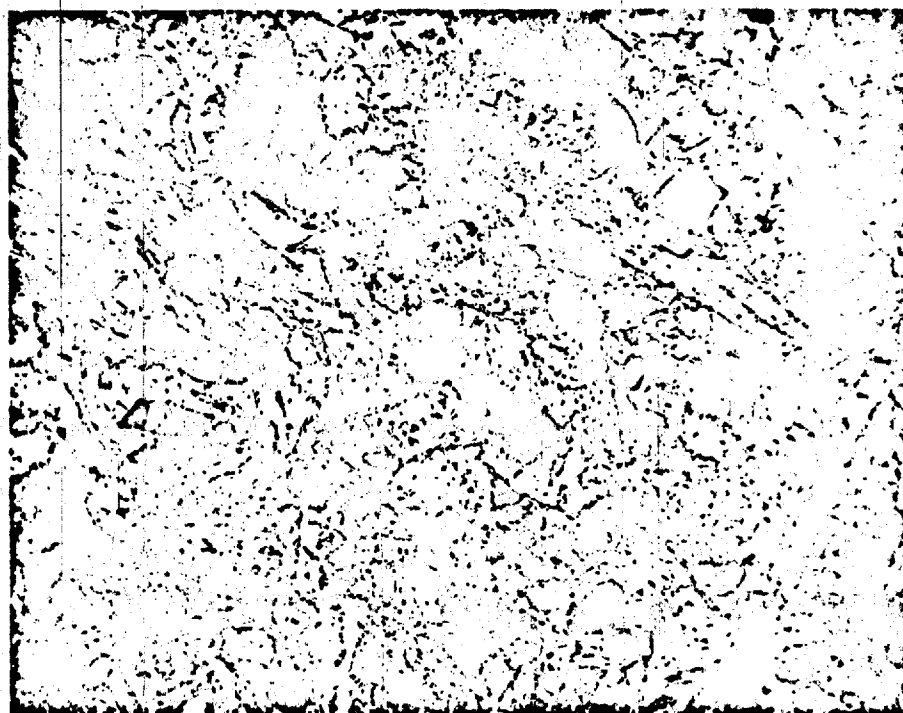


Fig. 17 Coarse-grained metabasalt. The albite laths pseudomorph the original labradorite. The opaque are nearly completely converted to leucoxene and apatite. Most of the matrix is actinolite. (24x)

markedly acicular and have ragged ends with long fibrous projections in the adjacent plagioclase grains. This indicates that the actinolite, contrary to the albite, does not perfectly pseudomorph the original pyroxene, but has grown outward into the plagioclase, using up some of the calcium released by the change from labradorite (?) to albite.

The local preservation of ophitic texture indicates, however, that in places the pseudomorphing of the pyroxene by actinolite is close to perfect and only the ends of the grains, due to a greater force of crystallization along the c-axis, show fibrous penetration into neighbouring grains.

The actinolite, in practically every thin section, is well intergrown with chlorite. The chlorite occurs in narrow bands parallel to the cleavage directions of actinolite, in patches throughout, and especially in the cores of the actinolite grains. One rock (specimen 54-163) is essentially composed of nothing but actinolite, chlorite, and minor ore minerals (Fig. 19). It was impossible in the field to decide whether this is an original mafic segregation in the bottom of a thick flow or in the bottom of a sill. The large actinolite grains all have a rotten-looking core of chlorite. In this chlorite core, tiny grains of actinolite are found in optical continuity with the actinolite of the rim. It is often difficult to decide the age relations of the chlorite and actinolite. In places the actinolite seems to grow into chlorite, but that relation is never too evident. In the case of 54-163, and many others, it may be that the first stage of metamorphism has caused a development of actinolite around cores of pyroxene, as exemplified further north

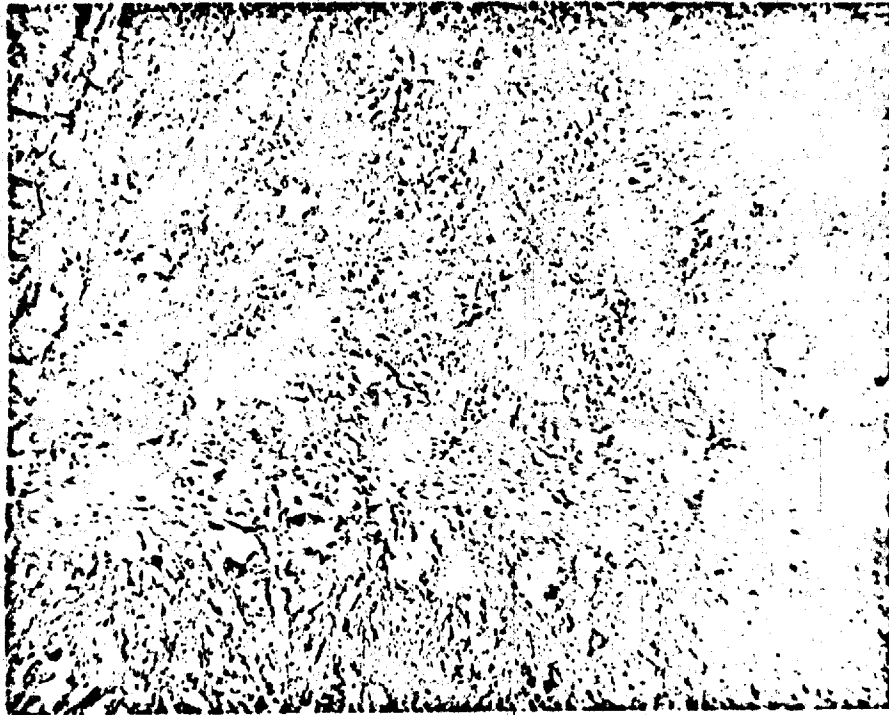


Fig. 18 Metaandesite or metabasalt with plunose texture. Note the fan-like arrangement of the amphibole laths. Most of the matrix is chlorite. Comparatively little opaque. (24 x)



Fig. 19 Large grains of actinolite (A) with cores of chlorite (C). Within the core, the small grains of actinolite are in optical continuity with the surrounding actinolite. (24 ex)

in the area mapped by Smith where a pyroxenite sill contains grains of pyroxene surrounded by a narrow rim of actinolite. Later on, slight changes of conditions, and access of plentiful water, would cause the alteration of the remaining chlorite to pyroxene. Since ~~pyroxene~~ actinolite had already formed around the grains and along cleavage cracks, it remains unaltered as separate little islands in the chlorite patches, always in optical continuity with the surrounding actinolite. The petrogenetic significance of actinolite will be discussed below.

As one progresses northward, actinolite gives place to chlorite in the metavolcanics, although it was found in sills intruding the metavolcanics. The significance of this point will also be taken up later.

Chlorite is the most conspicuous mineral in these rocks, not by its quantity as much as by its green color which imparts to the whole rock a marked green coloration, hence the term "greenstone" applied to these rocks.

Except for some feldspathic pyroclastics to the north, chlorite is ubiquitous in the greenstones.

Most thin sections studied (Table 1) contain chlorite with the following pleochroic formula:

- X: very pale yellow to colorless
- Y: pale green
- Z: pale green

and interference tints varying from Berlin blue to violet. These chlorites are negative and length slow. A few thin sections contain chlorite with the following pleochroism:

X: pale green

Y: pale green

Z: pale yellow

and the interference color is brown. This type of chlorite is positive. Hutton (1940) reports similar results on the study of chlorites from Western Otago, New Zealand:

"the birefringence varies from .006 to very low values, when anomalous blue (negative chlorites) and brown (positive chlorites) interference tints are shown (p. 19)".

Chlorite occurs in small grains between the plagioclase laths. Patches of chlorite with irregular outlines are common in the coarse-grained metabasalts and may pseudomorph original chlorophacite patches which are so common in the mesostasis of some basalt (Fig. 20). In some sections, chlorite has a fibrous habit and a radial arrangement which gives a sweeping extinction when the microscope stage is turned. Chlorite also occurs as amygdale-fillings and in this case, it is usually coarse-grained. As mentioned in the megascopic description, and in the remarks on structure, chlorite also occurs as chlorite weaves. In thin sections, these appear to be made up of a single large grain of green chlorite but under crossed nicols, the weaves appear to be made up of a single twisted large grain, or many large grains, curved, twisted and interlaced, or of many very small oriented flakes. Chlorite and calcite are very mobile minerals in these rocks, and are usually found cutting across plagioclase laths, even in fresh massive rocks which have suffered no deformation, and no apparent extraneous addition of material. This differs from the late veins of chlorite, calcite, quartz, and epidote which transect the whole rock and are certainly later than the very minor veinlets of chlorite which

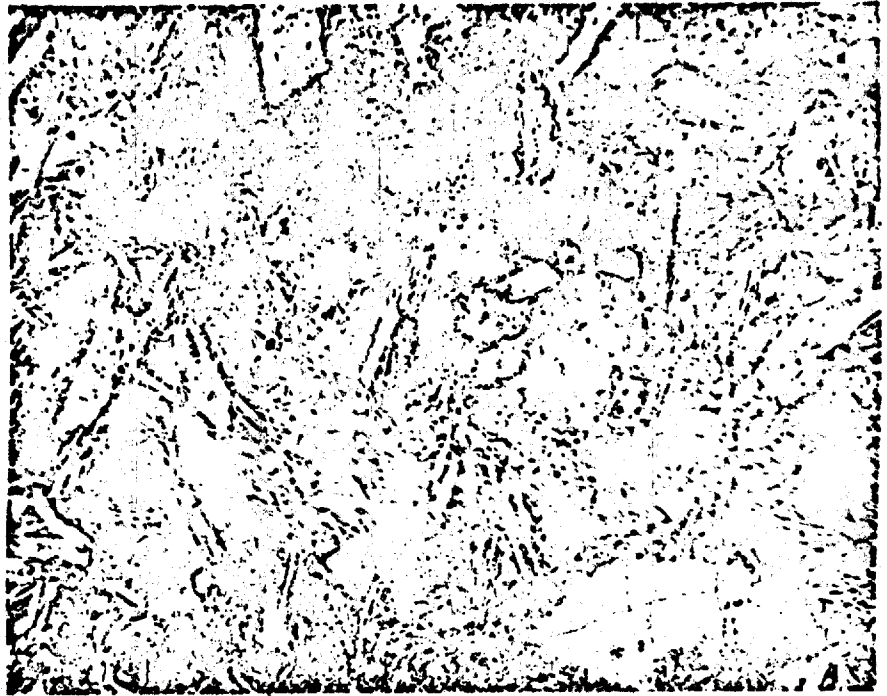


Fig. 20 Typical metabasalt with laths of albite in a matrix of chlorite and opaque. Note the irregular patches of chlorite which may pseudomorph original chlorophacite patches. (24 x)



Fig. 21 Hematized spherulitic rhyolite (?). Note the excellent preservation of the spherulites and of the texture in spite of the intense alteration and complete replacement of parts of the rock. (8.8 x)

transect the individual albite grains.

Epidote is not common in these rocks, and is restricted to the dark metabasalts at the base of the series, and to the basic sills intruded in the volcanic rocks. Further north, in the lighter-colored metavolcanic rocks, no epidote is found.

Epidote forms small granules disseminated here and there in the rock. Large euhedral crystals are occasionally found in chlorite-filled amygdules. Noticeable pleochroism (Y: pale yellow; Z: colorless) was only noted in a few sections. From the optical data obtained on some of these epidotes (Winchell 1927, p. 449) this mineral is an iron-rich variety of pistacite.

Epidote and quartz veinlets are very common in the more basic flows. They fill tensional fractures and they vary from pure quartz to pure epidote. Some of them attain 15 feet long and 18 inches wide. In general, they are smaller than these extreme dimensions. The epidote-rich ones could be called epidosites. Their origin will be taken up later.

Table 1 shows the great variation in the quantity of ores and leucoxene between the dark-colored flows (metabasalts) containing up to 24 per cent combined ores and leucoxene, and the light-colored ones with 5 per cent. This fact was noted in the field where some dark flows attract a hand magnet and cause a slight deviation of the compass needle. In general, what has been computed as opaque in the nodes is magnetite and ilmenite. A few euhedral grains of pyrite are included with the opaque. The ilmenite grains have a rim of leucoxene. In some sections, a core of opaque ilmenite remains intact, and in other sections,

the ilmenite is completely gone to leucoxene. By leucoxene is meant here a greyish brown dirty mass with high relief and with a birefringence nearly equal to that of sphene, although it is partly obscured by small grains of hematite or goethite or magnetite dispersed in this material. With low power, the leucoxene often appears opaque, but with high power and a strong source of light, the leucoxene is evidently made up largely of submicroscopic grains of sphene. In some cases, leucoxene grains show a close relationship with grains of epidote, and some grains of epidote have a clear rim and a core made up of leucoxene. Leucoxene is the result of the interaction of the titanium of the ilmenite with the calcium released by the transformation of labradorite (?) into albite.

#### Attitude of the Mesatin-type volcanic rocks

The volcanic rocks strike east to slightly north of east, and dip between 80 and 90 degrees north. Very few dips to the south were recorded, and they are all steep. The strike of the flows obtained from flow lines, flow contacts, long axes of pillows, porphyritic layers and variolitic layers is relatively regular and uniform. Metagabbro sills and belts of pillowed volcanic rocks also help in determining the strike of the volcanic rocks. Over 50 flow top determinations (shape of pillows, scoriaceous flow tops, position of porphyritic layers, attitude of the various petrographic units in the differentiated metagabbro sills) evenly distributed over the map-area and in the map-area mapped by J.E. Smith to the west and north indicate a normal succession of volcanic rocks with tops facing north.

Stretched varioles

Two horizons of variolitic metabasalt show a marked lineation. The best exposures are on the east edge of the high hill, 6200 feet north of Kokke Creek Bay. Varioles about 1.5 cm in diameter when undeformed are elongated and become lenticular bodies 5 cm long at their maximum by 1.6 cm wide and 2.5 mm thick (Fig. 22) .



Fig. 22. Variolitic metabasalt stretched along a shear zone. The plane of schistosity is vertical and the elongation of the varioles coincide with the "a-direction" (natural scale).

The flows are nearly vertical and so are the variolitic horizons. The long axis of the stretched varioles is vertical. The plane of stretching is vertical and is limited to a layer about two feet thick. On each side, there is a gradual decrease of the flattening until the varioles are spherical. No drag folds were noted along these planes. Along the faults and shear zones which transect

this area, drag folds, mineral orientation, gash veins, and other criteria indicate movement in a horizontal plane. In the case of the stretched varioles, the elongation of the varioles, the mineral orientation of the matrix, the gradual fading out of the stretching and the absence of any slickensides in a horizontal direction point to an orientation due to slippage of the flows past one another. When such a thick mass of flows is folded from a horizontal to a vertical position, such slippage is expected to take place, and the direction of movement, defined as the "a" direction, would be parallel to the actual long axis of the varioles. This is why this lineation is referred to here as an "a-lineation".

#### Chlorite smears

The metabasalts, in the lower part of the volcanic group, commonly contain elongated spindle-shaped dark green chlorite smears. A large number of these were measured and they invariably plunge from 80 degrees north to 80 degrees south.

The origin and exact significance of these chlorite smears is not clear. They may have been phenocrysts of augite metamorphosed to chlorite, or amygdule-fillings of chlorophaeite. The long axis of the spindles is vertical, the intermediate axis is horizontal in the north-south direction. This orientation indicates movement in a vertical direction which corresponds to the long axes of the stretched varioles described above. The stretched varioles are limited to a narrow band but the chlorite smears occur over large areas. They may be the result of penetrative deformation which took place

when the flows were folded to their actual position. In the folding of the flows the direction of transport is parallel to the long axes of the smears and the lineation they produce should be called an "a" lineation, "a" being defined as the direction of transport. The age relations of the chlorite smears to the metamorphism are impossible to determine. The chlorite smears could pseudomorph smeared pyroxene, or they could have been changed to chlorite and folded afterwards. The change could also have taken place at an intermediate stage, before the end of the folding.

#### Spilites or metabasalts?

In the description of the volcanic rocks, the writer called them metabasalts. Whether they are spilites or metabasalts should be studied.

British petrologists call rocks spilites which mineralogically agree with the metabasalts found in the Chibougamau district. The similarity is accentuated by the presence of variolites and pillow lavas.

All the metavolcanic rocks of the area are spilitic if our criterion for classification is only that the feldspar is albite. But the bulk composition is that of a normal basalt. Epidote and/or clinzoisite takes the place of the anorthite molecule of the original calcic plagioclase.

Sundius (1931) in Sweden believed in albitization by regional metasomatism. Bailey and Graham in 1909 thought of the albitization as a process of self-digestion or autolysis.

Dewey and Flett (1911) believed they had evidence to prove that the albitization took place soon after the rocks had solidified.

Hells (1923), to account for spilites invoked the action of resurgent water, the pressure of the water column above the flow, chemical action of sea water, joint action of magmatic and meteoric waters, and self-digestion of the lava causing retention of magmatic solutions.

All these people believed in some enrichment in soda. But saussuritization (the conversion of labradorite or bytownite into albite and epidote or clinozoisite) implies no enrichment in soda. The calcium liberated during the change from labradorite to albite is taken up by the actinolitic hornblende and epidote or clinozoisite. In some areas where epidote is absent in the rock, numerous quartz and epidote veins are found which could well account for the lack of epidote in the massive parts of some rocks. In still other examples, the calcium released by albitization of labradorite may be present in calcite.

Fairbairn (1934) plotted 127 analyses of spilites and metabasalts on an Anorthite-Albite-Orthoclase triangular diagram. He found there is no break in the continuity of the field in which the points lie, and nothing to distinguish spilite as an isolated species. He concluded that

"spilite is chemically transitional to low-soda metabasalt and the conception of a special spilitic magma is not justified".

In the case of the Chitcugamau metabasalts, a few thin sections revealed pyroxene remnants within amphibole grains.

Theoretical studies, and statistical observations throughout the world point to the incompatibility of crystallizing pyroxene and albite simultaneously. The common occurrence is pyroxene (augite or pigeonite) and labradorite or bytownite.

The author concludes that the volcanic rocks in the Chibougamau district are normal basalts which have been metamorphosed to the greenschist facies.

#### Fusion techniques

The idea that the refractive index of a glass is determined by its chemical composition has long been known. Michael Stark (1904) and Walter George (1924) attempted to correlate refractive indices of natural glasses with the content of their major constituent, silica, but with only limited success because silica alone does not determine the refractive index of the glass.

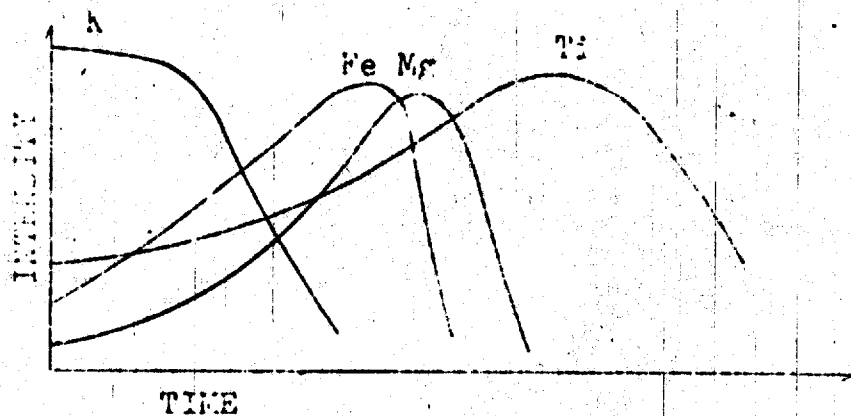
The method used here is an adaptation of that proposed by Mathews (1951). He demonstrated that within a single magmatic province, artificial glasses produced by fusion of the rock show a close correlation between their index of refraction and the bulk chemical composition. The process of fusion should be such as to change the composition only in volatile content and in the oxidation state of the iron. Mathews used a carbon arc lamp to fuse his specimens. The author used the apparatus described below.

A welding electrode holder is fixed to a carbon rod and connected to a variable resistance. A carbon block is drilled and also connected to the variable resistance. The latter is plugged

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in a 110 volt D.C. outlet. A small hole is gouged out of the surface of the carbon block and a few milligrams of the rock powder is poured into the hole. The carbon electrode is brought in contact with the block a few millimeters away from the specimen and arcing takes place. The electrode is moved to the specimen which is molten after a second or two of arcing. This produces a series of globules which float on the surface of either the block or the unfused portion of the rock powder. They have a very limited surface of contact with either. From the experiments done, it seems that the secret for obtaining a clear and homogeneous glass is to have the rock powdered very fine. To do this, the specimens were roughly broken in a steel mortar, ground by hand in an agate mortar, and then ground for two hours in a Fisher mechanical mortar. Examination of the broken glass bead under the microscope revealed very little to no contamination of the main portion of the bead.

Early in this investigation, Dugster (pers. communication) pointed out to the author the great ease of volatilization of alkalis in the arcing of a specimen. Ahrens (1950) gives the following curves for the volatilization of different elements in function of time during arcing.



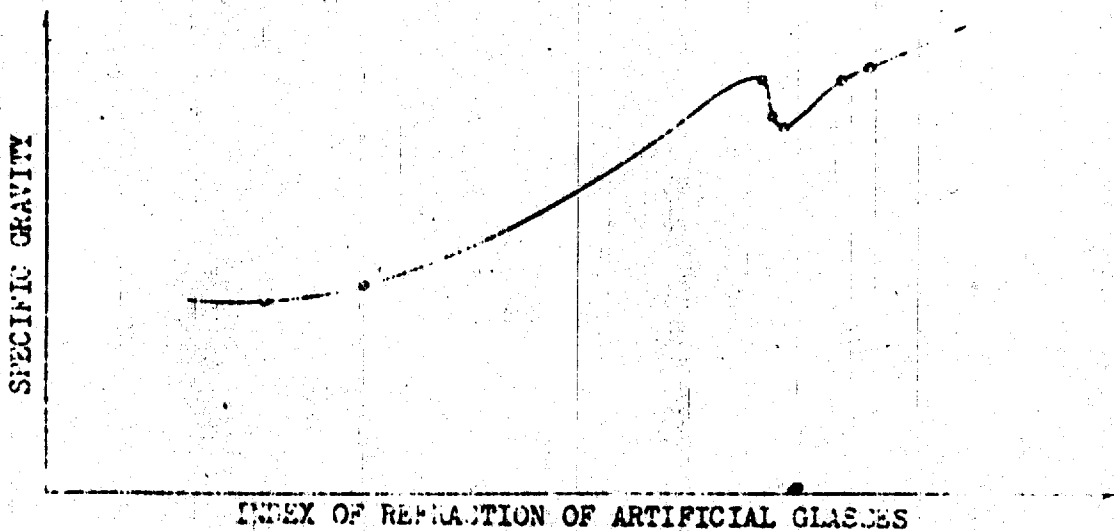
As explained above, if the rock is very finely powdered, only a second or less is necessary to produce a glass bead. From Ahrens curves, it would appear that the volatilization of alkalis would not be too serious here. Moreover, studies of the system  $\text{H}_2\text{O}-\text{Na}_2\text{O}-\text{SiO}_2$  by J.F. Schairer (pers. communication) indicate that loss of alkalis is considerable only if the mixture is very low in silica (Plate 3). In the case of metabasalt, silica would vary between 45 and 55 per cent of the rock and the alkalis make a very minor portion of the rock. The loss of alkalis through volatilization should therefore be negligible.

Metabasalts contain a great deal of chlorite and/or actinolite (Table 1) which, on fusion, is oxidized due to the loss of  $(\text{OH})$ .

The ferric iron is reduced to ferrous iron and even to metallic iron if arcing in the carbon arc (reducing atmosphere) takes place over a long period.

Theoretical studies of ternary and quaternary systems often include a determination of the index of the glass of different composition produced during the bomb runs. A few of these are grouped on Plate 3. These experiments show an increase in the index of the glass with an increase of  $\text{K}_2\text{O}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Fe}_2\text{O}_3$ . But all these studies are for 3-component systems. In a rock, like the metabasalts studied here, where six or seven oxides are present, and the changes of index are linked with changes in the amount of  $\text{SiO}_2$ , amount and state of oxidation of the iron and different amounts of the other oxides, one cannot establish the complete chemical significance of the index of the glass. Even if one cannot exactly

determine the chemical composition of a rock from determination of the glass index, this work, like the work of Mathews (1951) and George (1924) shows the practicability of studying the variations across a stratigraphic unit, within a limited area. Comparing fresh rocks to metamorphosed ones is difficult without chemical analyses, and the author, without an extensive set of good chemical analyses, is not ready to say that the fusion technique is applicable to the determination of chemical composition, but it is a practical and easy way to compare a group of rocks within a district and within a stratigraphic series. Table 1 shows the results obtained during the present work. The indices were measured using Na light and a refractometer to check the index of the oils.



METAGABBRO SILLS

In the northern part of the map-area, three metagabbro sills invade the metavolcanics. They crop out in rounded hills which provide excellent exposures. Sills are more abundant in the area to the north, mapped by J.R. Smith.

The sills are concordant and help in outlining the structure of the area. Their resistant outcrops parallel the trend of the volcanic belts. The sills are differentiated and afford good criteria for top and bottom determination. Determinations of the strike and direction of top of the volcanics as indicated by pillows, flow tops, etc, are everywhere confirmed by the sills.

The sills studied are approximately 400 feet thick and become thicker to the north. For example, J.R. Smith mapped a sill 2000 feet thick.

In the field, the author divided each sill into three subdivisions on mineralogical grounds: a mafic-rich layer at the base, a normal feldspathic metagabbro at the center, and a quartz-chlorite-rich portion at the top.

The three divisions are easy to identify in hand specimens. The mafic-rich portion consists of equant grains of amphibole and minor quantities of saussuritized plagioclase. The rock is medium to dark green and weathers brownish grey. The feldspathic metagabbro is made up of shiny pale green amphibole in equant grains, and olive-green saussuritized plagioclase. Gradually, this type of rock passes into the quartz-rich portions. First, a few clear grains of quartz can be detected. Proceeding upward, more and more quartz is

visible and saussuritized plagioclase and pale amphibole give way to clear plagioclase and chlorite. Sparse crystals of pyrite appear throughout. Magnetite increases in amount in the quartz-rich portion; a hand specimen will attract a small hand magnet.

Reports concerning areas underlain by similar rocks normally mention the difficulty of recognizing thick flows from sills. In the area under consideration, it is easily possible to differentiate between sills and flows in the field or by thin sections.

### Mineralogy

16 thin section from which 3 modal analyses (Table 2) were made form the basis for this discussion. The specimens chosen for modal analysis come from a suite taken across the sill immediately south of the Grandines road along a line running parallel to the creek which flow southward and veers eastward a little south of the sill (Plate 1). The sill is close to 400 feet thick and is well exposed from a few feet above the base to a point that is probably only a few feet below the chilled top contact.

Plagioclase forms euhedral and subhedral rectangular tablets up to 2mm in length with no marked orientation. It occurs either as individuals, or in poikilitic intergrowths with actinolite and in a few instances with chlorite and magnetite. In the lower portion of the sills, the plagioclase laths are dark brown to black when examined with low magnification (Fig. 23) and plain light. With a strong source of light, high magnification, and crossed nicols, the dark brown material has the properties of clinzoisite and epidote. A very narrow rim of clear albite and individual small patches of albite

TABLE 2

MODAL ANALYSES OF METAGABBRO SILLS

Specimen number	54-185	54-187	54-189
Height above base of sill	ca 40 feet	ca 150 feet	ca 300 feet
Glinzoisite	54.47	57.78	none
Clear plagioclase	11.3	tr	34.57
Actinolite	25.9	6.1	none
Chlorite	4.0	21	31.8
Opaque	.4	tr	11.2
Leucoxene	3.1	2.4	tr
Quartz	none	8.2	21.4
Calcite	.6	3.4	.5
Pyroxene	tr	none	none
Fine quartz & chlorite	none	.95	none
Number of points	1520	1470	1582
Specific gravity	3.03	2.94	2.89

surround the clinzoisite. In some rocks traces of cleavage and twinning are still visible through the clinzoisite mat. In the upper part of the sills, the plagioclase gradually clears until, in the quartz-rich portions, the plagioclase is fairly clear, although it is still dusty with tiny inclusions of chlorite, calcite, and sericite. Here too, it is well twinned according to the albite and Carlsbad laws.

In the adjacent volcanic rocks, the albite is clear (Fig.16) except for some chlorite and magnetite which replace original magnetite and glass inclusions. The difference between the plagioclase at the base and top of the sills is due to a difference in original composition. This will be discussed below.

Amphibole appears from the base of the sills to the quartz-rich portions but is not present in the latter. The amphibole is a pale to colorless actinolite, practically non pleochroic. A few thin sections show faint pleochorism with

Z: faint bluish green

X: colorless

Y: green

This actinolite has an index  $N_g$ : 1.651 and an extinction angle of 17-19°. The largest grains vary from 1.7 to 4.5 mm. The average is around 1.2 mm. Most grains are subrounded and equant with few blade-shaped ones. Twinning is common.

Small pyroxene grains with identical orientation enclosed within large grains of actinolite are evidence that the actinolite has pseudomorphed original pyroxene. The pyroxene is clear, colorless,



Fig. 23 Typical feldspathic metagabbro. The dark background is a mixture of saussuritized plagioclase and chlorite or actinolite. The large clear grains are actinolite (A) grains pseudomorphing original pyroxene grains. Note the ophitic texture preserved. (10.2 x )

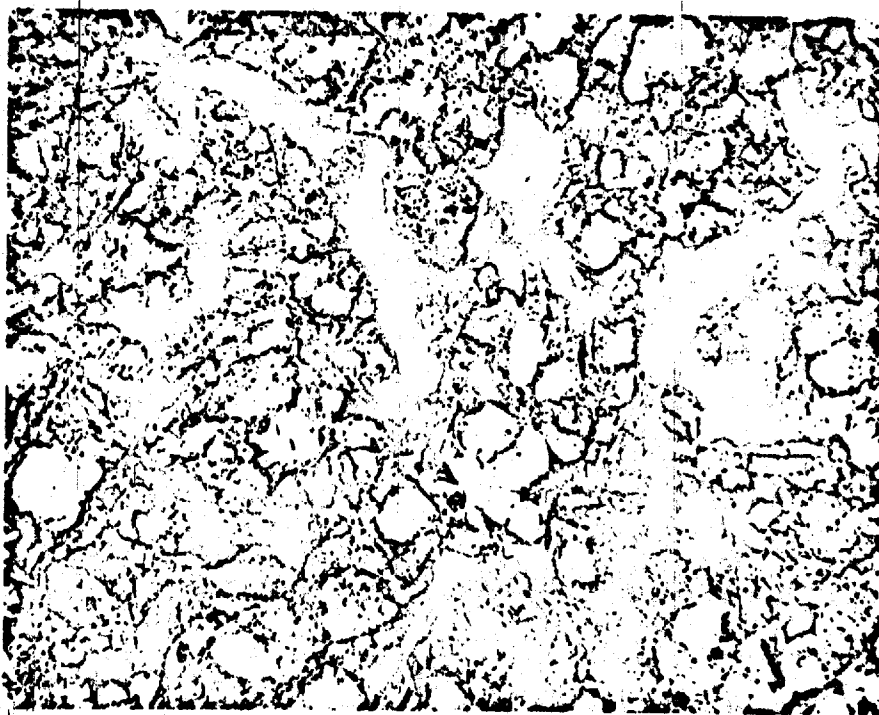


Fig. 24 Quartz-rich portion of the gabbro sills. Note the clear twinned plagioclase (P) and the chlorite background. Also the abundant opaque grains. (10.2 x )

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non pleochroic, but the grains are too small to obtain complete optical properties. The actinolite pseudomorphs show excellent ophitic and poikilitic textures toward the plagioclase blades, enclosing them wholly or in part (Fig. 23). This, plus the pyroxene-shape of the grains is corroborative evidence that they pseudomorph original pyroxene.

Chlorite patches are common within the actinolite grains. In some thin sections, calcite is intimately associated with actinolite and is not found outside of the actinolite. This calcite may represent the excess of calcium released by transformation of pyroxene into actinolite.

Grains of actinolite with pyroxene relicts do not contain grains of chlorite in their interior.

Chlorite is almost ubiquitous in these rocks. It occurs in the grains of actinolite and in the matrix of the lower and central portion of the sills. In the quartz-rich layers, chlorite takes the place of actinolite. The chlorite is of three different varieties. One has a brown interference tint, is positive, and has the following pleochroic formula:

- Z: very pale yellow
- X: pale green to medium green
- Y: pale green to medium green

Another has bluish or violet interference tints, is negative, and has the pleochroic formula:

- Z: medium green
- X: pale yellow
- Y: medium green

The third variety is pale grey under crossed nicols and is positive. It is pleochroic with

Z: pale yellow to colorless

X: very pale green to colorless

Y: very pale green to colorless

Our knowledge of chlorites is too limited at the present to assess the petrologic significance of these different chlorites, especially as regard to metamorphism and metamorphic processes. It is significant however that the third type is found in the lower and central parts of the sills. The brown positive type (pleochroic in darker tints) occurs in the upper part of the sills, and the negative blue type occurs in the topmost part where the sill is richest in quartz and magnetite.

The lower two thirds of the sills contain minor amounts of magnetite-ilmenite whereas the quartzose parts have considerable magnetite and minor amounts of ilmenite (Table 2). The ores appear to have crystallized later than the pyroxene and plagioclase. Due to the preferential alteration of ilmenite to fine brown material (probably partially crystallized sphene, though commonly called leucoxene), there is no need for polished section work on these rocks. The magnetite is either preserved or slightly chloritized.

Micrographic patches of quartz and plagioclase are common in the upper part of the sills (Fig. 24). The first quartz grains to appear are clear, anhedral, often wedge-shaped grains without any micrographic texture, which fill the angular interstices between plagioclase laths. Proceeding upward in the sill, the micrographic

patches become more and more abundant. The plagioclase is cloudy and could seldom be positively identified.

Clear grains of epidote locally appear in the chlorite patches. They are clear, colorless and do not show the brown color of the clinozoisite which pseudomorphs the plagioclase. In one instance, a group of epidote grains surrounded a grain of magnetite, and showed marked pleochroism from yellow to colorless. This is due to some diffusion of iron in the epidote.

The matrix or mesostasis of these rocks is variable and contains quartz, calcite, chlorite, clear plagioclase, and opaque. In volume, it does not amount to more than a few per cent of the rock.

#### Petrology

The petrography and field relations suggest that the gabbro sills were intruded in flat-lying volcanic rocks. During cooling, the sills were strongly differentiated. Later on (how much later cannot be determined from the evidence at hand) the whole assemblage has been metamorphosed to the greenschist facies and tilted to the vertical. Whether tilting occurred before, after, or during metamorphism cannot be decided, although the presence of chlorite seams in the volcanics indicate that some movement took place after chlorite was formed in the metavolcanics.

The sills before metamorphism were similar to gabbro sills the world over. The absence of olivine and apatite is noteworthy. The plagioclase of the lower portion of the sill was more calcic than the original plagioclase of the volcanics. It was zoned, with a very narrow outer rim more sodic. Going upward in the sill, the anorthite content of the plagioclase decreased considerably. This explains

the presence of clear plagioclase and little epidote and clinzoisite. This variation from a very calcic plagioclase at the base to more albitic at the top is characteristic of differentiated gabbro and dolerite sills: from An<sub>70</sub> to plagioclase in the Palisades sill (Walker 1940, p. 1069); from An<sub>75</sub> to An<sub>25</sub> in the Tasmania dolerites (Edwards 1942, p. 550); from An<sub>61</sub> to An<sub>30</sub> in the Skaergaard (Wager and Deer, 1939):

The increase in quartz and micrographic patches of quartz and plagioclase (or potash feldspar) is well shown in the 3 modal analyses (Table 2) where the quartz content goes from 0 through 8.2 per cent to 21.4 per cent. This is also common in the intrusions referred to above.

The increase in total opaques, and especially the increase of the magnetite/ilmenite ratio from bottom to top is also well shown in the modal analyses where leucoxene represents original ilmenite, and opaque original magnetite. This enrichment in iron toward the top is particularly well illustrated in the Skaergaard. In Tasmania, Edwards also mentions that the maximum development of iron ores is in the pegmatitic segregations.

A more complete discussion of the metamorphism will be included in the discussion of the metamorphism of the metavolcanic rocks.

The bulk composition of the sills, or the composition of the original magma may have been very close to the composition of the volcanic rocks which the sills intrude. The sills appear only above a certain height in the volcanic series and this may be explained by the excessive load over the lower part of the volcanic

pile. Higher up in the series, the force of intrusion of the magma might have been sufficient to pry apart the volcanics and make room for the magma between the flows.

### DORE LAKE LAYERED COMPLEX

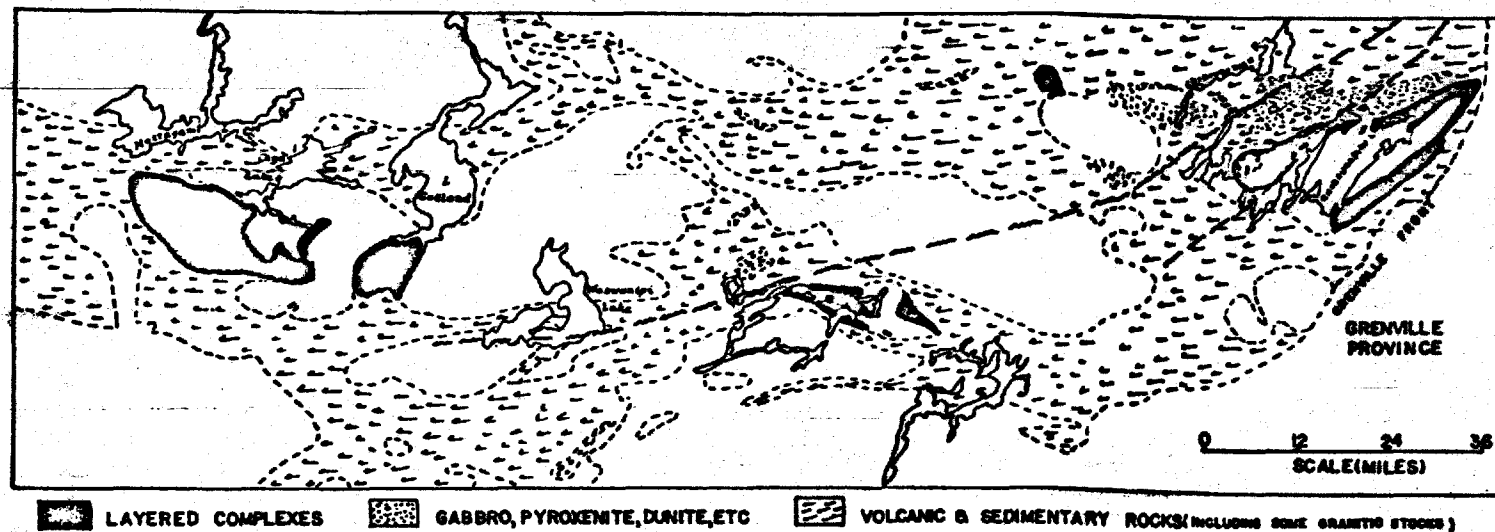
#### Introduction

The Dore Lake Complex is a layered intrusive made up of many different rock types varying from ultramafic members to very silicic ones and including a large body of anorthosite. This thick stratiform sheet has been arched up by the intrusion of the younger Chibougamau Lake batholith. The Complex has been metamorphosed to the greenschist facies, and some of the metamorphic products are kinds that have not been described in the geological literature.

The metamorphism and its effects vary according to the location with respect to later intrusives, original chemical composition, grain size, etc. The present mineral composition has also been influenced by the type and intensity of hydrothermal alteration along mineralized shear zones.

#### Regional setting

The Superior Province is underlain by belts of volcanic rocks, basic and ultrabasic sills, and granitic masses. Layered complexes containing anorthosite and ultramafic rocks such as the Dore Lake Complex have not been reported from this Province except in the Chibougamau area and around Waswanipi Lake (Fig.25).



DISTRIBUTION OF LAYERED COMPLEXES IN THE WASWANUPI-CHIBOUGAMAU AREA

Figure 25

They may be present in other areas but detailed mapping has been limited to mining districts and they have not been identified as such in mile-to-the-inch mapping. Figure 25 shows the distribution of layered complexes in the eastern part of the Superior Province, close to the Grenville contact. The Opawica and Bell River masses have not been mapped in detail.

The spatial distribution of similar layered complexes (as far as we know from reconnaissance surveys by Shaw (1939) and Freeman(1939) is such that it suggests a genetic and probable structural connection between them.

From the existing literature, they are all characterized by the large proportion of anorthosite, the identical composition of the plagioclase in the unaltered and unmetamorphosed layers of anorthosite ( $An_{60}$ ) and the effects and products of regional metamorphism.

The presence of these layered complexes with so much anorthosite so close to the Grenville contact has brought up the question of possible correlation between the large batholithic masses of anorthosite, common in the Grenville Province, and anorthosite of the Dore Lake Complex. But recent detailed mapping and petrographic studies by the writer make it clear that the anorthosite of the Dore Lake Complex is just a thick layer within the Complex. Field evidence does not leave any doubt as to the layering and folding of the mass. Mineralogically, the plagioclase of the Grenville anorthosite masses varies from  $An_{42}$  to  $An_{68}$  (F.F. Osborne, pers. communication). As seen on Plate 4, the An content

of the plagioclase in layered complexes varies between An<sub>70</sub> and An<sub>90</sub>. Moreover, the Dore Lake Complex and the other masses shown on figure 25 are well within the Superior Province petrographically, structurally, and geographically.

The original mapping of the Chibougamau district disclosed a large area underlain by anorthosite and associated rocks surrounding Dore Lake and adjacent parts of Chibougamau Lake.

In 1911, the Chibougamau Mining Commission report said:

"In addition, a rock which seems peculiar to this area has been called anorthosite because although it is of gabbroic type, there is usually a marked absence of ferromagnesian minerals, which are present and sometimes quite abundant in typical gabbros. The prevalent phase of this rock highly resemble the highly feldspathic gabbro to which the term anorthosite was first applied, and which is characteristic of the formation formerly classified as Upper Laurentian.

The Keewatin formation is made up of a series of decomposed and deformed basic magnesian rocks which may in general be described as greenstones and green schists. They are the oldest rocks of the district. They are penetrated by the batholithic masses of the anorthosite already mentioned...."

Hatty (1930) describes the "oligoclase anorthosite" but does not make any comments as to the presence of genetically related gabbros.

Mawdsley and Norman (1935) said:

p.27 "The northern mass of anorthosite forms a belt 2 to 2½ miles wide that extends in a direction slightly north of east almost continuously across the central part of the map-area from Lake David to Hepton bay. Anorthosite is the predominant rock of this belt. The associated gabbro occurs as a narrow marginal phase along the northern side of the anorthosite belt and occurs with serpentine both as marginal phases and as small masses within the anorthosite northeast of Lake Chibougamau."

p.29 "Gabbroic rocks composed either in part or entirely of dark ferromagnesian minerals and their alteration products are closely associated with the anorthosite. They are believed to be closely related to the anorthosite in origin

and to be of approximately the same age".

p.29 "The associated gabbro marginal to the anorthosite west of Bear Bay, in places show a transition into anorthosite. Away from the anorthosite, these rocks for the most part grade into highly altered ones that have little resemblance to the anorthosite and closely resemble rocks described as gabbro, diorite, quartz diorite, and their altered equivalents."

From these excerpts, Mawdsley and Norman seem to have the impression that the different rock types around the anorthosite mass are genetically related.

In 1951, Graham subdivided the rocks of Obalski township in two groups: the David Lake group and the Dore Lake group. From detailed mapping done since, it appears that these two groups are members of what the author calls the Dore Lake Complex.

This Complex is getting more and more important economically since the major ore deposits and showings in the Chibougamau district are found in the anorthosite member of this Complex. This is part of the reason why it has been studied in greater detail than the surrounding rocks. Moreover, the presence of magnetite-rich bands and other members with greatly different magnetic properties makes it possible to work out the structure of the area. Airborne magnetometer surveys are thus very useful in outlining the Complex and its various members.

#### General geology

The Dore Lake Complex, according to geologists who mapped the area on a large scale, is intrusive into the Keewatin-type metavolcanic rocks. In the map-area studied in detail by the writer,

the contact is the Lac Sauvage fault zone. No well exposed contacts were observed between the metagabbro and the metabasalt lens on Coulin Peninsula, between Dore Lake and Chibougamau Lake. Some shearing is indicated in the outcrops near the contact and the contact itself is likely a shearzone.

There is consensus of opinion regarding the younger age of the various members of the Chibougamau Lake batholith. The writer observed many instances of blocks of metanorthosite in the diorite, granodiorite, quartz diorite, and granite of the batholith. Dykes of granitic material cut the Dore Lake Complex near its contact with the Chibougamau Lake batholith.

Originally the David Lake anorthosite mass and the Dore Lake mass were thought to be independent bodies but recent detailed mapping shows that they are probably folded portions of the same members within the Dore Lake Complex.

#### Structure of the Complex

There is ample evidence pointing to the original (see p. 99) horizontality of the Complex. The original mass could have been a sill, laccolith or lopolith but the intrusion of the granitic batholith has obliterated part of the core. Moreover, faulting and lack of outcrops make it impossible to establish the exact original shape of the body.

The Dore Lake Complex has been arched by the Chibougamau Lake Complex into an anticlinal structure. In the area mapped by Graham and the writer, northwest of Chibougamau and Dore Lakes, the dip of the primary foliation and layering is to the northwest. The other

Hub is very little known. Neale and Pentstone (personal communications) have observed foliation and layering with a southeast dip. Airborne magnetometer work (Dominion Gulf Coy, personal communication) also indicates an anticline with a wrapping of the magnetite-rich layers around the nose of the anticline in McCorkill township (Plate 2).

As mentioned earlier, the north boundary of the Complex is a fault zone of major geologic and economic importance. It will be discussed in the chapter on Structural Geology.

#### Field data

The description and conclusions which follow are based upon detailed mapping of a portion of McKenzie township done in 1952, 1953, and 1954. To facilitate the study of the Complex, the author took the opportunity to log many critical drill holes in the surrounding townships during the summers of 1952, 1953, and 1954. Airborne geophysical data belonging to Dominion Gulf Coy were also very useful. The cooperation and fruitful discussion with the geologists and mining engineers working for the various mining companies was a great help in improving our understanding of the Dore Lake Complex.

#### Petrography

The Dore Lake Complex is made up of many different rock types. A number of them are only local and have not been found in the southeastern quarter of McKenzie township, but form definite horizons within the Dore Lake Complex elsewhere and are included for sake of completeness.

The following is a list of the major rock types encountered beginning with the lower members and proceeding generally upward in the Complex:

- anorthosite (minor in quantity)
- metaanorthosite (major in quantity)
- metagabbro
- transition between metaanorthosite and metagabbro:
  - gabbroic metaanorthosite
  - anorthositic metagabbro
- metapyroxenite (possibly some metaperidotite too)
- magnetite-rich metapyroxenite
- metapyroxenite
- magnetite-rich diorite (pegmatitic in places)
- granophyre

The principal primary minerals were bytownite, labradorite, andesine and oligoclase, depending on the member involved, monoclinic pyroxene, magnetite, titaniferous magnetite, ilmenite, spatite, and possibly rhombic pyroxene and olivine. No direct evidence of the presence of the latter two was found. The minerals actually present are minor bytownite, andesine and oligoclase in the diorites, large quantities of albite, clinzoisite, zoisite, and epidote, actinolitic hornblende, very minor clinopyroxene, tremolite, various types of chlorite, leucoxene, sphene, rutile, magnetite, titaniferous magnetite, ilmenite, sericite, apatite, and carbonates.

#### Anorthosite

Fresh unmetamorphosed anorthosite is present on the north shore of East Island, on a number of islands in Chibougamau Lake, east of Chibougamau Lake, and at different places along the contact

but not at the immediate contact, between the Chibougamau Lake batholith and the Dore Lake Complex. In some places, the anorthosite and metaanorthosite occur side by side, but the relation between the two could not be studied in detail. The islands are thickly forested and only a very narrow strip is exposed on the shores at low water level. Better outcrops and drilling are needed to study the spatial and genetic relations between unmetamorphosed and metamorphosed anorthosites.

The fresh anorthosite is pale grey to white in hand specimen and weathers white. The interstitial minerals are less resistant to erosion than the plagioclase and form pits which accentuate the texture of the rock on a weathered surface.

The rock is coarse- to very coarse-grained. Plagioclase tablets with shiny cleavage faces and clearly visible twinning planes attain 5 cm long. A number of U-Stage determinations give variations between An<sub>75</sub> and An<sub>83</sub>. J.R. Smith (personal communication) performed for the writer a careful temperature-controlled determination of the index of this plagioclase and found, using his curves (Smith, 1953) a composition of An<sub>79.5</sub> ( $\mu_x$ : 1.5670). The bytownite crystals do not show any zoning. The texture is hypautomorphic granular (Fig. 26). More than 85 per cent of the rock is bytownite and the rest consists of muscovite, chlorite, zoisite, clinzoisite, and a few grains of leucocrinized ilmenite.

Veinlets of clear albite, chlorite, and zoisite are common. The veinlets of clear albite (Fig. 27) are similar to those found in the metaanorthosite but are easy to detect because they are in



Fig. 26 Thin section of fresh anorthosite. Note the broad twinning lamellae of the bytownite crystals. Note also the minor amount of prooclasis. (5.5 x)

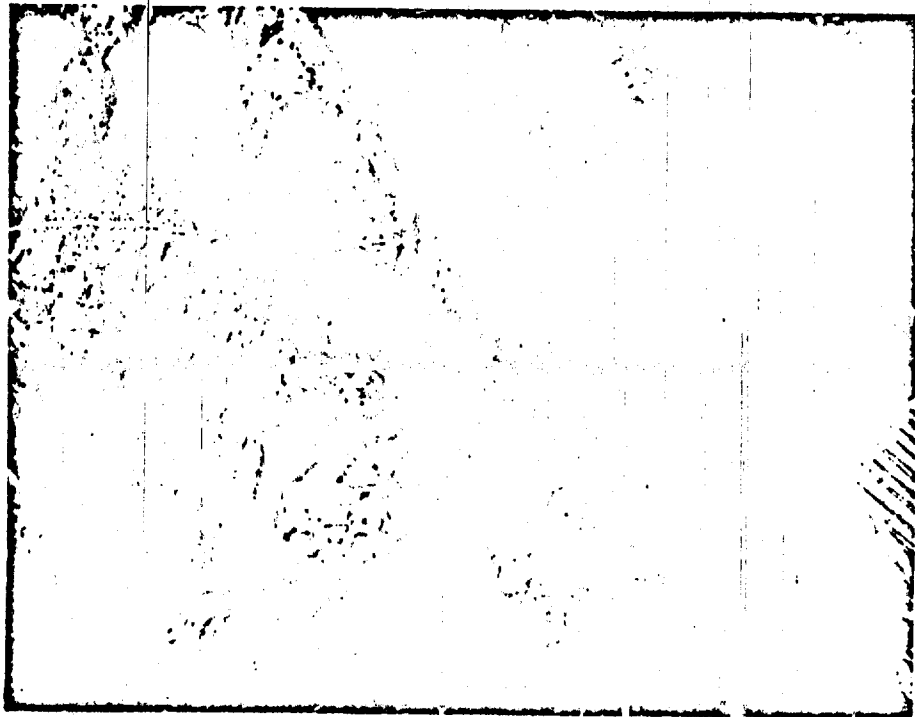


Fig. 27 Thin section of fresh anorthosite with a veinlet of clear albite in partial crystallographic continuity but not in optical continuity. Compare with Fig. 33 where the albite veinlet is cutting across meta-anorthosite. Note the later development of a grain of zoisite (Z). (42x)

partial to total crystallographic continuity with the crystals on each side but are not in optical continuity because of the large difference in chemical composition.

Some of the veins contain chlorite instead of albite, and zoisite appears along the walls of the veins. Hydrous solutions travelling along fractures have converted the bytownite to zoisite.

Grain boundaries are important in the alteration and metamorphism of this coarse-grained rock. Fig. 23 illustrates how muscovite is predominantly between the plagioclase grains, in some cases nearly completely encircling the bytownite crystals. The introduction of muscovite seems to be linked with the intrusion of the granitic members of the Chibougamau Lake batholith. The plagioclase grains of the anorthosite show very little sign of mortaring around the edges or very little protoclástico texture as one so commonly observes in the Grenville-type anorthosites.

#### Metaanorthosite

Metaanorthosite is the most common rock type in the Dore Lake area. In the field mapping, a rock was called metaanorthosite if it had more than 80 to 85 per cent of altered plagioclase. This is slightly different from Buddington's (1939) classification, but was necessary for correlation with previous geologists' work in this area and with local mining geologists' nomenclature.

The predominant minerals are albite, zoisite, clinzoisite, and chlorite. Leucoximized ilmenite, sphene, and rutile are very minor accessories.

The rock is white with pale yellowish green and dark green

interstitial areas (Fig. 30, 31, 32 ). It weathers grayish white and buff and the texture is brought out on the weathered surface by the differential weathering of the interstitial chlorite and the large crystals of metamorphosed plagioclase (Fig. 29).

No stratification was observed in the anorthosite but a crude layering must be present to account for outcrops of very coarse metaanorthosite next to outcrops of fine-grained metaanorthosite, or outcrops of anorthosite with a peculiar sandstone-like texture where all the grains are rounded and nearly spherical (Fig. 58).

In the David Lake area, along the shores of the lake and on the numerous islands in the middle of the lake, lenses of tremolite-chlorite rock (probably a metapyroxenite) in the metaanorthosite define the original layering and the attitude of the Complex. The metaanorthosite itself does not have any primary foliation, at least none observable in hand specimen, but the transition rock on the anorthosite side shows a well developed foliation which defines the attitude of the folded Complex.

The plagioclase crystals, in spite of intense zoisitization, often have sharp grain boundaries (Fig. 33 and 34). Cleavage faces and twinning plane traces are readily identified in hand specimens. A few thin sections showed elongation of the euhedral crystals, parallel to the a-axis. Their average dimensions are about half an inch to two inches although larger crystals were observed.

The composition of the plagioclase was determined with the Universal Stage. The limit of the plagioclase grains can be

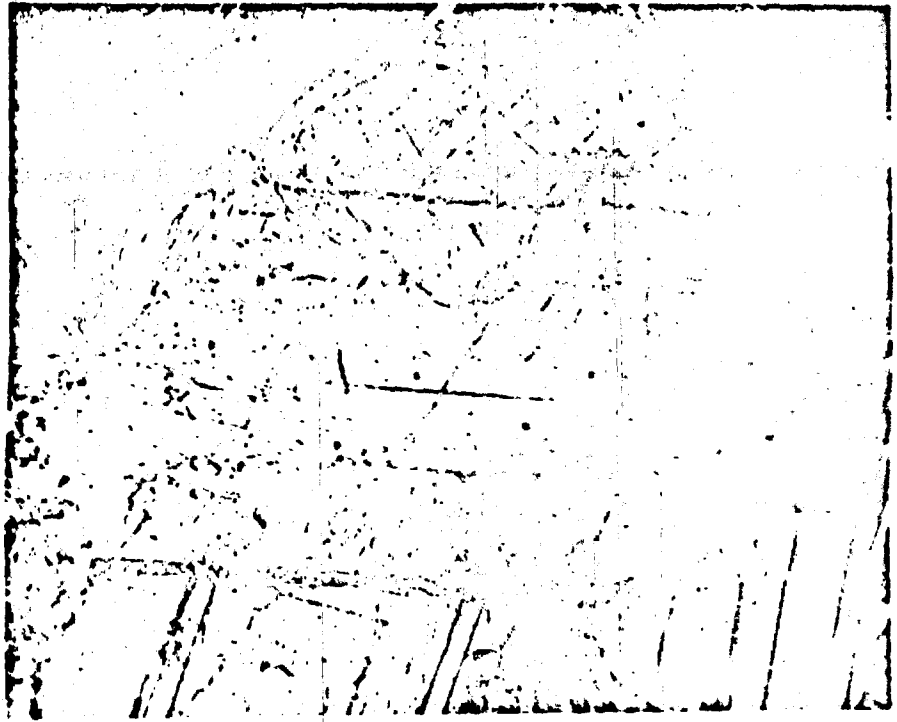


Fig. 28 Fresh anorthosite with good development of muscovite (M) at the grain boundaries. This illustrates the effect of grain boundaries on traveling solutions in a coarse-grained rock like anorthosite. (80 x)

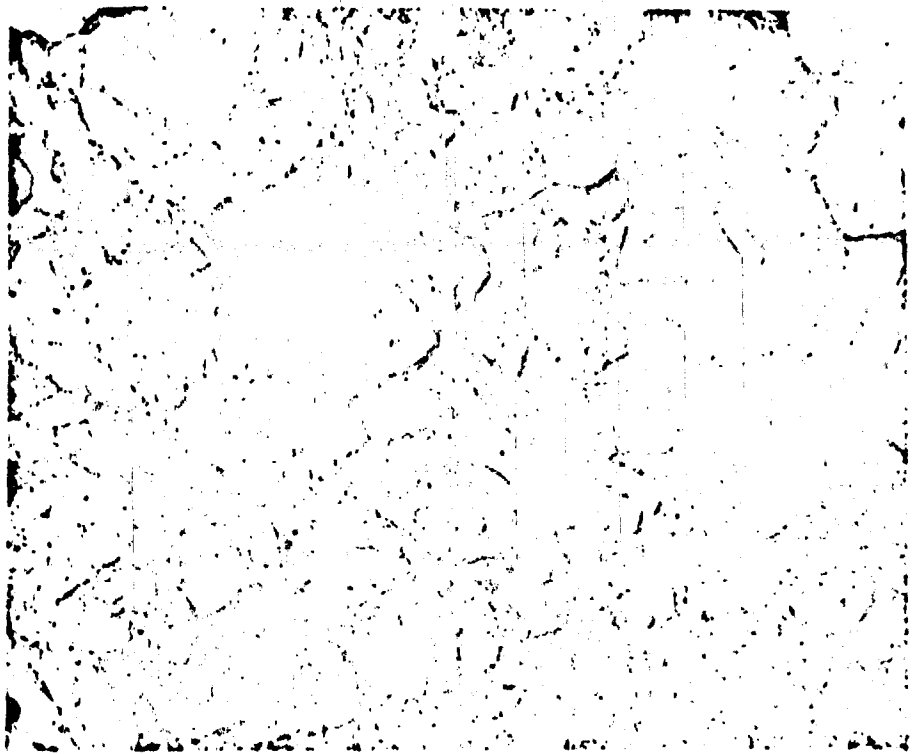


Fig. 29 Weathered outcrop of metamorphosed anorthosite. The plagioclase grains stand out in relief with respect to the surrounding chlorite matrix. The magnet is one inch across.

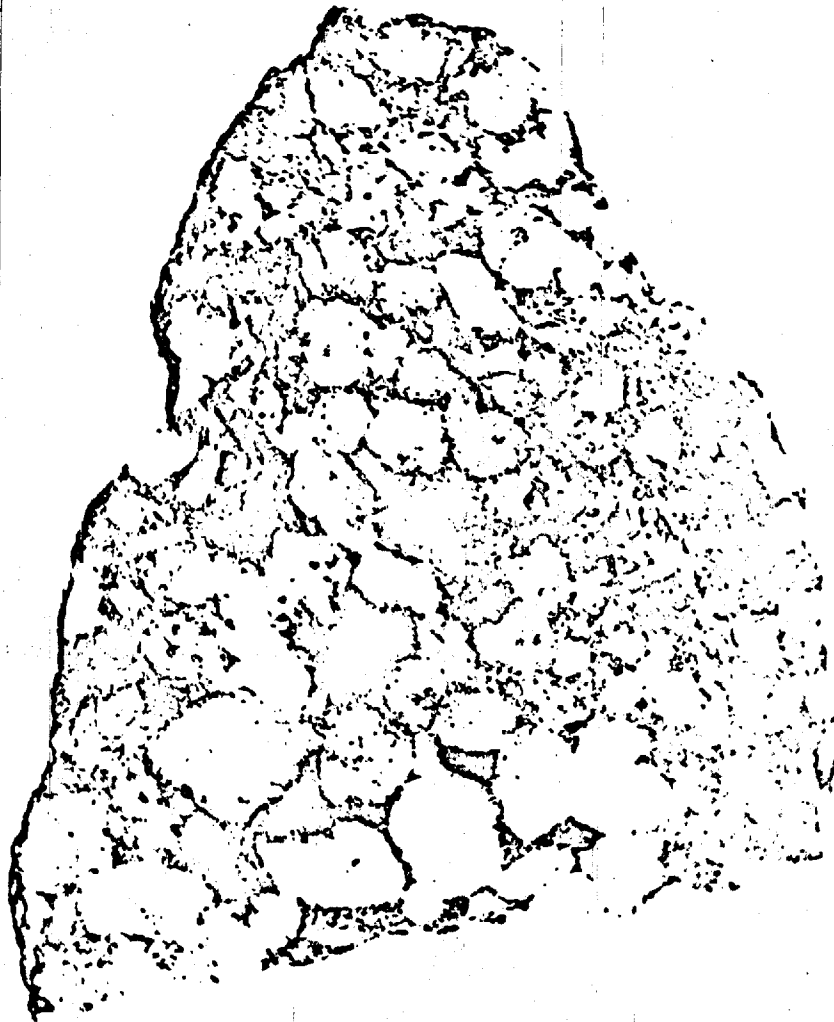


Fig. 30 Hand specimen (natural size) of the metabasite from near Lore Lake. Buddington's classification would make this a gabbroic amphibolite but in the Chibougamau mining terminology this is metabasite.



Fig. 31 Hand specimen of metanorthosite. The white crystals are saussuritized bytownite (or labradorite) grains and the dark green interstitial patches are chlorite aggregates. (.6 x)

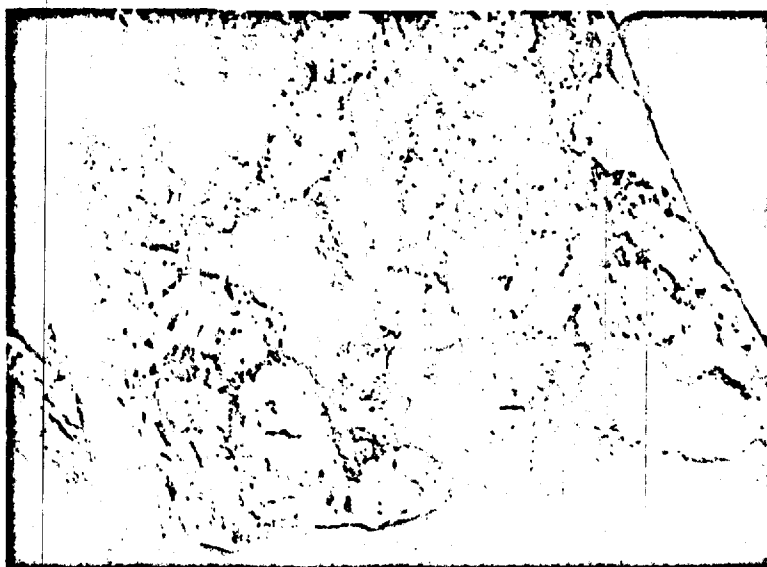


Fig. 32 Hand specimen of metanorthosite close to gabbroid metanorthosite. The patches of saussuritized plagioclase represent original single grains of bytownite. The dark interstitial patches are chlorite pseudomorphing pyroxene. (.6x)

determined because of the few clear patches in optical continuity throughout the section, but the presence of irregular areas of dirty brown to grey fine-grained zoisite and/or clinozoisite make optical work very difficult. On the U-Stage, the method of maximum extinction angle perpendicular to (010) is the only one applicable because of the very limited size of the clear albite patches. On the curves used (Winchell 1927, p.262) positive and negative values are possible and the use of the angle alone can lead to erroneous results.

The angles obtained in nearly one hundred measurements vary between 18 degrees and 15 degrees and average  $16\frac{1}{2}$  degrees. This represents a plagioclase of composition  $An_{2-6}$ . Over 60 check indices measurements against balsam showed that the plagioclase has an index lower than balsam. This index comparison eliminates the higher An content as obtained from extinction angle measurements proving the plagioclase is an albite close to the pure albite end member.

Primary inclusions, such as apatite, zircon and similar accessories are absent.

The interstices between plagioclase grains are either angular, or rounded, or both depending on the euhedralism of the bytownite in the original rock. The chlorite in these interstices is pale yellowish green in hand specimen. In thin section, it is very pale yellowish green to colorless with very weak pleochroism. The birefringence color is a pale olive grey green. The index is  $N_y = 1.6170$ . It is positive and would fall within the prochlorite family according to Winchell's table (1927, p.333).

In some cases, the chlorite-filled interstices have very sharp boundaries against the saussuritized plagioclase (Fig. 35 and 36). Whether the chlorite is the metamorphic pseudomorph of a pyroxene or olivine can seldom be positively established because there are no relicts of either mineral within the chlorite patches. In a few instances, the chlorite patches form single crystals with unique orientation over large areas and enclose many plagioclase grains. This is a relict ophitic texture which suggests the chlorite was derived from pyroxene (Fig. 35). Within the chlorite grains, a number of very small grains not positively identified but resembling sphene are aligned along what look like an original crystallographic direction. The direction could be the prismatic cleavage of pyroxenes or the exsolution lamellae of one pyroxene in another (Fig. 36).

Zoisite and clinozoisite are the predominant minerals in the metaorthosite (Table 3). In some places, they make only 40 to 60 per cent of the original plagioclase and in other cases they completely pseudomorph the original bytownite. These metamorphic minerals occur in three different ways: as a mat of extremely fine grains with dark grey to dark brown color in a background of albite which is nearly obliterated (Fig. 33). They also occur as clear irregular crystals dispersed in large grains of clear twinned albite. Finally, zoisite occurs as clear crystals without any albite. The rock, in the latter case, is very fine grained, massive, quite dense (d:3.2) and resembles a marble. This resemblance is also marked in thin section where the zoisite grains



Fig. 33 Typical metanorthosite with original plagioclase grains changed to a mix of albite with brownish clinzoisite. The light patches in the photograph are chlorite interstitial between the plagioclase grains. Note the excellent preservation of the original texture and grain boundaries. ( 5.7 x )

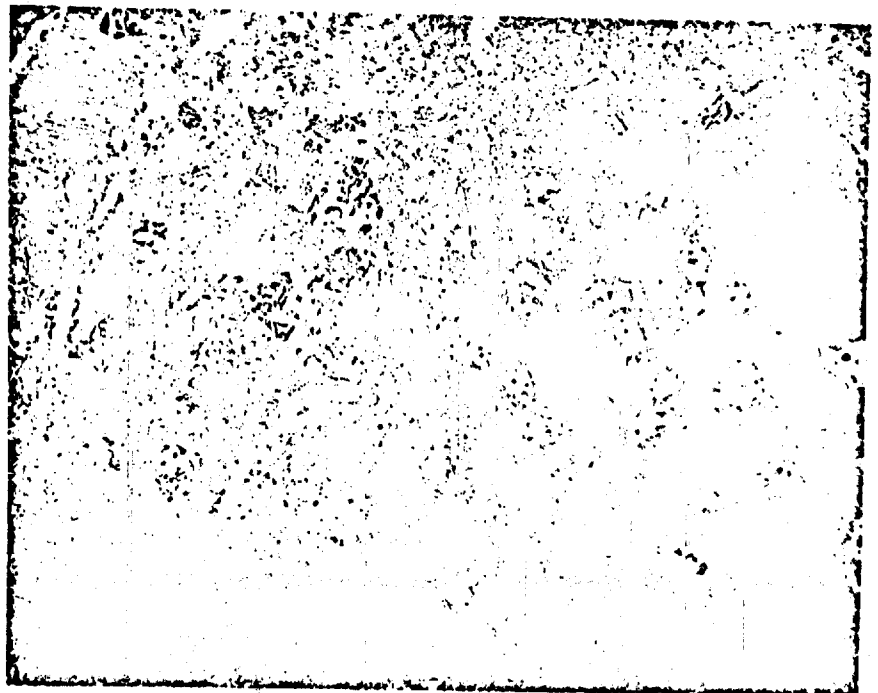


Fig. 34 Same as Fig. 33. Note the interstitial grains of titaniferous magnetite now converted to leucosene (opaque in the photograph) and chlorite (spaces between the opaque blades). ( 5.5 x )

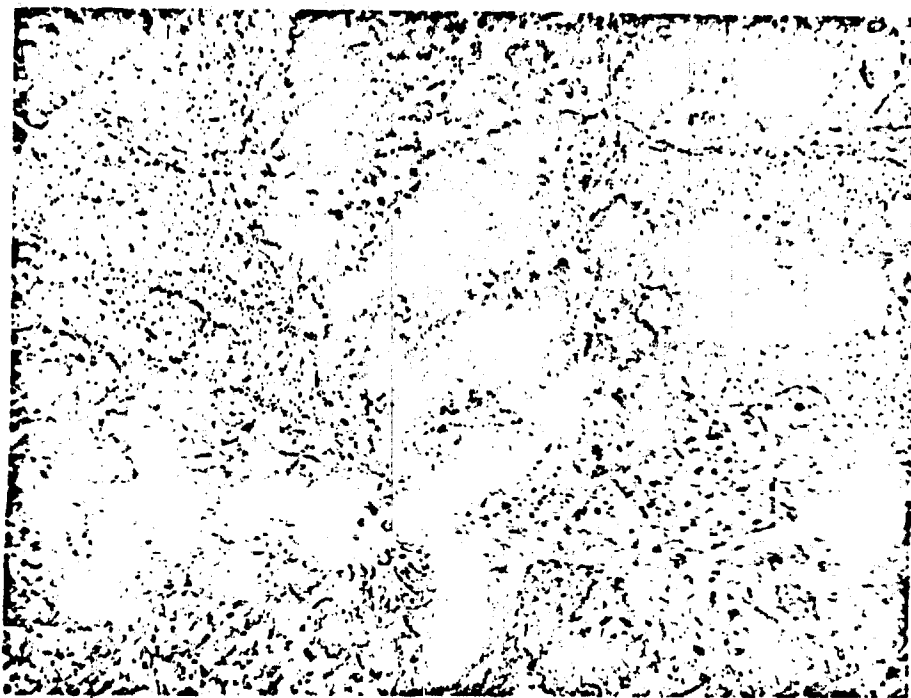


Fig. 35 Meta-northosite with saussuritized plagioclase grains (dark brown areas) in a matrix of chlorite (pale areas). All the chlorite patches have the same orientation, and pseudomorph an original large grain of pyroxene. (27.5 x )

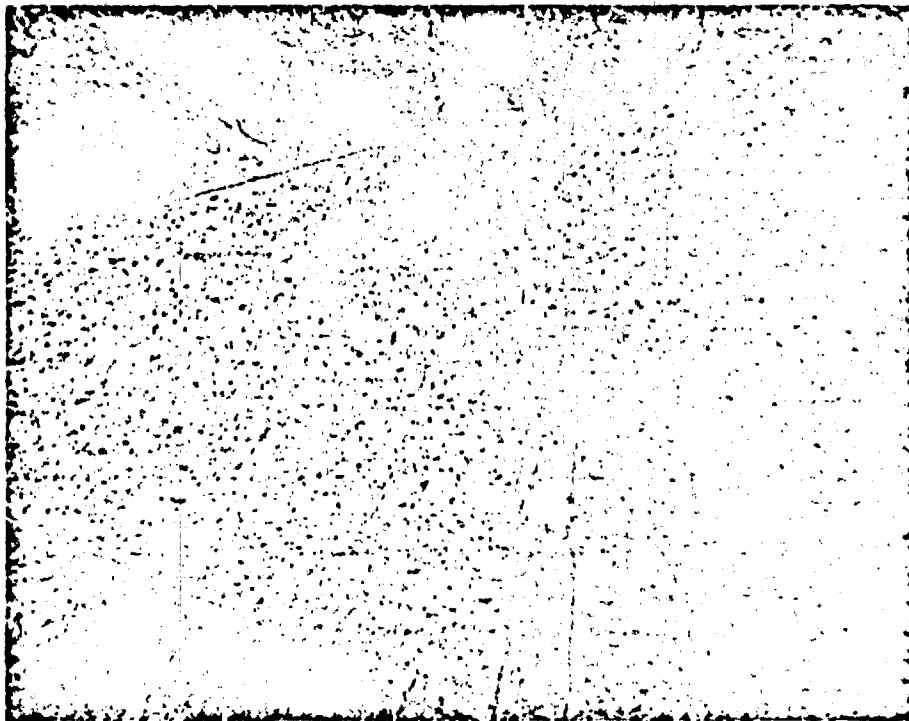


Fig. 36 Same as above, but magnified to show the alignment of small spine (?) grains in the chlorite. This probably represents an original crystallographic direction in the pyroxene. Note the sharp boundary of the chlorite against the saussuritized plagioclase. (80 x )

have a mosaic texture (Fig. 34). The rock is composed then of more than 90 per cent of clear zoisite. The rest is muscovite and chlorite. This facies of the metaorthosite is common in the David Lake area and along the Chibougamau Lake batholith contact. All the broken pieces of anorthosite engulfed in the diorite, quartz diorite, granodiorite and granite of the Chibougamau Lake batholith have been converted to this fine-grained mosaic of zoisite. They weather to a smooth buffish white surface.

The predominant accessory mineral in the anorthosite is ilmenite and titaniferous magnetite. Ilmenite is altered to leucoxene, a dark brown mixture which looks opaque under ordinary illumination and low power, but is transparent and has properties closely akin to sphene when examined with a very strong source of light. The Widmanstätten texture due to exsolution of ilmenite from magnetite is everywhere visible in thin section, provided a strong source of light is used. On cooling, the ilmenite lamellae tend to orient themselves with their (0001) direction parallel to the (111) direction of the magnetite. Under metamorphism, the ilmenite combines with some of the calcium released by saussuritization of the plagioclase and forms sphene, or leucoxene. The magnetite, through diffusion of silica and alumina, is converted to chlorite. In hand specimen, this is readily seen because of the dull green color of the chlorite and the bright orange or purple of the leucoxene (Fig. 38). In some cases, instead of a triangular network of orange blades (Fig. 39), the leucoxene strips are parallel throughout the whole grain (Fig. 40).

TABLE 3

MODAL ANALYSES OF ANORTHOHITE, METAANORTHOHITE, AND  
METAGABBRO FROM THE DUNE LAKE COMPLEX

Specimen number	15-357	54-263	54-19a	54-19b	53-600
Plagioclase	83.29	—	—	85.1	—
Altered plagio.	—	35.3	52.8	—	53
Zoisite	11.25	57.2	27	—	—
Kuscovite	4.2	.1	—	—	—
Rutile	—	.2	2.8	—	—
Opaque	tr	tr	2.1	3.7	5.8
Chlorite	.4	7	12	11.2	1.9
Sphene	tr	tr	.8	—	—
Calcite	tr	—	—	—	—
Quartz	.6	tr	—	—	1.2
Amphibole	—	—	—	—	38
Number of points	2274	1933	1912	2802	1656

15-357: fresh anorthosite. Figure 26.

54-263: metaanorthosite.

54-19a: metaanorthosite(actual).

54-19b: metaanorthosite(original). The chlorite reported here probably represents pyroxene. The mode was done on the metaanorthosite assuming that the saussuritized plagioclase patches represent original fresh plagioclase grains, and the chlorite patches original pyroxene.

53-600: metagabbro

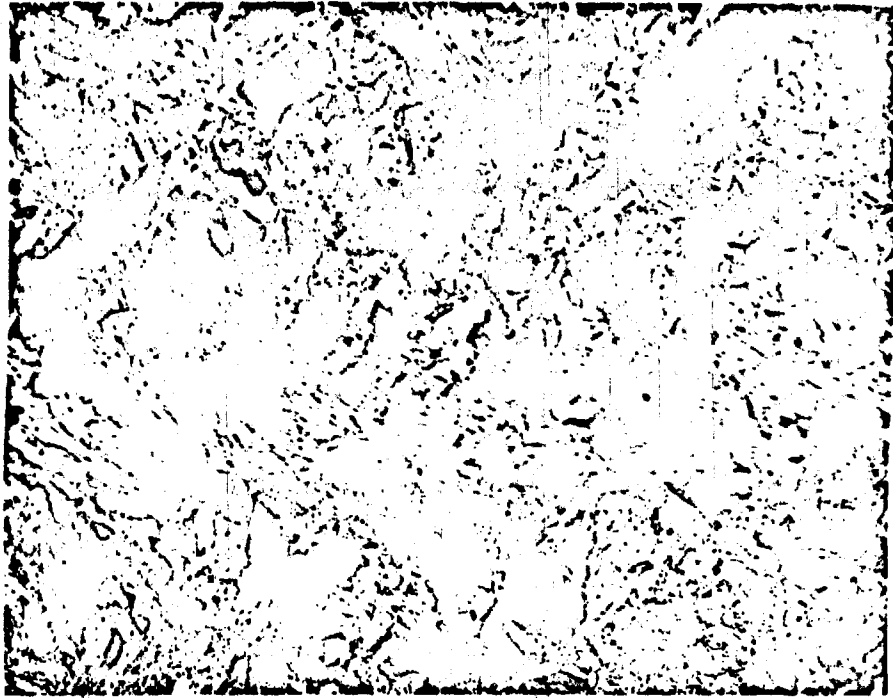


Fig. 37 meta-northosite converted to a mosaic of clear crystalline zoisite. (12.4 x)



Fig. 38 Enlarged photograph of a piece of drill core showing an original grain of magnetite and exsolved ilmenite completely altered. The ilmenite is changed to leucosand (orange-colored blades) and magnetite to chlorite (remainder of the grain). (2.4 x)

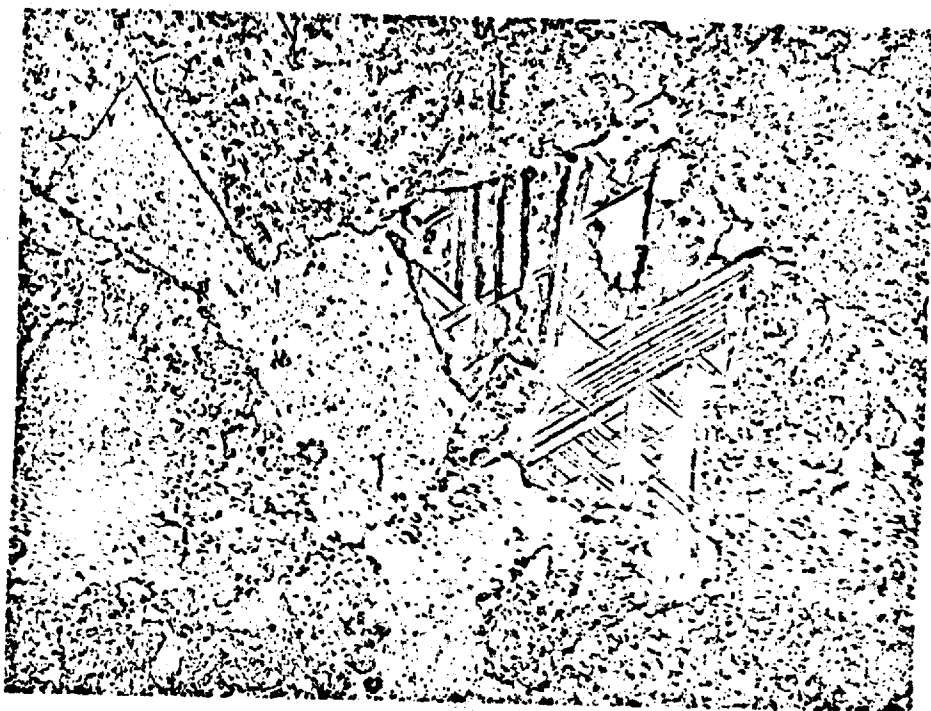


Fig. 39 Metanorthosite with saussuritized plagioclase grains and interstitial patch of chlorite. Large grain of titaniferous magnetite with excellently preserved widmanstätten texture (blades of leucoxene in a matrix of chlorite). Note the sharp grain boundaries in spite of the complete metamorphism of the original rock. ( 16 x )

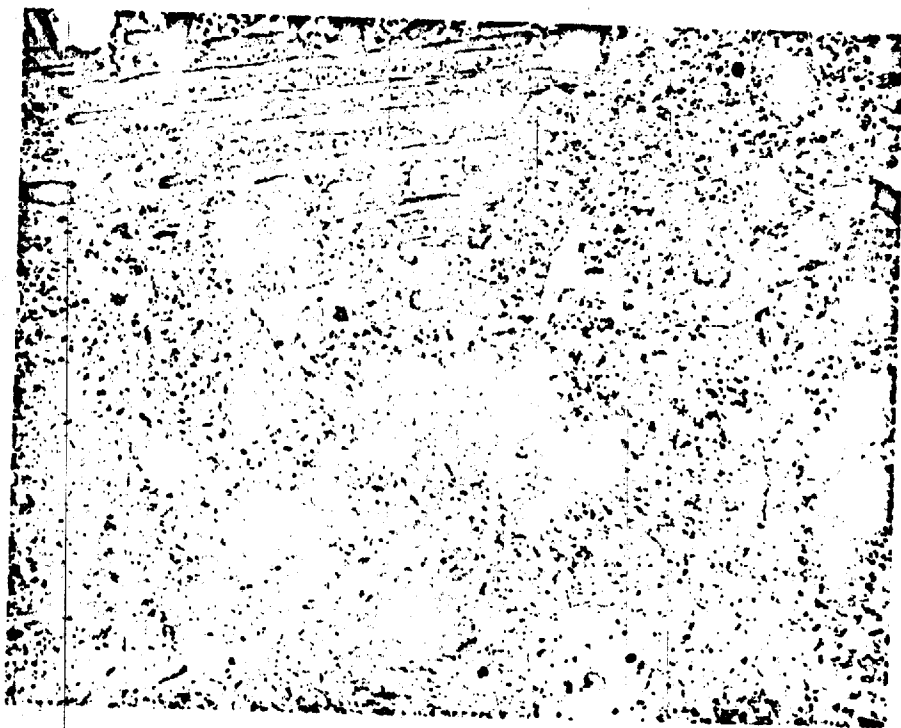


Fig. 40 Same as above with orange-colored blades of leucoxene parallel throughout the grain. Chlorite areas between the blades contain abundant small grains of sphene. Rest of the rock as in Fig. 39. ( 16 x )

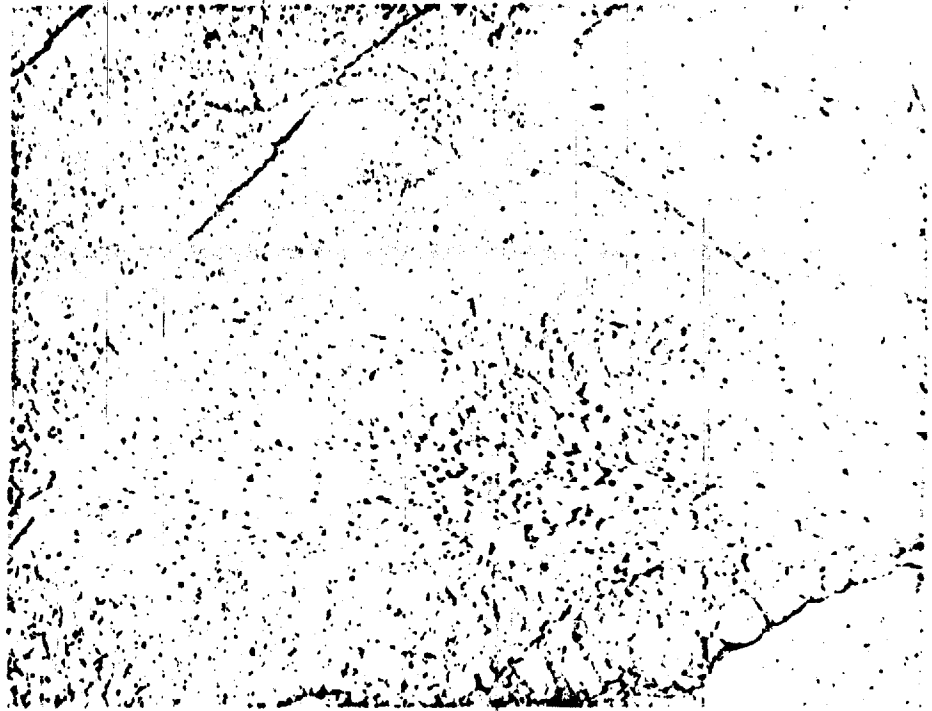


Fig. 41 Blocky structure in anorthosite. (Scale is 6 inches long). The outcrop is wave-polished. The main part of the outcrop is massive anorthosite with a block of gabbroic anorthosite in the middle of it, and without sharp contacts.

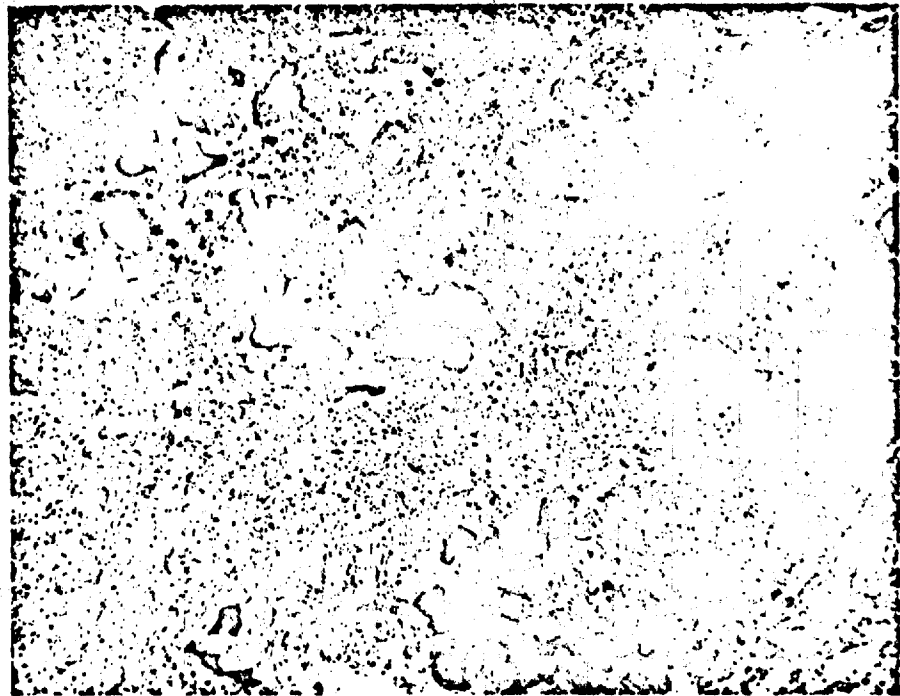


Fig. 42. Meta-anorthosite. Heavily saussuritized plagioclase with a few interstitial patches of chlorite and opaque minerals. (10.2 x)

This may have been an original grain of hematite with exsolved blades of ilmenite. The hematite is converted to chlorite and the ilmenite to leucoxene.

Transition rock between metaanorthosite and metagabbro

There is a complete transition from metaanorthosite to metagabbro with no sharp contacts between the various members of the sequence.

The metaanorthosite, by a decrease in the amount of plagioclase and an increase in mafic minerals, grades into what has been called transition rock. This transition zone should properly be called anorthositic gabbro and gabbroic anorthosite, but the lack of sharp contacts and the transitional nature of this zone make it more simple to call the whole member "transition zone".

The description given for the metaanorthosite applies equally well and will not be repeated here. The plagioclase is heavily saussuritized (Fig. 35) and the mafic minerals are gone over to chlorite. The ilmenite is partially altered to leucoxene.

Within this member, there is a repetition of thin lenses of metaanorthosite with very limited lateral extent. There are also zones rich in magnetite and/or titaniferous magnetite. A few lenses of a very coarse amphibole-rich rock are apparently the metamorphosed equivalent of concentrations of coarse crystals of pyroxene. A general characteristic of the transition zone is the very coarse grain size of the plagioclase grains.

Hydrocoronite

This variety of metaanorthosite or gabbroic anorthosite was found in the Grand Chibougamau Mines drilling in Obalski township, between Cache Lake and Dore Lake, and along the west shore of Dore Lake, close to the Obalski township centre line.

The rock is made up of large crystals of saussuritized plagioclase and a matrix of chlorite and quartz. The rock is very coarse-grained and differs from the transition rock only in having coronas around each plagioclase grain.

Figure 43 shows a piece of drill core and Figure 44 is a thin section photomicrograph of the same rock. The chlorite interstices are made up of a dark green chlorite rim around the white plagioclase grains and the center of the interstices is much paler green and is made up of a fine-grained mixture of quartz and chlorite.

In thin section, the corona is made up of coarse crystals of clear chlorite, similar to the chlorite normally found in the metaanorthosite. The interstices are made up of an aggregate of the same chlorite and small quartz grains.

No relicts of the original minerals were found. Coronites are common in anorthosite and gabbroic masses. The original may have consisted of bytownite jacketed by biotite or hornblende or some other amphibole, and the interstices may have been made up of pyroxene. However, there are some many combinations of minerals encountered in coronites that it is difficult to establish the original nature of the Chibougamau coronite.

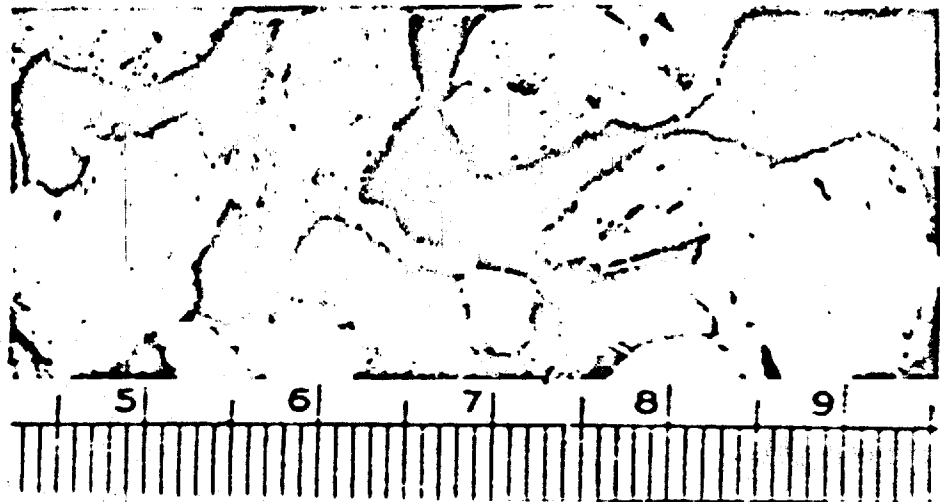


Fig. 43 Gabbroic metanorthosite with corona structure. (Scale in cm). White patches are heavily saussuritized plagioclase grains. Interstices are composed of a fine mixture of pale chlorite and quartz separated from the plagioclase by a rim of dark green chlorite.



Fig. 44 Thin section of specimen represented in Fig. 43. The dark patches are the saussuritized plagioclase grains. The center of the interstices is a fine mixture of quartz and chlorite. The two are separated by a shell of coarse-grained clear chlorite. (5.5 x)

### Magnetite-rich layers

Magnetite, titaniferous magnetite, and ilmenite are common accessories in every member of the Dore Lake Complex. Concentrations of these minerals in certain layers has led some mining companies to explore the possibilities of iron ore mining in the area. Too much titanium makes treatment of this iron ore impractical for the moment. Drilling by Grand Chibougamau Mines Ltd and other companies has given the writer an opportunity to study the field relations of these layers, but not enough thin sections and polished sections were made for a complete study.

The magnetite-rich layers are absent in the southeast quarter of McLenzie. They form a distinctive horizon in Obalski township, west of Dore Lake. They also occur on the north and southeast side of Chibougamau Lake. Here, airborne magnetometer surveys revealed high magnetic anomalies.

The magnetite-rich layers are essentially a magnetite-bearing metapyroxenite. The rock is composed of amphibole, magnetite (mostly titaniferous) and ilmenite. Some bands contain serpentine. No detailed work was done on these but they may have been peridotite or dunite originally. The amphibole is very fine-grained in Obalski township, but coarse in the metapyroxenite on Coulin Peninsula in the southeast quarter of the map-area (Plate 1). Each type of magnetite-rich rock has a limited lateral extent and does not extend all around the mass as a single layer, but the different magnetite lenses appear to be roughly at about the same horizon in the Complex.

The Grand Chibougamau type (Fig. 45 and 46) is a dark green to black rock with a peculiar granulitic texture: rounded silicate grains are uniformly distributed in a magnetite-ilmenite matrix. The silicates crystallized first. Table 4 below contains two modal analyses of this rock. The original silicate may have been pyroxene or olivine. No relicts of pyroxene were found. Some original grains resembling pyroxene in shape were metamorphosed to a single grain of pale actinolitic hornblende, and others to an array of small unoriented blades of colorless tremolitic amphibole. Some have a core speckled with magnetite dust probably released during the transformation of an iron-rich pyroxene to an iron-poor amphibole.

Some of the single grains have a colored core and pale to colorless rims, even if the grain is in contact with magnetite. Some of the large single grains also have exsolved magnetite. Some single grains are patchy with colorless patches and irregular pale to medium green areas. No differences in optical properties were

TABLE 4

Modal analyses of magnetite-rich metapyroxenite

<u>Specimen No.</u>	<u>53-110</u>	<u>13-225</u>
Magnetite and ilmenite of the matrix	33.8	40.2
Released magnetite	14.2	18.2
Amphibole	52	41.1
Number of points	1008	1963

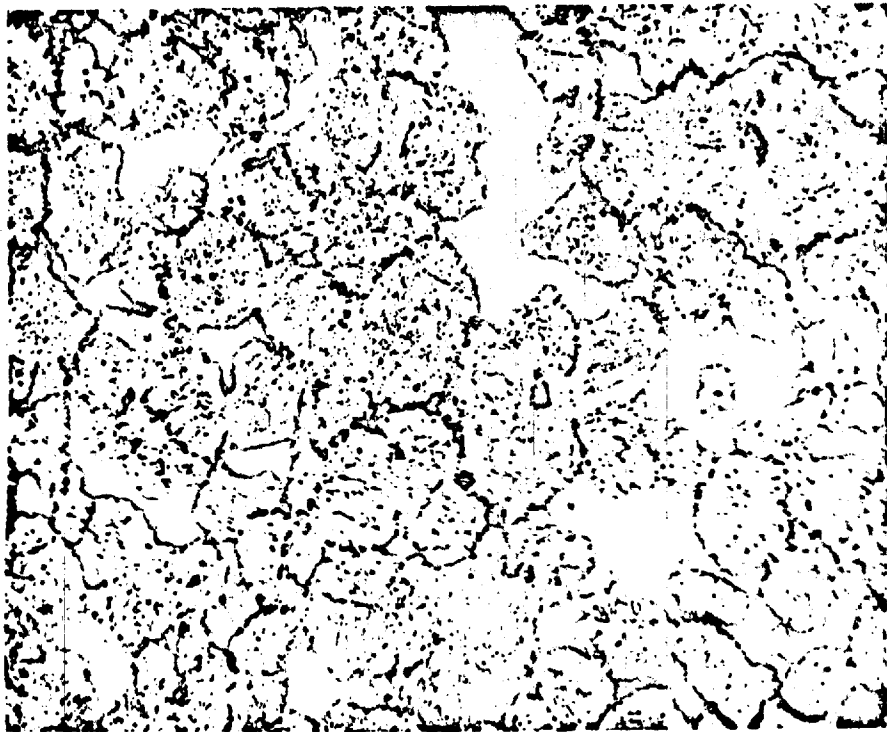


Fig. 45 Magnetite-rich metapyroxenite. Note the roundness of the mafic silicate grains in the matrix of magnetite. Some grains have a core dusty with released magnetite. The amphibole is nearly colorless, and is probably a tremolitic amphibole. ( 7.5 x )

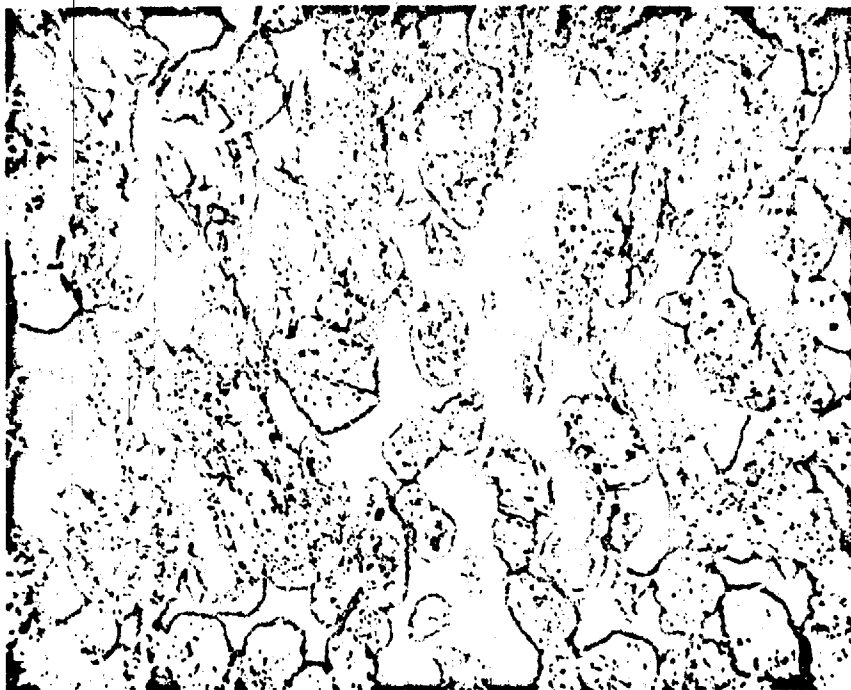


Fig. 46 Magnetite-rich metapyroxenite. The same remarks given above apply to this figure. ( 10.2 x )

noted between the colorless and the colored patches. Single grains have an extinction angle  $2 \Lambda e$  of 17-19 degrees ( $N_g: 1.653$ ) and  $2i$  around 79 degrees. The pleochroism is:

X: pale yellow to colorless

Y: colorless to pale greenish yellow

Z: patchy green to colorless

The small acicular grains of colorless tremolite are too small for accurate optical work.

The matrix, examined in polished sections, is made up of large grains of magnetite with exsolved blades of ilmenite and individual grains of ilmenite.

The magnetite-rich layers are interbanded with well foliated feldspathic metagabbro (Fig. 47). The latter becomes more and more abundant higher in the Complex until the magnetite-rich metapyroxenite gives place entirely to metagabbro. Fig. 49 illustrates diagrammatically the variations of the iron and titanium content across a section of this layer obtained in diamond drill hole No. 11 of Grand Chibougamau Mines Limited.

Magnetite-rich layers are frequent in the layered complexes found throughout the world, but the literature appears to contain no examples of metamorphosed magnetite pyroxenite.

Among reports on unmetamorphosed occurrences, Du Toit describes similar iron ore layers in a gabbro-pyroxenite mass in the Natal. The field relations match the Chibougamau occurrences very well but the mineralogy is different. He reports (Du Toit, 1919)

"titaniferous magnetite, basic labradorite, diallage, hypersthene, spinel, hornblende, olivine".



Adams and Barlow (1910) described the Glamorgan gabbro and the Fusay iron orebody which is made up of pyroxene and iron ore. The pyroxene has a purplish color, is faintly pleochroic, and holds bunches of minute black spicules toward the center. The pyroxene is enclosed by iron ore and is separated from the latter by a rim of brown hornblende.

Buddington (1939, p. 9 and 81) mentions magnetite-ilmenite pyroxenite layers within shonkinitic syenite bands. The ore forms 30 to 40 per cent of the rock and augite of a dark green variety constitutes about half the rock. Hypersthene is a minor accessory.

Palmunson (1925) describes an ilmenite-magnetite olivinite composed of 60 per cent olivine, 36 per cent ilmenite and magnetite, spinel and brown hornblende.

Johannsen (1931) mentions several rock types roughly similar in composition to our magnetite-rich metapyroxenite:

**anabohitsite:** an olivine and hornblende-bearing pyroxenite with 30 per cent ilmenite and magnetite.

**avezacite:** an ilmenite-rich pyroxene-bearing hornblendite.

**cumberlandite:** a rock made up of labradorite, hyalosiderite, magnetite, and ilmenite.

**ilmenite dunite:** rounded grains of olivine, green spinel, brown hornblende in a matrix of iron ore.

**Jacupirangite:** eighty per cent augite and twenty per cent magnetite and ilmenite

Ultrabasic sills to the north contain heavily serpentinized dunites and pyroxenites in which the pyroxene grains are surrounded by a rim of actinolite. Within the Dore Lake Complex, some serpentine was reported by Mawdsley and Herzan (1935) to the northeast of Chibougarau Lake. On Gouin Peninsula, some amphibole-rich metapyroxenite contain

small grains of serpentine and magnetite which are likely derived from olivine. This indirect evidence suggests an original pyroxene as the ancestor of the amphibole in the fine-grained magnetite-rich metapyroxenite illustrated in Fig. 45 and 46. The two types of amphibole could be pseudomorphs of two different pyroxenes. The fact that some of the larger single grains of amphibole have a rim which is colorless and supposedly poorer in iron could be due to an original deficiency in iron in the rim of a zoned pyroxene or possibly due to diffusion of the iron in the magnetite matrix. The textural arrangements of the ilmenite laths within the magnetite grains is such, however, that diffusion is ruled out for this mineral. Moreover, the presence of grains with abundant released magnetite in the cores (Fig. 46) also suggests an original zoning of the pyroxene.

#### Metagabbro

The metagabbro of the Dore Lake Complex was a coarse to medium-grained gabbro now metamorphosed to a rock composed of saussuritized plagioclase, actinolitic hornblende containing minor pyroxene, magnetite and titaniferous magnetite, chlorite, apatite, and other minor accessories.

The rock weathers pale greyish white. On a fresh surface, white plagioclase and dark green hornblende appear to be in equal proportion. Primary foliation is commonly well developed and permits accurate measurement of the attitude of the Complex.

The texture is hypautomorphic granular or granitoid.

Fig. 50 shows pictures taken of a thin section which cut across a band of gabbro and a band of magnetite-rich metapyroxenite. Fig. 47



Fig. 47 Hand specimens (drill core) of banded metagabbro and metapyroxenite. The boundaries between the bands are sharp but there is a good interlocking of grains across the boundaries (see Fig. 50). (Natural size)

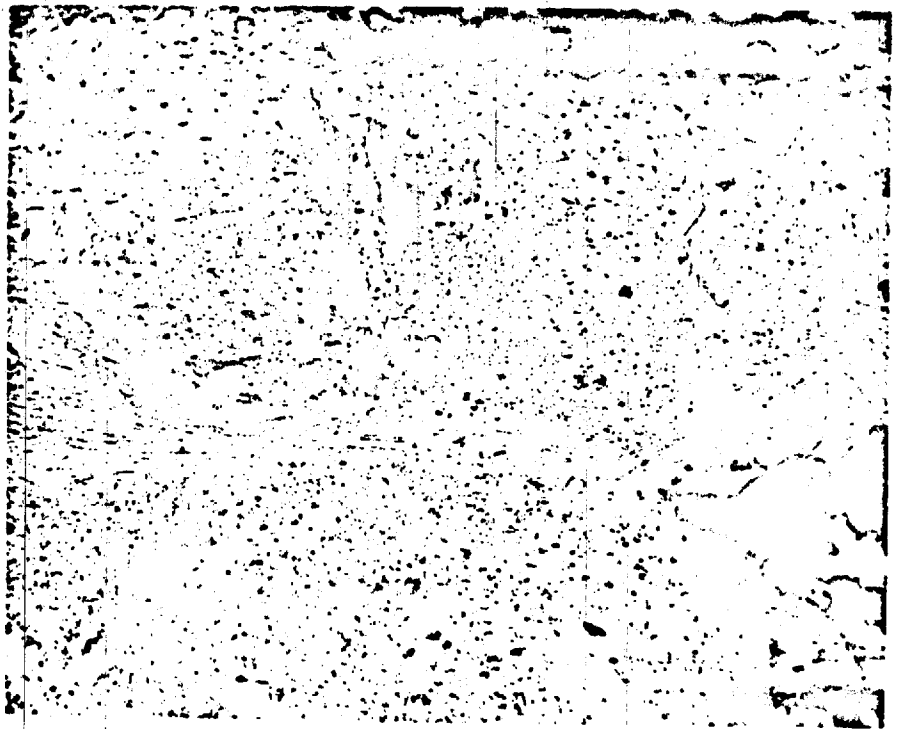


Fig. 48 Large actinolitic hornblende grain with relict patches of pyroxene (P). The pyroxene patches have a common optical orientation. (80 x)



Fig. 50 Photograph taken across the contact of a metagabbro and magnetite-rich layer. Note the elongated shape of the saussuritized plagioclase (r) grains which impart a distinct foliation to the rock. Note also the small pyroxene grains (p) left in the hornblende of the more mafic end, and the preservation of the Widmanstätten texture of the ore minerals. (9x)

also show hand specimens (drill core) of the typical metagabbro.

In the field, the anorthosite grades into an orthositic gabbro and gabbroic anorthosite (called transition rock). The latter gives place over a very short distance to either fine-grained magnetite-rich metapyroxenite (in Balski township) or to the metagabbro. In the area mapped in detail by the author, the transition zone is succeeded by metagabbro. The magnetite-rich metapyroxenite is interbanded and finally grades into metagabbro.

The original labradorite (possibly bytownite) is altered to albite with scattered grains of clinzoisite and shreds of chlorite, or to a granular aggregate of clinzoisite and carbonate with very minor albite in the background. In the gabbro, the plagioclase laths are euhedral to subhedral and elongated parallel to the *a*-axis. The foliation is marked, but there is no lineation within that foliation plane.

There are enough patches of clear albite to permit extinction angle measurement on the U-stage. The plagioclase is very close to the pure end member albite; its extinction angle varies between 15 and 17 degrees and its indices are always lower than balsam.

The pyroxene is more resistant to metamorphism than the feldspar. No relict labradorite was found, but relict pyroxene (Fig. 48) was observed in two thin sections. Pale green actinolitic hornblende plates pseudomorphic after pyroxene are comparable in size to the original pyrogenic pyroxene. This hornblende has a patchy color distribution, some areas of the same grain being dark green and others very pale green. In some specimens, the

actinolitic hornblende is both in aggregates of fine shreds, and in large single grains. It is possible that the two modes of occurrence represent two different original pyroxenes. Not enough sections of the metagabbro contained relict pyroxene to permit an accurate determination of the optical properties of the pyroxene itself, but it is a clinopyroxene with large optic angle. Some grains of this pyroxene have a grid of fine opaque lines that resemble diallage texture (Fig. 48).

Clinzoisite and epidote are always present in the metamorphosed plagioclase grains or in granular aggregates. Clinzoisite is more frequently tied up with the metamorphism of the original plagioclase, and epidote with the matrix or it may occur in cross-cutting veinlets commonly accompanied by quartz.

Minor calcite, quartz, and sericite are common but it is difficult to ascribe them to any particular original mineral.

Magnetite and titaniferous magnetite are commonly preserved. The Widmanstätten texture pseudomorphed by leucoxene, sphene, and chlorite are common (Fig. 50).

#### Metapyroxenite

On the south side of Gouin Peninsula, between Dore Lake and Chibougamau Lake, layers of coarse-grained amphibole-rich rocks are interlayered with anorthositic gabbro and gabbroic anorthosite. Anorthosite occurs to the south (lower in the Complex) and gabbro to the north.

Another layer is found on the north shore of Dore Lake, close to the Roy-McKenzie township line, but the exposures are limited to

the shore. Magnetometer surveys over the ice of Dore Lake indicate that this layer extends further south under Dore Lake.

The rock is medium- to very coarse-grained. Some specimens are made up of large dark green amphibole crystals in a fine-grained pale greenish yellow matrix. Other facies of this rock consist of long radiating needles of a dark green to pale green amphibole. Other types are made up of large anhedral patches of dark green chlorite and euhedral patches of pale green amphibole needles.

Sometimes, these different facies contain magnetite or ilmenite or both and there seems to be a concentration of these minerals along certain layers although they could not be mapped separately on Gouin Peninsula because of the nature of the topography and the very heavy blanket of moss covering the whole Peninsula.

The weathered surface of the metapyroxenite is very jagged and rough. The different types of amphibole weather differentially and the amphibole projects in marked relief when associated with chlorite. The magnetite and ilmenite grains also stand out on the weathered surface. The rock varies from dark green to brownish red.

In thin section, the large crystals of dark green hornblende are well zoned (Fig. 51, 52, and 53). They have an index  $n_g = 1.665$  and  $2\Delta c$  of 16 degrees, and  $2V$  of 72 degrees for the outer rim and center part and 82 for the intermediate rim. These figures were obtained on the U-Stage but are not too accurate. In the same thin section, with all the care possible, the variations between readings taken on different grains were so large as to make the determinations almost meaningless. Buddington and Leonard (1951) mentioned the same difficulty in their work on hornblendes.

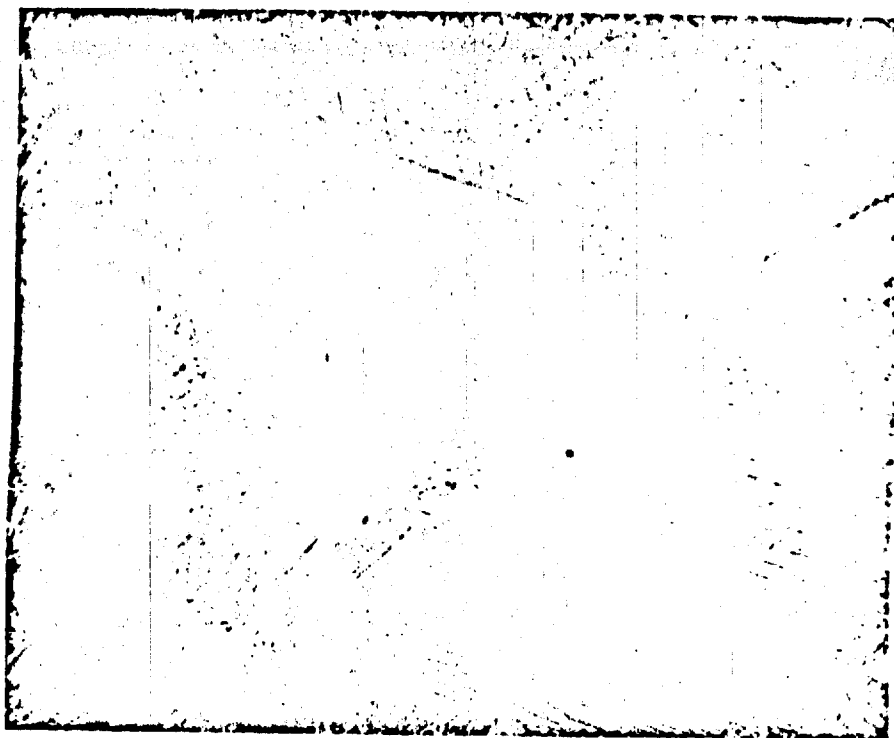


Fig. 51 Metaproxenite with large zoned amphibole grains. The center is dark green and the rim is pale to colorless. The matrix is a felt of very fine needles of tremolitic amphibole. Note the pyroxene termination on the dark core of the large crystal. (80 x)

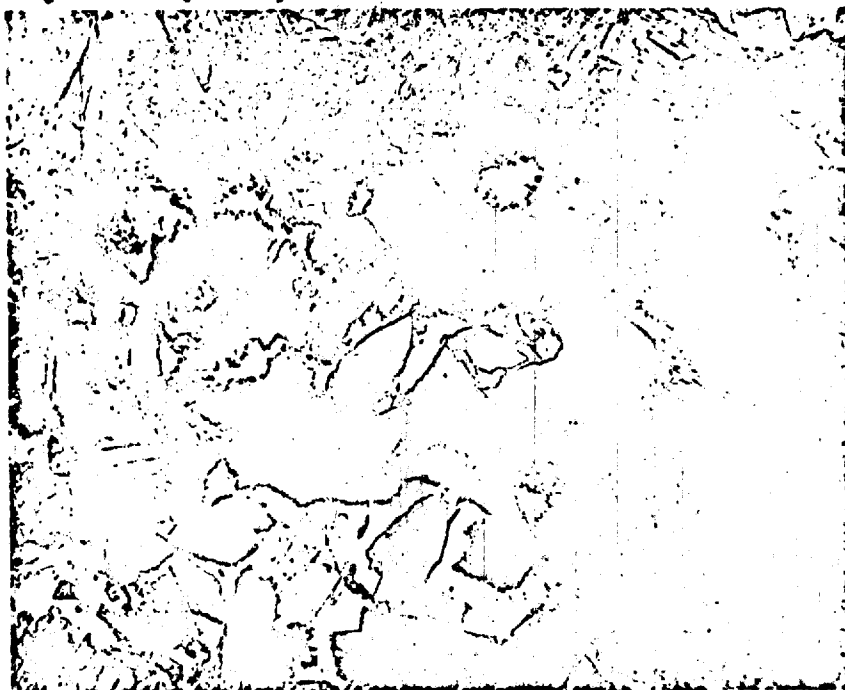


Fig. 52 Metaproxenite with large zoned crystals of colored hornblende in a matrix of quartz and tremolitic amphibole. (10.2 x)

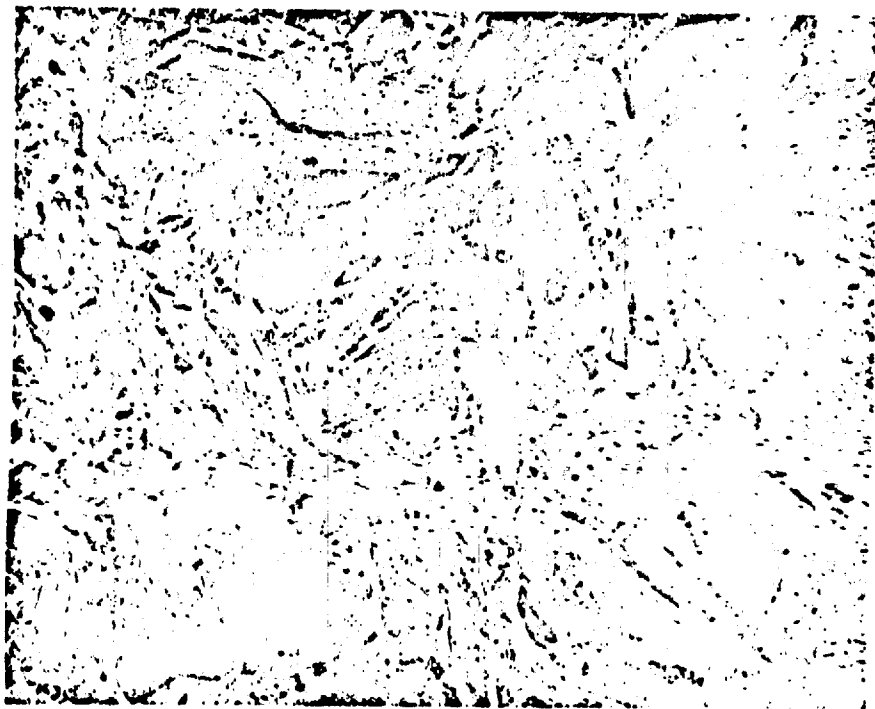


Fig. 53 Meta-groxenite with large crystals of colored hornblende in a matrix of very fine-grained colorless amphibole. Note the colorless rim around the colored grains, and the cracks in the large crystals filled with the amphibole of the matrix. ( 10.2 x )

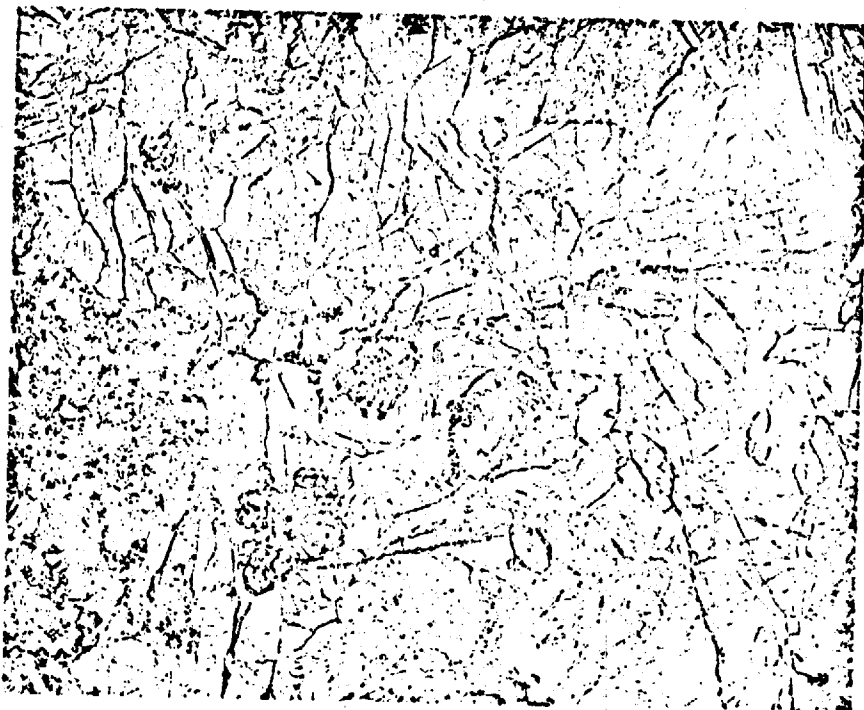


Fig. 54 Same as above, but zoning not so well developed. Note the few grains of opaques accompanied by amphibole and serpentine. They are probably derived from olivine grains. ( 10.2 x )

The pleochroic formula for this amphibole is:

- X: cream yellow
- Y: dark green center  
paler green on the outside
- Z: pale to medium green with bluish tints.

Lack of precise chemical work makes it difficult to name this amphibole, but from Minchell's (1927) diagrams, the amphibole is a calciferous hornblende, close to hastingsite.

These large crystals of hornblende are commonly sheared, bent, cracked, and twinned. The hornblende crystals have the external outlines of an amphibole but the interior of some crystals, due to tiny opaque inclusions (Fig. 51) suggest a relict pyroxene texture.

The pale yellowish matrix is made up of very tiny needles of colorless tremolitic amphibole. They are too small for accurate optical work, but the X-ray diffractometer pattern positively identified this material as an amphibole. This colorless amphibole of the matrix also fills the cracks in the large broken colored crystals. The index of the colorless amphibole is  $n_z: 1.640$  and the extinction angle is 17 degrees.

In some sections, large colorless porphyroclasts grow through the colorless amphibole of the matrix. In other cases, some crystals of colorless tremolite are growing through the matrix and through adjacent colored hornblende grains. The chlorite patches are dark green to black in hand specimen, but in thin section the chlorite is pale green, nearly isotropic with an olive green interference tint. Sometimes, a few needles of colorless amphibole grow through the chlorite patches.

Some sections contain anhedral grains of serpentine with

abundant released magnetite (fig. 54). These are likely derived from olivine grains.

Ilmenite is a very common accessory in the amphibole-rich rocks. Many ilmenite grains are broken and the cracks are filled with sphene. Ilmenite grains are generally rimmed by sphene.

In one section, grains of original ilmenite are altered to cores of calcite and rutile and rims of sphene.

No other accessories were noted.

For reasons mentioned above, these amphibole-rich rocks could be called metapyroxenite or metaperidotite. The growth of the hornblende crystals took place in steps: first, a pseudomorphing of the original pyroxene, followed by growth of a rim around this nucleus. At the same time, the original matrix was converted to a tremolitic felt in which grew some large tremolitic porphyroblasts. The growth of the ends of some of these into the colored hornblende indicates that it was one of the final minerals to develop in the rock.

Similar rocks have rarely been reported in the literature. Johannsen (1931) mentions a rock from Aussyolinkvaare, Lapland (Mikkola and Sahana) composed of colorless monoclinic amphibole (62 per cent), pyroxene (22 per cent), carbonate (19 per cent), and spinel (7 per cent). The pyroxene is replaced in places by hornblende. The interstices are filled by fine fibrous amphibole and carbonate. The rock resembles the amphibole-rich layers of the Lore Lake Complex, but Johannsen does not describe the field relations and the nature of the original rock.

Hornblende diorite

Magnetite-rich diorite

Porphyritic diorite

Fe-magnetitic diorite

These rock types were not seen in the area mapped by the writer, but were found in Obalski township and are included here for sake of completeness. Not enough thin sections were studied to get all the data necessary for a complete petrographic description.

The hornblende diorite is a very fine-grained rock, dark colored, with a faint foliation and fresh plagioclase. The plagioclase is markedly lath-shaped. The few equant grains show strong zoning from  $An_{46}$  to  $An_{33}$ . Green hornblende is common and associated with magnetite and apatite. There is a spatial relation between apatite and magnetite (Fig. 55). The latter occurs in small rounded grains or in long corroded grains full of embayments and full of apatite grains. The green hornblende is altered to chlorite.

The magnetite-rich diorites are composed of fresh anhedral interlocking grains of andesine and grains of pyroxene in a matrix of magnetite and ilmenite. The ore minerals have the "filling-in" texture with anhedral elongated patches filling the gaps between the plagioclase grains. The plagioclase grains are separated from the ore grains by a narrow corona of brown hornblende.

The porphyritic diorite is similar to the hornblende diorite described above but it has large phenocrysts of original calcic plagioclase now heavily saussuritised. The matrix had a plagioclase less calcic which was stable under the conditions of metamorphism

and has not been modified.

The pegmatitic diorite is similar to the magnetite-rich diorite but has a rather coarse grain size.

### Granophyre

A body of granophyre (called quartz gabbro by Graham (1953) and metasomatic complex by Smith (1954) underlies the hills north of Dore Lake near the McKenzie township center line (north south). Another body was found north of Simon Lake but was not mapped in detail. It was called granite by Norman during his regional mile-to-the-inch mapping.

The extent of the bodies of granophyre is quite limited, relative to the extent of the anorthosite and gabbro masses. In a number of places, the granophyre has been eroded off, and in others, it has been so intensely altered as to be unrecognizable, especially along the Lac Sauvage fault zone where intense carbonatization has obliterated the nature of the original rock.

The granophyre body in McKenzie township coincides with the large hill on which the fire ranger's tower is located. The preservel of this body is partly an effect of topography coupled with relatively low dips to the northwest.

The essential minerals are quartz, chlorite, and turbid sodic plagioclase. Quartz eyes are present everywhere and vary from .5 mm to 5 mm. Albite and quartz cannot always be separated in hand specimen, but where a good/feathered surface is available, the distinction is easy to make.

In a few instances, granophyre was traced into good

metagabbro or into transition rock. The passage is very gradual and marked by the appearance of few clear quartz grains at first and complete disappearance of saussuritized plagioclase.

This section studies showed that this rock is a true granophyre which has been altered and metamorphosed. The granophyric texture is well preserved in spite of intense alteration of the original plagioclase and mafic minerals. The clear quartz grains which appear to be single grains in hand specimen are composed of a great number of irregularly-shaped fragments having identical optical orientation (Fig. 56). The interstices between the fragments are filled with chlorite and heavily sericitized and/or chloritized plagioclase. The plagioclase commonly occurs as laths completely embedded or partly embedded in the quartz grains (Fig. 57). Laths of plagioclase are often chloritized with little plagioclase left. Tiny sericite flecks are common in the plagioclase.

A few sections contain actinolite. Large needles of apatite are common. Pyrite, sphene, calcite, titaniferous magnetite, and ilmenite occur as accessories. The magnetite is chloritized and the ilmenite changed to sphene and leucosene. Table 5 shows two modal analyses of granophyre

The field relations and microscopic data obtained on this type of rock indicate that it is one of the last members to crystallize in the formation of the Dore Lake Complex. The differentiation of the original basic magma produced a rest liquid richer in  $\text{SiO}_2$ , water,  $\text{K}_2\text{O}$ ,  $\text{H}_2\text{O}$ , which gave rise to the granophyre just described. A similar situation has been described in nearly



Fig. 55 Hornblende diorite. Note the lath-shape of the plagioclase grains and the spatial relations between the apatite (A) grains and the magnetite-ilmenite grains. ( 12.4 x )

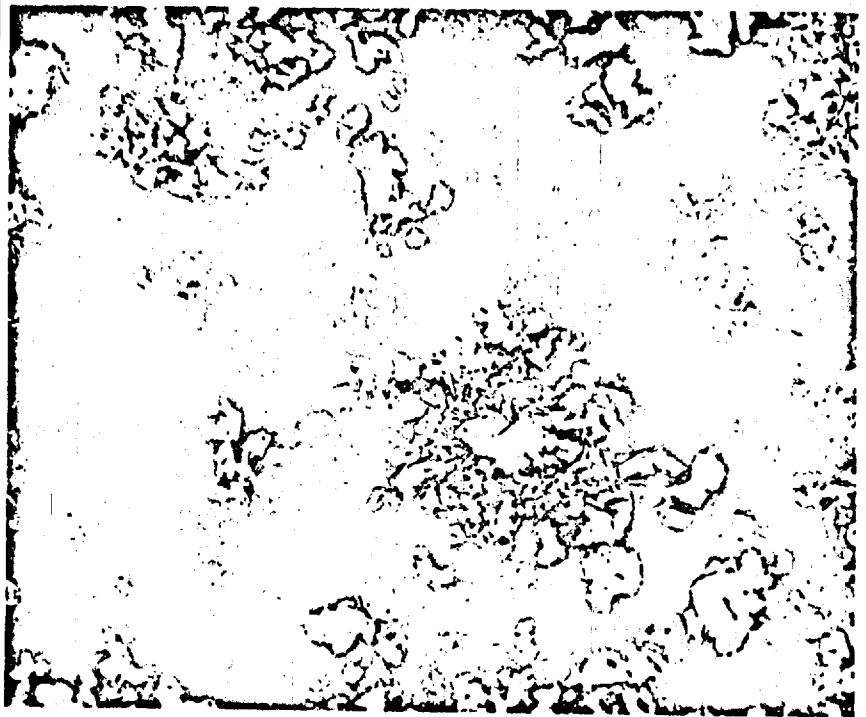


Fig. 56 Granophyre. The clear quartz grains are composite with many individual grains having identical optical orientation. Chlorite, actinolite, opaque, and apatite form the matrix. (10.2 x )

all layered complexes and large basic sills. The proximity of the granophyre areas to the Lac Sauvage fault zone and other zones of hydrothermal alteration makes it impossible to differentiate between the metamorphic products and the minerals resulting from hydrothermal alteration.

TABLE 5

Modal analyses of granophyre from Dore Lake Complex

Specimen number	53-151	53-241
Quartz	26	25.8
Altered plagioclase	53.8	39.4
chlorite	none	4.5
Actinolite	5.8	10.2
Opaque	13.5	11.7
Leucoxene	none	1.7
Apatite	.19	.07
Sphene	.06	tr
Epidote	.57	none
Unidentified	—	6
Number of points	1572	1345

Comparisons with other Layered Complexes.

The Dore Lake Complex has both similarity and differences with other layered complexes. These large mafic igneous masses are characterized by a wide variety of rock types, banding parallel to the floor, cryptic differentiation, and unique rock types. The principal features of some well known masses are tabulated in Table 6 and the Dore Lake Complex is included for comparisons.

Cooper (1936) divided stratiform sheets in two types:

Bushveld type

Mafic minerals poor in iron  
Troctolite rare  
Pyroxenite common  
Chromite concentrations in lower part

Duluth type

Mafic minerals rich in iron  
Troctolite common  
Pyroxenite absent (or very scarce)  
No chromite concentrations (titaniferous magnetite in lower part as well as upper)

The Dore Lake Complex resembles the Duluth type in the high tenor in iron and in the absence of chromite concentrations. It resembles the Bushveld in having pyroxenite and rare troctolite, although the metamorphism could have obliterated the original olivine. It is unique by the great abundance of anorthosite and gabbroic anorthosite (the anorthosite and gabbroic anorthosite layer may reach 10,000 feet thick in places where the whole Complex appears to be 12,000 to 15,000 feet thick). The metamorphism and metamorphic products of this Complex are also unique.

Problem of the position of the magnetite-rich layers within the Dore Lake Complex

The origin of layered complexes by differentiation raises

the problem of why the heavier magnetite-rich layers are on top of the anorthosite layers, and often quite high stratigraphically within the complexes.

As described above, the metaanorthosite grades imperceptibly upward into transition rock (gabbroic anorthosite and anorthositic gabbro). Within three inches, this transition rock passes to a magnetite-rich metapyroxenite with thin interbeds of feldspathic metagabbro. Many specimens of the magnetite-rich rock have a specific gravity around 3.8 while the metaanorthosite varies from 2.9 to 3.2. The fresh anorthosite has a density of 2.8.

A similar situation is reported from the Bushveld Complex where heavy titaniferous magnetite occurs near the top of the norite (Hall, 1932). A detailed section below Magnet Heights shows a band of magnetite 70 inches thick overlying anorthosite and overlain by medium-grained norite. This is a small scale version of the Dore Lake Complex.

Similarly, chromitite bands are both underlain and overlain by anorthosite, and in the Rustenburg district, the lower chromitite horizon rests on anorthosite and is overlain by pyroxenite. A similar situation was described in the Adirondacks by Buddington (1939).

Although most layered complexes (Table 6) show similar features, there is no definite horizon where the magnetite or ilmenite tends to be concentrated. Generally, the ilmenite and magnetite bands are near the center of the mass. Broderick (1935) explained a similar concentration within lava flows as due to gas transfer. Wager and Deer (1939) in their study of the Skaergaard sheet show that during the consolidation of 60 per cent of the

LOCALITY	GEOLOGICAL	LITHOLOGICAL	DIP	DIRECTION
Precambrian 30 miles 10 miles 10 miles	Precambrian 30 miles 10 miles 11,000 feet	Precambrian 30 miles 10 miles 11 miles (?)	Precambrian 27 miles 2-3 miles each 1150 over 10,000 feet	Precambrian 150 miles 100 miles 1000-5000 feet
<p>Self rocks Anorthosite-gabbro-felsite</p> <p>Gabbro, granophyre-bearing anorthosite Anorthosite, etc Anorthosite Diabase</p> <p>Norite 2 ilm.-mag. horizons Anorthosite Hypersthene-bearing diablage Diablage-bearing hypersthene</p> <p>Interbanded norite Diablage norite Bronzite Banded norite Bytownite anorthosite Diablage-bearing hypersthene</p> <p>Merensky reef Platinum Chromite horizons</p> <p>Basic norite Bronzite Bytownite anorthosite</p> <p>Basic transitional horizons</p>	<p>Top eroded</p> <p>Upper zone Anorthosite Anorthosite gabbro &amp; felsite anorthosite</p> <p>Banded zone Norite, coarse Anorthosite Norite Magy anorthosite bands</p> <p>Basic zone Bronzite Marginalite Bytownite subordinate disseminated dunite sulphides</p>	<p>Volcanics</p> <p>Gabbro, in part banded with troctolite, olivine gabbro Feldspathic Dunite with little pyroxenite</p> <p>Dunite peridotite subordinate pyroxenite dissem. near contains zones Cu-Ni zone of troctolite, sulphides gabbro, pyroxenite, feldspathic dunite, several peridotite, and chromite gabbroic anorthosite occurrences</p>	<p>Acid rocks granophyre</p> <p>Porphyritic diablage Upper Porphyritic zone diablage Magnetite-rich diablage</p> <p>Metagabbro Porphyritic metagabbro Centr. Titaniferous zone magnetite mag. Metapyroxenite and mag-rich metapyroxenite</p> <p>Lower zone Anorthositic metagabbro gabbro, pyroxenite Metaanorthosite gabbroic Metaanorthosite Anorthosite</p>	<p>Roof: Keweenaw lava Acid rock: red rock or granophyre</p> <p>Upper Anorthosite zone Anorthositic gabbro Olivine gabbro</p> <p>Olivine gabbro (makes up 2/3 of mass) Central zone with a little magnetite Gabbro near the middle</p> <p>Olivine gabbro and troctolite with peridotite bands</p> <p>Lower zone Troctolite with peridotite bands</p> <p>Chill zone Diabase or gabbro</p> <p>Ilmenite- magnetite bands Ilmenite- magnetite segregation Disseminate Cu-Ni sulphides scarce Small Cu-Ni sulphide body</p>

gabbroic magma, there was relatively little change in the composition of the residual liquid but most of the Fe and Ti crystallized after 75 per cent and before 95 per cent was crystalline and that the granophytic residuum amounted to only 5 per cent. In the case of the Skaergaard mass, the iron-rich mineral is an olivine. Whether the iron concentration shows in a ferrogabbro rich in iron-olivine or in layers of magnetite-rich metapyroxenite, or in magnetite-ilmenite layers, is unimportant as long as in either case the course of differentiation in mafic stratiform sheets leads to a maximum concentration of iron and titanium at an intermediate or relatively late stage.

Newhouse (1936) pointed out that in mafic rocks the iron oxides are not among the first minerals to crystallize. On the other hand, they are early in the crystallization of felsic magmas. This explains, why, in the Dore Lake Complex, the iron oxides did not appear in the anorthosite layer near the base. They only started crystallizing in significant quantity in the transition rock and at a later stage.

It is unfortunate that this Dore Lake Complex is completely metamorphosed and no study can be made of the variation in the iron content of the silicates. A cryptic differentiation was observed in the Palisade sill (Walker 1940), Skaergaard mass (Wager and Deer 1939), and other masses where detailed petrographic work has been done. In our case, variations in the anorthite content of the plagioclase from the anorthosite to the granophyre was likely accompanied by an iron enrichment of the silicates.

If all the minerals coming out of a crystallizing magma

were forming together, they would settle down through the liquid magma and density would become a controlling factor. But in the case of the Dore Lake Complex, bytownite was the first mineral to crystallize. The liquid left between the plagioclase grains at the bottom of the mass had the composition required to give pyroxene and ilmenite. There was less than 3 per cent of this liquid at the base but the quantity increased upward in the complex until it formed 50 per cent of the rock mass by volume and gave rise to the anorthositic gabbro member. The pyroxene is now metamorphosed to chlorite and the original ilmenite to leucoxene. The withdrawal of the calcium, silicon, aluminum, sodium, and other elements entering the anorthosite left the remaining liquid relatively enriched in iron, titanium, and magnesium. When the proper conditions of pressure, temperature, and concentrations occurred, the mafic silicates and the magnetite and ilmenite crystallized giving rise to the magnetite-rich pyroxenite. The texture of this rock (Fig. 45 and 46) indicates that the silicate grains were crystallizing in a matrix of magnetite and ilmenite. During the cooling, the titanium with the magnetite exsolved to form ilmenite laths inside magnetite grains. The excess titanium which was not taken up in the magnetite structure gave individual grains of ilmenite.

Textural evidence, paragenesis, and laboratory studies on silicate melts, show that the position of the magnetite-rich layers in the Dore Lake Complex, as well as in other layered complexes, is controlled by the crystallization history and the differentiation of the magma rather than by the density of the different minerals crystallizing out of the magma.

Inadequacy of transformation of sediments as the origin of the  
Dore Lake Complex

The idea of transforming sediments into rocks which some people ascribe to magmatic origin goes back to the beginning of the 19th century when European geologists described granitization in the Pyrenees. Granitization became a subject of much discussion, and a proven fact in many instances. More recently, rocks like anorthosite, gabbro, and other members of basic complexes have also been ascribed to metasomatism of sediments.

Ramberg (1952, p. 161) says:

"It is interesting to note that the so-called charnockite-anorthosite series of plutonic rocks belongs to the granulite facies. The explanation lies in the conclusion that these plutonic rocks are not igneous but are created through metamorphism and metasomatism under P-T conditions corresponding to the granulite facies".

Barth (1952, p.229), on the same subject, said:

"Perhaps anorthosite exhibits a similar mode of origin, thus confronting us with the problem of metasomatic anorthositization of batholithic dimensions".

One of the classical examples of Layered Complexes is the Bushveld Complex of South Africa. It is also one that has been studied in great detail. Recently, S. Van Biljon (1949) wrote a lengthy paper where he attempts to shuffle chemical analyses until he can show that anorthosites are derived by the transformation of calcareous cherts. The same process is applied to magnetite-rich bands and he concludes that

"the genetic relationship which has been suggested by field and microscopic work is therefore proved by chemical data and the magnetites in the Main Zone of the Bushveld Complex must be considered to have originated by metasomatic replacement of limestone bands on different horizons by iron-bearing solutions. This fact is crucial for it

disproves the supposed origin of the magnetites by the differentiation hypothesis".

As mentioned earlier, the Dore Lake Complex differs from other Complexes, the Bushveld Complex included, by having a much larger thickness of anorthosite and anorthositic gabbro in proportion to the other rock members. To transform a sediment into anorthosite, as shown in Table 7, a large quantity of material must be added and subtracted. Granitization of an arkose is relatively a simple chemical operation but the making of anorthosite is a problem requiring large volume of exchanged material.

As seen from the analyses of average sediments and anorthosite (Table 7), the latter has a much higher content of alumina, calcium (except for a limestone which is deficient in many other elements) and a lower content of potash. Anorthositization of a thin interband of sediment due to liquid and solid diffusion may be possible but the Dore Lake anorthosite layer is approximately 10,000 feet thick and 34 miles long. This would require mass migration of enormous amounts of material for which we have no evidence.

Moreover, the original plagioclase within the Complex was progressively more albitic upward in the succession from bytownite at the base to oligoclase or albite in the granophyre. Why would the anorthositing solutions or the chemical composition of the original sediment be such as to produce this cryptic differentiation? In the metagabbro and magnetite-rich metapyroxenite, why would the rock show the perfect layering, excellent foliation, and the interlocking of grains from one band to the other? No chilled facies was observed as yet in the mapping of the Dore Lake Complex, but they were in other Complexes, especially in the Bushveld

TABLE 7

	-1-	-2-	-3-	-4-	-5-	-6-	-7-
SiO <sub>2</sub>	58.10	78.33	5.19	57.95	48.90	47.48	53.15
TiO <sub>2</sub>	0.65	0.25	0.06	0.57	tr	tr	0.00
Al <sub>2</sub> O <sub>3</sub>	15.40	4.77	0.81	13.39	30.00	32.34	23.25
Fe <sub>2</sub> O <sub>3</sub>	4.02	1.07	0.54	3.47	0.50	0.70	0.95
FeO	2.45	0.30	—	2.08	1.30	0.38	2.15
H <sub>2</sub> O	2.44	1.16	7.89	2.65	0.55	0.38	0.85
CaO	3.11	5.50	42.57	5.89	16.90	16.00	11.15
Na <sub>2</sub> O	1.30	0.45	0.05	1.13	1.95	1.92	4.35
K <sub>2</sub> O	3.24	1.31	0.33	2.86	0.15	0.43	1.95
H <sub>2</sub> O	5.00	1.63	0.77	3.23	0.10	0.23	2.50
P <sub>2</sub> O <sub>5</sub>	0.17	0.08	0.04	0.13	tr	0.20	0.10
CO <sub>2</sub>	2.63	5.03	41.54	5.38	tr	0.04	tr
SO <sub>3</sub>	0.64	0.07	0.05	0.54	—	—	—
BaO	0.05	0.05	—	—	—	—	—
C	0.08	—	—	00.66	—	—	—

- 1- Average shale (Pettijohn, F.J., Sedimentary Rocks, Harper 1949)
- 2- Average sandstone (same, p. 82)
- 3- Average limestone (same, p. 82)
- 4- Average sediment (same, p. 82)
- 5- Anorthosite from Driekop, Lydenburg District. (Hall, A.L. 1932)  
Contains 96% plagioclase (An<sub>63</sub>) and 4% bronzite. Sp.gr.: 2.79
- 6- Anorthosite from Vlakfontein No. 902, Rustenburg District. (Hall, A.L. 1932)  
Contains 98% plagioclase (An<sub>80</sub>) and 2% bronzite. Sp.gr.: 2.728
- 7- Anorthosite from the immediate vicinity of the principal magnetite horizon in the main zone below Magnet Heights. (Hall, A.L. 1932)  
Contains 94% plagioclase (An<sub>59</sub>) and 6% bronzite. Sp.gr.: 2.79

Complex. A chilled contact, and a baking of adjacent rocks has been too frequently observed in diabase dykes, sills, fresh flows, etc, to be denied even by the most ardent transformationists.

While it may be possible to derive anorthosite from sediments in local exceptional cases, the author supports the view that the Dore Lake Complex is a plutonic layered complex produced by differentiation of a gabbroic magma.

#### METAMORPHISM

The description of the different rock types in the chapter on Petrography shows that the whole area under study has been metamorphosed to the greenschist facies. The basalt and andesite flows have been changed to metabasalt and metaandesite. The differentiated sills between those flows have also been changed to the same degree as the flows. The members of the Dore Lake Complex have been thoroughly metamorphosed or left intact depending on the original composition and the geographical location. Some layers of the Complex have produced practically unique rock types through metamorphism: metaanorthosite and pure zoisite have rarely been reported.

The flows and sills were composed chiefly of plagioclase, (labradorite in flows, and more calcic in the bottom of some differentiated sills) and pyroxene, with ore minerals and other rare accessories. This assemblage has been changed to albite, chlorite, and/or actinolite, epidote and/or clinzoisite, calcite, magnetite, sphene and leucoxene. Commonly the texture has been perfectly

preserved, even in the finest of details (Fig. 15). For example, the ophitic texture in the lower gabbroic part of a sill is well preserved (Fig. 23) in spite of the total mineralogical change during metamorphism. The same is true of the granophyric portion of the sills between the flows although the quartz has not been recrystallized during metamorphism.

In the flows, the typical intergranular (or interstitial) texture is well preserved, even if there is some extension of actinolite needles into the albite laths. Many amoeba-shaped patches of chlorite probably preserve original small vesicles originally filled with chlorophaeite. Where chlorite is the only mafic mineral present, there is little infringement of the chlorite into the albite laths.

The scoriaceous and fragmental tops are perfectly preserved even in minute microscopic details. This in spite of metamorphism and folding which has tilted the flows from an original near-horizontal position to the vertical.

The relation of folding to metamorphism is not entirely clear. The presence in many flows of elongated vertical chlorite swears is best explained if we assume the chlorite to have been present before the folding or at least before the end stages of the folding. The chlorite swears may be pseudomorphs of original pyroxene (or olivine) phenocrysts or of chlorophaeite patches. From studies of recent flows, the chlorophaeite is relatively short-lived and decomposes to chlorite and nontronite. If these chlorite swears are derived from chlorophaeite, it is possible that they are pre-metamorphism. If they were original phenocrysts, they are linked

with the metamorphism but they are not necessarily pre-folding. They could have been formed before the last stage of folding.

The major transformation took place at constant volume (complete preservation of texture) and at near-constant composition. The major change is an addition of water. Pyroxene and labradorite contain no water in their composition, while chlorite contains around 13 per cent of water and zoisite or epidote nearly 2 per cent. Table 1 (modal analyses) shows a variation between 1.8 and 36 per cent for the chlorite content. When the whole rock is recalculated into chemical composition, this gives between 1.9 and 4.4 per cent of water by weight.

The provenance and role of this water is important. There are a few bands of tuff at flow contacts or especially at the bottom of the whole series. The Lac Sauvage fault zone could have been part of a tuffaceous horizon. But this small volume of tuffs (and possible sediments) could hardly provide enough water for the metamorphism of a thickness of 5 miles of flows and sills.

The Dore Lake Complex has also been subjected to metamorphism within the greenschist facies. In the anorthosite, bytownite was converted to albite plus zoisite or clinozoisite. The pyroxene (or olivine) was changed into chlorite and the ilmenite into leucosene. Thin sections studies indicate an equivolume change.

In the metagabbro and metapyroxenite, the pyroxene has been converted to amphibole and the plagioclase has been saussuritized. All these changes require addition of water, but only minor rearrangement of the other constituents. The introduction of water

is controlled by availability, water pressure, grain size, porosity of the rock, pressure and temperature of the rock mass, and the presence of hydrous minerals in the original rock.

Laboratory studies so far have dealt with high temperature and pressure but very little is known about metamorphic reactions which are thought to occur around 200° C. Yoder (1952) has shown that chlorite and sericite (actinolitic hornblende can perhaps also be included) will form over a wide range of physical conditions.

#### Epidote and quartz veins

In the metabasalts, numerous veins of epidote and quartz (they vary from pure quartz to pure epidote) fill tension fractures. Whether they are hydrothermal veins or are segregations due to diffusion during metamorphism is difficult to establish but the recalculated analyses (Table 1) when compared to analyses of fresh basalts, suggest some diffusion of silica, calcium, alumina and iron out of the rock to make the quartz and epidote veins. Some of the recalculated analyses are undoubtedly in error due to the difficulty in making a good modal analysis on this type of rock, and also in selecting the proper chemical composition for each mineral which enters into the mode. But the fact that the majority of the metabasalts are too low in both silica and lime suggests a metamorphic origin for the numerous quartz and epidote veins.

#### Chlorite vs amphibole

In the metabasalts, some flows have abundant actinolite (Table 1), others abundant chlorite, and others have both. In the Dore Lake

Complex, the mafic mineral in metaanorthosite is chlorite but in the metagabbro, sometimes only inches or feet away, the original pyroxene is pseudomorphed by actinolitic hornblends.

In both cases, the solution to the problem would require better rock exposures, a large number of thin sections, and many more modal analyses and chemical analyses than were available for this study.

In the metabasalts, the spatial relations do not help in solving the problem. Actinolite appears to be more common in the metabasalt at the base of the series than in the metaandesite to the north, but this statement is based on too few observations, and should be checked with more detailed petrographic work.

The modal analyses (Table 1) of Specimen 53-292, 53-293, 54-30, and 54-72, show abundant actinolite in the rock but no calcite. On the other hand, 53-52 and 54-249 contain no actinolite but calcite. There are exceptions to this relation which could be easily be explained since carbonate is a common mineral along the shear zones. The carbonate permeates the wall rock of the shears, however, and has no connection with actinolite or chlorite. It is a hydrothermal product and is not a breakdown mineral due to metamorphism. As far as the metamorphic calcite is concerned, the connection between actinolite and calcite is easily explained by the presence of calcium in actinolite and its absence in chlorite. Some calcium is released by the change from pyroxene to either actinolite or chlorite and if abundant water is present (normally accompanied of carbon dioxide) chlorite and calcite may form. If water is present in minor quantities, the calcium is taken up in actinolite and epidote.

In the metagabbro sills of the Keewatin-type series, the pyroxene at the base and in the center of the sills has been changed to actinolite, but the original hornblende and/or biotite from the quartz-rich differentiates have been changed to chlorite. This difference could be explained by the chemical difference between the original minerals: pyroxene contains less iron and alumina, substances needed for chlorite but not for actinolite.

The contrast between the metamorphism of mafic minerals in the anorthosite and gabbro of the Dore Lake Complex is best explained by the porosity, grain size, and availability of water, in each rock type. The anorthosite (Fig. 30) is very coarse-grained, and has a high porosity while the gabbro (Fig. 47) is finer and more even-grained. In the anorthosite, the interstices between plagioclase grains can transmit circulating waters. In the gabbro, the rock is tighter and less water can reach the pyroxene resulting in conversion of the pyroxene into actinolitic hornblende.

#### Diffusion

Modern literature contains numerous references to solid diffusion, fluid diffusion, ionic diffusion, migration of material under one form or another. The ardent granitizationists will transform mountains of sediments into granitic rocks by one of these types of diffusion. Since the rocks described above have all suffered radical mineralogical changes, the question of diffusion should be raised. How much material has been added or lost during metamorphism?

From field and microscopic evidence, the author believes there

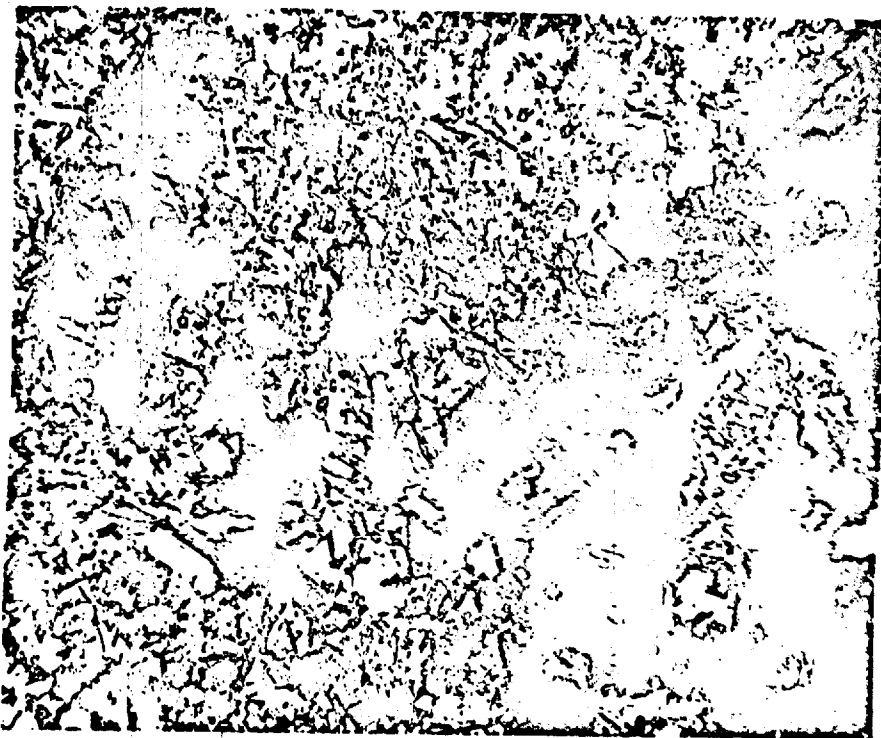


Fig. 57 Granophyre. The large quartz grains (clear) partly enclose laths of sericitized and chloritized plagioclase. Matrix of chlorite and opaque minerals. (10.2 x)



Fig. 58 Gabbroic metaanorthosite with large euhedral grains of plagioclase. They are converted to clinozoisite (Z) in the center, and to epidote (E) around the edges where the plagioclase was in contact with the pyroxene (now chlorite) (C). Shows the limited distance of diffusion. (14.4 x)

has been almost no migration of material during metamorphism. In the metabasalts, as mentioned earlier, the constituents making up the quartz and epidote veins may have migrated through the rock to the nearest dilational openings. But these veinlets are small and closely spaced; migration has probably not exceeded a few tens of feet, and has produced almost no change in the bulk chemical composition of large rock masses.

The pseudomorphing of labradorite by albite, and pyroxene by actinolite, and the excellent preservation of textures indicate a breakdown of original minerals in situ with very little migration of material.

In the Dore Lake Complex, the same remarks apply. One thin section of gabbroic anorthosite shows the very limited extent of diffusion (Fig. 58). Large grains of bytownite or labradorite were in contact with pyroxene. The core of the plagioclase grains has been changed to clinzoisite but on the outside of the grains, where the plagioclase is in contact with pyroxene, a small quantity of iron has migrated from the pyroxene and epidote was formed instead of clinzoisite. This is good evidence of diffusion, but diffusion over only a few millimetres. The same is true of the large titaniferous magnetite grains where the ilmenite blades have been converted to sphene (Fig. 39 and 40) or leucoxene and the magnetite to chlorite. This double change requires diffusion to the ilmenite of some calcium and removal of some iron, and in magnetite removal of iron and introduction of silica, alumina, magnesia and water. The magnetite grains are always found in the chlorite interstices

and the introduced components enumerated above may come from the change of the pyroxene into chlorite. Diffusion may thus have taken place over only a few millimetres. The water and carbon dioxide necessary to all the metamorphic changes are the only components which have travelled considerable distances. The veinlets of albite, (Fig. 27 and 33) which are present in nearly all specimens of anorthosite, metaanorthosite, and metagabbro may have been introduced with the intrusion of the granitic batholith, may be linked with the saussuritization of the original bytownite, or with the hydrothermal solutions responsible for the formation of the orebodies. The fact that most veinlets cut through the rock irrespective of original grains suggest that the rock was shattered during folding. But the albite in the cracks is often limited to the places where the veinlets are cutting original plagioclase grains. Where the veinlets are cutting across mafic patches, chlorite takes the place of albite. This suggests that the crack filling may be linked with metamorphism and that the material filling the cracks has moved only slight distances by diffusion.

One thin section (Fig. 59 and 60) shows interesting metamorphic effects. The original rock was an anorthosite with a sandstone-like texture. The bytownite grains were completely saussuritized. Carbon dioxide-bearing waters permeated the whole rock traveling especially at grain boundaries. Some calcium was taken from the zoisite and calcite peds were formed. This left a narrow rim of albite around the grains. Where a larger interstice was present, a larger patch of calcite was formed clearing the zoisite from the albite over a larger area. The albite grain next to the calcite



Fig. 59 Meta-northosite with very heavily saussuritized plagioclase grains. Note the development of a very narrow rim of clear albite around many grains, and limited to grain boundaries. Note also the veinlets of clear albite going through the whole rock. This clearing of the albite at the grain boundaries is probably due to hydrous carbon-dioxide-bearing solutions traveling along grain boundaries and taking some of the calcium out of the clinzoisite, leaving albite. ( 8.8 x )



Fig. 60 Same as above, but detailed. Shows an interstice where calcite (C) has formed, and a larger area of albite (A) has cleared itself of the clinzoisite. ( 24 x )

is clear of inclusions but the twinning lamellae can be traced inside and throughout the zoisite-rich areas.

Cause and temperature of metamorphism

Students of metamorphism have suggested increase in pressure and/or temperature to explain the metamorphism of rocks over considerable areas. Recently, Yoder (1952) put forward the idea of different metamorphic facies produced at one temperature level because of variations in water content of the rocks. Difference in original chemical composition also strongly affect the metamorphic products.

The source of heat and water required for metamorphism is not clearly evident. Heat could be given off by crystallizing magma. The end stage residual liquids given off by granitic magma could also provide some of the water necessary for the metamorphism of adjacent rocks. Whether the Chibougamau Lake batholith could have given off enough water to metamorphose the Dore Lake Complex is a difficult question to answer. The amount of water present in the initial and final stages of a granite magma is still an unknown factor in our calculations.

The temperature necessary for "low-grade" metamorphism has not been established with certainty. Billings put the chlorite zone between 150°C and 250°C. Rosenqvist's (1952) diagrams indicate a temperature below 200°C for the greenschist facies. If the heat was due to a granitic magma, a temperature gradient should be observed. It is difficult to compare the metamorphism of anorthosite with other rock types which have been

used by Eskola, Turner, and others in classifying metamorphic rocks. The blocks of anorthosite found in the granitic rocks at the edge of the batholith are metamorphosed to a fine-grained rock made up of a mosaic of clear crystals of zoisite (Fig. 37). This differs from the metamorphism of the anorthosite further north where it is metamorphosed to a mixture of albite and clinzoisite or zoisite. Our knowledge of the epidote group of minerals is too limited to establish the pressure-temperature significance of zoisite. The mixture albite-clinzoisite is a normal low-grade product for biotomite undergoing metamorphism, but a complete change to zoisite with the texture shown on Fig. 37 may be the equivalent of medium- or even high-grade metamorphism. This difference could be explained by the temperature gradient necessarily present at the contact of the anorthosite and the granitic rocks of the Chibougamau Lake batholith. The foliation and banding in the David Lake area are steeper than in the Dore Lake area and the anorthosite is heavily zoisitized. There is a possibility that heat generated during folding could produce a thermal gradient similar to the gradient postulated at the granite contact.

Radioactive decay is another source of nonmagmatic heat. James (1955) calculated that with a granite having ten times the radioactivity of the average granite, a vertical cylinder extending to the level of the present surface would have to be 20 km in diameter to produce the necessary thermal gradient. The Chibougamau Lake granite has a very low radioactivity as shown by aerial scintillometer surveys. These geologically reasonable combination

of dimensions and radioactivity rule out the possibility of radioactive decay as the ultimate source of heat for the metamorphism.

This leaves three sources, all of which could have been operative concurrently or alone: heat from subjacent bodies of magma, geothermal heat of deep burial, and frictional heat generated during folding.

The source of water is difficult to determine. The volcanic flows and associated tuffs could contain abundant original water. Pillow lavas extruded in lakes and rivers could trap a great deal of water. But a mass like the Dore Lake Complex contained very little water originally. Some granites are remarkable by the large number of pegmatites present in their vicinity. The author has never seen any pegmatites in the area around the Chibougamau Lake batholith. On the other hand, there are numerous ore zones and large shear zones where the original rock has been changed to a sericite-chlorite and chloritoid schist. The volume of water necessary to convert the anorthosite and gabbro into a sericite-chlorite schist is very great. There is a possible connection between the hydrothermal solutions which gave rise to ore zones, the wall rock alteration, and the metamorphism. They could have a common origin but the period during which each process was operative must have been long. If metamorphism and hydrothermal alteration were closely connected, one would expect the metamorphism to vary with the proximity to ore zones. This was never observed.

If we assume that this area is part of a sizable geosyncline which was deformed in Precambrian time, the water could be derived

from sediments which have never been observed as such but could be present at greater depth or could have been metamorphosed to granulites or granitized with simultaneous expulsion of metamorphic water.

#### CHLORITOID-BEARING ZONES

In the summer of 1952, the author found a dark green mineral along the siderite vein found on Copper Cliff Consolidated Mining Corporation property. On the basis of its external characteristics, the mineral was tentatively called chloritoid. It was the first time this mineral had been reported from Chibougamau. Mapping of the southeast quarter of McKenzie township showed that chloritoid is abundant and is present in most shear zones.

Chloritoid was named by G. Rose in 1837 (Dana, 5th edit., p. 509) from material at Kosobrod in the Ural Mountains. It was subsequently found in many localities throughout the world. The mineral is commonly found in diagenetically metamorphosed sediments, but its exact meaning with respect to the facies principle is still ill defined. Barker thought that chloritoid was a stress mineral. Turner and Verhoogen (1951, p. 468) mention that

"there is an important group of aluminous schists, relatively low in  $K_2O$ , in which chloritoid appears, giving rise to the second pelitic assemblage".

Rasberg (1952, p. 146) includes chloritoid in the mineral assemblages of the greenschist facies.

Chloritoid has been reported as a hydrothermal alteration product along ore zones but is rather uncommon. It is found at

Malcoerlie, Australia (Simpson 1951) (Frider 1947), Porcupine, Ontario (Gustafson 1946), North Carolina (Stuckey 1926) as well as at Chibougamau. It occurs in veins either around ore deposits or in the associated low-grade metamorphic rocks. In the area mapped by the author, chloritoid occurs in shear zones in metanorthosite, metagabbro, transition rock, and metabasalts. A number of these shear zones are copper-bearing (chalcopyrite) and mining is progressing on five of these zones. Plate 1 shows the distribution and extent of the chloritoid-bearing zones. During the present investigation, 22 thin sections were studied and thousands of feet of diamond drill core were logged.

The field identification of chloritoid was confirmed by petrographic work and X-Ray studies. The X-Ray determinations were checked by V. Hurst (personal communication) who compared it with Dutchess County specimens and by L. Halferdahl. Halferdahl reports that the Chibougamau chloritoid is near the iron end-member containing less than one per cent MgO and half a per cent of MnO. The following analysis of the Chibougamau chloritoid was reported by Halferdahl (personal communication):

SiO <sub>2</sub>	24.30	CaO	0.09
TiO <sub>2</sub>	0.18	K <sub>2</sub> O	0.01
Al <sub>2</sub> O <sub>3</sub>	39.92	K <sub>2</sub> O	0.06
Fe <sub>2</sub> O <sub>3</sub>	1.80	H <sub>2</sub> O+	6.86
FeO	25.63	H <sub>2</sub> O-	0.07
MnO	0.41	F	0.05
MgO	0.77	less O:F	0.02
			<hr/> 100.13
			<hr/> 100.13

### Distribution

Chloritoid in the shear zones occurs with siderite, ankerite, chlorite, sericite, and quartz. Typical localities are the small island at the mouth of a bay in the southwest corner of Gilman Lake, and along the shear zone at the southeast corner of Gilman Lake. Diamond drill holes on the north shore of Little Gilman Lake (drilling southward) provided excellent specimens of chloritoid in the metabasalt along the walls of the Lac Sauvage fault and in the fault zone itself.

Some of the best specimens of chloritoid come from the footwall of the siderite-chalcopyrite vein on the Siderite Hill showing of Copper Cliff Consolidated Mining Corporation and from both walls of the Jaculet ore zone and the Mashin Point zone where shaft sinking is in progress. The latter occurrences are in metaorthosite and in transition rock between metaorthosite and metagabbro. Chloritoid is also present in the dykes along these shear zones.

The Lac Sauvage fault zone is chloritoid-bearing throughout the map-area. Whether the chloritoid should be regarded as a product of regional metamorphism or hydrothermal alteration along the fault zone is not entirely clear. The main minerals found along this fault zone are carbonate (siderite and/or ankerite), chloritoid, chlorite, quartz, minor sericite. Little ore has been found along this zone although it appears to be a controlling structure for many known ore zones. From field evidence, there is a possibility that this fault took place along a tuffaceous horizon,

and that therefore not all the material found in the zone was introduced hydrothermally.

Petrography

The chloritoid in the Chibougamau area occurs as rosettes (sheafs of twinned individuals) (Fig. 63) or as individual prisms. The mineral is dark green to black and is easy to differentiate from chlorite because it is much harder, has good cleavage, and different optical properties.

The pleochroic formula is

Z: pale yellow to green yellow

X: dark to medium green

Y: bluish to pale green

The high dispersion and index of refraction make optical work difficult. The index of refraction was determined but more measurements should be made in order to get a better average.

$N_x$ : 1.724 and  $N_y$ : 1.729

These properties correspond to those obtained by Milne, Simpson, Harth and Balk, and Stuckey.

Different analysts have reported varying results for the chemical composition of chloritoid, the variations being likely dependent upon the amount of inclusions so often found in this mineral. It is possible that there is a family of chloritoid minerals with Fe, Mg, and Mn end-members. This would explain why ottrelite, sissondine, salinite, masonite, and other names have been proposed for minerals very closely alike in their chemical composition. In any case, the majority of the analyses indicate

TABLE 8

MODAL ANALYSES OF CHLORITOID-BEARING ROCKS

Specimen number	53-73	53-102	53-120	C35-145	54-2	54-166
Carbonate	48.6	--	2.2	61.2	--	--
Chloritoid	28.2	69.2	19	17	27	30.5
Quartz	18.2	27.5	76.3	17.2	.7	66.2
Muscovite	--	--	2	2.3	61	.2
Opaque	--	2.6	2.2	2.2	1.7	3.1
Leucoxene	5	--	--	--	--	--
Chlorite	--	.6	--	--	9.6	--
Number of points	1507	1739	1753	1545	2765	1506
Specific gr.	2.99	--	--	3.3	--	--

**53-73:** typical metasomatized greenstone dyke along the ore zones. The original intergranular texture of the rock can be seen best with reflected light. Specimen at the top of figure 61.

**53-102:** dark green rock on the north side of the siderite vein at the Siderite Hill showing of Copper Cliff Cons. Min. Corporation.

**53-120:** well banded rock, drag folded, in the shear zone going across Little Gilman Lake, about 1000 feet east of the lake shore.

**C35-145:** mixture of siderite and chloritoid on the north wall of the siderite vein. Contains very little chalcopyrite.

**54-2:** muscovite schist on the south wall of the Siderite Hill showing. Specimen at the bottom of figure 61, and photomicrograph of figure 63.

**54-166:** banded quartz-chloritoid rock in a replaced shear zone on Nachin Point. Slightly contorted. Figure 68.

that the mineral formula  $\text{FeO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2 \cdot \text{H}_2\text{O}$  is a very close approximation.

The following mineral assemblages have been recorded along with the chloritoid in the study of thin and polished sections:

carbonate (siderite and/or ankerite)—quartz—opaque

carbonate (siderite and/or ankerite)—chalcopyrite or pyrite

quartz—opaque

quartz—sericite—carbonate—opaque (bleucoxene)

quartz—sericite—opaque

quartz—chlorite—opaque—sericite

pyrite

The most common assemblage is quartz—carbonate—sericite. Quartz may predominate over carbonate or vice versa. The extreme types (Table 8) occur less frequently: nothing but quartz and chloritoid in a drag folded shear zone replacement at Machin Point (Spec. 53-102); massive siderite and chloritoid at the Siderite Hill showing (Spec. C-35, 145); practically nothing but muscovite and chloritoid along the same ore zone (Spec. 54-2) and chloritoid and pyrite exclusively along the pyrite ore zone, south of the Lac Sauvage fault zone, and south of Little Gilman Lake.

Chloritoid varies in size from an average of .3 mm to prisms 3 mm long and .5 mm wide. The size varies with the host rock and this is shown in Fig. 61 where samples are pictured side by side. In the muscovite schists (Dr H. Yoder identified this white mica as 2M muscovite from an X-Ray Diffractometer pattern) chloritoid attains its maximum dimensions. In the replaced greenstone dykes along the ore zones (the dyke was a basalt originally but is now

carbonate-quartz-chloritoid-leucocoxene) chloritoid is evenly distributed throughout the rock and averages .4  $\mu$ m (Fig. 61a). The difference may be due to the fact that the dyke rock, in spite of complete replacement, is still very massive whereas the muscovite schist is permeable and permits ingress of solutions and easy growth of the chloritoid.

The habit of chloritoid varies from single grains (Fig. 62) to radiating crystals or sheafs (Fig. 63). It is noticeable that the 4 thin sections (33-73-105-16a) from rocks positively identified as dykes showed only disseminated individual grains. On the other hand, all the specimens from sheared well banded rocks show alternating bands of nearly pure chloritoid and bands containing carbonate-quartz-sericite (Fig. 64, 65, and 66). In these, the chloritoid always occurs as sheafs of crystals with a fan shape, constricted at the center, and fanning out at the ends. In places, perfect radial rosettes were observed. In these, the chloritoid does not show the typical hourglass structure, and polysynthetic twinning is very well developed. The difference in the morphology of chloritoid between the different rock types cannot be explained from the evidence at hand. There is a suggestion that the physical nature of the rock (hardness, brittleness, compactness, original grain size, ingress of solutions, availability of solutions) has much to do with these differences in morphology.

In the well banded rocks, the minerals reflect the intense penetrative deformation suffered by the rock: small quartz grains (average of .02  $\mu$ m) are lency, well strained, with good mosaic texture,

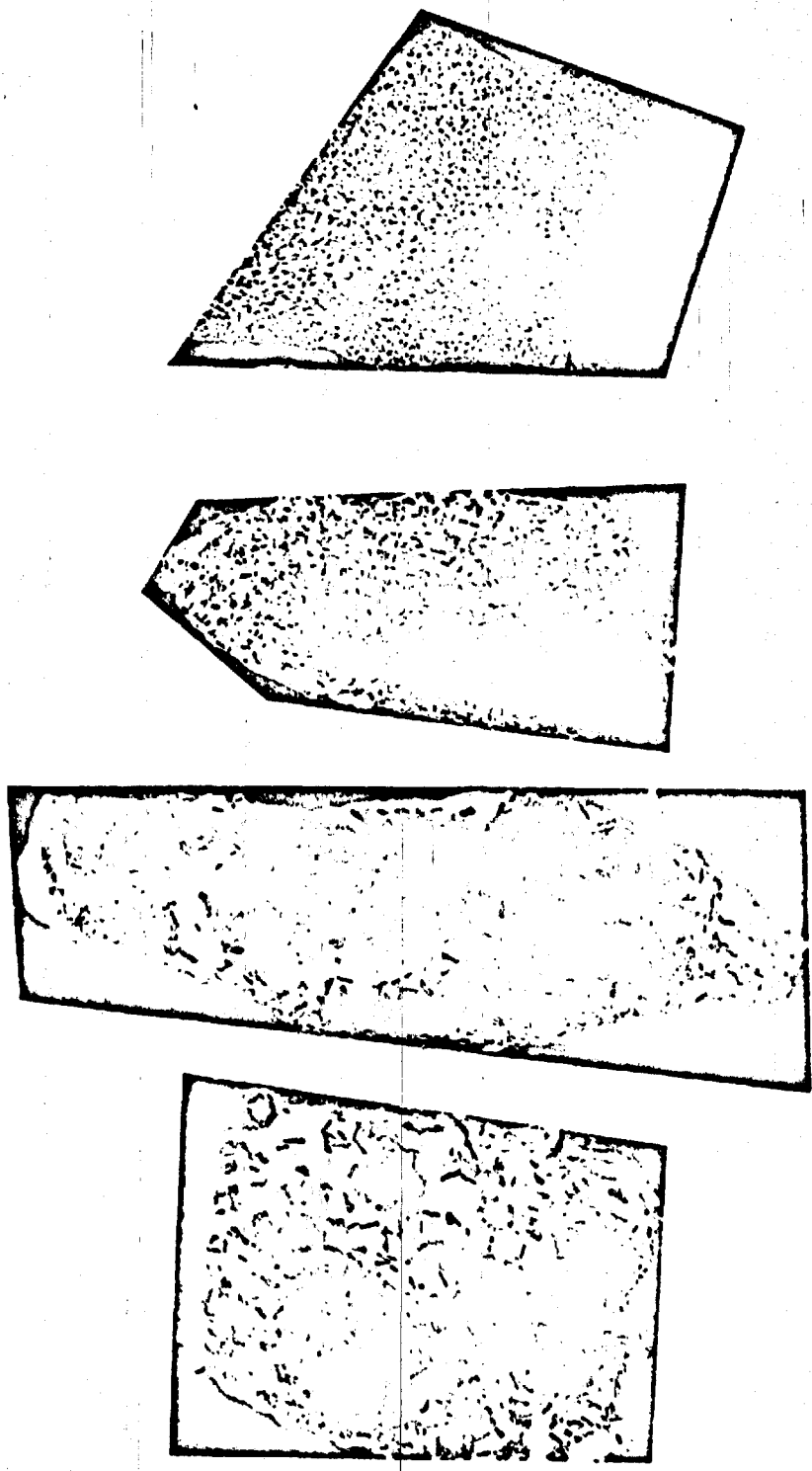


Fig. 61

Chloritoid-bearing rocks showing different grain size of the chloritoid depending on the type of host rock.

- a) very fine-grained in a replaced greenstone dyke
- b) sericite schist from the replacement of anorthosite
- c) same as b) but stronger shearing
- d) same as b) but extremely sheared. Contains almost nothing but muscovite (2:1 variety) and the grains of chloritoid seen on the photograph.

All natural scale

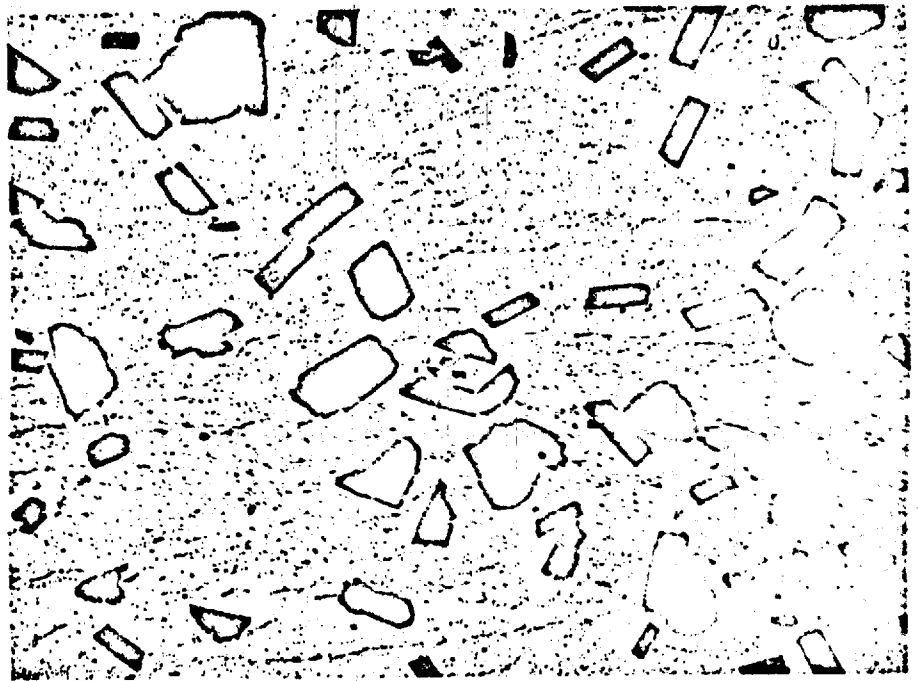


Fig. 62 Chloritoid porphyroblasts in a sericite schist. Note the schistosity going through the chloritoid in the form of small inclusions. The hourglass structure common in chloritoid is well developed. ( 9.7 x )



Fig. 63 Chloritoid in a muscovite schist. Compare the sheaf-habit of the chloritoid in this rock with the individual grains of fig. 62. Also note the lack of inclusions giving the hourglass structure and the good twinning. The vein across the photograph is chlorite and quartz. ( 8.5 x )



Fig. 64 Chloritoid porphyroblasts in muscovite schist. The muscovite abuts in the sides of the chloritoid crystals, but the direction of schistosity is preserved in the chloritoid because of small elongated quartz grains, and other inclusions. ( 16 x )



Fig. 65 Well banded rock, from a shear zone replacement. Rock is made up of alternating bands of chloritoid and bands of sericite and carbonate. The opaque streaks along the schistosity planes are made up of leucoxene derived from ilmenite. ( 6.8 x )

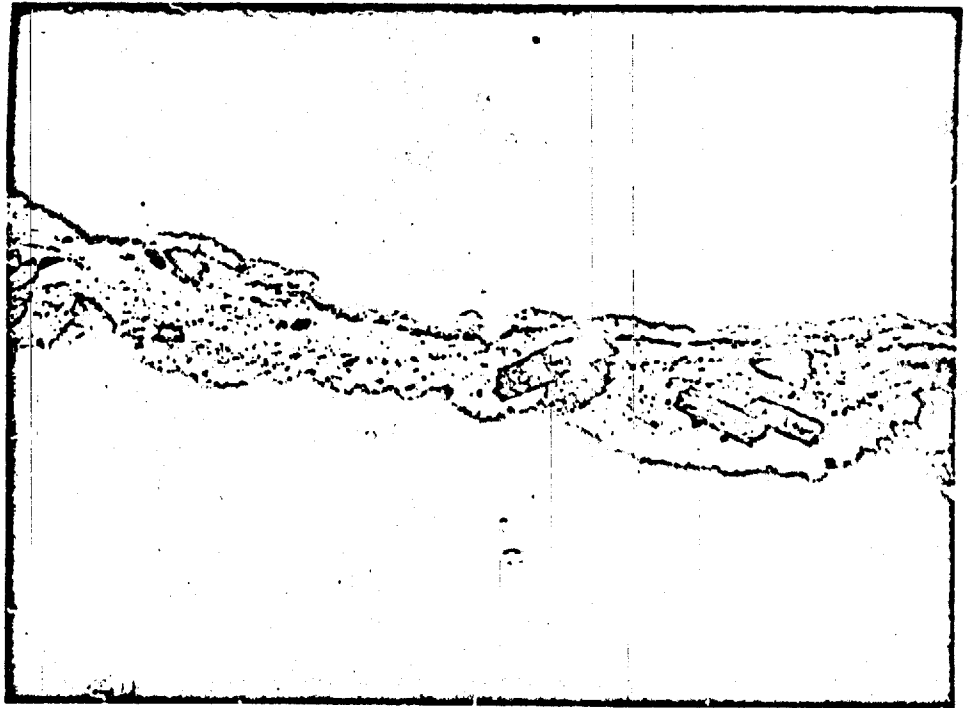


Fig. 67 Chloritoid in a vein. The host rock is a massive fine-grained siderite, speckled with pyrite and other opaque minerals. The vein is made up of muscovite, chloritoid, chalcopyrite, and quartz (9.8 x)

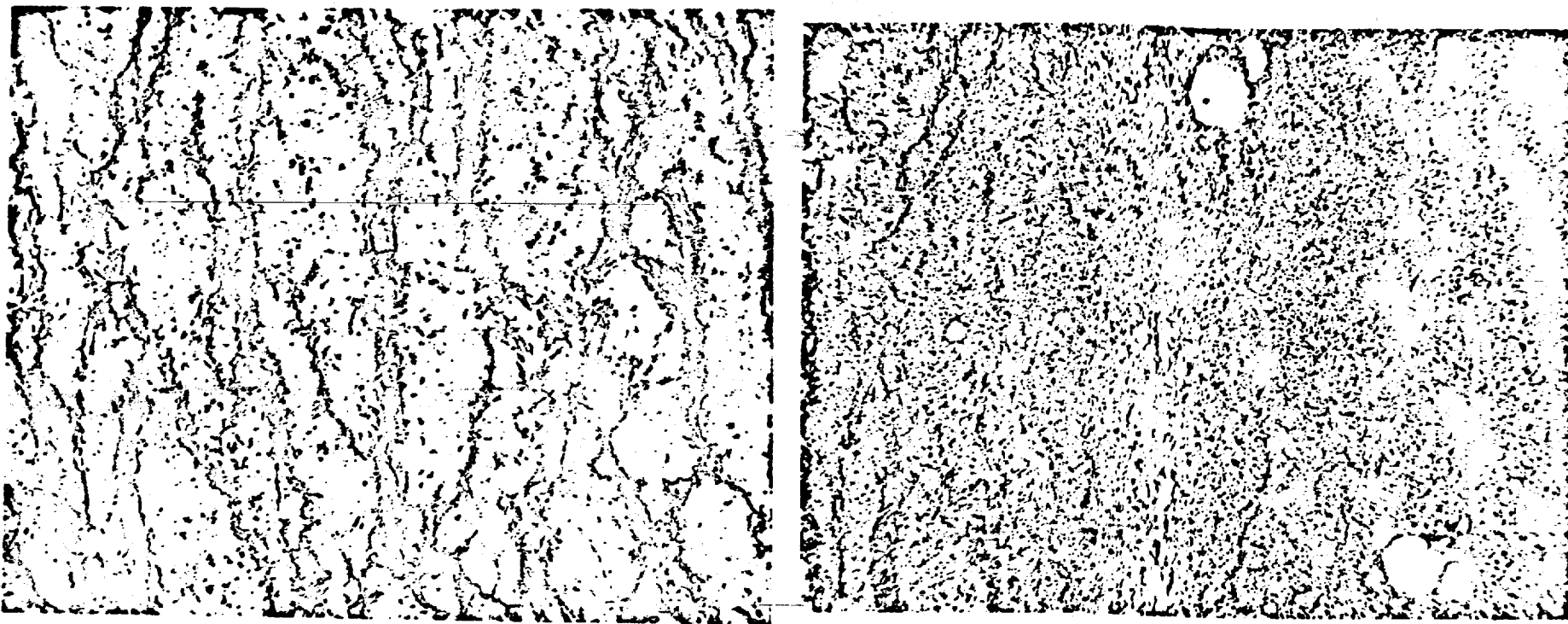


Fig. 62 Thin section (natural light on the left and crossed nicol on the right) of a banded rock made up of layers of chloritoid and layers of very fine quartz. The right side photograph shows the very fine-grained size of this hydrothermal quartz. This rock is a shear zone replacement from Machin Point. (5.5.x)

their long axes parallel to the long axes of the carbonate grains and the long direction of the muscovite flakes. The quartz, however, shows no granulation or mortar structure around the edge of the grains. Some larger grains, up to 1 mm in diameter, are seldom encountered and show intense strain effects, and cracking, the cracks being filled by carbonate, sericite, and fine-grained quartz of a younger generation. This fine-grained quartz grew after most of the shearing took place, but before the final phase of the deformation. These features combine to give a schistose look to the rock when examined in thin section, although the hand specimen is commonly very massive. Sometimes, a strong foliated structure is brought out by the alternation of bands rich in chloritoid and chloritoid-free layers (Fig. 65, 66, and 68). In thin section, the chloritoid shows no preferred orientation. The chloritoid porphyroblasts preserve the opaque and sometimes the elongated quartz grains as helicitic inclusions parallel to the foliation (Fig. 64 and 65). The chloritoid is not broken and shows no sign of deformation. This indicates that it grew after the final phase of deformation in a static medium, and could not absorb all of the quartz and opaque in the original sheared rock. On the other hand, muscovite abuts into the sides of the chloritoid crystals and is not preserved as inclusions. This implies that it has been taken up by the chloritoid during growth: the change from muscovite to chloritoid involves a loss of 21 per cent silica, 11.8 per cent  $H_2O$ , and a gain of 28 per cent  $Fe_2O_3$  and 2.5 per cent water. The gain of water and iron is easily explained by the association of chloritoid with hydrothermal solutions which give rise

to so much siderite, ankerite, pyrite, and chalcocite. The loss of  $K_2O$  is more difficult to explain since no other mineral in the rock will take up  $K_2O$ . This excess  $K_2O$  does not appear to be fixed anywhere in the rock and one is forced to conclude that it escaped from the rock following growth of the chloritoid. The size of the potassium ion makes solid diffusion through the rock unlikely, but it could easily be removed by water vapor since steam easily extracts alkalis from rocks (Morey and Coranson, 1937). In a few sections, narrow veinlets filled with carbonate cut the chloritoid-rich bands and indicate that solutions were present after the growth of chloritoid.

In some rocks, the muscovite is wrinkled on a very minute scale. Some of the chloritoid is clear (Fig. 63) and 95 per cent free of inclusions, but locally the chloritoid has hardly started to develop and it is still so full of inclusions (Fig. 65), especially carbonate, that it is hard to identify.

#### Dyke rocks rich in chloritoid

The dyke (Modal analysis of No 53-73, Table 8) and specimen at the top of figure 61 ) was considered to be intrusive in the field mapping because of its sharp contacts. Moreover, the close relationship between ore and dyke rocks is thought to be more than coincidence and will be discussed in the chapter on structure, under the heading Structure and relation to ore deposition. This dyke rock was examined in a number of outcrops and drill holes, but is so altered to a mixture of fine-grained chloritoid, carbonate, and quartz that its original nature could not be established.

There are four different types of dyke rock in the area:

feldspar porphyry, quartz-feldspar porphyry, "grey dykes" (actinolite ?) and greenstone dykes. At the end of the summer 1954, the author logged drill hole no C 27 and at a depth of 432 feet found that this extremely altered rock, which was assumed to be a dyke, imperceptibly graded into a relatively fresh greenstone dyke, somewhat carbonatized and with sparse chloritoid grains, but still positively identifiable as a greenstone dyke. This is the chilled contact of the dyke

One thin section (No. 53-73) showed a faint intergranular texture with plagioclase laths completely replaced by a mosaic of fine quartz and minor carbonate and the remainder of the rock replaced by carbonate. The original ilmenite is outlined as tiny leucoxene clusters disseminated throughout the rock.

#### Chloritoid and carbonate

As a general statement, one could assert that more than 90 per cent of all the chloritoid in the Chibougamau area is associated with an iron carbonate, either ankerite or siderite. In cases where it is associated with muscovite, quartz, or pyrite there is carbonate in the same zone, or in the immediate vicinity. In places, this carbonate was identified as siderite. In others, this determination is not so definite because a mixture of siderite and very fine quartz can look very much like ankerite. Siderite, on weathering, produces a deep brownish red weathered surface while ankerite gives a light yellowish brown color to the surface. This field observation was verified by partial analyses done by the Quebec Department of Mines Laboratories. But, as mentioned earlier, a fine

mixture of quartz and siderite may give a weathered surface much like ankerite.

#### Hydrothermal origin

The hydrothermal origin of the chloritoid is evident from the mineralogical assemblages, the spatial relations to shear zones and ore-bearing zones, and the fact that it is found in shear zones cutting such diverse rocks as metabasalts, metagabbros, metaorthosites, and in the altered dykes found along these shear zones. The constant association with shear zones marked by extensive penetrative deformation, metasomatism, and hydrothermal alteration, and by an iron carbonate filling, are features which have to be considered in order to get an idea of the nature of the ore solutions and the conditions leading to the formation of chloritoid.

In other localities, the presence of iron-rich minerals is also indicated. At Porcupine, Ontario, Gustafson (1946) mentions that

"sheared Keewatin lava flows ranging from albite dacite to albite andesite underlie the mine area... The microscope reveals a rock composed of 50 per cent or more of ankerite".

In the Deep River Region of North Carolina, Stuckey found chloritoid in the footwall of the orebody (pyrophyllite). An iron breccia makes the footwall of the orebody, and Stuckey (1926) says:

"some of the coarse acid breccia contains considerable iron in the form of grains of hematite and magnetite and has been called an iron breccia".

In Kalgoorlie, Australia, the situation is similar to Porcupine in that ankeritization is common in the volcanics.

In the Chibougamau area, the ore solutions must have been rich in Fe, Al, K, CO<sub>2</sub>, and SiO<sub>2</sub> as evidenced by the abundant

development of chloritoid, muscovite, siderite, and quartz. The ratio S / CO<sub>2</sub> / Fe must be the critical factor which determines the mineralogy of the sulphides. At Campbell Chibougamau Mines, to the south, chloritoid is present only at one or two places. The main sulphide is pyrrhotite. In the area mapped by the author, there is little pyrite and no pyrrhotite and the main sulphide is chalcopyrite. The main alteration mineral is chloritoid. The iron which went into pyrrhotite and pyrite in the Campbell orezone formed chloritoid and an iron carbonate in the Copper Cliff and New Royran orezones. There was more sulfur present at Campbell but by forming pyrrhotite and pyrite there was less sulfur left to make chalcopyrite and the ratio pyrite or pyrrhotite to chalcopyrite is less at Copper Cliff and New Royran although the ore can be economically as good.

The paragenesis of any one ore zone cannot be accurately determined because the specimens collected and studied cover a large area, and there is no certainty that two ore zones with similar mineralogy have developed at the same time. Chloritoid appears to be one of the latest mineral to form in these zones, though a few specimens show narrow veinlets of quartz and carbonate cutting the chloritoid. There could be two ages of chloritoid, but it could not be proven during this limited study. An approximation of the sequence of events at the Siderite Hill showing, perhaps typical of other zones also, would be as follows:

- fracturing
- introduction of dykes, in swarms, with southeast strike
- fracturing, shearing of the areas between the dykes

hydrothermal alteration producing sericitization, chloritization, and some carbonatization of the metaorthosite and actinogabbro

shearing

very intense development of sericite along the main shears

major period of carbonatization, silicification, and possible development of some chloritoid

sulfides: pyrite first, followed by chalcopyrite. Some chloritization with the ore.

fracturing

abundant development of chloritoid

fracturing, very minor

very minor silicification and carbonatization

#### Chloritoid, stress mineral ?

The influence of stress on the formation of certain minerals has led to many arguments and discussions.

Marker, studying minerals formed by dynamothermal and thermal metamorphism put forward the idea that each process gives rise to characteristic minerals. He called stress minerals those formed in crystalline schists and included chloritoid amongst the stress minerals (Marker, 1932, p. 150):

"some may be said of other distinctly stress minerals, such as chloritoid, ottrelite, and staurolite".

Turner (1948, p. 30) said:

"The number of minerals belonging to the first category (stress minerals) is very limited, chloritoid and possibly kyanite being the only common examples".

The necessity of stresses for the formation of chloritoid was discussed and rejected by Eskola (1934). A recent study by J. Michot (1955) included a complete review of the literature on

examples of chloritoid occurrences where stress was not operative. He also added his own studies made on the genesis of chloritoid along a quartz vein in phyllites. The Chibougamau occurrence should be added to the list of examples mentioned by Michot.

Gustafson (1946) believes that the sericitization and ankeritization took place after the rock had been sheared and laminated under the influence of directed stresses. Chloritoid grew after these minerals. In the same areas, veins of quartz and ankerite contain chloritoid. This is another case where chloritoid-bearing veins and hydrothermally produced chloritoid are present.

Frider (1947), however, thought that in Kalgoolie the chloritoid was formed after the period of hydrothermal action. The latter has prepared the environment making it chemically suitable for the formation of chloritoid which developed under the influence of stresses.

The writer prefers Gustafson's version for the reasons given before. Moreover, Frider gives examples of isolated crystals of chloritoid in a dolerite strongly altered but containing undeformed sericitized plagioclase. This is very similar to the chloritoid-bearing altered greenstone dykes described in the Chibougamau area.

Michot's conclusions (1955, p. 46) are identical to the writer's although they are derived from the study of a completely different area. He said:

"Toutes ces occurrences, jointes à celle que nous avons étudiée dans le premier chapitre, démontrent à suffisance que le chloritoïde, tant manganésif que ferreux, est un minéral, pour la genèse duquel les forces tectoniques ne sont pas intervenues.

Le chloritoïde peut être engendré en milieu purement statique."

STRUCTURAL GEOLOGY

The Chibougamau area is located in the easternmost part of the Superior Province (Fig. 4). The northern portion of the area is underlain by volcanic rocks and ultrabasic sills. They form the south limb of a large syncline whose axis lies 3 miles north of Gilman Lake. The southern portion of the area is underlain by members of the Dore Lake Complex, a thick stratiform complex, arched up by the intrusion of the Chibougamau Lake Complex, made up mostly of granite, diorite, and quartz diorite (Plate 2, 5, and 6).

The attitude of the volcanic rocks was determined by the mapping of flow tops, direction of flow contacts, layers of phenocrysts, amygdaloidal horizons, belts of pillow lavas. The attitude of the Dore Lake Complex was determined by the primary foliation within some members, especially the metagabbro and metapyroxenite members, the layering and contacts between layers of different composition, and the distribution of specific rock types along certain horizons within the Complex.

Faults and shear zones

The area is transected by three sets of shears (Plate 6), two of which are important: one striking northeast, and the other southeast. Both sets may be complementary in origin, but have had different history following their inception. By definition, a fault should have measurable displacement along its course, but in this area, no markers are available which permit identification of the

shear zones as faults with measurable displacements. The major northeast-striking fault zone was called the Lac Sauvage Fault because of the remarkable continuity, intensity of shearing and alteration, and excellent drag folding exposed on the high hill close to the eastern boundary of the map-area. All the shear zones are marked by extensive development of carbonate (ankerite and siderite), quartz, chlorite, chloritoid, and muscovite. An attempt has been made to differentiate between shear zones with different mineralogy on the map (Plate 1), but the division is somewhat arbitrary since the shear zones vary in composition along strike when they go from one type of host rock to another.

#### The Lac Sauvage fault zone

This fault zone derives its name from a small lake west of Little Gilman Lake. Smith mapped this fault in detail for 5 miles and the author mapped it for an additional 5 miles. Horacroft (personal communication) traced it across Portage Island giving it an additional 3 miles and it is known to be present at Williams Lake, 3 miles west of the western limit of Smith's map (1953), giving it a total length of at least 16 miles. It may continue westward much farther. Some shearing had been reported at various places along this fault but it was not recognized as a major structural feature of the Chibougamau district until this detailed mapping. The only mention of the structure made by Hawdaley and Norman (1935) is the following:

"The zone of carbonated and sheared rocks that extends westward for 3 1/2 miles from the northern part of Dere Lake and passes 1/4 mile north of the head of Cedar Bay, forms

an important part of the rock structure near Dore Lake. It may be a zone of faulting, but its relation to other zones of shearing and faulting on Dore Lake is not known".

In the area mapped by the writer, it is a wide zone of shearing marked by extensive development of an iron carbonate and chloritoid. Some sections of it are rich in chlorite, quartz and sericite, but the predominant mineral along the fault is this iron carbonate which gives a deep brownish red color to the weathered surface. Frag folding was observed in 3 or 4 places and always indicates a displacement of the north block to the east with respect to the south block (Plate 1). Since there are no available horizon markers, the true direction and amount of movement cannot be established. In many localities, the rock is massive but extremely well banded, especially where alternate layers of carbonate and chloritoid make up most of the rock.

In the eastern portion of the map-area, this fault zone separates two major bodies of rocks, the Keewatin-type volcanic rocks to the north and the Dore Lake Complex to the south. Further west, the fault splits into two branches: the north branch carries through the volcanics, and the south branch angles to the southwest and is called the "pyrite zone" because of the body of pyrite which was drilled on top of the large hill south of Little Gilman Lake. Pyritization is common along this southern branch of the Lac Sauvage fault. This pyrite zone separates the Keewatin-type volcanics and the Dore Lake Complex. Except for the pyrite body mentioned above, which contains low copper and zinc values, no commercial ore bodies have been found along the Lac Sauvage fault

zone itself.

Bedded tuffs were found in 3 or 4 localities along this branch of the fault (marked T on Plate 1), and there is a strong suggestion that the fault took place along a tuffaceous horizon.

Dore Lake fault (McKenzie Narrows fault zone?)

This controversial structural feature was named after the McKenzie Narrows at the northeast corner of Chibougamu Lake by Hawsley and Norman (1935). In that area, it brings in contact nearly flat-lying (Huronian ?) sediments and steeply-dipping Kewatin-type volcanics. Further south, Hawsley and Norman reports:

"the strike and magnitude of the McKenzie Narrows fault in the northeastern part of the map-area suggest that this fault may extend southwestward across Dore Lake and along the straight, narrow arm of this lake that receives the drainage from Cache Lake. A fault line occurs along the stream bed beside the first portage from Dore to Cache Lake and is in accord with a possible continuation of the McKenzie Narrows fault to this locality. The fault line is indicated by the narrow trench, trending north 30 degrees east, through which the stream descends into Dore Lake, and also by the intense shattering of the rocks along the walls and center of the trench. Abundant evidence of deformation is presented by both shear zones and joints in the rocks around Dore Lake, but their correlation with any system of faulting cannot be made from the information obtained up to the present".

Graham in his report (1951) mentions that he found the fault in the creek which joins Cache Lake with Dore Lake and that it is indicated by drilling east of Merrill Island.

These reports bring the fault to the boundaries of the present map-area, but within the area studied by the writer, the fault is everywhere concealed by the waters of Dore Lake. Indirect evidence points to the presence of a fault joining the two sections mentioned

by Mawdsley and Norman and by Graham. The topography strongly supports the idea of a major shear zone along the axis of Dore Lake: anorthosite is hard and quite resistant to erosion when massive, as evidenced by the group of high hills in the western part of the map-area, north of Dore Lake, and the presence of a major shear zone might be the controlling factor in the development of the actual topography.

One diamond drill hole (hole D-2 of Copper Cliff Consolidated Mining Corporation) drilled from the point of land across Dore Lake from Machin Point intersected a core length of about 175 feet (hole at 45 degrees) of a very heavily sheared chlorite-sericite schist. Without additional drill holes, this shear zone cannot be positively identified as the extension of the McKenzie Narrows fault and the name Dore Lake fault should be applied to the fault which Graham projected along Cache Lake and west of Merrill Island and to the fault indicated in the drilling between Machin Point and the main land to the west. If further work proves this fault to be the continuation of the McKenzie Narrows fault, the name Dore Lake fault should be dropped and the name McKenzie Narrows applied since it has time priority.

#### Southeast-trending shear zones

A set of southeast-trending shear zones is very well developed in the map-area and is important economically since they are the copper-bearing zones. A number of them have been drilled and mining development is progressing along five of these zones within the map-area.

These zones are characterized by intensive shearing, extensive hydrothermal alteration leading to a complete replacement of the host rock by carbonate (siderite mostly), chlorite, chloritoid, sericite, and quartz. Very sparse drag folding indicates that the movement, at least in the last stage of the deformation, took place in a horizontal direction. No horizon markers indicate the extent and direction of the movement. The southeast-trending shears are shorter than the larger northeast-striking fault zones. Dykes are very common in this area, and generally have a southeasterly trend. A great number of them have been introduced along shear zones. The majority of commercial orebodies are found along dykes and their emplacement was structurally controlled by the dykes. The dykes may or may not be sheared themselves and are commonly heavily altered.

The mineralogy of these shear zones depends on the presence or absence of orebodies and hydrothermal alteration, degree of shearing, and chemical composition of the host rock. In the north-south zone, when hydrothermal alteration is at a minimum, the rock is changed to a sericite schist with minor calcite and chlorite. When the shear zone is accompanied by mineralization, the rock becomes quite chloritic. If gabbro or transition rock is the host rock to the shear, chlorite and ankerite with minor sericite are the most common minerals. If mineralization is present, siderite and chloritoid are present. All these are generalizations which suffer exceptions, but which have a wide range of applications and can be useful in prospecting for copper-bearing shear zones.

The third set of shears strikes in a north-northeast direction and is very poorly known. Field mapping does not suggest shearing

in that direction, but recent mining work and drilling has suggested the presence of this set of shears. They may have been important in the control of the mineralization but underground workings will be necessary before they can be assessed properly.

#### Ore deposits and structure

The Chibougamau district is becoming an important copper-producing area. Campbell Chibougamau Mines went in production in June of 1955, and is mining 1750 tons a day averaging close to 3 per cent copper and .10 ounce of gold per ton. At the same time, Copper Cliff Consolidated Mining Corporation and New Royan Copper Mines did extensive exploration work and started shaft sinking on the two properties. They later amalgamated and formed Copper Rand Chibougamau who is contemplating building a 7000 tons per day mill. Quebec Chibougamau Goldfields is shaft sinking and planning to build a 1000 tons per day mill. Douzan Mines is also planning shaft sinking. Campbell Chibougamau Mines is unwatering its Cedar Bay shaft and plans have also been made to sink a shaft on the Lokko Creek ore zone. Recently, Chibougamau Jaculet Mines has found a large tonnage of good grade copper ore in three ore zones. They are planning shaft sinking in the Fall of 1956. All these ore zones are located within the area mapped by the writer (Plate 1).

In all cases, the ore material is a shear zone replacement along a dyke. All the ore-bearing zones have a southeast strike and dip steeper than 45°. The ore replaces a sericite-chlorite schist. Chloritoid is a common alteration mineral and it has been discussed

above. The exact relations of the ore to the N 70 E and to the N 20 E shear zones have not yet been established but the distribution of the ore zones bears a close geographical relation to the Fore Lake fault and to the Lac Sauvage fault zone. Any movement along these faults, after the introduction of hard brittle dykes within the incompetent shear zones, would tend to create dilational openings on each side of the dykes. One side of the dyke may be more favourable for ore deposition because of the damming effect of the dyke on the ore solutions.

Underground work will have to be done before these hypotheses can be verified. However, assumptions along this line of thought have been used in prospecting and exploration for the last three years and have been very successful.

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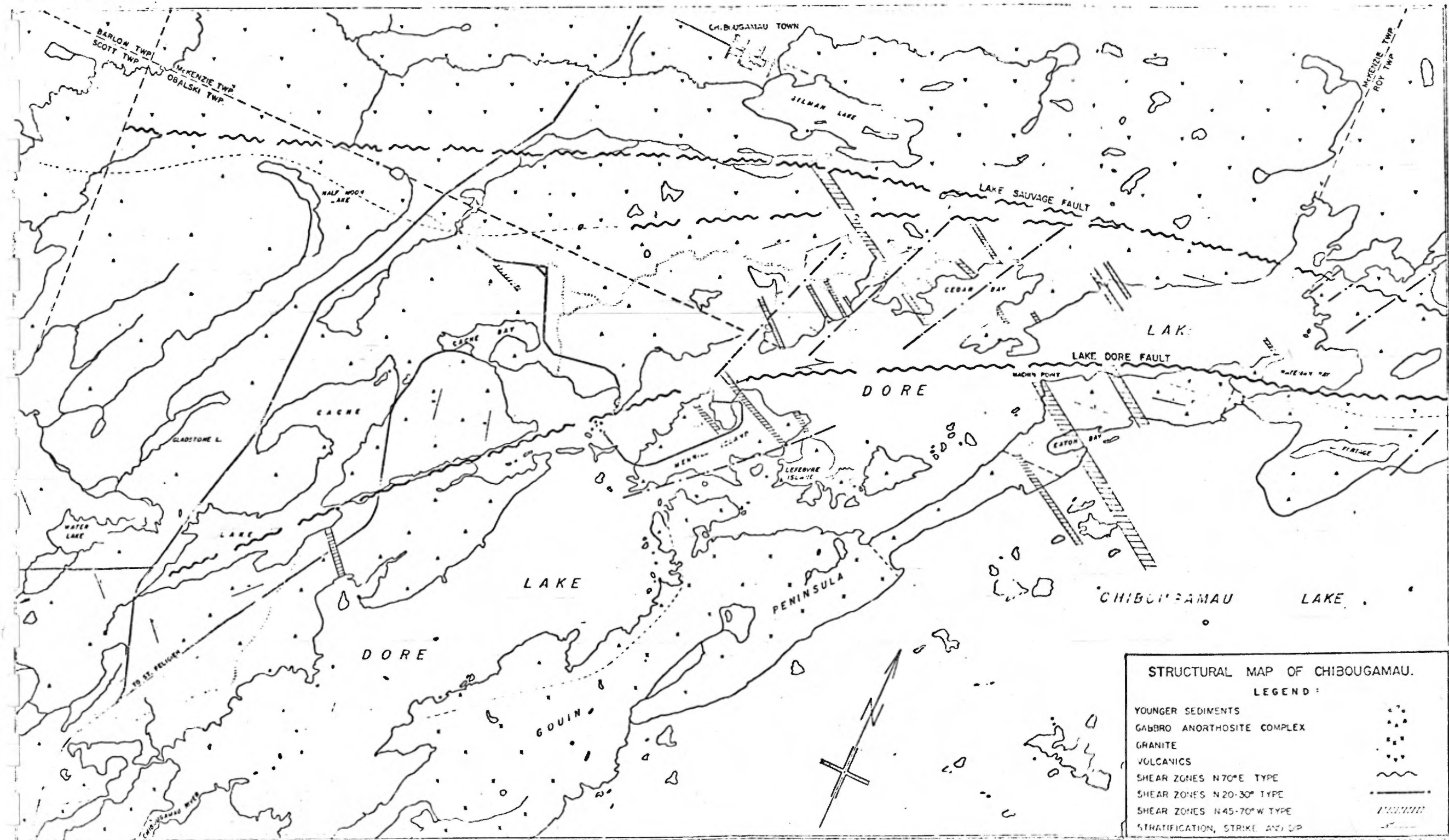
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







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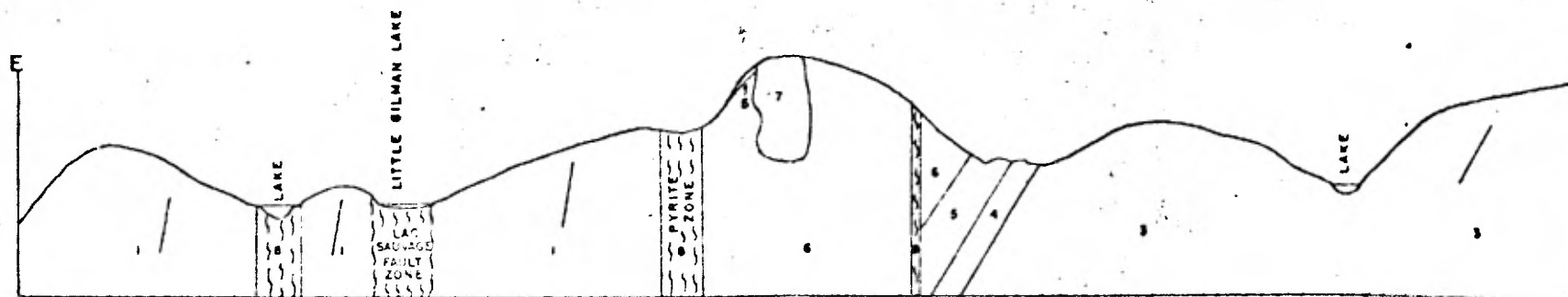
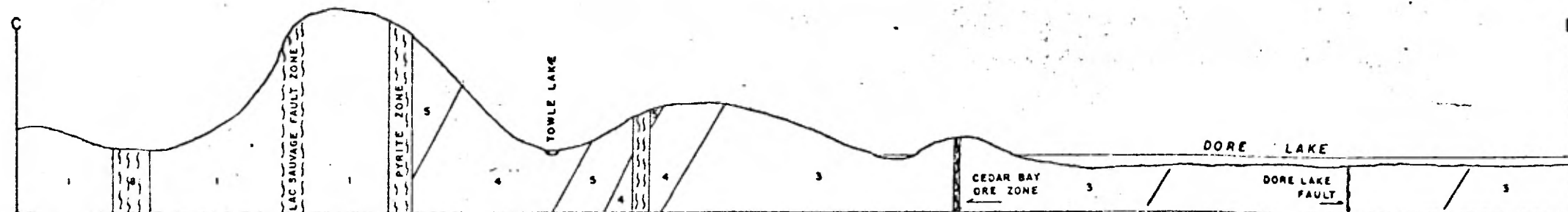
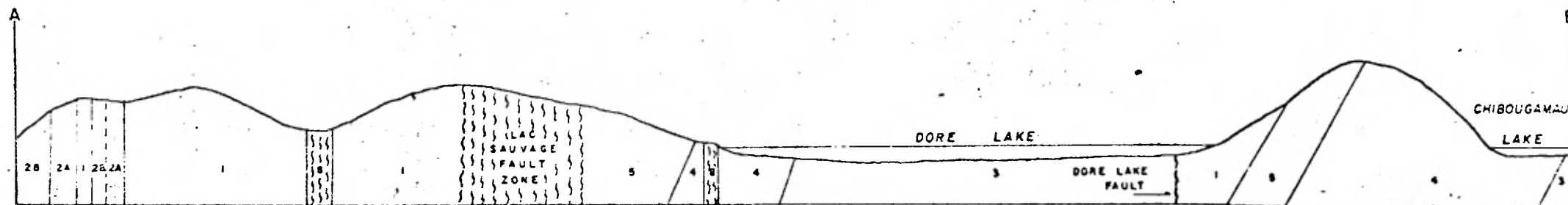


**STRUCTURAL MAP OF CHIBOUGAMAU.**

**LEGEND :**

- YOUNGER SEDIMENTS 
- GABBRO ANORTHOSITE COMPLEX 
- GRANITE 
- VOLCANICS 
- SHEAR ZONES N70°E TYPE 
- SHEAR ZONES N20-30° TYPE 
- SHEAR ZONES N45-70° TYPE 
- STRATIFICATION, STRIKE AND DIP 

SECTIONS LOOKING NORTHEAST  
ACROSS  
THE SOUTHEAST QUARTER OF MCKENZIE TOWNSHIP

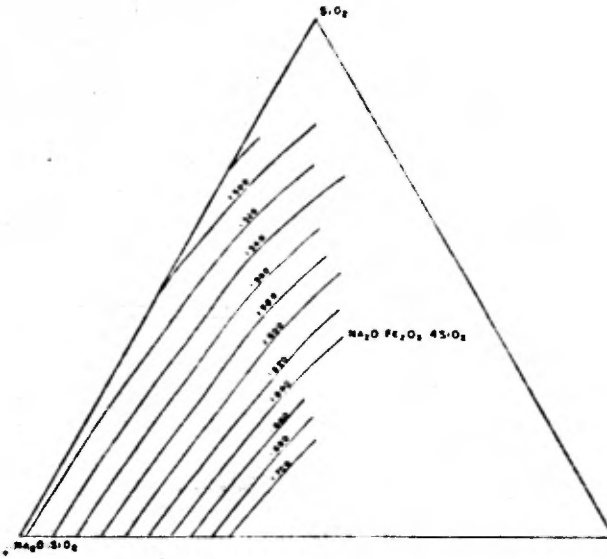


- |    |                           |   |                                    |   |                                |
|----|---------------------------|---|------------------------------------|---|--------------------------------|
| 1  | METABASALT                | 3 | METAANORTHOSITE                    | 6 | GRANOPHYRE                     |
| 2A | MAFIC PART OF SILLS       | 4 | TRANSITION ZONE AND METAPYROXENITE | 7 | QUARTZ FELDSPAR PORPHYRY       |
| 2B | GRANOPHYRIC PART OF SILLS | 5 | METAGABBRO                         | 8 | ZONES OF SHEARING AND FAULTING |

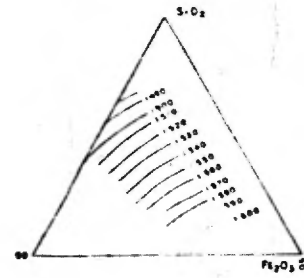
VERTICAL SCALE EXAGGERATED

HORIZONTAL SCALE 1" = 1000'

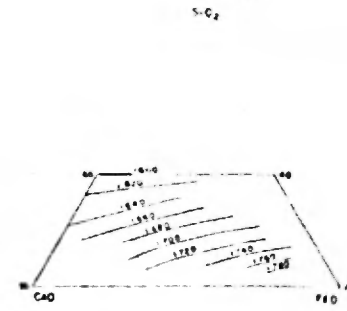
REFRACTIVE INDEX OF ARTIFICIAL GLASSES



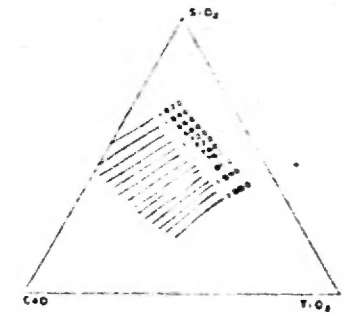
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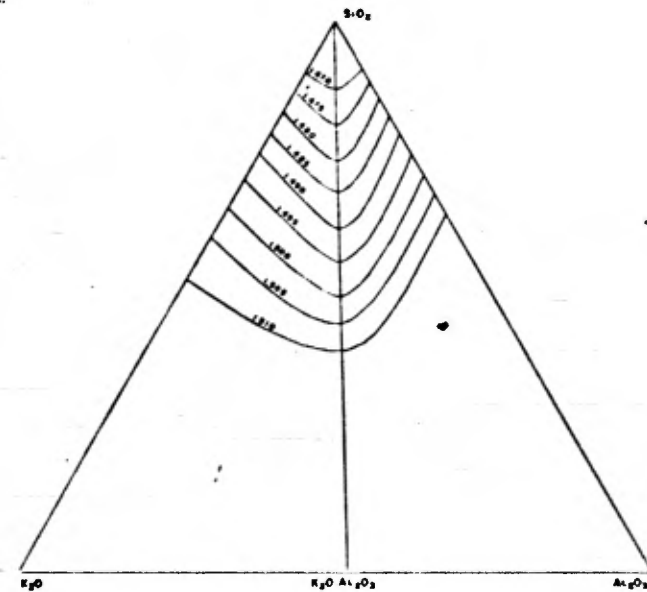
GW MOREY (1954)



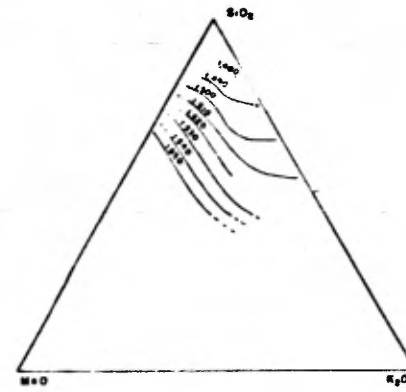
NL BOWEN, JF SHAIRER AND E POSNJAK (1933)



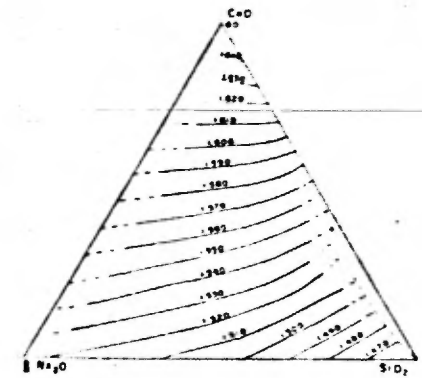
RC DE VRIES ET AL (1955)



JF SHAIRER (1955)



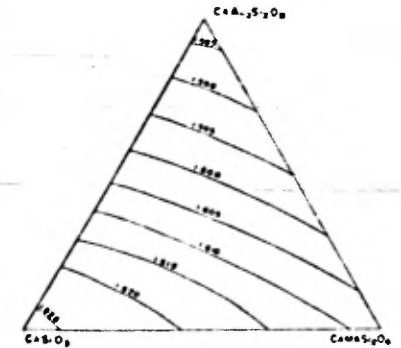
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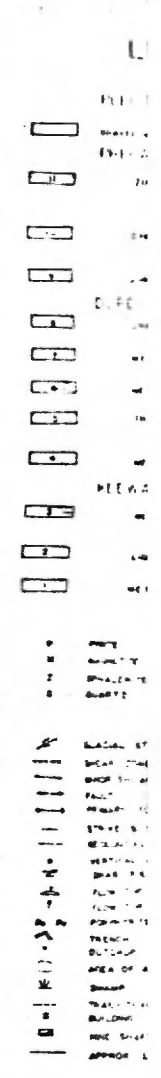
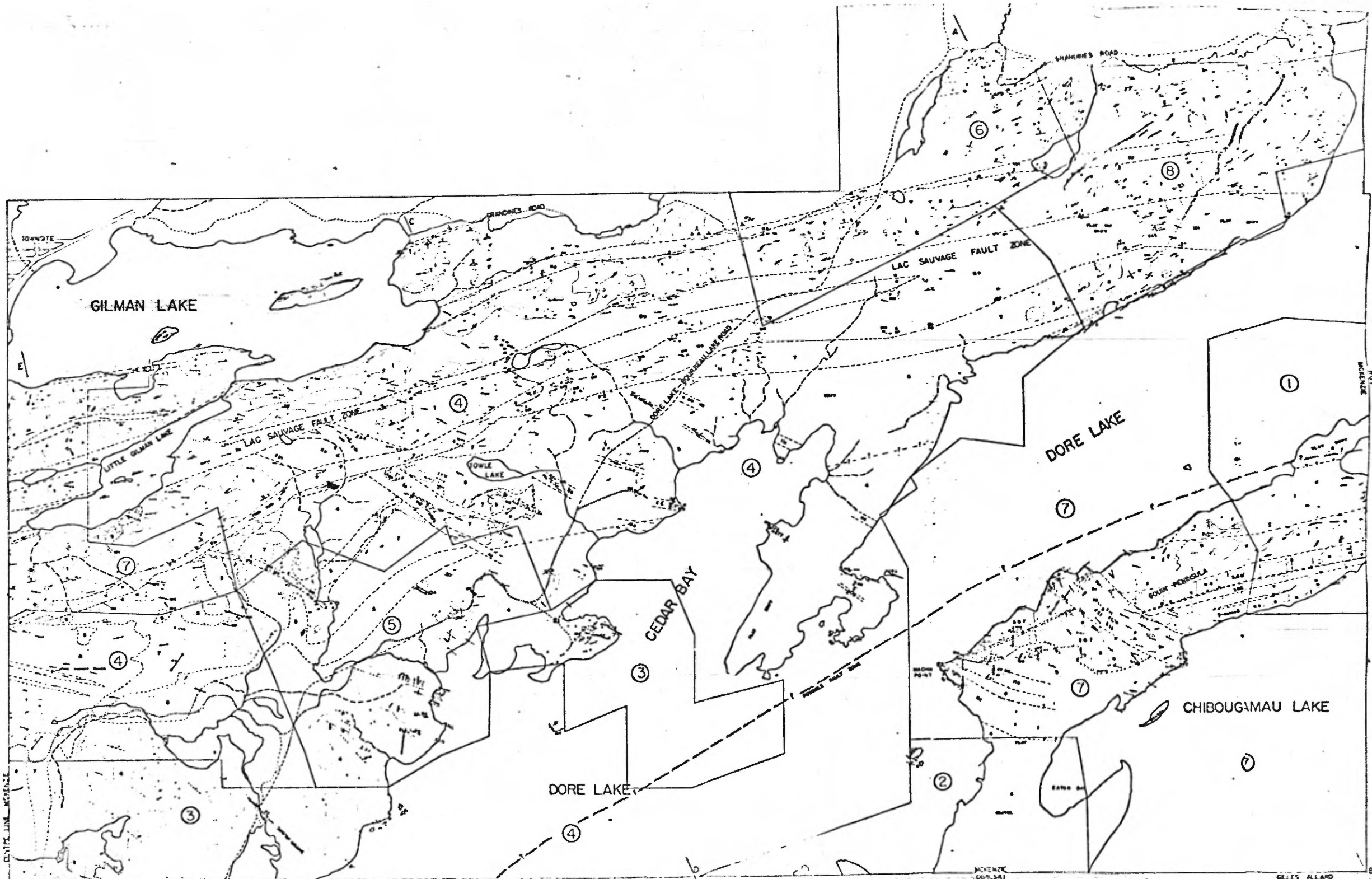
GW MOREY AND HE MERWIN (1932)



JF SHAIRER AND NL BOWEN (1947)



E FOSBORN (1942)



PORTION SOUTHEAST QUARTER M. KENZIE TOWNSHIP