GEOLOGY OF CALUMET MINES LTD

Thesis submitted to the Department of Geological Sciences of McGill University in partial fulfilment of the requirements for the Degree of
Master of Science

By

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INTRODUCTION

Location.

The lead and zinc deposit described in this thesis is at Calumet Island, Pontiac County, Province of Quebec, about fifty-eight miles northwest of Ottawa. The deposit occurs on the southwestern part of the island, on lots 3 to 12, range IV.

The railroad station near the island is Campbell's Bay, on the north shore of the channel, on a branch line of the Canadian Pacific Railway. From this station a four mile motor road runs south to Bryson where a bridge crosses to the island. Campbell's Bay can be reached by a ferry from Calumet Island village.

References.

Data on the zinc production of Calumet Island since 1892 are in the annual reports of the Government of the Province of Quebec and the Geological Survey of Canada. In all, about 1200 tons of ore were shipped from the property, most of it before 1900.

INDEX-MAP

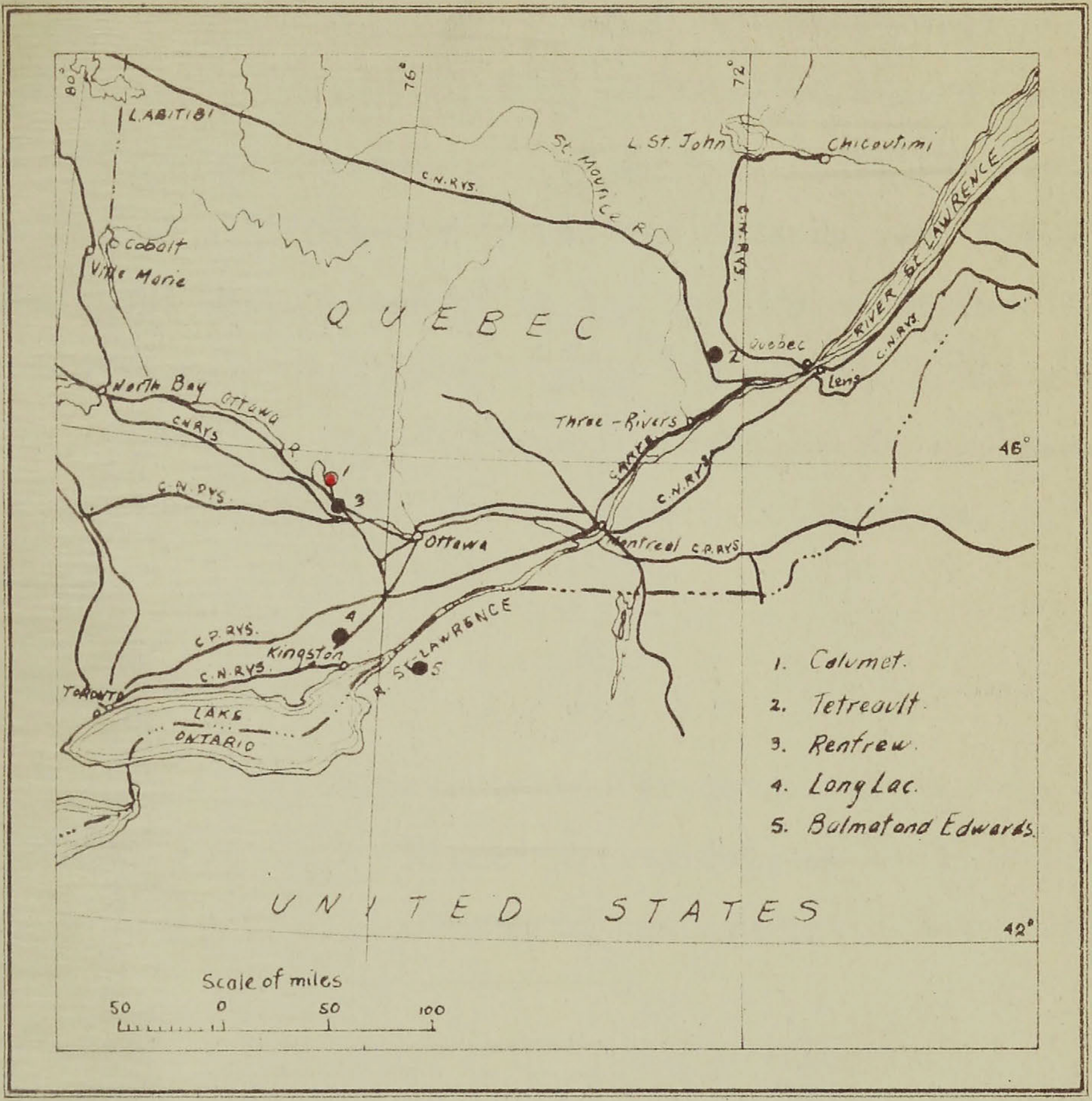

FIGURE I

Index-map showing the location of the Calumet property, and the relative position of the other similar deposits in the Grenville sub-province of Quebec and Ontario in Canada, and of the Adirondacks in United-States.

In 1908, a report in which the occurrence of ore is mentioned was published by R.W. Ells (1) on a large area including Calumet Island. In 1916, W.L. Uglow (2) described the lead and zinc deposit of Calumet Island. In 1925, R.W. Goranson (3) wrote a report on the geology of Calumet Island accompanied by a geological map of the island. During the summer of 1939, F. Fitz Osborne (4) revised the geology of the southern part of the island and made a detailed map of the outcrops.

History of the Deposit.

The property was staked in 1893. In 1897 it was operated by the Grand Calumet Mining Company of Ottawa who shipped to Belgium 1,100 tons of ore averaging 32% zinc and

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(1) Ells R.W., Geology of Portions of Pontiac, Carleton and Renfrew Counties, Geol. Surv. Can., Rept. No. 977.

(2) Uglow W.L., Lead and Zinc Deposits in Ontario and Quebec and in Eastern Canada, Ont. Bureau of Mines, Vol. XXV, pt. 2, pp. 5-7, 1916.

(3) Goranson R.W., Calumet Island, Pontiac County, Geol. Sur. Can., Summ. Rept., 1925 C, pp. 105-124.

(4) Osborne F. Fitz, report under preparation.

9% lead. In 1911, a concentrating mill with a capacity of 150 tons was erected, but it burned soon after. The British Metals Corporation of Canada in 1926 took an option on the property and did some work but soon after let the option lapse. In 1937, the Calumet Mines Limited acquired the property and started a program of diamond drilling under the supervision of Dr. Paul Armstrong. More than two hundred holes were put down with an aggregate length of about 80,000 feet.

Acknowledgements.

The author is indebted to Dr. F.Fitz Osborne of the Department of Geological Sciences, McGill University, for his kind assistance in the preparation of this thesis. Personal communications from Mr. W.W.Moorhouse, graduate student at Columbia University, were highly appreciated.

SOUTHERN PART OF CALUMET ISLAND
PONTIAC COUNTY

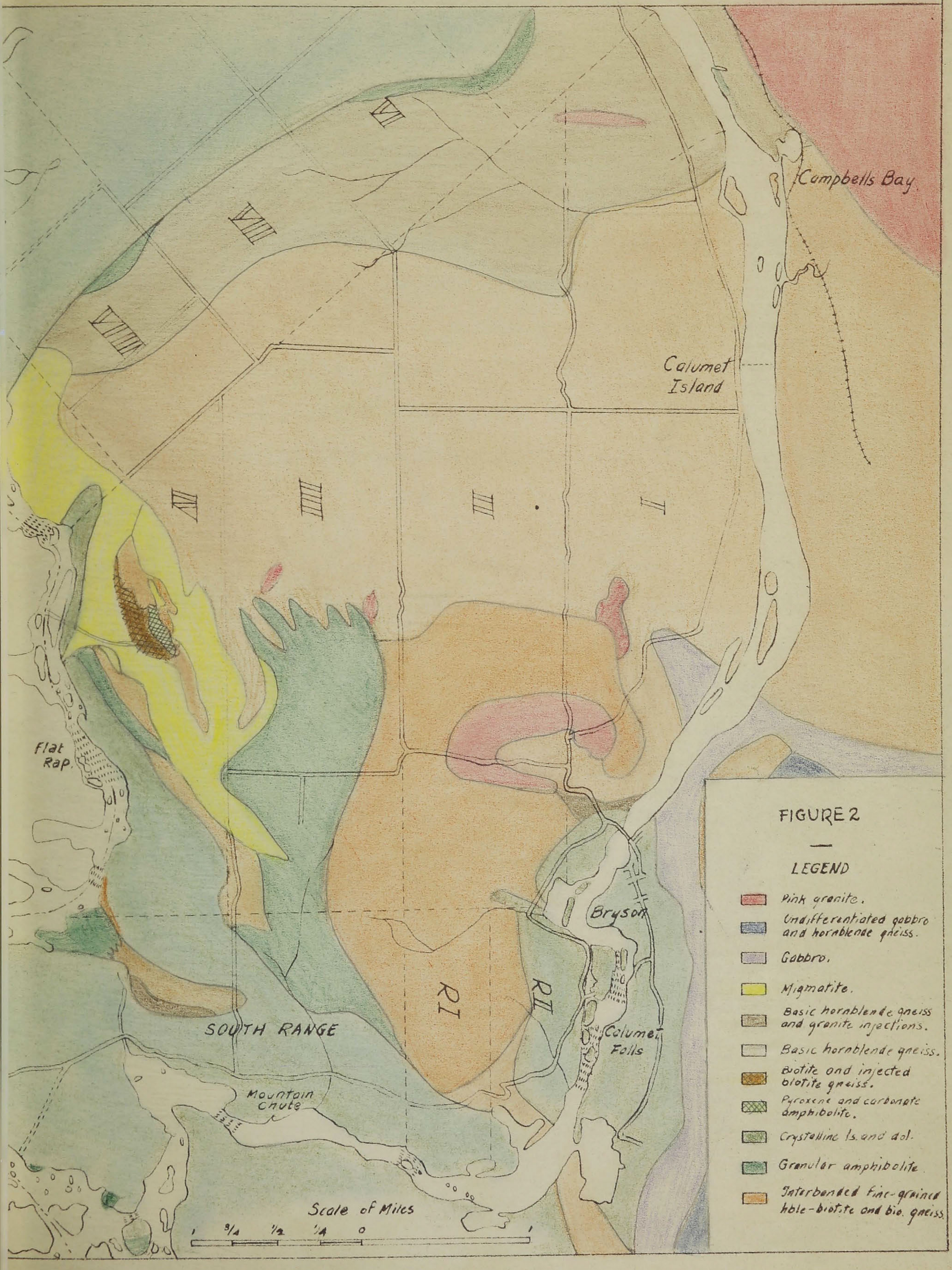

FIGURE 2

PART I

GENERAL GEOLOGY

The southern part of Calumet Island is underlain by rocks of the Grenville series consisting of crystalline limestone, biotite and amphibolite gneisses, and their injected equivalents. These rocks are intruded by Buckingham gabbro and granite of the Morin series. Aplites, pegmatites, lamprophyres and diabase dykes are found occasionally. In the northern part of the island these rocks are covered by Paleozoic limestones.

The geology of the area is quite complex. Of many types of rocks shown on the regional map, it is believed that they were only few originally but, due to metamorphism and injection of grantic material, the rocks have been altered to such an extent in their mineralogical composition, and their structure has been so modified that their original composition and structural relation can be treated only approximately before a detailed mapping of the adjacent area is available.

Osborne considers that the rocks now making the Grenville paragneisses consisted originally of impure argillaceous sedimentary rocks with intercalated limy or magnesian beds passing by gradation into relatively pure limestone with minor clastic zones at the base of the limestone. He assumes that the limestone is at the top of the series referring to a statement by Ells (1) that the limestones are near the top of the Archean, and by correlation with the limestone in the type locality for the Grenville limestone, where it appears to stand higher in the series than the quartzites and the gneisses.

Summary of the Geological History.

Osborne (2) summarizes as follows the geological history:

1. Grenville sedimentation of clastic and impure carbonate beds followed by limestone.
2. Folding and overturning of the Grenville series. Formation of amphibolite and gneisses.
3. Migmatization of the rocks yielding a pseudomorph of the older structure.
4. Migmatization controlled by the east-west shearing tending to obliterate the earlier structure.
5. Injection of Buckingham gabbro.
6. Injection of pink granite with accompanying diopsidation.
7. Injection of aplites and pegmatites.
8. Formation of ore at Calumet Mines property.

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(1) Ells R.W., op. cit.

(2) Osborne F. Fitz., op. cit.

9. Injection of lamprophyre and diabase dykes.
10. Erosion.
11. Deposition of lower Paleozoic rocks (evident on north part of island.)
12. Faulting.
13. Erosion.

Grenville Limestone.

By regional metamorphism, the limestone was recrystallized to a medium- to coarse-grained crystalline limestone. There are thin beds of finer-grained siliceous dolomitic material. Some layers are entirely replaced by silicates consisting of diopside and serpentine, accompanied by others such as tremolite, phlogopite, scapolite, chondrodite and titanite, from impurities in the original sediments and addition of material of magmatic origin. These silicate minerals occur as disseminated grains and pockets and are quite abundant in places, diopside forming sometimes important masses. The original bedding has been practically all destroyed and is now replaced by a well-defined schistosity in general parallel to the contact with the silicates rocks; layering and schistosity may be mistaken for bedding. At or near the contact between the limestone and the gneisses are bands of amphibolites.

Beds containing anhydrite and gypsum were intersected in drilling at the mine. Brucite is a common accessory mineral in the southern part of the island, locally it is sufficiently abundant to be considered as a possible source of magnesia according to Osborne.

Moorhouse noted that serpentine is associated with calcite in the dolomite. This is probably according to the process of de-dolomitization suggested by Adams in the following equation:

$$\underset{\text{(dolomite)}}{CaMg(CO_3)_2} + 2SiO_2 = \underset{\text{(diopside)}}{CaMg(SiO_3)_2} + 2CO_2$$

$$\underset{\text{(diopside)}}{3CaMg(SiO_3)_2} + 3CO_2 + 2H_2O = \underset{\text{(Serpentine)}}{H_4Mg_3Si_2O_9} + \underset{\text{(calcite)}}{3CaCO_3} + 4SiO_2$$

Biotite Gneisses and Granitic Migmatites.

The less calcareous members of the Grenville series yielded the biotite schists and gneisses, hornblende being formed in minor amount; in places however where there was more lime and magnesia in the sediments, the biotite gneisses pass gradually to amphibolites. The micaceous schists were apparently fissile and were easily injected by granitic material, in places accompanied by pyrite and pyrrhotite, and the resulting rocks are now represented by the granitic migmatites and the rusty-weathering gneisses, so called because of their rusty appearance on surface due to the oxidation of iron. Bands of highly granitic migmatites are found below and above the ore shoots.

Amphibolites and Related Hornblende- and Hornblende-Biotite Gneisses.

In the calcareous members of the series containing much lime and magnesia, pyroxene, amphibole, and medium calcic plagioclase were formed in abundance and various types of amphibolites resulted. These rocks were later metamorphozed to basic hornblende- and hornblende-biotite gneisses. The amphibolites show various structures; an important variety is gneissose and contains carbonates. In general, they are massive and resemble diorites in structure and texture. Some were injected to various degrees by the same material that formed the granitic migmatites. In places the layered character of the rock was destroyed and the rock is converted to basic or hornblende migmatite.

In general the amphibolites were not very susceptible to injection, and instead of being replaced like the biotite gneisses they yielded composite gneisses along their contact with other rocks or zones of strong shearing, and lit-par-lit gneisses resulted from the introduction of magmatic material along the foliation.

The amphibolites and related rocks underlie the greater part of the southern half of the island.

Granite.

At the north-east of the map is shown part of a large mass of granite on the mainland. In places it is strongly gneissic and contains inclusions; elsewhere it is pink and porphyritic. On the island, dykes, sills, and small masses of pink granite are quite common. Osborne mentions the case of a narrow dyke of pink granite cutting the gabbro half a mile north of the bridge to Calumet Island, with an alteration zone of 100 feet bounding it and the conversion of the gabbro to a granular diopside rock with veins of quartz and occasional crystals of phlogopite. Sometimes it injects the gneisses in the lit-par-lit fashion in certain zones, or the silicate rocks along their contacts with the limestone. In places it is injected along the east-west striking shear structure. The granite is assigned to the acidic part of the Morin or Pine Hill series.

Gabbro and Hornblende Gneisses.

A large area of gabbro and hornblende gneisses is shown on the south-east part of the map. Two small stocks cut the limestone west of Carswell's quarry. There is also a dyke of similar material near the north end of Bryson and this dyke outcrops also on the island across the channel.

The gabbro has a prevailing dark gray colour and a medium granularity; in some places however it is light coloured and coarse grained. This gabbro resembles the basic intrusions of the Morin and Buckingham series enough to be correlated to these.

Diabase and Lamprophyre.

A dyke of fine-grained diabase cuts the ore at the Calumet property. Another dyke is found on lots A and B, south range, on the island.

Small dykes of lamprophyre cut the ore zone and are found in a few localities in the region. The age relation between the diabase and lamprophyre is not known for certain although the lamprophyre is probably the older.

STRUCTURAL GEOLOGY

Little is known of the structural geology. The mapped area is small and the rocks are so intensively metamorphozed that most of the primary structures have been obliterated. Osborne mentions four structural elements in his report. The most conspicuous one is the banding as shown for instance by the rocks on the mountain at the south-eastern end of the island, where bands from 50 to 100 feet wide of fine-grained leucocratic biotite gneisses alternate with fine grained more mafic hornblende biotite gneisses.

In describing the limestone the assumption was made that it stands higher than the clastic sediments in the stratigraphic column. The limestone outcrops all around the southern part of the island and across the river on the mainland. On the east side of the island, the beds dip at low angle to the east, and the same relation is found for the ones outcropping on the west side of the island. It is then suggested that the structure is an overturned anticline to the west with its axis pitching south.

A third important structure is the shearing striking east-west and north-west south-east as indicated by the foliation and the schistosity. The east-west direction of shearing is better developed and is younger; in places, it has developed at the expense of the one striking north-west. At some places an older schistosity probably parallel to the bedding can be seen.

The last element is the constancy of the direction of the linear features such as the direction of the elongation of the crystals and the axis of plication over practically all the mapped area. This direction strikes east-west and pitches 20° to 30° east. This structure is superimposed on the others.

PART II

THE CALUMET LEAD AND ZINC MINE.

Foreword.

More than two-hundred diamond drill holes with a total length of more than eighty-thousand feet were put down at the Calumet property to prove the ore-deposit. The diamond drill cores were examined by F. Fitz Osborne for the Quebec Bureau of Mines, and vertical sections, in part completed by the writer, were made from his logging to correlate the various types of rocks encountered in drilling and to study the extent and attitude of the ore-bodies and the structure in general at the mine. Sixty-five thin-sections of representative samples picked up from the cores for petrographic study, were examined by the author and the results of his study are included in the following pages.

Summary of the Local Geology.

The Calumet property is on the west side of the island, (see Fig. 2) on what is believed to be the west limb on an overturned anticline, if the assumption that the limestone is at the top of the Grenville series in this area, or of an overturned syncline in the other alternative.

The rocks have a general strike N 15° W and dip to the east at about 30°. From the river to the east in the vicinity of the Calumet Mine the succession of the different types of rocks is as follows: Limestone outcrops on the shore of the river with interbanded silicified layers, and amphibolites lenses near the contact with the granitic gneisses. It is overlain to the east by granitic migmatites followed by biotite and injected biotite gneisses also called the rusty-weathering gneisses, including various amphibolites and contact-metamorphic rocks and containing the main ore-body. Pyroxene and carbonate amphibolites form the hanging-wall of the ore zone of the mine. These amphibolites are overlain by a complex of amphibolite gneisses and migmatites followed by leucocratic injected gneisses less granitized than the migmatites overlying the limestone and forming two large masses, the one to the south being still less granitized. To the east, these rocks are followed by hornblende gneisses and porphyroblastic amphibolites similar to the massive amphibolites of the hanging wall. These rocks contain a minor zone of mineralization on which are the Longstreet shaft and the Belgian pit. These are followed in turn by siliceous hornblende and biotite gneisses including amphibolite lenses. Near the eastern boundary of the property are massive amphibolites in place injected to medium-mafic migmatites.

A diabase dyke cuts the rocks on the property from the river to the end of the amphibolites of the hangingwall of the ore zone. It is about one hundred feet wide, strikes N 80° W and dips about 75° N. Narrow trap dykes were intersected in drilling.

General attitude of the Rocks at the Mine.

Three types of rocks were intersected in drilling the ore-zone at the mine. These are from west to east: 1) the biotite and injected biotite gneisses, 2) the pyroxene and carbonate amphibolites, and 3) the amphibolite gneisses-migmatite complex.

A typical cross-section made from information secured from drilling shows the succession and attitude of the different rocks, the general shape and distribution of the ore-shoots and their relations to the country rock. (See Fig.3).

The most characteristic feature of this section from a structural point of view is the sill-like shape of the amphibolites forming the hanging-wall of the ore zone. This lenticular layer is quite irregular and is from one-hundred to four-hundred feet thick, but its general attitude is found persistent in all the sections made. The average dip of the hanging-wall is about 35°; the section shows however the different formations dipping more steeply near the surface and flattening downward to the east. This tendency is shown better by the trend of the ore itself and suggests drag folding in the vertical plane along the dip, the east part having moved upward.

The lower zone includes lenses of amphibolites and contact metamorphic rocks. Lenses of heterogeneous rocks are present also in the hanging wall and in the rocks above. The presence and distribution of these lenses indicate the complex character of the original sediments metamorphosed to rocks of various compositions still later modified by granitic injection.

PETROGRAPHY

1. The Biotite and Injected Biotite Gneisses.

Locally these gneisses are finely banded and extremely contorted thus clearly indicating their sedimentary origin, but more often they are massive on account of their intensive injection by granitic and siliceous material. This zone is quite complex; it includes numerous lenses of normal and cummingtonite-bearing amphibolites, contact metamorphic rocks and pegmatitic patches scattered throughout the gneisses. The ore-deposit is in these rocks near or at the contact with the overlying amphibolites. The gneisses are separated from the underlying garnet migmatites by a narrow band of normal amphibolite gneisses.

The rocks of this zone will be divided for petrographic description into three general groups: A - The quartz-anorthoclase-mica-sillimanite gneisses, called in the field the biotite and injected biotite gneisses, which are the more abundant, B - The amphibolite gneisses and C - The contact metamorphic rocks, the last two groups occurring as lenses in the first group. These will be subdivided again into different mineral associations based on microscopic examination.

A - The quartz-anorthoclase-mica-sillimanite gneisses.

It is excessively difficult to unravel the history of these rocks and to separate those that are due simply to the recrystallization of the original sediments from those that are the product of recrystallization plus injection. On surface the rocks that show banding are the least injected members and represent more closely the original composition of the sediments. They are fine-grained and consist of a quartz-feldspar mosaic with accessory mica and sillimanite. The injected type which is the more important consists of abundant quartz with potassic feldspars and all the minerals show evidence of replacement by quartz. One section only shows a cataclastic texture.

For practical purpose the quartz-bearing rocks although presenting different associations are grouped together with the exception of the rocks containing cordierite which will be described separately. They all contain mica and sillimanite in greater or less amount. When present, plagioclase is andesine. Anorthoclase (cryptoperthite?) was identified in most sections while microcline (?) and possibly also orthoclase (?) would not be common. Hypersthene was found in one section. Various sulphides are present, of these, pyrrhotite is the most abundant with pyrite and chalcopyrite.

Sphalerite, galena and graphite (?) are found also occasionally.

Microscopic Characters of Minerals.

Most of QUARTZ crystals have irregular rounded outlines. Some are fractured, others show parallel lines of gaseous or liquid inclusions, and in general fine sillimanite needles are uniformly distributed throughout the crystals. Biotite and iron sulphide grains are distributed at random and the crystals often present a sieve-like structure in the more extensive replacements. Quartz replaces all other minerals except sillimanite.

PLAGIOCLASE is andesine. Its composition varies from section to section between An_{32} and An_{49}. The crystals show usually albite twinning. They may have all kinds of inclusions and in the more injected types, they have numerous rounded grains and patches of quartz. They are slightly altered to sericite.

ANORTHOCLASE (cryptoperthite?) is very abundant in the quartz-bearing rocks, often it makes up to 35% of the minerals. Like quartz it includes sillimanite needles. The crystals which are sometimes quite large, have concave outlines due to replacement by quartz and often become interstitial to quartz when replaced more extensively. Sections normal to the Z-bisectrix give an extinction angle with (001) cleavage of about 7°, and in such sections almost submicroscopic pericline twinning lines can be seen making an angle of 75° with (001) cleavage, which is characteristic of anorthoclase. Sections normal to the X-bisectrix give an extinction angle of about 4° with (001) cleavage and show an acute-bisectrix figure indicating a medium axial angle. From an optic-axis figure, the axial angle is seen to be small and is estimated to be near 45° , which value is again characteristic of the mineral. The crystals have usually a peculiar appearance under the microscope that sometimes suggests microcline but the mineral is probably cryptoperthite (See p. 38). The crystals are slightly altered to sericite.

MICA - Light brown PHLOGOPITE is the most abundant mica. Its pleochroic formula is:

X = very pale brownish yellow (almost uncoloured).
Y = Z pale brownish yellow.

The axial angle is almost zero. Dark pleochroic haloes around small apatite (and zircon ?) grains are sometimes abundant. It is replaced by sillimanite and iron sulphides (See Fig.4) MUSCOVITE was found in few sections associated with phlogopite and is also replaced by sillimanite. One section shows biotite altered to chlorite through an intermediate high index product. Mica is replaced by quartz.

SILLIMANITE is the fibrolite variety. It occurs as fine needles crowded together with a sheaf-like arrangement. It replaces quartz and is intimately associated with biotite and occasional muscovite both of which it replaces. The mineral has a high index of refraction and a low byrefringence, it has parallel extinction, it is positive and almost uniaxial. The bundles of crystals usually develop with their axis at about right angle to the lines of inclusion in the other minerals, thus indicating more clearly its origin later to injection. It is also present as fine needles uniformally distributed in the other minerals.

MICROCLINE ? Crystals with scotch-plaid twinning are found associated with anorthoclase. Unfortunately these are not present in sufficient amount to check all the optical properties of the mineral.

APATITE is rare in the quartz bearing rocks.

IRON SULPHIDES occur along cleavage planes in biotite, or filling cracks in quartz and replace all silicate minerals. Pyrrhotite and pyrite are the more important. Their abundance in the quartz-bearing rocks indicates a genetic relation of the ore to the solutions producing granitization.

Cordierite-Bearing Associations.

An interesting group of associations includes cordierite. This mineral was identified in two thin sections within the present zone, and in another one in the amphibolites of the hanging-wall near the contact with the biotite gneisses. In each case the association is different. The two thin sections in the actual zone consist of the following minerals:

1. Quartz - cordierite - biotite - plagioclase.
2. Quartz - sillimanite - plagioclase - biotite - cordierite.

In the amphibolites the association is :

3. Anthophyllite - cordierite - biotite - plagioclase.

Associations 1 and 2 differ only by the presence of sillimanite in the latter. Association 3 is entirely different from the others and represents a metasomatic rock.

1. Quartz - cordierite - biotite - plagioclase association.

The section consists almost entirely of quartz with cordierite, plagioclase and biotite. Biotite is also included in the quartz crystals with pyrrhotite and pyrite. Quartz crystals show parallel cracks and lines of inclusions. Cordierite is in small colorless irregular rounded crystals interstitial to quartz or sometimes included in quartz. It has few yellow pleochroic haloes that disappear as the stage is rotated and these haloes furnish an obvious indication of the presence of the mineral. The crystals have short cracks normal to the edges and can be distinguished from quartz by a slight difference in their limpidity.

2. Quartz-sillimanite-plagioclase-biotite-cordierite association.

Quartz is again the most abundant mineral. Sillimanite occurs in slender prisms grouped together and also as grains replacing the other minerals especially biotite. Plagioclase An_{20} is slightly altered to sericite and is replaced by quartz. Biotite with pleochroic haloes around rutile grains is in fair amount and is accompanied by a little muscovite. Some of the biotite is altered to a green mineral (chlorite or serpentine) accompanied by a high-index and high birefringent negative uniaxial mineral (carbonate ?). Cordierite is in larger grains than in the previous association but is still in small amount. The crystals have small inclusions uniformly distributed. The optic sign is positive and the axial angle in near 80°. Pyrrhotite and pyrite replace mica.

3. Anthophyllite-cordierite-biotite-plagioclase association.

Cordierite is very abundant in this association. It is in anhedral interlocking crystals with the same characteristics as in the above associations and replaces anthophyllite. It is present also as small crystals forming the outside zone of medium size eyes having inside an uncoloured medium-index uniaxial negative mineral with birefringence colour of the first order (mica ?) including an uncoloured high index isotropic mineral (spinel or garnet ?) occuring as small angular grains grouped together near the centre of the eyes, apparently a secondary product of replacement; apatite sometimes accompanies the latter. Cordierite has more pleochroic haloes than in the above associations. It is quite possible that cordierite replaces mica in the "eye" structure. Large uncoloured crystals with elongated fibrous habit occuring in radiating aggregates and sheaves form about 40 % of the minerals. It has pale yellow birefringence colour of the first order, parallel undulatory extinction, positive elongation, a large optic axis angle and a positive sign (?). The mineral is probably anthophyllite and the refractive index for Z being 1.64 + it would consist of meganthophyllite ($H_2Mg_7Si_8O_{24}$) 20 mol % and feranthophyllite ($H_2Fe_7Si_8O_{24}$) 80 mol % (1). Many crystals have black inclusions. It replaces biotite and it is replaced in turn by plagioclase, cordierite

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(1) Winchell, A.N., op. cit.

and quartz. The lines of fracturing of anthophyllite are preserved in the replacing minerals.

Remarks on the cordierite-bearing associations.

Until lately, cordierite was not known to be a common mineral in the Canadian Shield. It was described for the first time in Canada in 1910 by Adams and Barlow (1) from the Haliburton and Bancroft areas of Ontario, in association with gedrite. It is now mentioned quite often in the reports on the Adirondacks of United States. N.L. Wilson (2) described paragneisses from Montauban with cordierite and anthophyllite in which the presence of these two minerals vary from small amounts to rocks consisting entirely of cordierite and anthophyllite. In the Scandinavian countries it was described especially from Finland by Eskola (3). It is known also from the Waite-Amulet area of Abitibi where it is found in the dalmatianite related

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(1) Op. cit., pp. 157-172.

(2) An Investigation of the Metamorphism of the Orijarvi Type with Special Reference to the Zinc-Lead Deposits at Montauban-les-Mines, P.Q., unpublished Doctor's degree thesis, McGill University, 1939.

(3) Op. cit., pp. 1-277.

to greenstone.

The cordierite-anthophylite rocks are considered to be a product of magnesian metasomatism by Eskola in Finland and Wilson at Montauban.

At Calumet, cordierite is found in two different types of rocks; a metasomatic type (association No. 3) and an intensively silicified type (association No. 1 and 2). Both types result from injection of igneous solutions and since cordierite is found only in the more injected rocks it is logical to believe that magnesia was introduced by these solutions. Another hypothesis is that the various associations represent different degrees of replacement as a result of a variation in the composition of the sediments in which cordierite has developed from the recrystallization of agrilaceous layers deficient in lime, under the effect of thermal injection.

B - The Included Amphibolites.

The second group of rocks found in this zone consists of amphibolites. There are two principal types of associations grading one into the other:

a) The plagioclase-cummingtonite-biotite-hornblende ± garnet amphibolites.

b) The plagioclase-hornblende-biotite amphibolites.

Cummingtonite is developed typically near the contact of the rusty-weathering gneisses with the overlying carbonated and gneissic amphibolites.

a) The Plagioclase-cummingtonite-biotite-hornblende garnet amphibolites.

The texture is fine to medium. The minerals are arranged in allotriomorphic aggregates and a gneissose structure is common. Plagioclase is the most abundant mineral of these amphibolites, and its composition varies on a wide range from one section to another. The characteristic mineral is cummingtonite amphibole. Biotite is usually abundant but common hornblende less so. In some sections garnet is present where as in others, it is absent. Apatite and iron sulphides are also present. One section shows numerous veinlets of serpentine cutting the other minerals. Another one consists almost entirely of actinolite with few areas where the amphibole is bleached and replaced by cummingtonite. In these rocks quartz is absent.

PLAGIOCLASE is present as sub-angular to rounded irregular interlocking crystals. It may or may not show albite twinning and sometimes the crystals are fractured. Often they have inclusions of the associated ferromagnesian minerals. The composition varies between wide limits (An_{10} to An_{46}) from one section to another. The crystals are usually fresh but they are sometimes slightly altered to sericite.

CUMMINGTONITE is in elongated fibrous non-terminated crystals usually grouped together in bundles with the individuals oriented in the same general direction. It is found also replacing hornblende by bleaching, the structure of the latter being often preserved, and there is evidence that it replaces biotite. The mineral has a very pale brownish yellow tint but shows no distinct pleochroism. The crystals are twinned characteristically along planes closely spaced parallel to (100) and the mineral is easily identified by this peculiar twinning, especially when present in very small amount. The indices of refraction are:

$$X = 1.64 -$$
$$Y = 1.65$$
$$Z = 1.66 +$$

The birefringence is very high and give yellow colours of the second order and from this is estimated to be above 0.30. The maximum extinction angle $Z \wedge c$ is about 20°. The elongation is positive. The optic angle is very large and estimated to be more than 80°, from the curvature of the isogyre of an optic axis figure. The optic sign is positive and the dispersion is $v > \rho$.

From the above observations, the amphibole is considered to belong to the isomorphous kupfferite ($H_2Mg_7Si_8O_{24}$) grunerite ($H_2Fe_7Si_8O_{24}$) series, and from (1) Winchell graph would consist of about 40 mol % of grunerite and should be named cummingtonite. These optical properties fit very well with the description of the above amphibole in bulletin 848 by Larsen and Berman (2).

BIOTITE has often a chocolate brown pleochroic colour. In few sections it is olive green. Pleochroic haloes are always abundant.

HORNBLENDE is usually present in the same proportion as plagioclase, but sometimes constitutes as much as seventy per cent of the minerals of the rock. Ordinarily it is of the normal green colour but often it has a bluish tint and the following pleochroic formula:

X = pale greenish yellow.
Y = pale green.
Z = pale bluish green.

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(1) Winchell A.N., Elements of Optical Mineralogy, Part II, 1933, p. 244. Also, Winchell A.N., Further Studies in the Amphibole Group, the American Mineralogist, June 1931, Vol. 16, No. 6.

(2) Larsen A.S. and Berman H., The Microscopic Determination of the Non-Opaque Minerals, 2nd. Ed., Bull.848, U.S. Dept. of Int., 1934.

This type of amphibole has a birefringence of about 0.020, positive elongation, an extinction angle $Z \wedge c = 16^{\circ}$ and an optical angle smaller than 60° with strong dispersion $\rho > \nu$. Often the crystals are bleached especially around the edges and sometimes only a green spot is left in the central part of the crystal. This bleached area often shows the peculiar polysynthetic twinning of cummingtonite. Some crystals include rounded grains of plagioclase.

GARNET is pale brownish red. It occurs as idioblastic crystals usually fractured. From its complete absence of birefringence, it is classed in the pyralspite group and is believed to be ANDRADITE. It has inclusions of cummingtonite and iron sulphides and replaces all the other minerals.

b) The Plagioclase-hornblende-biotite amphibolites.

In general the texture is fine-grained granoblastic but gneissose structures were also observed. The minerals are fresh and have small inclusions. These amphibolites resemble igneous rocks. The essential minerals are plagioclase, hornblende, and biotite. Carbonate is present in small amount replacing plagioclase. Cummingtonite may also replace hornblende, thus indicating the transition from the plagioclase-hornblende-biotite amphibolites to the plagioclase-cummingtonite-biotite-hornblende amphibolites.

PLAGIOCLASE varying in composition from An_{10} to An_{35} from one section to another is present in various amounts from 25% to 60%. Much of it is not twinned and shows undulatory extinction. Small crystals of hornblende are found as inclusions. When plagioclase is abundant, evidence of replacement of hornblende by the former is given by the concave outline of the hornblende crystals. Some of the crystals are slightly altered. In the same section, crystals of hornblende include plagioclase while plagioclase crystals include hornblende.

HORNBLENDE ranges from 25% to 70% in amount, more often it has the bluish tint already mentioned.

BIOTITE has the common brown pleochroic colour and is present in various amounts. It has dark pleochroic haloes around small inclusions.

APATITE and PYRRHOTITE are found occasionally.

C - Contact-metamorphic rocks.

The biotite and injected biotite gneisses described above are fine-grained in general. They are represented mainly by the quartz-bearing rocks with their minerals grouped in a more or less definite association and include minor amounts of amphibolites, one group being characterized by cummingtonite ± garnet and the other consisting mainly of plagioclase hornblende and biotite. Within the same horizon there are also minor zones of medium- to coarse-grained rocks, amphibolites for most of them, some of which have peculiar associations and these will be here referred to as the CONTACT-METAMORPHIC rocks. They include of course the cordierite-bearing rocks already described.

Section No. 9.

The association is: Biotite (?) gedrite and zoisite (?).

BIOTITE (?). The mineral is in plates up.to a centimeter in diameter and has a greenish grey colour in hand specimen with some green spots in places. The lamellae are flexible but not elastic. It is uncoloured in thin section. Some sections show a uniaxial figure, others a small optic angle. The index of refraction of the mineral oriented with the cleavage parallel to the stage of the microscope (about N_m) is a little less than 1.59. The birefringence is high. In places it is altered to chlorite along cleavages and it is apparently replaced by gedrite.

GEDRITE is grey in hand specimen but uncoloured in thin section. The mineral has a brownish dirty appearance under the microscope, but some smaller crystals are absolutely fresh, (two different minerals ?). The indices of refraction are:

$$X = 1.62 -$$
$$Y = 1.62 +$$
$$Z = 1.63 +$$

The mineral has parallel extinction, the optic sign is negative, the optic angle is large and the dispersion is $\rho > \nu$.

ZOISITE (?). The mineral is in fractured uncoloured crystals, it has high refractive index and apparently low birefringence. It is biaxial negative and has an axial angle of about 75° with $\rho > \nu$ about X. The mineral has probably parallel extinction.

There are abundant pyrrhotite and pyrite.

Section No. 45.

Gedrite amphibole makes the bulk of the minerals of the section and is accompanied by accessory pale yellow biotite and a deep green isotropic mineral, (complete absence of biregrigence) without crystal outlines, averaging 1 m.m. (one grain 2 m.m.) and with an index of refraction greater than 1.78, probably gahnite ($ZnAl_2O_4$). The mineral dissolves entirely in the microcosmic salt thus indicating absence of silica. Quartz is present in small amount. The ore minerals are pyrrhotite with inclusions of chalcopyrite, and a little galena; these are grouped around spinel which they seem to replace.

Section No. 10.

The section is merely an aggregate of chlorite and carbonate. Chlorite has the characteristic Berlin-blue interference colour, and the crystals have numerous pleochroic haloes around small inclusions. A little pyrite is present.

Section No. 50.

This peculiar association consists of cummingtonite wilsonite, diopside and carbonate, the minerals being named in their order of importance and accessory quartz, sphene and apatite.

CUMMINGTONITE has a greenish greyish white colour in hand specimen. It is uncoloured in thin section, shows no twinning, has an extinction angle of 18° , all the other optical properties being normal.

WILSONITE: The mineral has a peculiar pale purple colour in hand specimen but is uncoloured in thin section and has aggregate polarization.

Sections Nos. 53 and 46.

Both sections are a medium-grained aggregate of brown biotite and fibrolite with small amounts of plagioclase An_{20}, quartz, apatite, pyrrhotite and pyrite. The coarser texture is the only peculiar feature of these two sections. Some plagioclase crystals have a myrmekitic texture in section No. 53 and pyrrhotite has reaction rim in section No.46.

Section No. 40.

Over 80% of the section is actinolite with narrow zones of untwinned cummingtonite (bleached actinolite). The rest of the section consists of brown biotite and a little basic plagioclase An_{48} having undulatory extinction. Pyrrhotite is also present. The texture is medium-grained with many crystals over 1 m.m.

Section No. 47.

Only two minerals are present, actinolite and plagioclase, with small grains of apatite. Actinolite crystals range between 1 and 2 m.m., while plagioclase crystals An_{36} are about 0.5 m.m.

<u>NOTE</u> - Actinolite was identified also in at least three other thin sections with fine-grained texture viz. Nos. 17-8-41.

Section No. 17 is a normal amphibolite consisting of about 40% actinolite, the rest being made of basic plagioclase An_{63} and quartz with little biotite,apatite and carbonate replacing plagioclase.

Section No. 8 is a peculiar association of about 80% of quartz crystals about 1 m.m. with relatively small crystals of actinolite, diopside, brown biotite, zoisite (?), carbonate, and apatite interstitial to quartz or as inclusions in the latter.

Section No. 41. In their order of importance the minerals are pyroxene, actinolite, brown mica, basic plagioclase, and apatite as accessory minerals. Up to 1 m.m. eyes of small plagioclase crystals are surrounded by a narrow zone of biotite crystals separating plagioclase from actinolite. Inside the eyes plagioclase is altered to sericite (?) resembling the inside zone of the eyes in the cordierite association section No. 11.

General Considerations on the Biotite and Injected Biotite Gneisses.

The outstanding character of this zone is the high degree of silification that has transformed most of the rocks into migmatites. Apparently the original metamorphosed rocks were open to the magmatic solutions by which they were injected and replaced. Enough patches and lenses of banded sediments are left however to establish their sedimentary origin.

The ability of injection in lit-par-lit fashion by magmatic fluids is explained by Alling (1) as due to the high pressure developed during cooling and crystallization of the magma, in deep zones where the pressure is so great on account of the cover rock that the above type of injection takes place instead of fracturing.

The amphibolites forming lenses in these rocks and the ones resulting in places from the gneisses by increase of the ferromagnesium minerals, are interpreted as metamorphic rocks resulting from the metamorphism of calcareous sediments intercalated in the siliceous ones.

The contact-metamorphic rocks are most likely due to the presence of impurities in the sediments and addition of material of igneous origin.

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1. Alling H.L. op. cit., p. 255 and 259.

REMARKS ON THE MINERALS.

a) The Quartz-bearing Rocks.

Anorthoclase is an unusual potassic mineral in the Grenville rocks. Microcline instead is mentioned in all the descriptions. In the Adirondacks of U.S. microperthite is very commin and Buddington (1) described microperthite in association with quartz, cordierite, sillimanite, biotite, garnet etc., in the contact aureoles of the Alexandria-type granite in argillaceous rocks. Its association is very similar to the one of anorthoclase at Calumet Island, moreover, anorthoclase and microperthite have identical composition and according to Alling (2) the potash-soda feldspars form an inverted Y by ex-solution with falling temperature:

anorthoclase
↓
cryptoperthite
↓
microperthite
↓
perthite
↙ ↘
(-K Al Si_3O_8) orthoclase Albite (-Na Al Si_3O_8)
(monoclinic) (triclinic)

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(1) Buddington A.F., *op. cit.*, p. 172.

(2) Alling H.L., *op. cit.*, p. 205

Most likely then, anorthoclase of Calumet Island and microperthite of the Adirondacks have similar origin. Anorthoclase has a peculiar appearance under the microscope, and all the intermediates between ordinary and something similar to microcline twinning can be observed. Buddington again mentions the alteration of microperthite to microcline and oligoclase in a syenite rock however, but the mineral at Calumet is probably cryptoperthite, its appearance being similar to the picture of that mineral given in Alling, (1). The microcline structure is produced from orthoclase by pressure and that even grinding will alter orthoclase to microcline. It is then possible that pressure is responsible of giving anorthoclase the appearance of microcline that, combined with its alteration to cryptoperthite.

Anorthoclase crystals are usually fresh looking while plagioclase is injected by quartz and altered to sericite. It is quite probable that the mineral resulted from the injection of aplitic solutions containing potassium and sodium.

Sillimanite is a characteristic mineral of the Grenville series. As already mentioned, it is found as

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(1) Alling, op. cit., p. 70, fig. F.

almost sub-microscopic needles in the quartz and anorthoclase crystals, and it is present as longer needles grouped in bundles replacing the other minerals, especially mica. The presence of sillimanite in these rocks indicates that the original sediments were rich in alumina which entered first in combination in the form of mica with which reacted silica to form sillimanite, K-feldspars and accessories by thermal metamorphism.

Biotite is normally pale brown when associated with sillimanite but there are exceptions. In one section consisting of quartz anorthoclase and plagioclase the mica is reddish brown so that we must conclude that the mica is not affected by the presence of anorthoclase.

The occurrences of cordierite and anthophyllite (?) have already been discussed.

b) Amphibolites.

There is no quartz in the included lenses and patches of amphibolites in the gneisses. Apparently the amphibolites were less fissile than the biotite gneisses and escaped silicification. On the other hand plagioclase is replacing the other minerals and appears to have been injected.

Cummingtonite amphibole and garnet deserve special attention. Cummingtonite and pargasite are both uncolored in thin section, they are positive and have similar extinction angle but the indices of refraction, the birefringence and the optic angle are greater in cummingtonite than in pargasite and the dispersion is different. It is on these differences that we decided to call the mineral cummingtonite.

	Cummingtonite		Pargasite (1)	
	Calumet	Winchell(1)	Edenville	Pargas
N_g	1.66+	1.66-1.70	1.6410	1.6519
N_m	1.65	1.64-1.67	1.6256	1.6380
N_p	1.64-	1.63-1.66	1.6188	1.6329
N_g-N_p	0.030	0.025-0.030	0.0222	0.0190
2V	80°	65°- 85°	70°	63°
Dispersion	$v>\rho$	$v>\rho$	$\rho>v$	$\rho>v$

The replacement of hornblende ($H_2NaCa_2(Mg,Fe)_4Al_3Si_6O_{24}$) by pargasite($H_2NaCa_2(Mg,Fe)_5AlSi_7O_{24}$) instead than by cummingtonite ($H_2(Fe,Mg)_7Si_8O_{24}$) would be more easily explained, their formula being more similar. In both cases however there would be a removal of Al, most likely used up in the formation of ALMANDITE garnet.

Hornblende has often a bluish tint. Eskola (2)

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(1) Winchell A.N., Elements of Optical Mineralogy.

(2) Eskola Pentti, op. cit.,p. 129.

observed a similar variety in Finland and suggests that this bluish color given by the presence of sodium, indicates that the amphibole was formed from plagioclase.

Mica varies in colour from ordinary brown in the normal amphibolites to deep chocolate reddish brown in some of the cummingtonite bearing amphibolites in which it is also olive-green occasionally. According to Hall (1) from plotting of analysis of many biotites, the colours of the more common biotites are dependent upon their relative content of iron, magnesia and titania, iron producing the green colours, titania the brown and red colours, while magnesia appears to mask the colours produced by titania.

Apparent Paragenesis of Amphibolites.

Cummingtonite and hornblende are found in close association the former replacing the latter selectively, but it is found also replacing biotite. A good example of the first case is shown in (plate 9). Plagioclase replaces cummingtonite, hornblende and biotite, (plate 7). Garnet was formed later replacing the previous mentioned minerals. Serpentine cuts all the minerals.

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(1) The Relation Between Colour and Chemical Composition in the Biotites, Hall A. Jean, The American Mineralogist, Vol. 26, No. 1, 1941.

2. Hanging-wall Amphibolites.

Above the ore-body formed mainly in the biotite and injected biotite gneisses is a sill-like mass of carbonate and pyroxene amphibolites. This band of amphibolites was fairly well outlined by diamond drilling and it constitutes a characteristic feature of the ore zone as was emphasized before.

The amphibolites are thinly layered or massive. Schistosity is developed along the margins of the bands and in few zones in the interior but it is always much less apparent than in the hornblende and hornblende-biotite gneisses.

From the logging of the diamond drill holes several varieties of amphibolites were identified. Usually however, these varieties are so heterogeneously distributed that they could not be correlated in the vertical sections made from these holes. One variety is a clotted-appearing amphibolite consisting of hornblende, biotite, pyroxene and medium calcic plagioclase. Another one contains abundant carbonates in layers, suggesting it is an original constituent of the rock but it is sometimes as veinlets as if it has been introduced. A third variety with much biotite is called biotite amphibolite. A special variety is characterized by porphyroblasts of biotite, or pyroxene and is called porphyroblastic amphibolite. This variety is found near the edge of the carbonate amphibolite and sometimes within the main mass, it is usually massive but sometimes schistose. By gradation the amphibolites pass to more schistose hornblende gneisses through porphyroblastic gneisses. Osborne believes that some of the differences between the composition of the amphibolites and hornblende gneisses are due to granitic injection.

Petrographic Description.

Although the amphibolites form a massive and apparently homogeneous lenticular body, the mineral composition of these rocks is not uniform. According to the different mineral associations as determined from the thin-sections, the zone will be divided into two types of rocks; 1. The normal amphibolites consisting simply of plagioclase, hornblende and some biotite, (this type has already been described p.30). 2. The pyroxene and the carbonate amphibolites composed of pyroxene, carbonate, hornblende, intermediate plagioclase and biotite, and often containing a fair amount of scapolite. The latter represents the most important type. There is gradation of course from one type to the other. In both types quartz is absent.

Pyroxene and Carbonate Amphibolites.

The more important group of associations in the rocks of the hanging-wall is represented by the pyroxene and carbonate amphibolites. Pyroxene is abundant and carbonate is found in various amounts. Scapolite is usually present, sometimes in fair amount and it might be of some interest to note that it is found only in rocks containing pyroxene whereas carbonate may be absent. Hornblende and plagioclase are always present, but biotite is sometimes missing. Apatite is usually as accessory mineral and sphene often. Epidote was identified in one section, all the thin sections contain sulphides.

Fine- to medium-grained granoblastic and porphyroblastic textures are common. The segregation of calcite and pyroxene from the other constituents often impart a gneissose structure to the rock.

PYROXENE crystals form large porphyroblasts or occur as smaller rounded grains. It is almost uncoloured with a greenish tint but shows no distinct pleochroism. Prismatic cleavage is distinct and parting parallel to basal cleavage (001) is common. The index of refraction for Z is equal to 1.69 + . The optic sign is positive and the optic angle is near 60°. The extinction angle is around 40° and the mineral is believed to be diopside. In few sections however the extinction angle was found to be about 45° and in that case some of the pyroxene would belong to the diopside-hedenbergite series. The crystals are slightly altered to serpentine or chlorite along cracks, cleavages and partings. In places it is replaced by hornblende.

PLAGIOCLASE is acidic andesine and shows a fairly uniform composition which is quite an unusual feature for the rocks described in this thesis, unless this is by pure coincidence. The crystals are generally untwinned and may show undulatory extinction. The fact that the plagioclase is not very calcic for the amount of calcite present in the rocks would suggest that the carbonates were introduced after the formation of the plagioclase. A veinlet containing calcite and plagioclase suggests that the two minerals would have been simultaneously introduced.

HORNBLENDE is of the common green type and occurs as subhedral crystals or rounded grains replacing pyroxene and replaced in turn by cummingtonite.

SCAPOLITE was identified in four thin-sections in which pyroxene is present. In one section carbonate is abundant, it is in small amount in the second one and absent in the two others. The crystals are usually fresh but sometimes they are altered to a fibrous brownish aggregate (pinite). One good cleavage is shown usually. The mineral is uniaxial negative and has parallel extinction, the indices of refraction are: $N_o = 1.58$ and $N_e = 1.55$ and the birefringence is estimated to be about 0.030 from the interference colour. Referring to the diagram in Winchell (1), the mineral is found to consist of $Ma_{60} - Me_{40}$ and is MIZZONITE. It is in large crystals replacing selectively equally large crystals of pyroxene (see plate 12) but it occurs also as small interlocking crystals.

CARBONATE shows numerous twinnings and without other determinations is considered to be calcite. APATITE is sometimes present in anhedral grains. EPIDOTE was found in good-size crystals in a brecciated type of carbonate anphibolite in which the hornblende is broken up into small angular fragments.

Remark.

Scapolite as well as apatite are very common in the amphibolites and are considered to be a product of pneumatolitic metamorphism (2).

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(1) Winchell A.N., op. cit., p. 294.

(2) Harker A., op. cit., p. 324.

Apparent Paragenesis.

No attempt is made here to establish definitely the order of formation of all the minerals. Some observations made during the study of the thin-sections suggest however certain relations between the minerals. Criteria of replacement are illustrated by some of the best examples furnished by the thin-sections. PYROXENE is replaced by hornblende, carbonate, plagioclase and scapolite. No evidence is furnished as to its origin however. BIOTITE is cut by veinlets of carbonate and plagioclase and is replaced by scapolite. HORNBLENDE is replaced by cummingtonite, carbonate, plagioclase and scapolite. CARBONATE and PLAGIOCLASE are both present in veinlets as if introduced late. Carbonate is replaced by plagioclase and plagioclase is found in the central part of the veinlets. SCAPOLITE apparently replaces all the other minerals but especially pyroxene. In one section it replaces plagioclase.

In the Ducktown deposits quartz and feldspars are extensively replaced by carbonates (1) while in the present case it is the ferromagnesium minerals that are replaced by the carbonates.

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(1) Ross, op. cit., p. 34.

From the preceding remarks based on the relations between the minerals as observed under the microscope, carbonate apparently replaces most of the minerals and appears to have been introduced lately. Nevertheless, the origin of the carbonate is doubtful. In many sections, carbonate and pyroxene are segregated from the other minerals and form lenses as if they were related one to the other, (~~see plate~~) but in one section showing banding, a veinlet of carbonate and plagioclase cuts across the banding as if it had been later introduced. One section shows pyroxene replaced by plagioclase and carbonate and it is rather doubtful whether pyroxene could be formed from calcite of the same age that the one by which it is replaced. Most likely however, pyroxene was formed from residual carbonate and later carbonate was introduced with plagioclase.

Carbonates are very plastic and soluble minerals. They are easily recrystallized and metamorphosed to contact-metamorphic minerals when a rock containing these is injected by igneous material. It is then almost impossible from the study of the thin sections alone to assign to these carbonates a definite place in the paragenesis. Most logically however they are residual from the amphibolitization of dolomitic sediments, but it is also possible that some carbonate was introduced; both hypothesis are probable and this is the opinion of Osborne (1).

It is interesting to consider the opinion of C.S.Ross about the Ducktown copper deposits in which he believes that the carbonates are of epigenetic origin. He concludes that: "The copper bearing deposits of the Ducktown type in the southern Appalachian region were not dependent on the presence of limestone lenses for their formation and that the carbonates in these deposits are not the remnants of partly replaced limestone lenses but are vein minerals that have been deposited from hydrothermal solutions." (2)

There is surely a genetic relation between pyroxene, scapolite and carbonate, since these three calcium-bearing minerals occur together. The relations found from microscopic examination are the following: when pyroxene and scapolite are in large amounts, carbonate is less abundant and as noted before, when pyroxene is present, carbonate is also present usually but not necessarily scapolite, although in few cases pyroxene

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(1) Osborne F.F., report under preparation.

(2) Ross C.S., Origin of the Copper Deposits of the Ducktown Type in the Southern Appalachian Region, U.S. Geol. Survey, P.P. 179.

or carbonate were found alone. Pyroxene always accompanies scapolite while carbonate may or may not do so.

Amphibolite Gneisses-Migmatite Complex.

The amphibolites of the hanging wall are overlain by a complex amphibolite gneisses with intercalated patches of leucocratic biotite gneisses. The least injected variety has a granoblastic texture and consists of abundant hornblende and interstitial quartz and feldspar. The more granitized rocks show different textures. The even grain type has a pepper-and-salt appearance in hand specimens, but more commonly the rocks are gneissose due to the segregation into layers of the ferro-magnesian minerals. Some are porphyroblastic with porphyroblasts of pyroxene, another type has clots of hornblende and biotite and is called clotted amphibolite.

The amphibolite gneisses consist of hornblende, plagioclase, quartz, pyroxene, carbonate biotite, sphene, garnet, and apatite. The alteration products are serpentine, and sericite. Pyrrhotite, pyrite and other sulphides may also be present in minor amounts. Plagioclase varies between An_{10} to An_{20} from one section to another. Sphene is particularly abundant in this zone.

The most striking feature of the amphibolite gneisses is the injection and replacement of hornblende and biotite by feldspar mainly and quartz giving rise to sieve-like and poeciloblastic structures in the most advanced stages of granitization.

The pyroxene-bearing amphibolites of this zone are different from the ones of the hanging-wall in that they contain quartz, a pale brownish red garnet (almandite) and titanite. Again some of the hornblende has a bluish pleochroic colour in the direction of the slow ray.

The migmatites have the appearance of gray granite gneisses. They contain hornblende and biotite. In places these rocks have relic structures that may represent original schistosity and bedding similar to that of the biotite gneisses of the ore zone. It suggests that they are granitized rocks originally similar to the biotite gneisses, more material being introduced however.

Origin of Amphibolites.

Goranson considered the amphibolites of Calumet Island as resulting from the metamorphism of diorites and (1)

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(1) Goranson R.W., Calumet Island, Pontiac County, Quebec, Geol. Surv. Can., Summ. Rept., 1925 pt C, p. 15.

gabbros; evidently sufficient data were not then available to establish their true origin.

Let us recall briefly four different ways by which amphibolites can originate:

1. By metamorphism of gabbro and diorite.
2. By recrystallization of impure limestone with some addition of material.
3. By replacement of limestone by thermal solutions.
4. By metamorphism of volcanics.

Pentti Eskola, in the Orijarvi district, described amphibolites arising from the metamorphism of impure limestones, gabbros, basic dykes or basic volcanic rocks (1). Adams and Barlow, in the Haliburton and Bancroft districts also described crystalline limestones metamorphosed into typical hornblende-feldspar amphibolites under the influence of granite intrusions (2).

Finally Buddington, in the Adirondacks of U.S. in accord with Adams' and Barlow's theory considers that the amphibolites found in the garnet gneisses and in the limestones

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(1) Eskola Pentti, op. cit.

(2) Adams F.D. and Barlow A.E., The Haliburton and Bancroft Districts, Ont. Geol. Surv. Cal., Mem. 6, 1910, p. 104.

were formed by the replacement of limestone by granitic emanations. In other areas he considers that amphibolites, of one or the other above noted mode of origin, are found with certainty (1).

A common feature to most of the amphibolites from the various known districts of the world is a sill-like or lenticular habit. These rocks occur as dark bands intercalated with or intruded into the granitic gneisses and have a same general strike. In the case of the pyroxene-bearing amphibolites, Eskola concludes that there is no more doubt however as to their origin and that they are the product of metamorphism of sediments richer in lime (calcareous shales), than the ones that produced ordinary amphibolites (2).

The recognized bedding in the less granitized members in zones in which furthermore amphibolites occur as lenses, as in the biotite and the injected biotite gneisses, the formation of amphibolites at or near the contact between the limestone and garnet gneisses, the mineralogical associations in the pyroxene and carbonate amphibolites (abundance of carbonates and calcium-bearing minerals like diopside and

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(1) Buddington A.F., <u>op</u>. <u>cit</u>., p. 169 and p. 257.

(2) Eskola Pentti, op. cit., pp. 121-130.

scapolite), and a wide range of feldspars in all the rocks of the area (1) give sufficient evidence of the sedimentary origin of these rocks.

The amphibolites of Calumet Island are then considered to be the product of recrystallization of clastic sediments containing more or less calcium and magnesium carbonates, hornblende arising from the reaction between calcite and chlorite (2) or being formed directly from clays poor in silica or by any other way. Calcite when present, would represent the mineral left over after the formation of hornblende has exhausted the available magnesia. Apparently the calcite recrystallized subsequently and replaced the other minerals, and it is not impossible that some carbonate was introduced later. In amphibolites without calcite no lime would have been left over but its absence could also be explained by its removal by solution or squeezing out. By shearing the amphibolites gave rise to dark mafic gneisses and by injection to hornblende and hornblende garnet migmatites. The carbonate-bearing amphibolites being more plastic were

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(1) Carlson C.J., A Test of the Feldspar Method for the Determination of the Origin of Metamorphic Rocks, Jour. of Geol., Vol. 28, 1920, pp. 632-644.

(2) Harker A., <u>op</u>. <u>cit</u>., p. 267.

less susceptible to open structures and injection.

4. Diabase Dyke.

One thin section was made of the diabase dyke that cuts the rocks at the mine. It shows a fine-grained ophitic texture (large plates of pyroxene enclosing feldspar laths.) and a mineralogical composition consisting of about 50% augite ($Z \wedge c = 40^{\circ}$) and 50% labradorite with little magnetite and pyrite. Some of the pyroxene crystals have a dirty brownish appearance under the microscope and many feldspar crystals are altered to a greenish pleochroic mineral.

Anhydrite and Gypsum.

At different horizons beds containing anhydrite and gypsum were intersected in drilling, as for example No. 6b hole at the mine. In places the anhydrite is mauve and coarsely crystallized but more commonly it is of medium grain and consists of a pale violet variety mixed with carbonates. It occurs also with coarse-grained salmon calcite.

Five thin sections from this hole show the intimate association of carbonate, anhydrite, gypsum, tremolite and diopside, carbonate anhydrite and gypsum predominating and being present in all proportions. Other minerals are muscovite and apatite. All except one section, which is fine-grained, are medium-grained. The amphibole is uncoloured and from the following optical properties is found to be tremolite: The optic sign is negative with $\nu > \rho$, the optic angle is about 80°, the extinction angle $Z \wedge c$ is around 15° and the birefringence is strong. The pyroxene has an extinction angle $Z \wedge c$ equal to 44° and is considered to consist of diopside 60 mol. % and hedenbergite 30 mol. %.

The apparent paragensis is: silicates (pyroxene and tremolite), carbonates, anhydrite and gypsum. The silicate relics in the carbonate crystals seem to point out to a later introduction of carbonates. Anhydrite and gypsum are closely associated, gypsum replacing anhydrite extensively and it is often seen forming a ring around the anhydrite crystals. Anhydrite replaces carbonates and silicates and it is quite possible that it is of magmatic origin. In section 43, consisting mainly of quartz 40%, biotite 30%, plagioclase An35 20% and garnet 10% (pale reddish brown), few crystals of anhydrite are also present. This section shows extensive replacement by serpentine. In that section the other minerals are cummingtonite, apatite, pyrites and magnetite (?). Similar alteration by serpentine is shown also by a section consisting of carbonates 80%, garnet 10% and cummingtonite, the ore minerals being sphalerite, pyrite and galena. 15% of the minerals are altered to serpentine.

From the study of its mode of occurrence at Balmat and Britannia where both gypsum and barite are present, Osborne concludes that: "Anhydrite may appear as a peripheral phase of the alteration near zinc-lead deposits", and that: "The geographical distribution coupled with the evidence that anhydrite occurs near mineral deposits in non-sulphate bearing country rock suggest that it is of magmatic origin" (1), by reaction of acid waters on calcareous beds.

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(1) Osborne, F. Fitz, Anhydrite and Gypsum at Calumet Mine, Calumet Island, P.Q., In Press.

ECONOMIC GEOLOGY

Mineralization.

Mineralization is found at three different horizons at the mine, but there is a single ore-body of economic importance in the biotite and injected biotite gneisses near the contact with the carbonate amphibolites. Closely spaced diamond-drill holes indicated about 1,500,000 tons of ore averaging 2.51% of lead, 8.16% of zinc, 0.036 ounces of gold and 5.76 ounces of silver. About 86,000 tons of ore containing 18% of zinc and $6.90 in gold and silver were also reported (1). A second zone of mineralization called the Longstreet zone similar to the first one and apparently connected to it, is found to the east in amphibolites. Diamond drilling however did not disclose any important ore body. The third zone is along the river where disseminated sulphides occur in streaks in the limestone. One diamond-drill hole 3,000 feet east of the limestone reached that horizon and disclosed same mineralization indicating possible continuity.

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(1) Osborne, F.Fitz., Report under preparation.

Structural Relations of the Bowie Ore-Body.

The shape, attitude and relationship to the Country rock of the main ore-body known as the Bowie ore-body, were fairly well established by drawing vertical sections along lines of diamond-drill holes one-hundred feet apart, the holes being spaced one-hundred feet and in some instances being as close as fifty feet.

The ore-body is found to consist of a lenticular layer occurring almost entirely in the biotite and injected biotite gneisses at or near the contact with the overlying amphibolite. It is conformable in strike and dip with the gneisses, striking N 55° W and dipping between 25° to 30°E. Other small lenses and sheets are found also below and above or in the extension of the main ore body near the surface. These are usually associated with granitic lenses which they seem to replace.

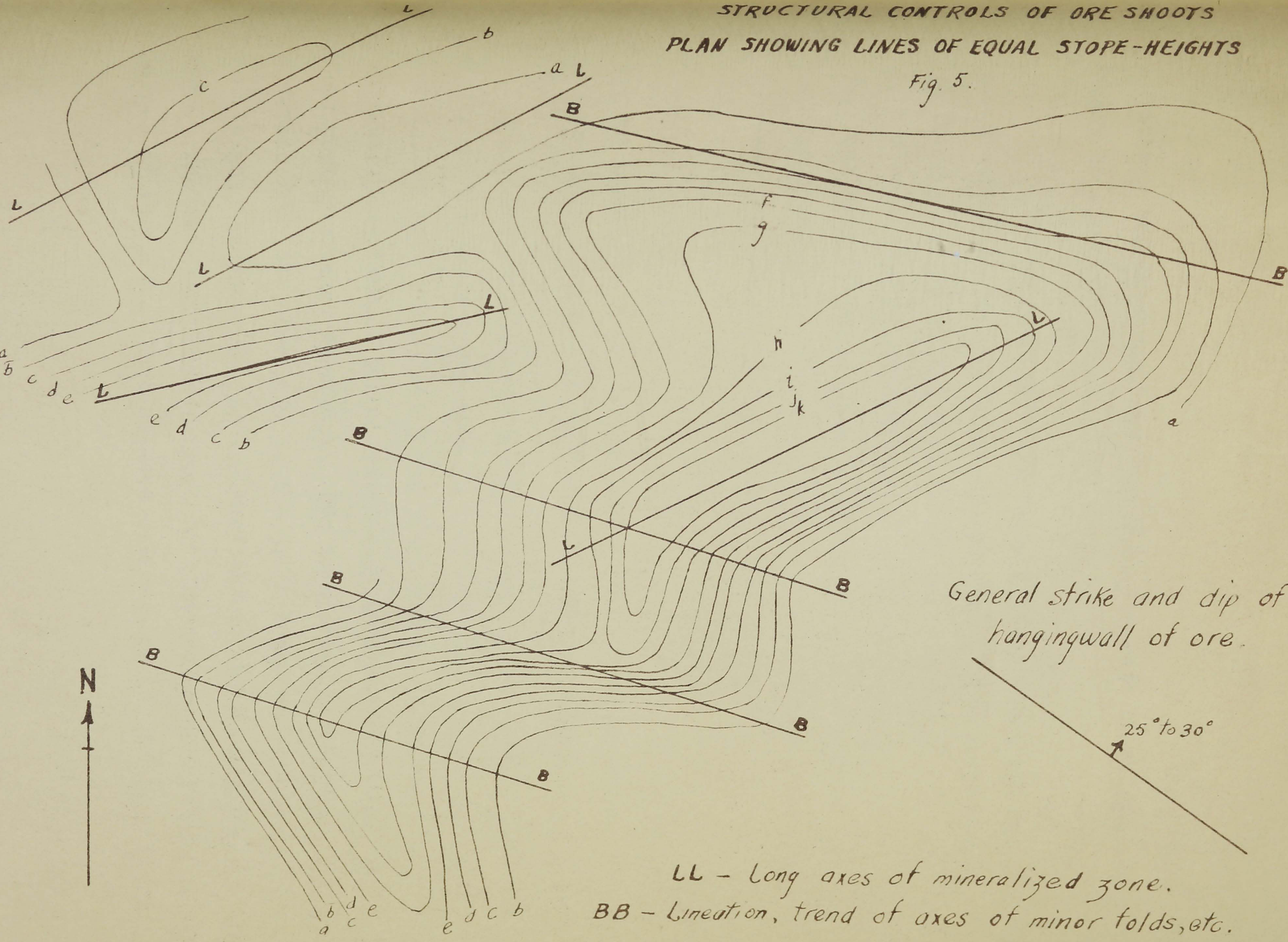
Minor ore-bodies to the north along this zone and showing the same conformity with the gneisses on surface are believed to have similar structural relations that the Bowie ore-body has.

The more important feature of the Bowie ore-body is the elongation in the direction N 65° E as shown by the

STRUCTURAL CONTROLS OF ORE SHOOTS

PLAN SHOWING LINES OF EQUAL STOPE-HEIGHTS

Fig. 5.



General strike and dip of hangingwall of ore.

LL - Long axes of mineralized zone.

BB - Lineation, trend of axes of minor folds, etc.

thickness contours map (see Fig. 5), the rake or plunge being about 25°.

The second important feature about the shape of the ore-body is the direction of the axes of the large warps, striking a little south of east. It coincides with the one of the same element of structure in the hanging-wall, with the long axes of the mineral and even with the strike of the diabase dyke. This direction observed to be fairly constant all over the island, is the direction of lineation. It is then justifiable to conclude that this direction does not coincide accidently with the lineation, but that the lineation was an important factor in the determination of the shape and possibly also the localization of the ore.

The distribution and the shape of the various rock units on the surface map seem to indicate that the rocks were acted upon by a tangential force resulting in a northeast - southwest compression force, that squeezed the rocks in a northwest-southeast direction. The tangential force is inferred from the convexity to the east of the massive amphibolite and the convexity to the west of the rocks of the ore zone. The ore-body is sandwiched between two irregular flat lenses of rocks that have escaped complete migmatization and striking at right angle to the hypothetic compressive stress. The plunge of the ore-body is in the direction of the force.

Apparently the amphibolites of the hanging-wall were quite plastic on account of the carbonates present and were less susceptible to injection than the biotite gneisses below. Most likely the difference of brittleness between the resulting two types of rocks was responsible for the location of a fracture at their contact which fracture was later filled by the ore-bearing solutions. The amphibolites being more plastic than the underlying gneisses further acted as an impervious wall preventing the escape of the mineralizing solutions so that the amphibolites can be considered as having played the most important role in the emplacement of the ore-body.

Ore and Gangue Minerals.

The ore consists of a medium-grained aggregate of sphalerite, pyrrhotite, marcasite, pyrite, galena, chalcopyrite, arsenopyrite, tetrahedrite and others in approximate order of abundance. Molybdenite is found in small amount. Native gold was reported, but usually gold and silver occur with the sulphides.

The gangue minerals consist of the following contact metamorphic silicates: cummingtonite, diopside, light coloured phlogopite and dark biotite. Calcite, dolomite and iron bearing carbonates are abundant. Scapolite, serpentine, chlorite and talc are found in small amounts. Some commercial ore occurs also in the country rock.

The sulphides are widely disseminated in the gneisses below the hanging-wall of the main ore-body. Near the contact with the hanging-wall they are concentrated into irregular undulating and branching bodies up to 70 feet of thickness of ore of commercial value with few thin sheets in the hanging-wall itself. In these bodies, the sulphides are irregularly distributed, being present as disseminated grains or massive lenses separated by almost barren quartz, calcite and leucocratic gneisses.

Paragenesis.

The paragenesis of the sulphides as determined by Moorhouse is the following: Pyrite (and arsenopyrite ?), sphalerite, pyrrhotite, galena, chalcopyrite, tetrahedrite. Marcasite replaces pyrite and pyrrhotite, its relation with the other sulphide is not known. Marcasite is always considered a low-temperature mineral of the supergene zone and its association with pyrrhotite, a high temperature mineral, is a peculiarity of this deposit. On the other hand, serpentine, replacing pyrrhotite, phlogopite and amphibole, and occurring also as veinlets cutting the other minerals and sulphides is found as rim around marcasite grains. Both marcasite and serpentine must be due to paulopost alteration.

The ore minerals replace all the other minerals, in preference the ferromagnesians to quartz and feldspar when occurring together. The age relation of the carbonate is not very clear, the contact-metamorphic silicates and the ore minerals are replacing carbonates either present originally in the gneisses or introduced by solutions. Osborne favors the second hypothesis. In the amphibolites, however, he believes that some of the carbonates are original but that the rest is younger than the silicates.

Pink pegmatites are common within the ore zone. The relation of these pegmatites with the contact silicates is not clear, but some sulphides replace the minerals of these pigmatites, so that the solutions producing granitization, contact silicates, pegmatites and ore might have been closely related to the pink granite, the only one younger than the regional metamorphism.

Type of Deposit.

The presence of high temperature minerals like pyrrhotite, pyrite, and arsenopyrite, in a gangue of contact metamorphic silicates like lime amphiboles, pyroxene, biotite, garnet and others, and the irregular shape of the ore-bodies are characteristic of high-temperature metasomatic deposits.

The widespread mineralization in the injected biotite gneisses and the presence of a zone of mineralization in the limestone along the river near the contact with the granitic migmatites indicate a close relation between the magmatic material introduced and the deposition of the sulphides.

SIMILAR DEPOSITS IN THE GRENVILLE SUB-PROVINCE OF THE CANADIAN SHIELD AND THE ADIRONDACKS OF THE UNITED STATES.

The Tetreault Mine, Notre-Dame-des-Anges, P.Q. (1)

Grenville garnet - biotite-sillimanite paragneisses make the bulk of the rocks of the ore that consists also of quartzites and limestone. The rocks are intruded by granite and grandiorite gneisses, amphibolite dykes and sills, and pegmatites.

The ore zone, about three thousand feet long, is along a narrow overturned syncline of Grenville paragneisses and limestone surrounded by migmatites and is associated with amphibolite dykes. The siliceous paragneisses were altered to cordierite-anthophyllite while the carbonates yielded tremolite and diopside (skarn rock) from replacement by solutions rising through a shear zone concordent with the axial plane of the fold. The principle metallic minerals are sphalerite, galena, pyrrhotite, and chalcopyrite. Tetrahedrite, stibnite, molybdenite, and arsenopyrite are of sporadic occurrence. The ore-bodies occur in calcium bearing silicates and to a minor amount in the cordierite-anthophyllite rocks.

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(1) Tetreault Mine, Montauban-les-Mines, Portneuf County, P.Q. by John J. O'Neill and F. Fitz. Osborne, Quebec Bureau of Mines, P.R. No. 136, 1939.

N.L. Wilson, op. cit.

The ore has replaced a band of limestone. The structure and the type of rocks were important factors in the formation of the ore bodies.

About 1,100,000 tons of ore have been mined of which 120,000,000 lbs. of zinc, and 40,000,000 of lead were extracted.

Long Lac Mine. (1)

The mine is located in Frontenac County, Ontario, about 42 miles northwest of Kingston. The rocks of the surrounding region are of the typical Grenville type and consist of crystalline limestone, quartzite, paragneisses and green schists, intruded by gneissic gabbro and diorite intruded in turn by granite.

The one occurs as lenses or is disseminated in a belt of coarsely crystalline limestone varying in width up to 400 ft. and 4,000 ft. in length dipping steeply and enclosed in gneissic diorite and gabbro.

The ore consists of sphalerite with varying amounts of pyrite, pyrrhotite and small quantities of galena and

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(1) Alcock, F.J., Zinc and Lead Deposits of Canada, Geol. Surv. Can., Eco. Geol. Ser. No. 8 , 1930.

chalcopyrite. The chief gangue is the calcite of the limestone but diopside, quartz and calcite veins are also associated with the ore.

F.J.Alcock considers that the deposit has an origin similar to the one of Calumet and Tetreault and that the solutions came from the intrusive granite intruded after the metamorphism of the limestone.

Renfrew Zinc Prospect. (1)

The deposit is located about thirty miles southeast of Pembroke in Renfrew County, Ontario. The rocks are Grenville sediments consisting mainly of limestone with tremolite and phlogopite. Bands of quartzites and sedimentary gneisses represent metamorphozed plastic beds in the limestone. With these rocks are associated amphibolites interbanded with or intruding the limestone. All the rocks are intruded by pink biotite granite and to a minor amount by pegmatites.

The ore occurs disseminated in the Grenville limestone and consists of sphalerite and galena with small amounts of pyrite and chalcopyrite. The gangue minerals are calcite, tremolite and diopside. Most of the ore is of low grade.

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(1) Alcock, F.J. op. cit., pp. 132-136.

It is a contact metamorphic deposit formed by excess of granite intruding limestones and accompanied rocks. It is similar to the one of Montauban.

The Balmat and Edwards Zinc Mine of the Adirondacks of United States. (1)

Balmat mine is 12 miles south of Edwards mine. The rocks of the district are all of pre-Cambrian age. The sedimentary rocks consist of garnet gneisses and limestone and the igneous rocks of gabbro, amphibolites, syenite and granite. The major feature of the structure is a dome slightly overturned.

At Balmat the ore-deposit is about three thousand feet long and consists in the replacement along bedding of an impure dolomite layer intercalated in a dominant limestone series. The ore minerals consist of sphalerite 19%, pyrite 18%, calcite 1.29% and accessories such as willemite, pyrrhotite and chalcopyrite. The gangue minerals are calcite and dolomite, garnet, diopside, tremolite, quartz and mica. Barite, anhydrite and gypsum are post-ore. The hydrothermal altercation minerals are talc from tremolite and diopside,

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(1) Brown, J.S., Structure and Primary Mineralization at Balmat Zinc Mine, Eco. Geol., vol. 31, No. 3, pp. 233-58, 1936.

and serpentine replacing the diopside.

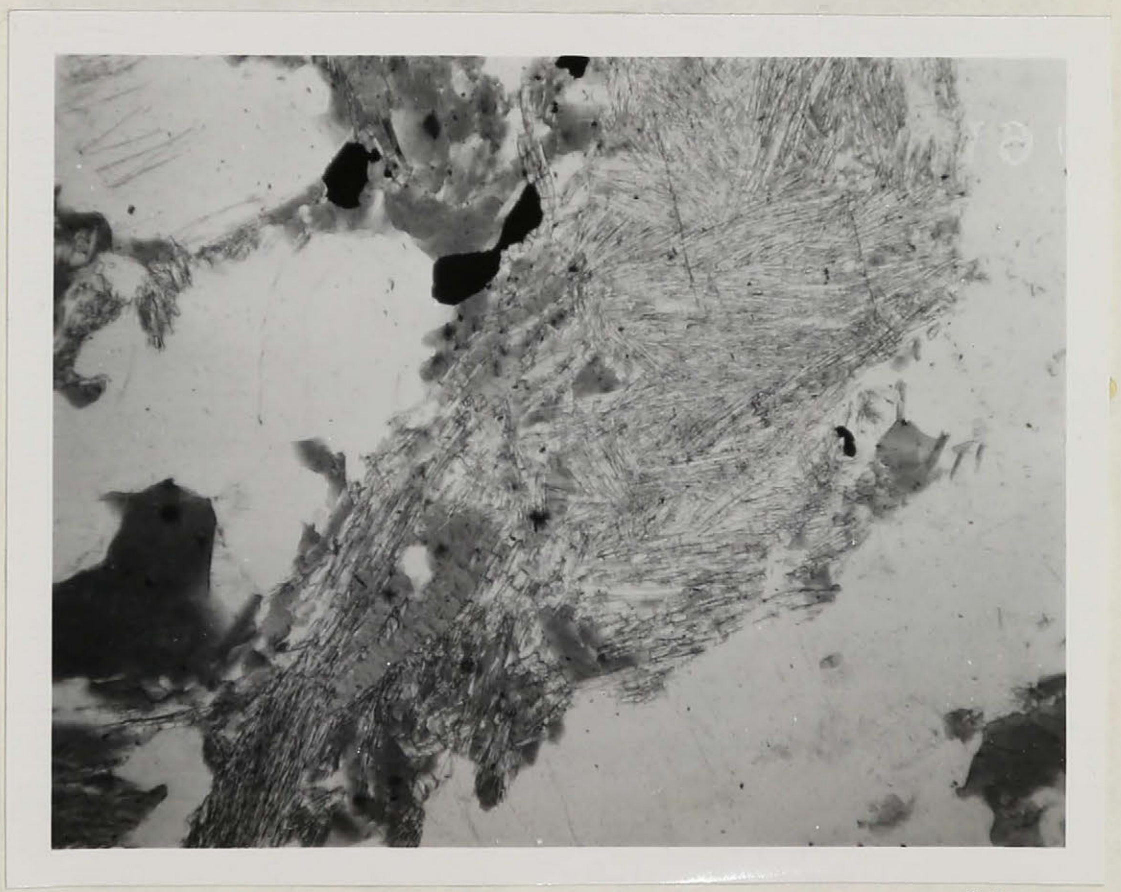
The Edwards deposit is similar to the one just described. Brown believes that the solutions that form these ore-deposits were derived from an underlying igneous mass of pre-Cambrian granite.

Fig. 1. x35
Texture of highly injected biotite gneiss. The predominating minerals are quartz and anorthoclase (a).

Fig. 2. x 108
Section showing the peculiar appearance of anorthoclase (cryptoperthite ?) under X nicols. The concave outline of the crystal suggests replacement by quartz.

X 108

Fig. 3.
Injected biotite gneiss. Two crystals of anorthoclase ressembling microcline are shown at the bottom right and left of the picture. Grains of iron sulphides (black) are abundant.



X35

Fig. 4.
Bundle of sillimanite needles (fibrolite) replacing mica with numerous dark pleochroic haloes around small inclusions.

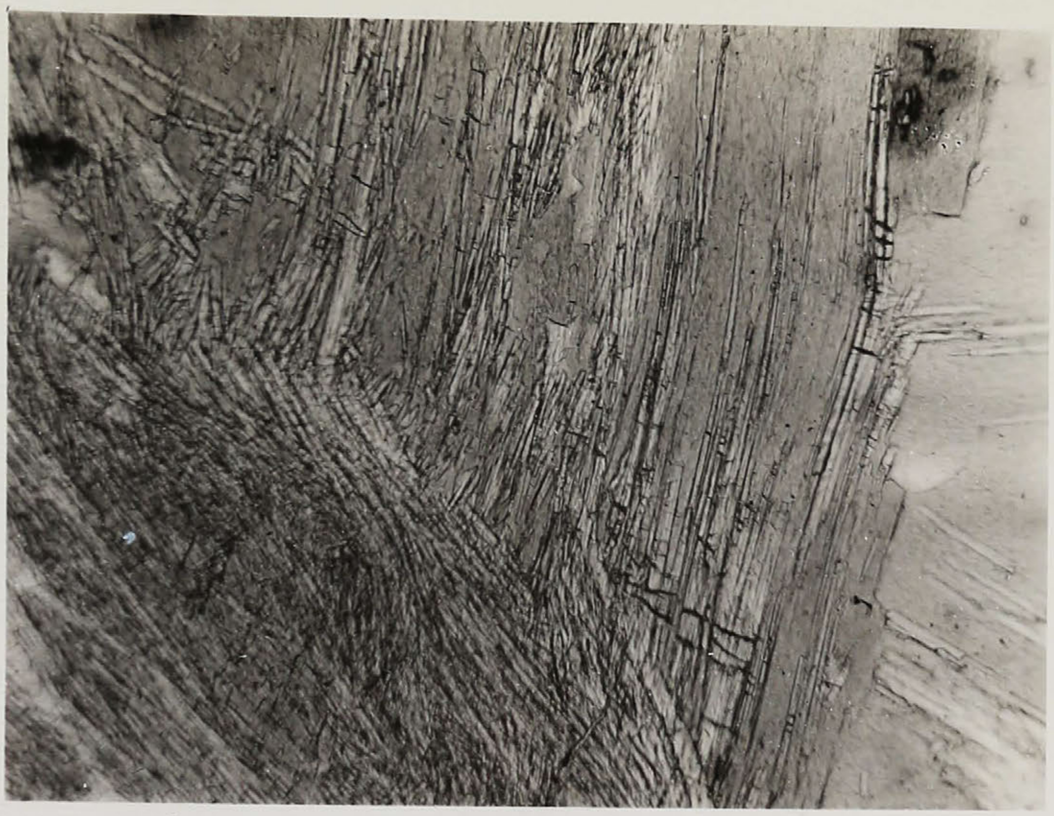
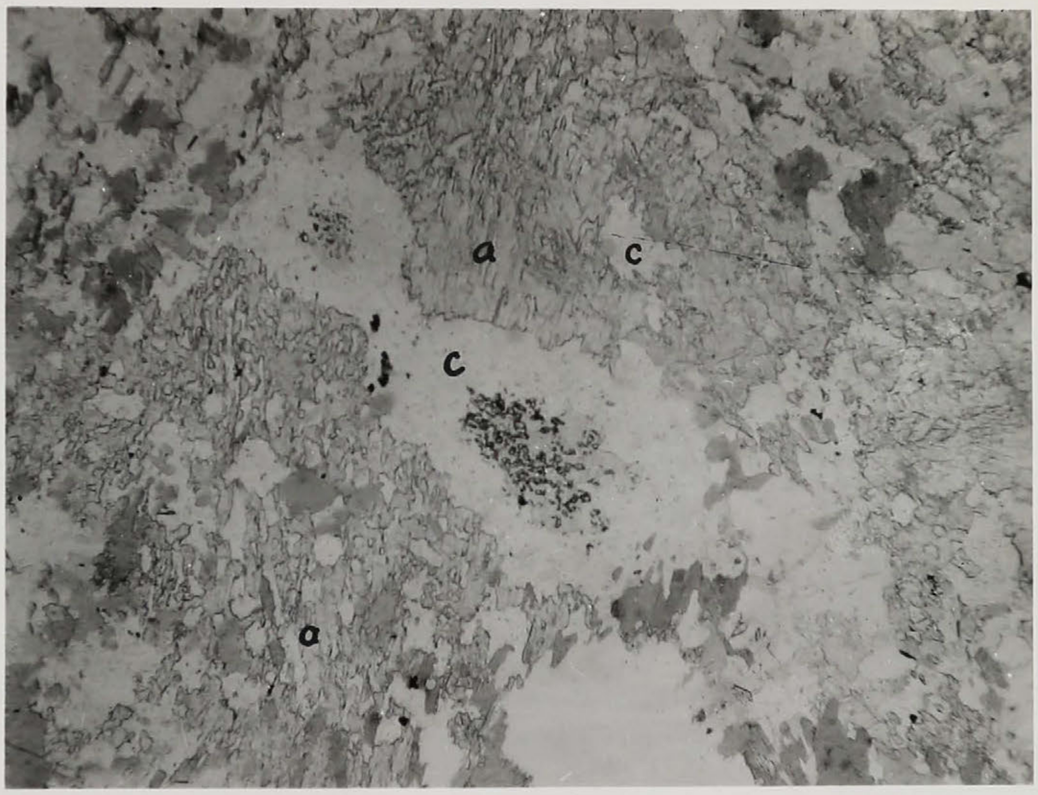


Fig. 5. X 108

Same as Fig. 4 (enlarged). One pleochroic halo (top right).



X 35

Fig. 6.

Eye structure in anthophyllite? - cordierite-biotite-plagioclase association with isotropic grains in the centre of the eyes. Anthophyllite (a), cordierite (c).

Fig. 7. X35

Typical texture of plagioclase (p) - cummingtonite (c) - biotite (b) - hornblende (h) - andradite (a) amphibolite.

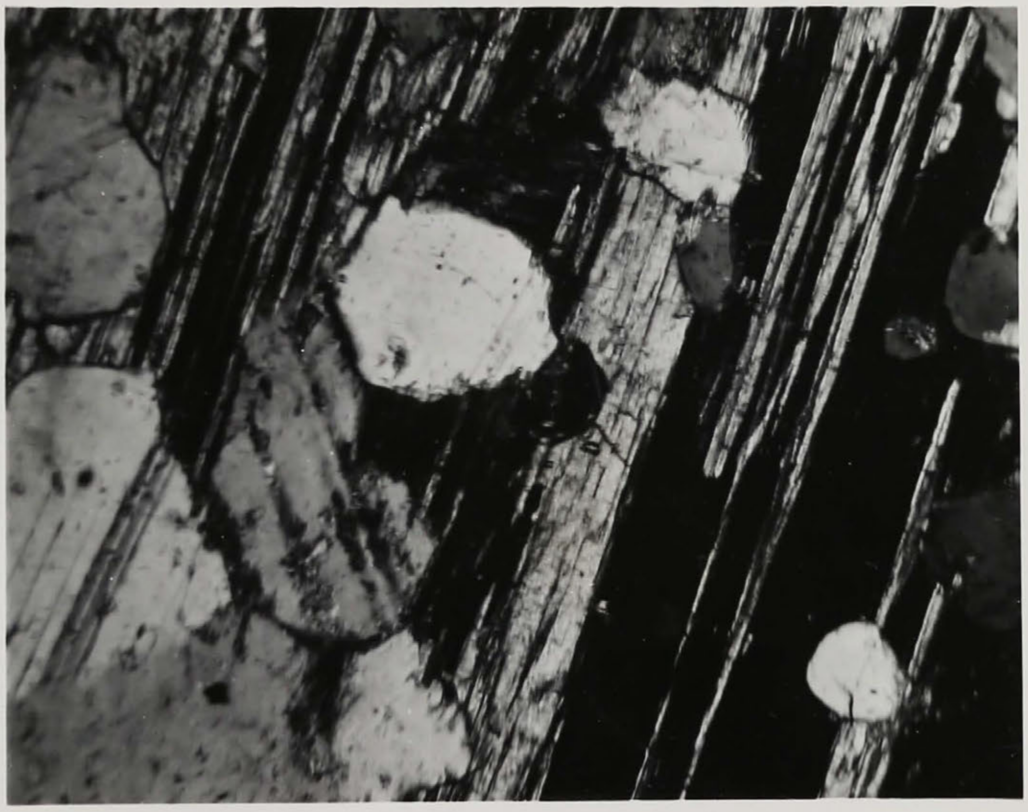


Fig. 8. X108

Twinned crystal of cummingtonite with inclusions of plagioclase.

Fig. 9 . X 108

Hornblende replaced by cummingtonite. Two dark pleochroic green spots A and B with closely spaced parallel lines and same optical orientation, are left in the central part of the crystal.

Fig. 10. X 108

Pyroxene (p) replaced by hornblende (h) in turn replaced by cummingtonite (c), the whole system replaced by plagioclase (white).

Fig. 11. X35
Section showing the typical texture of pyroxene and carbonate amphibolite. The minerals are pyroxene (p), carbonate (c), hornblende (h) and acidic andesine (a).

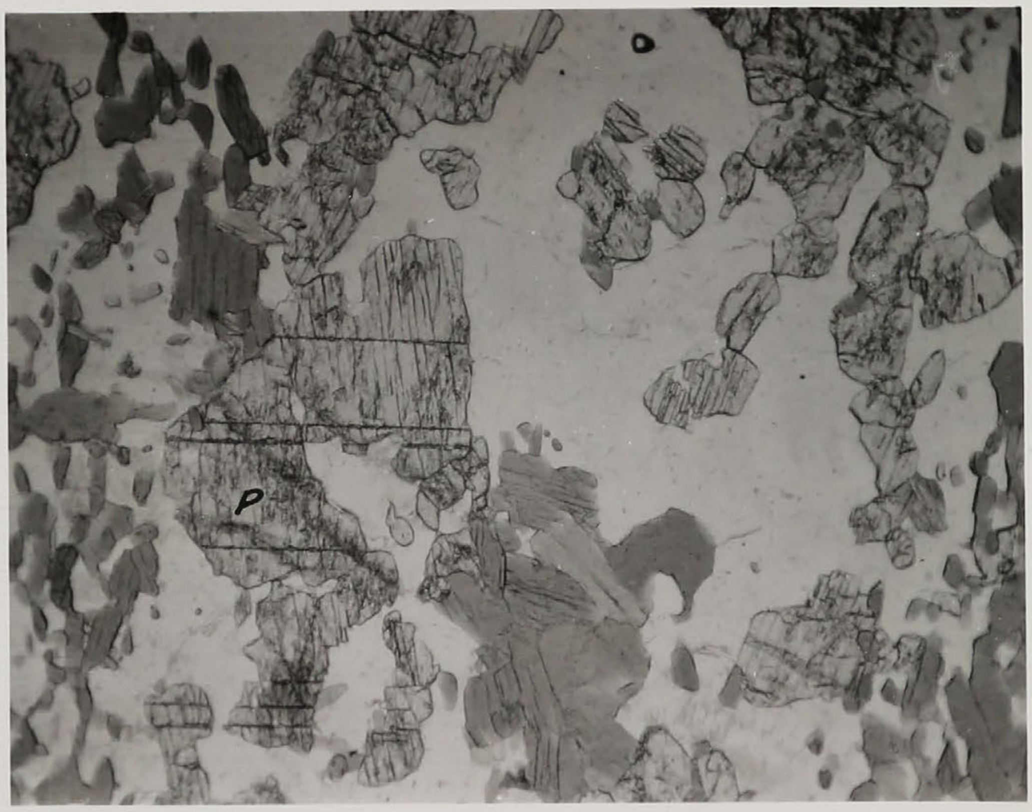
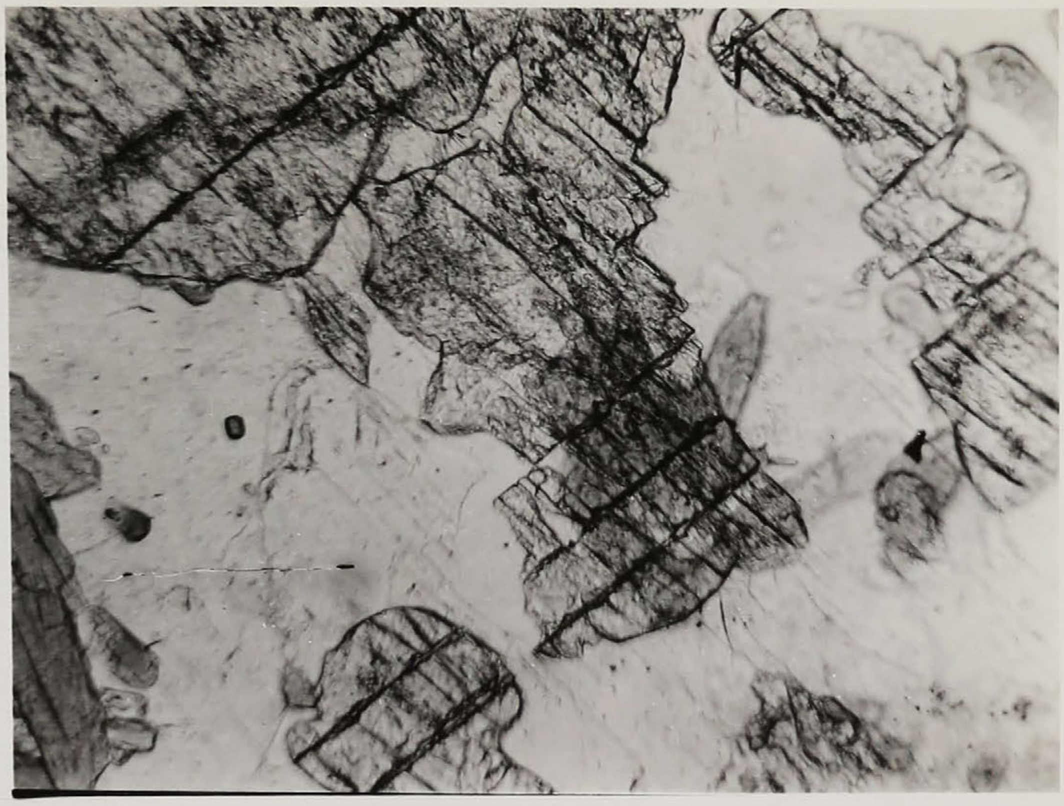
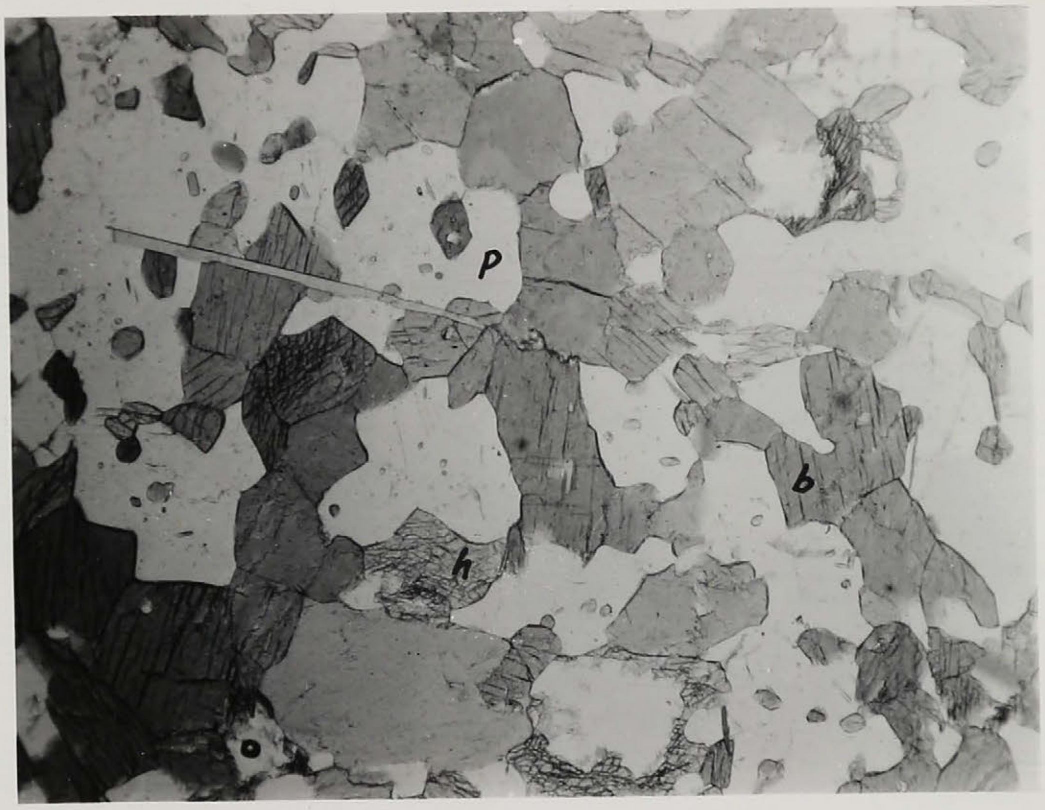


Fig. 12. X35
Scapolite-bearing pyroxene amphibolite. A porphyroblast of pyroxene (p) with basal parting to the left, and small rounded grains of pyroxene (top right). The white mineral is scapolite, the third one is hornblende.



X 105

Fig. 13.
Section showing evidence of replacement of pyroxene (dark grey) by scapolite (white).



X 35

Fig. 14.
Plagioclase-hornblende-biotite amphibolite with granoblastic texture. Plagioclase (p), hornblende (h), biotite (b).

Fig. 15. x35

Typical texture of injected amphibolites overlying the pyroxene amphibolites of the hanging wall. The minerals are: plagioclase, quartz, pyroxene (top centre), carbonate, biotite, sphene, garnet and apatite.

Fig. 16. x35

Wilsonite (w) untwinned cummingtonite (c), granular diopside (d) and carbonate (cb).

Fig. 17. x 35

Relation between anhydrite (a), diopside (d) and carbonate (c). The concave outline of carbonate crystals seems to indicate replacement by anhydrite.

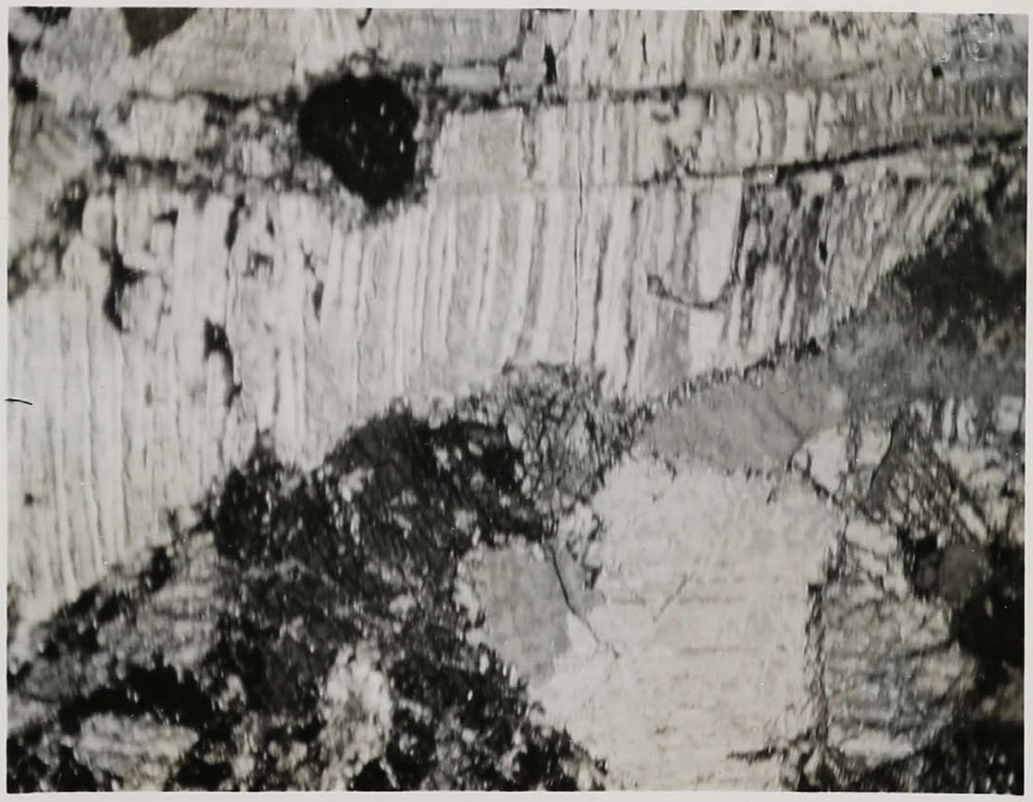


Fig. 18. x 35

Anhydrite replaced by gypsum forming rims around the former. Carbonate and pyroxene are also present. The peculiar appearance of anhydrite is apparently due to deformation of crystal in grinding X nicols.

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GEOLOGY OF CALUMET MINES LTD

Thesis submitted to the Department of Geological
Sciences of McGill University in partial fulfilment of the requirements for the Degree of
Master of Science

By

Pierre Mauffette

Montreal, May 3rd, 1941.

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INTRODUCTION

PART I

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PART II

THE CALUMET LEAD AND ZINC MINE

INTRODUCTION

Location.

The lead and zinc deposit described in this thesis is at Calumet Island, Pontiac County, Province of Quebec, about fifty-eight miles northwest of Ottawa, The deposit occurs on the southwestern part of the island, on lots 3 to 12, range IV.

The railroad station near the island is Campbell's Bay, on the north shore of the channel, on a branch line of the Canadian Pacific Railway. From this station a four mile motor road runs south to Bryson where a bridge crosses to the island. Campbell's Bay can be reached by a ferry from Calumet Island village.

References.

Data on the zinc production of Calumet Island since 1892 are in the annual reports of the Government of the Province of Quebec and the Geological Survey of Canada. In all, about 1200 tons of ore were shipped from the property, most of it before 1900.

INDEX-MAP

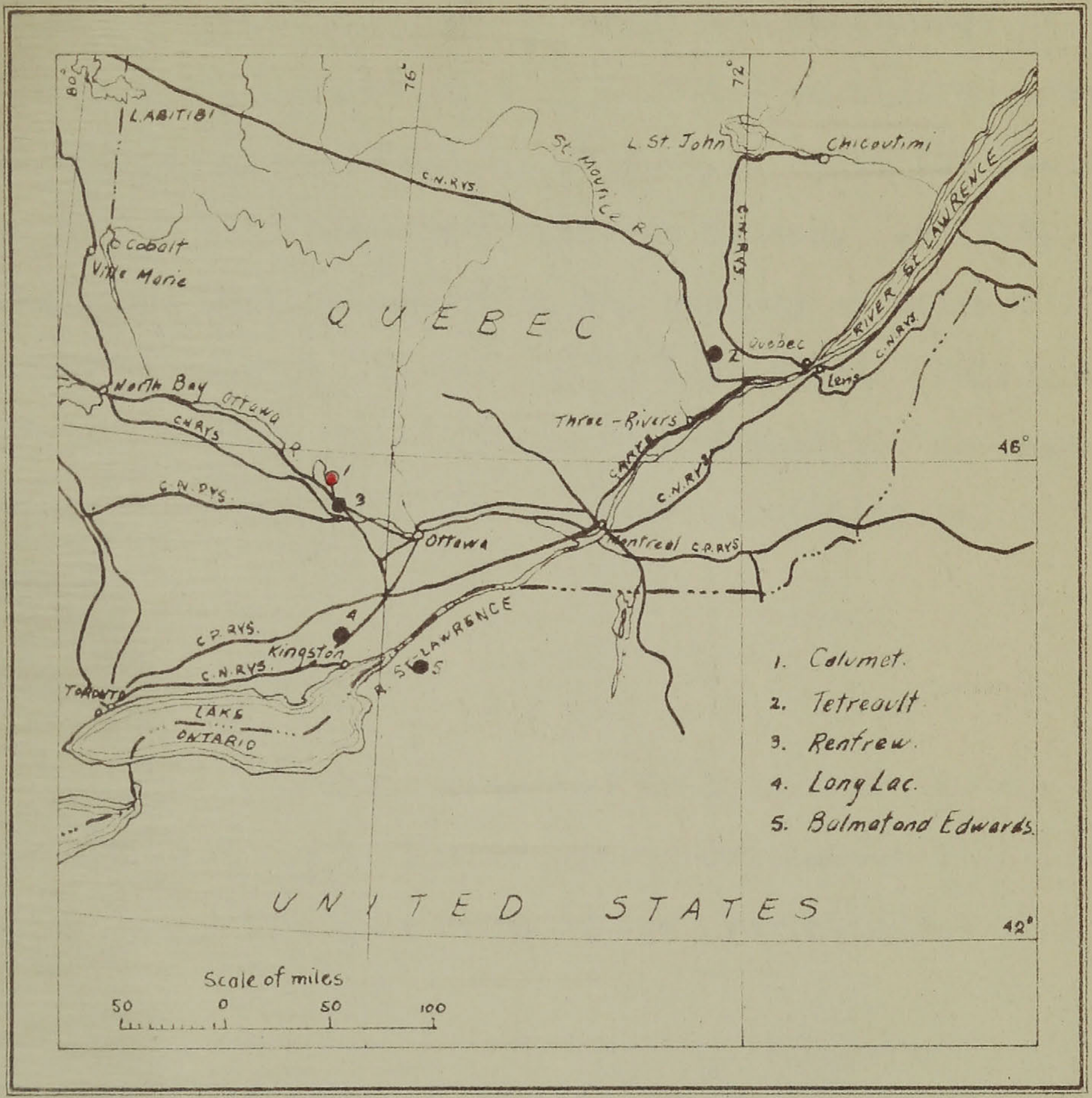

FIGURE I

Index-map showing the location of the Calumet property, and the relative position of the other similar deposits in the Grenville sub-province of Quebec and Ontario in Canada, and of the Adirondacks in United-States.

In 1908, a report in which the occurrence of ore is mentioned was published by R.W. Ells (1) on a large area including Calumet Island. In 1916, W.L. Uglow (2) described the lead and zinc deposit of Calumet Island. In 1925, R.W. Goranson (3) wrote a report on the geology of Calumet Island accompanied by a geological map of the island. During the summer of 1939, F. Fitz Osborne (4) revised the geology of the southern part of the island and made a detailed map of the outcrops.

History of the Deposit.

The property was staked in 1893. In 1897 it was operated by the Grand Calumet Mining Company of Ottawa who shipped to Belgium 1,100 tons of ore averaging 32% zinc and

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(1) Ells R.W., Geology of Portions of Pontiac, Carleton and Renfrew Counties, Geol. Surv. Can., Rept. No. 977.

(2) Uglow W.L., Lead and Zinc Deposits in Ontario and Quebec and in Eastern Canada, Ont. Bureau of Mines, Vol. XXV, pt. 2, pp. 5-7, 1916.

(3) Goranson R.W., Calumet Island, Pontiac County, Geol. Sur. Can., Summ. Rept., 1925 C, pp. 105-124.

(4) Osborne F. Fitz, report under preparation.

9% lead. In 1911, a concentrating mill with a capacity of 150 tons was erected, but it burned soon after. The British Metals Corporation of Canada in 1926 took an option on the property and did some work but soon after let the option lapse. In 1937, the Calumet Mines Limited acquired the property and started a program of diamond drilling under the supervision of Dr. Paul Armstrong. More than two hundred holes were put down with an aggregate length of about 80,000 feet.

Acknowledgements.

The author is indebted to Dr. F.Fitz Osborne of the Department of Geological Sciences, McGill University, for his kind assistance in the preparation of this thesis. Personal communications from Mr. W.W.Moorhouse, graduate student at Columbia University, were highly appreciated.

SOUTHERN PART OF CALUMET ISLAND
PONTIAC COUNTY

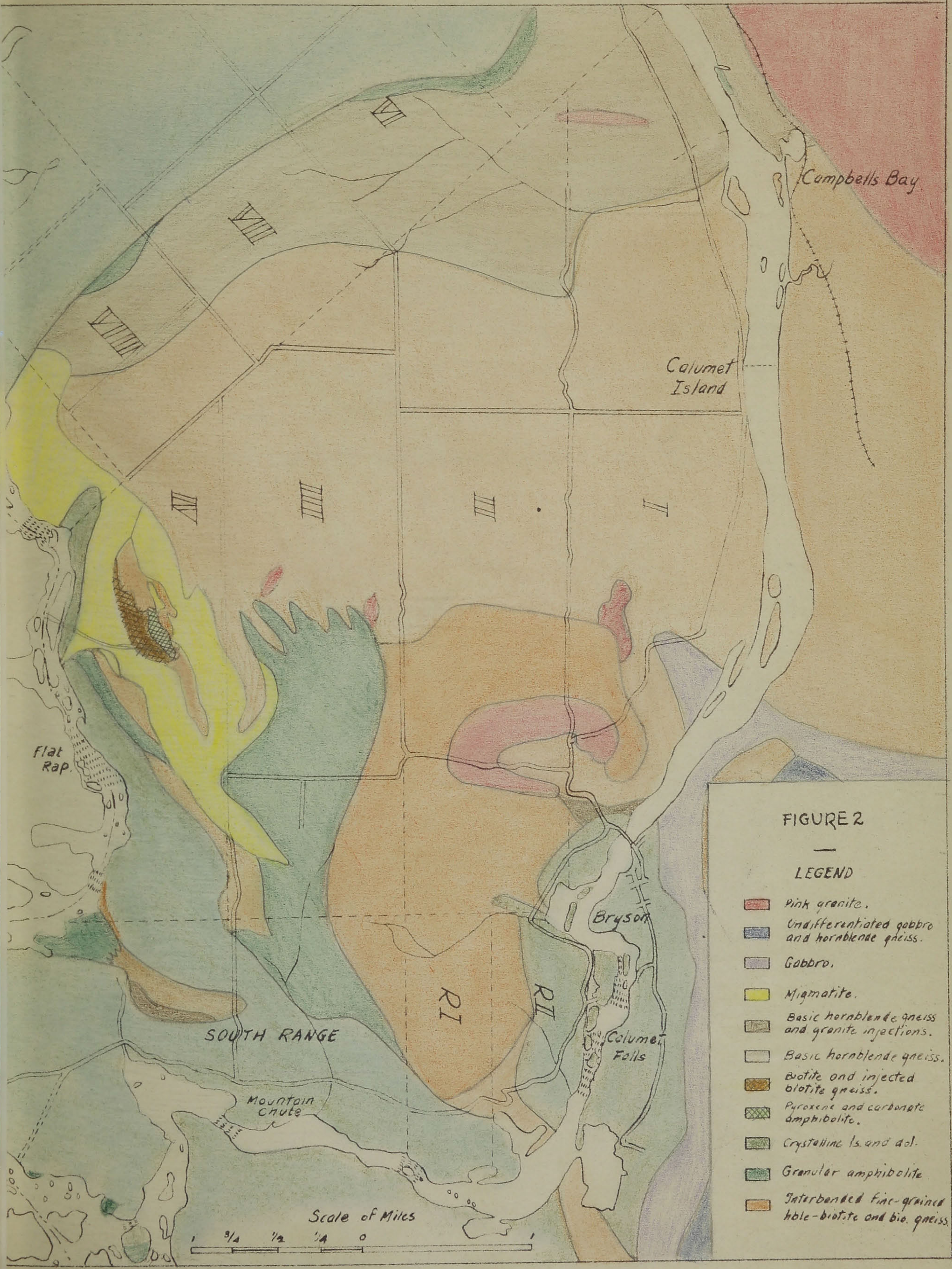

FIGURE 2

PART I

GENERAL GEOLOGY

The southern part of Calumet Island is underlain by rocks of the Grenville series consisting of crystalline limestone, biotite and amphibolite gneisses, and their injected equivalents. These rocks are intruded by Buckingham gabbro and granite of the Morin series. Aplites, pegmatites. lamprophyres and diabase dykes are found occasionally. In the northern part of the island these rocks are covered by Paleozoic limestones.

The geology of the area is quite complex. Of many types of rocks shown on the regional map, it is believed that they were only few originally but, due to metamorphism and injection of grantic material, the rocks have been altered to such an extent in their mineralogical composition, and their structure has been so modified that their original composition and structural relation can be treated only approximately before a detailed mapping of the adjacent area is available.

Osborne considers that the rocks now making the Grenville paragneisses consisted originally of impure argillaceous sedimentary rocks with intercalated limy or magnesian beds passing by gradation into relatively pure limestone with minor clastic zones at the base of the limestone. He assumes that the limestone is at the top of the series referring to a statement by Ells (1) that the limestones are near the top of the Archean, and by correlation with the limestone in the type locality for the Grenville limestone, where it appears to stand higher in the series than the quartzites and the gneisses.

Summary of the Geological History.

Osborne (2) summarizes as follows the geological history:

1. Grenville sedimentation of clastic and impure carbonate beds followed by limestone.
2. Folding and overturning of the Grenville series. Formation of amphibolite and gneisses.
3. Migmatization of the rocks yielding a pseudomorph of the older structure.
4. Migmatization controlled by the east-west shearing tending to obliterate the earlier structure.
5. Injection of Buckingham gabbro.
6. Injection of pink granite with accompanying diopsidation.
7. Injection of aplites and pegmatites.
8. Formation of ore at Calumet Mines property.

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(1) Ells R.W., *op. cit.*

(2) Osborne F. Fitz., *op. cit.*

9. Injection of lamprophyre and diabase dykes.
10. Erosion.
11. Deposition of lower Paleozoic rocks (evident on north part of island.)
12. Faulting.
13. Erosion.

Grenville Limestone.

By regional metamorphism, the limestone was recrystallized to a medium- to coarse-grained crystalline limestone. There are thin beds of finer-grained siliceous dolomitic material. Some layers are entirely replaced by silicates consisting of diopside and serpentine, accompanied by others such as tremolite, phlogopite, scapolite, chondrodite and titanite, from impurities in the original sediments and addition of material of magmatic origin. These silicate minerals occur as disseminated grains and pockets and are quite abundant in places, diopside forming sometimes important masses. The original bedding has been practically all destroyed and is now replaced by a well-defined schistosity in general parallel to the contact with the silicates rocks; layering and schistosity may be mistaken for bedding. At or near the contact between the limestone and the gneisses are bands of amphibolites.

Beds containing anhydrite and gypsum were intersected in drilling at the mine. Brucite is a common accessory mineral in the southern part of the island, locally it is sufficiently abundant to be considered as a possible source of magnesia according to Osborne.

Moorhouse noted that serpentine is associated with calcite in the dolomite. This is probably according to the process of de-dolomitization suggested by Adams in the following equation:

$$\underset{\text{(dolomite)}}{CaMg(CO_3)_2} + 2SiO_2 = \underset{\text{(diopside)}}{CaMg(SiO_3)_2} + 2CO_2$$

$$\underset{\text{(diopside)}}{3CaMg(SiO_3)_2} + 3CO_2 + 2H_2O = \underset{\text{(Serpentine)}}{H_4Mg_3Si_2O_9} + \underset{\text{(calcite)}}{3CaCO_3} + 4SiO_2$$

Biotite Gneisses and Granitic Migmatites.

The less calcareous members of the Grenville series yielded the biotite schists and gneisses, hornblende being formed in minor amount; in places however where there was more lime and magnesia in the sediments, the biotite gneisses pass gradually to amphibolites. The micaceous schists were apparently fissile and were easily injected by granitic material, in places accompanied by pyrite and pyrrhotite, and the resulting rocks are now represented by the granitic migmatites and the rusty-weathering gneisses, so called because of their rusty appearance on surface due to the oxidation of iron. Bands of highly granitic migmatites are found below and above the ore shoots.

Amphibolites and Related Hornblende- and Hornblende-Biotite Gneisses.

In the calcareous members of the series containing much lime and magnesia, pyroxene, amphibole, and medium calcic plagioclase were formed in abundance and various types of amphibolites resulted. These rocks were later metamorphozed to basic hornblende- and hornblende-biotite gneisses. The amphibolites show various structures; an important variety is gneissose and contains carbonates. In general, they are massive and resemble diorites in structure and texture. Some were injected to various degrees by the same material that formed the granitic migmatites. In places the layered character of the rock was destroyed and the rock is converted to basic or hornblende migmatite.

In general the amphibolites were not very susceptible to injection, and instead of being replaced like the biotite gneisses they yielded composite gneisses along their contact with other rocks or zones of strong shearing, and lit-par-lit gneisses resulted from the introduction of magmatic material along the foliation.

The amphibolites and related rocks underlie the greater part of the southern half of the island.

Granite.

At the north-east of the map is shown part of a large mass of granite on the mainland. In places it is strongly gneissic and contains inclusions; elsewhere it is pink and porphyritic. On the island, dykes, sills, and small masses of pink granite are quite common. Osborne mentions the case of a narrow dyke of pink granite cutting the gabbro half a mile north of the bridge to Calumet Island, with an alteration zone of 100 feet bounding it and the conversion of the gabbro to a granular diopside rock with veins of quartz and occasional crystals of phlogopite. Sometimes it injects the gneisses in the lit-par-lit fashion in certain zones, or the silicate rocks along their contacts with the limestone. In places it is injected along the east-west striking shear structure. The granite is assigned to the acidic part of the Morin or Pine Hill series.

Gabbro and Hornblende Gneisses.

A large area of gabbro and hornblende gneisses is shown on the south-east part of the map. Two small stocks cut the limestone west of Carswell's quarry. There is also a dyke of similar material near the north end of Bryson and this dyke outcrops also on the island across the channel.

The gabbro has a prevailing dark gray colour and a medium granularity; in some places however it is light coloured and coarse grained. This gabbro resembles the basic intrusions of the Morin and Buckingham series enough to be correlated to these.

Diabase and Lamprophyre.

A dyke of fine-grained diabase cuts the ore at the Calumet property. Another dyke is found on lots A and B, south range, on the island.

Small dykes of lamprophyre cut the ore zone and are found in a few localities in the region. The age relation between the diabase and lamprophyre is not known for certain although the lamprophyre is probably the older.

STRUCTURAL GEOLOGY

Little is known of the structural geology. The mapped area is small and the rocks are so intensively metamorphozed that most of the primary structures have been obliterated. Osborne mentions four structural elements in his report. The most conspicuous one is the banding as shown for instance by the rocks on the mountain at the south-eastern end of the island, where bands from 50 to 100 feet wide of fine-grained leucocratic biotite gneisses alternate with fine grained more mafic hornblende biotite gneisses.

In describing the limestone the assumption was made that it stands higher than the clastic sediments in the stratigraphic column. The limestone outcrops all around the southern part of the island and across the river on the mainland. On the east side of the island, the beds dip at low angle to the east, and the same relation is found for the ones outcropping on the west side of the island. It is then suggested that the structure is an overturned anticline to the west with its axis pitching south.

A third important structure is the shearing striking east-west and north-west south-east as indicated by the foliation and the schistosity. The east-west direction of shearing is better developed and is younger; in places, it has developed at the expense of the one striking north-west. At some places an older schistosity probably parallel to the bedding can be seen.

The last element is the constancy of the direction of the linear features such as the direction of the elongation of the crystals and the axis of plication over practically all the mapped area. This direction strikes east-west and pitches 20° to 30° east. This structure is superimposed on the others.

PART II

THE CALUMET LEAD AND ZINC MINE.

Foreword.

More than two-hundred diamond drill holes with a total length of more than eighty-thousand feet were put down at the Calumet property to prove the ore-deposit. The diamond drill cores were examined by F. Fitz Osborne for the Quebec Bureau of Mines, and vertical sections, in part completed by the writer, were made from his logging to correlate the various types of rocks encountered in drilling and to study the extent and attitude of the ore-bodies and the structure in general at the mine. Sixty-five thin-sections of representative samples picked up from the cores for petrographic study were examined by the author and the results of his study are included in the following pages.

Summary of the Local Geology.

The Calumet property is on the west side of the island, (see Fig. 2) on what is believed to be the west limb on an overturned anticline, if the assumption that the limestone is at the top of the Grenville series in this area, or of an overturned syncline in the other alternative.

The rocks have a general strike N 15° W and dip to the east at about 30°. From the river to the east in the vicinity of the Calumet Mine the succession of the different types of rocks is as follows: Limestone outcrops on the shore of the river with interbanded silicified layers, and amphibolites lenses near the contact with the granitic gneisses. It is overlain to the east by granitic migmatites followed by biotite and injected biotite gneisses also called the rusty-weathering gneisses, including various amphibolites and contact-metamorphic rocks and containing the main ore-body. Pyroxene and carbonate amphibolites form the hanging-wall of the ore zone of the mine. These amphibolites are overlain by a complex of amphibolite gneisses and migmatites followed by leucocratic injected gneisses less granitized than the migmatites overlying the limestone and forming two large masses, the one to the south being still less granitized. To the east, these rocks are followed by hornblende gneisses and porphyroblastic amphibolites similar to the massive amphibolites of the hanging wall. These rocks contain a minor zone of mineralization on which are the Longstreet shaft and the Belgian pit. These are followed in turn by siliceous hornblende and biotite gneisses including amphibolite lenses. Near the eastern boundary of the property are massive amphibolites in place injected to medium-mafic migmatites.

A diabase dyke cuts the rocks on the property from the river to the end of the amphibolites of the hangingwall of the ore zone. It is about one hundred feet wide, strikes N 80° W and dips about 75° N. Narrow trap dykes were intersected in drilling.

General attitude of the Rocks at the Mine.

Three types of rocks were intersected in drilling the ore-zone at the mine. These are from west to east: 1) the biotite and injected biotite gneisses, 2) the pyroxene and carbonate amphibolites, and 3) the amphibolite gneisses-migmatite complex.

A typical cross-section made from information secured from drilling shows the succession and attitude of the different rocks, the general shape and distribution of the ore-shoots and their relations to the country rock. (See Fig.3).

The most characteristic feature of this section from a structural point of view is the sill-like shape of the amphibolites forming the hanging-wall of the ore zone. This lenticular layer is quite irregular and is from one-hundred to four-hundred feet thick, but its general attitude is found persistent in all the sections made. The average dip of the hanging-wall is about 35°; the section shows however the different formations dipping more steeply near the surface and flattening downward to the east. This tendency is shown better by the trend of the ore itself and suggests drag folding in the vertical plane along the dip, the east part having moved upward.

The lower zone includes lenses of amphibolites and contact metamorphic rocks. Lenses of heterogeneous rocks are present also in the hanging wall and in the rocks above. The presence and distribution of these lenses indicate the complex character of the original sediments metamorphosed to rocks of various compositions still later modified by granitic injection.

PETROGRAPHY

1. The Biotite and Injected Biotite Gneisses.

Locally these gneisses are finely banded and extremely contorted thus clearly indicating their sedimentary origin, but more often they are massive on account of their intensive injection by granitic and siliceous material. This zone is quite complex; it includes numerous lenses of normal and cummingtonite-bearing amphibolites, contact metamorphic rocks and pegmatitic patches scattered throughout the gneisses. The ore-deposit is in these rocks near or at the contact with the overlying amphibolites. The gneisses are separated from the underlying garnet migmatites by a narrow band of normal amphibolite gneisses.

The rocks of this zone will be divided for petrographic description into three general groups: A - The quartz-anorthoclase-mica-sillimanite gneisses, called in the field the biotite and injected biotite gneisses, which are the more abundant, B - The amphibolite gneisses and C - The contact metamorphic rocks, the last two groups occurring as lenses in the first group. These will be subdivided again into different mineral associations based on microscopic examination.

A - The quartz-anorthoclase-mica-sillimanite gneisses.

It is excessively difficult to unravel the history of these rocks and to separate those that are due simply to the recrystallization of the original sediments from those that are the product of recrystallization plus injection. On surface the rocks that show banding are the least injected members and represent more closely the original composition of the sediments. They are fine-grained and consist of a quartz-feldspar mosaic with accessory mica and sillimanite. The injected type which is the more important consists of abundant quartz with potassic feldspars and all the minerals show evidence of replacement by quartz. One section only shows a cataclastic texture.

For practical purpose the quartz-bearing rocks although presenting different associations are grouped together with the exception of the rocks containing cordierite which will be described separately. They all contain mica and sillimanite in greater or less amount. When present, plagioclase is andesine. Anorthoclase (cryptoperthite?) was identified in most sections while microcline (?) and possibly also orthoclase (?) would not be common. Hypersthene was found in one section. Various sulphides are present, of these, pyrrhotite is the most abundant with pyrite and chalcopyrite.

Sphalerite, galena and graphite (?) are found also occasionally.

Microscopic Characters of Minerals.

Most of QUARTZ crystals have irregular rounded outlines. Some are fractured, others show parallel lines of gaseous or liquid inclusions, and in general fine sillimanite needles are uniformly distributed throughout the crystals. Biotite and iron sulphide grains are distributed at random and the crystals often present a sieve-like structure in the more extensive replacements. Quartz replaces all other minerals except sillimanite.

PLAGIOCLASE is andesine. Its composition varies from section to section between An_{32} and An_{49}. The crystals show usually albite twinning. They may have all kinds of inclusions and in the more injected types, they have numerous rounded grains and patches of quartz. They are slightly altered to sericite.

ANORTHOCLASE (cryptoperthite?) is very abundant in the quartz-bearing rocks, often it makes up to 35% of the minerals. Like quartz it includes sillimanite needles. The crystals which are sometimes quite large, have concave outlines due to replacement by quartz and often become interstitial to quartz when replaced more extensively. Sections normal to the Z-bisectrix give an extinction angle with (001) cleavage of about 7°, and in such sections almost submicroscopic pericline twinning lines can be seen making an angle of 75° with (001) cleavage, which is characteristic of anorthoclase. Sections normal to the X-bisectrix give an extinction angle of about 4° with (001) cleavage and show an acute-bisectrix figure indicating a medium axial angle. From an optic-axis figure, the axial angle is seen to be small and is estimated to be near 45° , which value is again characteristic of the mineral. The crystals have usually a peculiar appearance under the microscope that sometimes suggests microcline but the mineral is probably cryptoperthite (See p. 38). The crystals are slightly altered to sericite.

MICA - Light brown PHLOGOPITE is the most abundant mica. Its pleochroic formula is:

X = very pale brownish yellow (almost uncoloured).
Y = Z pale brownish yellow.

The axial angle is almost zero. Dark pleochroic haloes around small apatite (and zircon ?) grains are sometimes abundant. It is replaced by sillimanite and iron sulphides (See Fig.4) MUSCOVITE was found in few sections associated with phlogopite and is also replaced by sillimanite. One section shows biotite altered to chlorite through an intermediate high index product. Mica is replaced by quartz.

SILLIMANITE is the fibrolite variety. It occurs as fine needles crowded together with a sheaf-like arrangement. It replaces quartz and is intimately associated with biotite and occasional muscovite both of which it replaces. The mineral has a high index of refraction and a low byrefringence, it has parallel extinction, it is positive and almost uniaxial. The bundles of crystals usually develop with their axis at about right angle to the lines of inclusion in the other minerals, thus indicating more clearly its origin later to injection. It is also present as fine needles uniformally distributed in the other minerals.

MICROCLINE ? Crystals with scotch-plaid twinning are found associated with anorthoclase. Unfortunately these are not present in sufficient amount to check all the optical properties of the mineral.

APATITE is rare in the quartz bearing rocks.

IRON SULPHIDES occur along cleavage planes in biotite, or filling cracks in quartz and replace all silicate minerals. Pyrrhotite and pyrite are the more important. Their abundance in the quartz-bearing rocks indicates a genetic relation of the ore to the solutions producing granitization.

Cordierite-Bearing Associations.

An interesting group of associations includes cordierite. This mineral was identified in two thin sections within the present zone, and in another one in the amphibolites of the hanging-wall near the contact with the biotite gneisses. In each case the association is different. The two thin sections in the actual zone consist of the following minerals:

1. Quartz - cordierite - biotite - plagioclase.
2. Quartz - sillimanite - plagioclase - biotite - cordierite.

In the amphibolites the association is :

3. Anthophyllite - cordierite - biotite - plagioclase.

Associations 1 and 2 differ only by the presence of sillimanite in the latter. Association 3 is entirely different from the others and represents a metasomatic rock.

1. Quartz - cordierite - biotite - plagioclase association.

The section consists almost entirely of quartz with cordierite, plagioclase and biotite. Biotite is also included in the quartz crystals with pyrrhotite and pyrite. Quartz crystals show parallel cracks and lines of inclusions. Cordierite is in small colorless irregular rounded crystals interstitial to quartz or sometimes included in quartz. It has few yellow pleochroic haloes that disappear as the stage is rotated and these haloes furnish an obvious indication of the presence of the mineral. The crystals have short cracks normal to the edges and can be distinguished from quartz by a slight difference in their limpidity.

2. Quartz-sillimanite-plagioclase-biotite-cordierite association.

Quartz is again the most abundant mineral. Sillimanite occurs in slender prisms grouped together and also as grains replacing the other minerals especially biotite. Plagioclase An_{20} is slightly altered to sericite and is replaced by quartz. Biotite with pleochroic haloes around rutile grains is in fair amount and is accompanied by a little muscovite. Some of the biotite is altered to a green mineral (chlorite or serpentine) accompanied by a high-index and high birefringent negative uniaxial mineral (carbonate ?). Cordierite is in larger grains than in the previous association but is still in small amount. The crystals have small inclusions uniformly distributed. The optic sign is positive and the axial angle in near 80°. Pyrrhotite and pyrite replace mica.

3. Anthophyllite-cordierite-biotite-plagioclase association.

Cordierite is very abundant in this association. It is in anhedral interlocking crystals with the same characteristics as in the above associations and replaces anthophyllite. It is present also as small crystals forming the outside zone of medium size eyes having inside an uncoloured medium-index uniaxial negative mineral with birefringence colour of the first order (mica ?) including an uncoloured high index isotropic mineral (spinel or garnet ?) occuring as small angular grains grouped together near the centre of the eyes, apparently a secondary product of replacement; apatite sometimes accompanies the latter. Cordierite has more pleochroic haloes than in the above associations. It is quite possible that cordierite replaces mica in the "eye" structure. Large uncoloured crystals with elongated fibrous habit occuring in radiating aggregates and sheaves form about 40% of the minerals. It has pale yellow birefringence colour of the first order, parallel undulatory extinction, positive elongation, a large optic axis angle and a positive sign (?). The mineral is probably anthophyllite and the refractive index for Z being 1.64+ it would consist of meganthophyllite ($H_2Mg_7Si_8O_{24}$) 20 mol % and feranthophyllite ($H_2Fe_7Si_8O_{24}$) 80 mol % (1). Many crystals have black inclusions. It replaces biotite and it is replaced in turn by plagioclase, cordierite

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(1) Winchell, A.N., op. cit.

and quartz. The lines of fracturing of anthophyllite are preserved in the replacing minerals.

Remarks on the cordierite-bearing associations.

Until lately, cordierite was not known to be a common mineral in the Canadian Shield. It was described for the first time in Canada in 1910 by Adams and Barlow (1) from the Haliburton and Bancroft areas of Ontario, in association with gedrite. It is now mentioned quite often in the reports on the Adirondacks of United States. N.L. Wilson (2) described paragneisses from Montauban with cordierite and anthopyllite in which the presence of these two minerals vary from small amounts to rocks consisting entirely of cordierite and anthophyllite. In the Scandinavian countries it was described especially from Finland by Eskola (3). It is known also from the Waite-Amulet area of Abitibi where it is found in the dalmatianite related

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(1) Op. cit., pp. 157-172.

(2) An Investigation of the Metamorphism of the Orijarvi Type with Special Reference to the Zinc-Lead Deposits at Montauban-les-Mines, P.Q., unpublished Doctor's degree thesis, McGill University, 1939.

(3) Op. cit., pp. 1-277.

to greenstone.

The cordierite-anthophylite rocks are considered to be a product of magnesian metasomatism by Eskola in Finland and Wilson at Montauban.

At Calumet, cordierite is found in two different types of rocks; a metasomatic type (association No. 3) and an intensively silicified type (association No. 1 and 2). Both types result from injection of igneous solutions and since cordierite is found only in the more injected rocks it is logical to believe that magnesia was introduced by these solutions. Another hypothesis is that the various associations represent different degrees of replacement as a result of a variation in the composition of the sediments in which cordierite has developed from the recrystallization of agrilaceous layers deficient in lime, under the effect of thermal injection.

B - The Included Amphibolites.

The second group of rocks found in this zone consists of amphibolites. There are two principal types of associations grading one into the other:

a) The plagioclase-cummingtonite-biotite-hornblende ± garnet amphibolites.

b) The plagioclase-hornblende-biotite amphibolites.

Cummingtonite is developed typically near the contact of the rusty-weathering gneisses with the overlying carbonated and gneissic amphibolites.

a) The Plagioclase-cummingtonite-biotite-hornblende garnet amphibolites.

The texture is fine to medium. The minerals are arranged in allotriomorphic aggregates and a gneissose structure is common. Plagioclase is the most abundant mineral of these amphibolites, and its composition varies on a wide range from one section to another. The characteristic mineral is cummingtonite amphibole. Biotite is usually abundant but common hornblende less so. In some sections garnet is present where as in others, it is absent. Apatite and iron sulphides are also present. One section shows numerous veinlets of serpentine cutting the other minerals. Another one consists almost entirely of actinolite with few areas where the amphibole is bleached and replaced by cummingtonite. In these rocks quartz is absent.

PLAGIOCLASE is present as sub-angular to rounded irregular interlocking crystals. It may or may not show albite twinning and sometimes the crystals are fractured. Often they have inclusions of the associated ferromagnesian minerals. The composition varies between wide limits (An_{10} to An_{46}) from one section to another. The crystals are usually fresh but they are sometimes slightly altered to sericite.

CUMMINGTONITE is in elongated fibrous non-terminated crystals usually grouped together in bundles with the individuals oriented in the same general direction. It is found also replacing hornblende by bleaching, the structure of the latter being often preserved, and there is evidence that it replaces biotite. The mineral has a very pale brownish yellow tint but shows no distinct pleochroism. The crystals are twinned characteristically along planes closely spaced parallel to (100) and the mineral is easily identified by this peculiar twinning, especially when present in very small amount. The indices of refraction are:

$$X = 1.64 -$$
$$Y = 1.65$$
$$Z = 1.66 +$$

The birefringence is very high and give yellow colours of the second order and from this is estimated to be above 0.30. The maximum extinction angle $Z \wedge c$ is about 20°. The elongation is positive. The optic angle is very large and estimated to be more than 80°, from the curvature of the isogyre of an optic axis figure. The optic sign is positive and the dispersion is $v > \rho$.

From the above observations, the amphibole is considered to belong to the isomorphous kupfferite ($H_2Mg_7Si_8O_{24}$) grunerite ($H_2Fe_7Si_8O_{24}$) series, and from (1) Winchell graph would consist of about 40 mol % of grunerite and should be named cummingtonite. These optical properties fit very well with the description of the above amphibole in bulletin 848 by Larsen and Berman (2).

BIOTITE has often a chocolate brown pleochroic colour. In few sections it is olive green. Pleochroic haloes are always abundant.

HORNBLENDE is usually present in the same proportion as plagioclase, but sometimes constitutes as much as seventy per cent of the minerals of the rock. Ordinarily it is of the normal green colour but often it has a bluish tint and the following pleochroic formula:

X = pale greenish yellow.
Y = pale green.
Z = pale bluish green.

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(1) Winchell A.N., Elements of Optical Mineralogy, Part II, 1933, p. 244. Also, Winchell A.N., Further Studies in the Amphibole Group, the American Mineralogist, June 1931, Vol. 16, No. 6.

(2) Larsen A.S. and Berman H., The Microscopic Determination of the Non-Opaque Minerals, 2nd. Ed., Bull.848, U.S. Dept. of Int., 1934.

This type of amphibole has a birefringence of about 0.020, positive elongation, an extinction angle $Z \wedge c = 16^\circ$ and an optical angle smaller than 60° with strong dispersion $\rho > v$. Often the crystals are bleached especially around the edges and sometimes only a green spot is left in the central part of the crystal. This bleached area often shows the peculiar polysynthetic twinning of cummingtonite. Some crystals include rounded grains of plagioclase.

GARNET is pale brownish red. It occurs as idioblastic crystals usually fractured. From its complete absence of birefringence, it is classed in the pyralspite group and is believed to be ANDRADITE. It has inclusions of cummingtonite and iron sulphides and replaces all the other minerals.

b) The Plagioclase-hornblende-biotite amphibolites.

In general the texture is fine-grained granoblastic but gneissose structures were also observed. The minerals are fresh and have small inclusions. These amphibolites resemble igneous rocks. The essential minerals are plagioclase, hornblende, and biotite. Carbonate is present in small amount replacing plagioclase. Cummingtonite may also replace hornblende, thus indicating the transition from the plagioclase-hornblende-biotite amphibolites to the plagioclase-cummingtonite-biotite-hornblende amphibolites.

PLAGIOCLASE varying in composition from An_{10} to An_{35} from one section to another is present in various amounts from 25% to 60%. Much of it is not twinned and shows undulatory extinction. Small crystals of hornblende are found as inclusions. When plagioclase is abundant, evidence of replacement of hornblende by the former is given by the concave outline of the hornblende crystals. Some of the crystals are slightly altered. In the same section, crystals of hornblende include plagioclase while plagioclase crystals include hornblende.

HORNBLENDE ranges from 25% to 70% in amount, more often it has the bluish tint already mentioned.

BIOTITE has the common brown pleochroic colour and is present in various amounts. It has dark pleochroic haloes around small inclusions.

APATITE and PYRRHOTITE are found occasionally.

C - Contact-metamorphic rocks.

The biotite and injected biotite gneisses described above are fine-grained in general. They are represented mainly by the quartz-bearing rocks with their minerals grouped in a more or less definite association and include minor amounts of amphibolites, one group being characterized by cummingtonite ± garnet and the other consisting mainly of plagioclase hornblende and biotite. Within the same horizon there are also minor zones of medium- to coarse-grained rocks, amphibolites for most of them, some of which have peculiar associations and these will be here referred to as the CONTACT-METAMORPHIC rocks. They include of course the cordierite-bearing rocks already described.

Section No. 9.

The association is: Biotite (?) gedrite and zoisite (?).

BIOTITE (?). The mineral is in plates up to a centimeter in diameter and has a greenish grey colour in hand specimen with some green spots in places. The lamellae are flexible but not elastic. It is uncoloured in thin section. Some sections show a uniaxial figure, others a small optic angle. The index of refraction of the mineral oriented with the cleavage parallel to the stage of the microscope (about N_m) is a little less than 1.59. The birefringence is high. In places it is altered to chlorite along cleavages and it is apparently replaced by gedrite.

GEDRITE is grey in hand specimen but uncoloured in thin section. The mineral has a brownish dirty appearance under the microscope, but some smaller crystals are absolutely fresh, (two different minerals ?). The indices of refraction are:

X = 1.62 -
Y = 1.62 +
Z = 1.63 +

The mineral has parallel extinction, the optic sign is negative, the optic angle is large and the dispersion is $\rho > \nu$.

ZOISITE (?). The mineral is in fractured uncoloured crystals, it has high refractive index and apparently low birefringence. It is biaxial negative and has an axial angle of about 75° with $\rho > \nu$ about X. The mineral has probably parallel extinction.

There are abundant pyrrhotite and pyrite.

Section No. 45.

Gedrite amphibole makes the bulk of the minerals of the section and is accompanied by accessory pale yellow biotite and a deep green isotropic mineral, (complete absence of biregrigence) without crystal outlines, averaging 1 m.m. (one grain 2 m.m.) and with an index of refraction greater than 1.78, probably gahnite ($ZnAl_2O_4$). The mineral dissolves entirely in the microcosmic salt thus indicating absence of silica. Quartz is present in small amount. The ore minerals are pyrrhotite with inclusions of chalcopyrite, and a little galena; these are grouped around spinel which they seem to replace.

Section No. 10.

The section is merely an aggregate of chlorite and carbonate. Chlorite has the characteristic Berlin-blue interference colour, and the crystals have numerous pleochroic haloes around small inclusions. A little pyrite is present.

Section No. 50.

This peculiar association consists of cummingtonite wilsonite, diopside and carbonate, the minerals being named in their order of importance and accessory quartz, sphene and apatite.

CUMMINGTONITE has a greenish greyish white colour in hand specimen. It is uncoloured in thin section, shows no twinning, has an extinction angle of 18° , all the other optical properties being normal.

WILSONITE: The mineral has a peculiar pale purple colour in hand specimen but is uncoloured in thin section and has aggregate polarization.

Sections Nos. 53 and 46.

Both sections are a medium-grained aggregate of brown biotite and fibrolite with small amounts of plagioclase An_{20}, quartz, apatite, pyrrhotite and pyrite. The coarser texture is the only peculiar feature of these two sections. Some plagioclase crystals have a myrmekitic texture in section No. 53 and pyrrhotite has reaction rim in section No.46.

Section No. 40.

Over 80% of the section is actinolite with narrow zones of untwinned cummingtonite (bleached actinolite). The rest of the section consists of brown biotite and a little basic plagioclase An_{48} having undulatory extinction. Pyrrhotite is also present. The texture is medium-grained with many crystals over 1 m.m.

Section No. 47.

Only two minerals are present, actinolite and plagioclase, with small grains of apatite. Actinolite crystals range between 1 and 2 m.m., while plagioclase crystals An_{36} are about 0.5 m.m.

<u>NOTE</u> - Actinolite was identified also in at least three other thin sections with fine-grained texture viz. Nos. 17-8-41.

Section No. 17 is a normal amphibolite consisting of about 40% actinolite, the rest being made of basic plagioclase An_{63} and quartz with little biotite,apatite and carbonate replacing plagioclase.

Section No. 8 is a peculiar association of about 80% of quartz crystals about 1 m.m. with relatively small crystals of actinolite, diopside, brown biotite, zoisite (?), carbonate, and apatite interstitial to quartz or as inclusions in the latter.

Section No. 41. In their order of importance the minerals are pyroxene, actinolite, brown mica, basic plagioclase, and apatite as accessory minerals. Up to 1 m.m. eyes of small plagioclase crystals are surrounded by a narrow zone of biotite crystals separating plagioclase from actinolite. Inside the eyes plagioclase is altered to sericite (?) resembling the inside zone of the eyes in the cordierite association section No. 11.

General Considerations on the Biotite and Injected Biotite Gneisses.

The outstanding character of this zone is the high degree of silification that has transformed most of the rocks into migmatites. Apparently the original metamorphosed rocks were open to the magmatic solutions by which they were injected and replaced. Enough patches and lenses of banded sediments are left however to establish their sedimentary origin.

The ability of injection in lit-par-lit fashion by magmatic fluids is explained by Alling (1) as due to the high pressure developed during cooling and crystallization of the magma, in deep zones where the pressure is so great on account of the cover rock that the above type of injection takes place instead of fracturing.

The amphibolites forming lenses in these rocks and the ones resulting in places from the gneisses by increase of the ferromagnesium minerals, are interpreted as metamorphic rocks resulting from the metamorphism of calcareous sediments intercalated in the siliceous ones.

The contact-metamorphic rocks are most likely due to the presence of impurities in the sediments and addition of material of igneous origin.

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1. Alling H.L. op. cit., p. 255 and 259.

REMARKS ON THE MINERALS.

a) The Quartz-bearing Rocks.

Anorthoclase is an unusual potassic mineral in the Grenville rocks. Microcline instead is mentioned in all the descriptions. In the Adirondacks of U.S. microperthite is very commin and Buddington (1) described microperthite in association with quartz, cordierite, sillimanite, biotite, garnet etc., in the contact aureoles of the Alexandria-type granite in argillaceous rocks. Its association is very similar to the one of anorthoclase at Calumet Island, moreover, anorthoclase and microperthite have identical composition and according to Alling (2) the potash-soda feldspars form an inverted Y by ex-solution with falling temperature:

anorthoclase
↓
cryptoperthite
↓
microperthite
↓
perthite
↙ ↘
(-K Al Si_3O_8) orthoclase   Albite (-Na Al Si_3O_8)
(monoclinic)   (triclinic)

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(1) Buddington A.F., op. cit., p. 172.

(2) Alling H.L., op. cit., p. 205

Most likely then, anorthoclase of Calumet Island and microperthite of the Adirondacks have similar origin. Anorthoclase has a peculiar appearance under the microscope, and all the intermediates between ordinary and something similar to microcline twinning can be observed. Buddington again mentions the alteration of microperthite to microcline and oligoclase in a syenite rock however, but the mineral at Calumet is probably cryptoperthite, its appearance being similar to the picture of that mineral given in Alling, (1). The microcline structure is produced from orthoclase by pressure and even grinding will alter orthoclase to microcline. It is then possible that pressure is responsible of giving anorthoclase the appearance of microcline that, combined with its alteration to cryptoperthite.

Anorthoclase crystals are usually fresh looking while plagioclase is injected by quartz and altered to sericite. It is quite probable that the mineral resulted from the injection of aplitic solutions containing potassium and sodium.

Sillimanite is a characteristic mineral of the Grenville series. As already mentioned, it is found as

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(1) Alling, op. cit., p. 70, fig. F.

almost sub-microscopic needles in the quartz and anorthoclase crystals, and it is present as longer needles grouped in bundles replacing the other minerals, especially mica. The presence of sillimanite in these rocks indicates that the original sediments were rich in alumina which entered first in combination in the form of mica with which reacted silica to form sillimanite, K-feldspars and accessories by thermal metamorphism.

Biotite is normally pale brown when associated with sillimanite but there are exceptions. In one section consisting of quartz anorthoclase and plagioclase the mica is reddish brown so that we must conclude that the mica is not affected by the presence of anorthoclase.

The occurrences of cordierite and anthophyllite (?) have already been discussed.

b) Amphibolites.

There is no quartz in the included lenses and patches of amphibolites in the gneisses. Apparently the amphibolites were less fissile than the biotite gneisses and escaped silicification. On the other hand plagioclase is replacing the other minerals and appears to have been injected.

Cummingtonite amphibole and garnet deserve special attention. Cummingtonite and pargasite are both uncolored in thin section, they are positive and have similar extinction angle but the indices of refraction, the birefringence and the optic angle are greater in cummingtonite than in pargasite and the dispersion is different. It is on these differences that we decided to call the mineral cummingtonite.

	Cummingtonite		Pargasite (1)	
	Calumet	Winchell(1)	Edenville	Pargas
N_g	1.66+	1.66-1.70	1.6410	1.6519
N_m	1.65	1.64-1.67	1.6256	1.6380
N_p	1.64-	1.63-1.66	1.6188	1.6329
N_g-N_p	0.030	0.025-0.030	0.0222	0.0190
2V	80°	65°- 85°	70°	63°
Dispersion	$v>\rho$	$v>\rho$	$\rho>v$	$\rho>v$

The replacement of hornblende ($H_2NaCa_2(Mg,Fe)_4Al_3Si_6O_{24}$) by pargasite($H_2NaCa_2(Mg,Fe)_5AlSi_7O_{24}$) instead than by cummingtonite ($H_2(Fe,Mg)_7Si_8O_{24}$) would be more easily explained, their formula being more similar. In both cases however there would be a removal of Al, most likely used up in the formation of ALMANDITE garnet.

Hornblende has often a bluish tint. Eskola (2)

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(1) Winchell A.N., Elements of Optical Mineralogy.

(2) Eskola Pentti, op. cit.,p. 129.

observed a similar variety in Finland and suggests that this bluish color given by the presence of sodium, indicates that the amphibole was formed from plagioclase.

Mica varies in colour from ordinary brown in the normal amphibolites to deep chocolate reddish brown in some of the cummingtonite bearing amphibolites in which it is also olive-green occasionally. According to Hall (1) from plotting of analysis of many biotites, the colours of the more common biotites are dependent upon their relative content of iron, magnesia and titania, iron producing the green colours, titania the brown and red colours, while magnesia appears to mask the colours produced by titania.

Apparent Paragenesis of Amphibolites.

Cummingtonite and hornblende are found in close association the former replacing the latter selectively, but it is found also replacing biotite. A good example of the first case is shown in (plate 9). Plagioclase replaces cummingtonite, hornblende and biotite, (plate 7). Garnet was formed later replacing the previous mentioned minerals. Serpentine cuts all the minerals.

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(1) The Relation Between Colour and Chemical Composition in the Biotites, Hall A. Jean, The American Mineralogist, Vol. 26, No. 1, 1941.

2. Hanging-wall Amphibolites.

Above the ore-body formed mainly in the biotite and injected biotite gneisses is a sill-like mass of carbonate and pyroxene amphibolites. This band of amphibolites was fairly well outlined by diamond drilling and it constitutes a characteristic feature of the ore zone as was emphasized before.

The amphibolites are thinly layered or massive. Schistosity is developed along the margins of the bands and in few zones in the interior but it is always much less apparent than in the hornblende and hornblende-biotite gneisses.

From the logging of the diamond drill holes several varieties of amphibolites were identified. Usually however, these varieties are so heterogeneously distributed that they could not be correlated in the vertical sections made from these holes. One variety is a clotted-appearing amphibolite consisting of hornblende, biotite, pyroxene and medium calcic plagioclase. Another one contains abundant carbonates in layers, suggesting it is an original constituent of the rock but it is sometimes as veinlets as if it has been introduced. A third variety with much biotite is called biotite amphibolite. A special variety is characterized by porphyroblasts of biotite, or pyroxene and is called porphyroblastic amphibolite. This variety is found near the edge of the carbonate amphibolite and sometimes within the main mass, it is usually massive but sometimes schistose. By gradation the amphibolites pass to more schistose hornblende gneisses through porphyroblastic gneisses. Osborne believes that some of the differences between the composition of the amphibolites and hornblende gneisses are due to granitic injection.

Petrographic Description.

Although the amphibolites form a massive and apparently homogeneous lenticular body, the mineral composition of these rocks is not uniform. According to the different mineral associations as determined from the thin-sections, the zone will be divided into two types of rocks; 1. The normal amphibolites consisting simply of plagioclase, hornblende and some biotite, (this type has already been described p.30). 2. The pyroxene and the carbonate amphibolites composed of pyroxene, carbonate, hornblende, intermediate plagioclase and biotite, and often containing a fair amount of scapolite. The latter represents the most important type. There is gradation of course from one type to the other. In both types quartz is absent.

Pyroxene and Carbonate Amphibolites.

The more important group of associations in the rocks of the hanging-wall is represented by the pyroxene and carbonate amphibolites. Pyroxene is abundant and carbonate is found in various amounts. Scapolite is usually present, sometimes in fair amount and it might be of some interest to note that it is found only in rocks containing pyroxene whereas carbonate may be absent. Hornblende and plagioclase are always present, but biotite is sometimes missing. Apatite is usually as accessory mineral and sphene often. Epidote was identified in one section, all the thin sections contain sulphides.

Fine- to medium-grained granoblastic and porphyroblastic textures are common. The segregation of calcite and pyroxene from the other constituents often impart a gneissose structure to the rock.

PYROXENE crystals form large porphyroblasts or occur as smaller rounded grains. It is almost uncoloured with a greenish tint but shows no distinct pleochroism. Prismatic cleavage is distinct and parting parallel to basal cleavage (001) is common. The index of refraction for Z is equal to 1.69 + . The optic sign is positive and the optic angle is near 60°. The extinction angle is around 40° and the mineral is believed to be diopside. In few sections however the extinction angle was found to be about 45° and in that case some of the pyroxene would belong to the diopside-hedenbergite series. The crystals are slightly altered to serpentine or chlorite along cracks, cleavages and partings. In places it is replaced by hornblende.

PLAGIOCLASE is acidic andesine and shows a fairly uniform composition which is quite an unusual feature for the rocks described in this thesis, unless this is by pure coincidence. The crystals are generally untwinned and may show undulatory extinction. The fact that the plagioclase is not very calcic for the amount of calcite present in the rocks would suggest that the carbonates were introduced after the formation of the plagioclase. A veinlet containing calcite and plagioclase suggests that the two minerals would have been simultaneously introduced.

HORNBLENDE is of the common green type and occurs as subhedral crystals or rounded grains replacing pyroxene and replaced in turn by cummingtonite.

SCAPOLITE was identified in four thin-sections in which pyroxene is present. In one section carbonate is abundant, it is in small amount in the second one and absent in the two others. The crystals are usually fresh but sometimes they are altered to a fibrous brownish aggregate (pinite). One good cleavage is shown usually. The mineral is uniaxial negative and has parallel extinction, the indices of refraction are: N_o = 1.58 and N_e = 1.55 and the birefringence is estimated to be about 0.030 from the interference colour. Referring to the diagram in Winchell (1), the mineral is found to consist of Ma_{60} - Me_{40} and is MIZZONITE. It is in large crystals replacing selectively equally large crystals of pyroxene (see plate 12) but it occurs also as small interlocking crystals.

CARBONATE shows numerous twinnings and without other determinations is considered to be calcite. APATITE is sometimes present in anhedral grains. EPIDOTE was found in good-size crystals in a brecciated type of carbonate anphibolite in which the hornblende is broken up into small angular fragments.

Remark.

Scapolite as well as apatite are very common in the amphibolites and are considered to be a product of pneumatolitic metamorphism (2).

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1) Winchell A.N., op. cit., p. 294.

2) Harker A., op. cit., p. 324.

Apparent Paragenesis.

No attempt is made here to establish definitely the order of formation of all the minerals. Some observations made during the study of the thin-sections suggest however certain relations between the minerals. Criteria of replacement are illustrated by some of the best examples furnished by the thin-sections. PYROXENE is replaced by hornblende, carbonate, plagioclase and scapolite. No evidence is furnished as to its origin however. BIOTITE is cut by veinlets of carbonate and plagioclase and is replaced by scapolite. HORNBLENDE is replaced by cummingtonite, carbonate, plagioclase and scapolite. CARBONATE and PLAGIOCLASE are both present in veinlets as if introduced late. Carbonate is replaced by plagioclase and plagioclase is found in the central part of the veinlets. SCAPOLITE apparently replaces all the other minerals but especially pyroxene. In one section it replaces plagioclase.

In the Ducktown deposits quartz and feldspars are extensively replaced by carbonates (1) while in the present case it is the ferromagnesium minerals that are replaced by the carbonates.

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(1) Ross, op. cit., p. 34.

From the preceding remarks based on the relations between the minerals as observed under the microscope, carbonate apparently replaces most of the minerals and appears to have been introduced lately. Nevertheless, the origin of the carbonate is doubtful. In many sections, carbonate and pyroxene are segregated from the other minerals and form lenses as if they were related one to the other, (~~see plate~~) but in one section showing banding, a veinlet of carbonate and plagioclase cuts across the banding as if it had been later introduced. One section shows pyroxene replaced by plagioclase and carbonate and it is rather doubtful whether pyroxene could be formed from calcite of the same age that the one by which it is replaced. Most likely however, pyroxene was formed from residual carbonate and later carbonate was introduced with plagioclase.

Carbonates are very plastic and soluble minerals. They are easily recrystallized and metamorphosed to contact-metamorphic minerals when a rock containing these is injected by igneous material. It is then almost impossible from the study of the thin sections alone to assign to these carbonates a definite place in the paragenesis. Most logically however they are residual from the amphibolitization of dolomitic sediments, but it is also possible that some carbonate was introduced; both hypothesis are probable and this is the opinion of Osborne (1).

It is interesting to consider the opinion of C.S.Ross about the Ducktown copper deposits in which he believes that the carbonates are of epigenetic origin. He concludes that: "The copper bearing deposits of the Ducktown type in the southern Appalachian region were not dependent on the presence of limestone lenses for their formation and that the carbonates in these deposits are not the remnants of partly replaced limestone lenses but are vein minerals that have been deposited from hydrothermal solutions." (2)

There is surely a genetic relation between pyroxene, scapolite and carbonate, since these three calcium-bearing minerals occur together. The relations found from microscopic examination are the following: when pyroxene and scapolite are in large amounts, carbonate is less abundant and as noted before, when pyroxene is present, carbonate is also present usually but not necessarily scapolite, although in few cases pyroxene

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(1) Osborne F.F., report under preparation.

(2) Ross C.S., Origin of the Copper Deposits of the Ducktown Type in the Southern Appalachian Region, U.S. Geol. Survey, P.P. 179.

or carbonate were found alone. Pyroxene always accompanies scapolite while carbonate may or may not do so.

Amphibolite Gneisses-Migmatite Complex.

The amphibolites of the hanging wall are overlain by a complex amphibolite gneisses with intercalated patches of leucocratic biotite gneisses. The least injected variety has a granoblastic texture and consists of abundant hornblende and interstitial quartz and feldspar. The more granitized rocks show different textures. The even grain type has a pepper-and-salt appearance in hand specimens, but more commonly the rocks are gneissose due to the segregation into layers of the ferromagnesian minerals. Some are porphyroblastic with porphyroblasts of pyroxene, another type has clots of hornblende and biotite and is called clotted amphibolite.

The amphibolite gneisses consist of hornblende, plagioclase, quartz, pyroxene, carbonate biotite, sphene, garnet, and apatite. The alteration products are serpentine, and sericite. Pyrrhotite, pyrite and other sulphides may also be present in minor amounts. Plagioclase varies between An_{10} to An_{20} from one section to another. Sphene is particularly abundant in this zone.

The most striking feature of the amphibolite gneisses is the injection and replacement of hornblende and biotite by feldspar mainly and quartz giving rise to sieve-like and poeciloblastic structures in the most advanced stages of granitization.

The pyroxene-bearing amphibolites of this zone are different from the ones of the hanging-wall in that they contain quartz, a pale brownish red garnet (almandite) and titanite. Again some of the hornblende has a bluish pleochroic colour in the direction of the slow ray.

The migmatites have the appearance of gray granite gneisses. They contain hornblende and biotite. In places these rocks have relic structures that may represent original schistosity and bedding similar to that of the biotite gneisses of the ore zone. It suggests that they are granitized rocks originally similar to the biotite gneisses, more material being introduced however.

Origin of Amphibolites.

Goranson considered the amphibolites of Calumet Island as resulting from the metamorphism of diorites and (1)

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(1) Goranson R.W., Calumet Island, Pontiac County, Quebec, Geol. Surv. Can., Summ. Rept., 1925 pt C, p. 15.

gabbros; evidently sufficient data were not then available to establish their true origin.

Let us recall briefly four different ways by which amphibolites can originate:

1. By metamorphism of gabbro and diorite.
2. By recrystallization of impure limestone with some addition of material.
3. By replacement of limestone by thermal solutions.
4. By metamorphism of volcanics.

Pentti Eskola, in the Orijarvi district, described amphibolites arising from the metamorphism of impure limestones, gabbros, basic dykes or basic volcanic rocks (1). Adams and Barlow, in the Haliburton and Bancroft districts also described crystalline limestones metamorphosed into typical hornblende-feldspar amphibolites under the influence of granite intrusions (2).

Finally Buddington, in the Adirondacks of U.S. in accord with Adams' and Barlow's theory considers that the amphibolites found in the garnet gneisses and in the limestones

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(1) Eskola Pentti, op. cit.

(2) Adams F.D. and Barlow A.E., The Haliburton and Bancroft Districts, Ont. Geol. Surv. Cal., Mem. 6, 1910, p. 104.

were formed by the replacement of limestone by granitic emanations. In other areas he considers that amphibolites, of one or the other above noted mode of origin, are found with certainty (1).

A common feature to most of the amphibolites from the various known districts of the world is a sill-like or lenticular habit. These rocks occur as dark bands intercalated with or intruded into the granitic gneisses and have a same general strike. In the case of the pyroxene-bearing amphibolites, Eskola concludes that there is no more doubt however as to their origin and that they are the product of metamorphism of sediments richer in lime (calcareous shales), than the ones that produced ordinary amphibolites (2).

The recognized bedding in the less granitized members in zones in which furthermore amphibolites occur as lenses, as in the biotite and the injected biotite gneisses, the formation of amphibolites at or near the contact between the limestone and garnet gneisses, the mineralogical associations in the pyroxene and carbonate amphibolites (abundance of carbonates and calcium-bearing minerals like diopside and

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(1) Buddington A.F., op. cit., p. 169 and p. 257.

(2) Eskola Pentti, op. cit., pp. 121-130.

scapolite), and a wide range of feldspars in all the rocks of the area (1) give sufficient evidence of the sedimentary origin of these rocks.

The amphibolites of Calumet Island are then considered to be the product of recrystallization of clastic sediments containing more or less calcium and magnesium carbonates, hornblende arising from the reaction between calcite and chlorite (2) or being formed directly from clays poor in silica or by any other way. Calcite when present, would represent the mineral left over after the formation of hornblende has exhausted the available magnesia. Apparently the calcite recrystallized subsequently and replaced the other minerals, and it is not impossible that some carbonate was introduced later. In amphibolites without calcite no lime would have been left over but its absence could also be explained by its removal by solution or squeezing out. By shearing the amphibolites gave rise to dark mafic gneisses and by injection to hornblende and hornblende garnet migmatites. The carbonate-bearing amphibolites being more plastic were

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(1) Carlson C.J., A Test of the Feldspar Method for the Determination of the Origin of Metamorphic Rocks, Jour. of Geol., Vol. 28, 1920, pp. 632-644.

(2) Harker A., *op. cit.*, p. 267.

less susceptible to open structures and injection.

4. Diabase Dyke.

One thin-section was made of the diabase dyke that cuts the rocks at the mine. It shows a fine-grained ophitic texture (large plates of pyroxene enclosing feldspar laths.) and a mineralogical composition consisting of about 50% augite ($Z \wedge c = 40^{\circ}$) and 50% labradorite with little magnetite and pyrite. Some of the pyroxene crystals have a dirty brownish appearance under the microscope and many feldspar crystals are altered to a greenish pleochroic mineral.

Anhydrite and Gypsum.

At different horizons beds containing anhydrite and gypsum were intersected in drilling, as for example No. 6b hole at the mine. In places the anhydrite is mauve and coarsely crystallized but more commonly it is of medium grain and consists of a pale violet variety mixed with carbonates. It occurs also with coarse-grained salmon calcite.

Five thin-sections from this hole show the intimate association of carbonate, anhydrite, gypsum, tremolite and diopside, carbonate anhydrite and gypsum predominating and being present in all proportions. Other minerals are muscovite and apatite. All except one section, which is fine-grained, are medium-grained. The amphibole is uncoloured and from the following optical properties is found to be tremolite: The optic sign is negative with $\nu > \rho$, the optic angle is about 80°, the extinction angle $Z \wedge c$ is around 15° and the birefringence is strong. The pyroxene has an extinction angle $Z \wedge c$ equal to 44° and is considered to consist of diopside 60 mol. % and hedenbergite 30 mol. %.

The apparent paragensis is: silicates (pyroxene and tremolite), carbonates, anhydrite and gypsum. The silicate relics in the carbonate crystals seem to point out to a later introduction of carbonates. Anhydrite and gypsum are closely associated, gypsum replacing anhydrite extensively and it is often seen forming a ring around the anhydrite crystals. Anhydrite replaces carbonates and silicates and it is quite possible that it is of magmatic origin. In section 43, consisting mainly of quartz 40%, biotite 30%, plagioclase An_{35} 20% and garnet 10% (pale reddish brown), few crystals of anhydrite are also present. This section shows extensive replacement by serpentine. In that section the other minerals are cummingtonite, apatite, pyrites and magnetite (?). Similar alteration by serpentine is shown also by a section consisting of carbonates 80%, garnet 10% and cummingtonite, the ore minerals being sphalerite, pyrite and galena. 15% of the minerals are altered to serpentine.

From the study of its mode of occurrence at Balmat and Britannia where both gypsum and barite are present, Osborne concludes that: "Anhydrite may appear as a peripheral phase of the alteration near zinc-lead deposits", and that: "The geographical distribution coupled with the evidence that anhydrite occurs near mineral deposits in non-sulphate bearing country rock suggest that it is of magmatic origin" (1), by reaction of acid waters on calcareous beds.

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(1) Osborne, F. Fitz, Anhydrite and Gypsum at Calumet Mine, Calumet Island, P.Q., In Press.

ECONOMIC GEOLOGY

Mineralization.

Mineralization is found at three different horizons at the mine, but there is a single ore-body of economic importance in the biotite and injected biotite gneisses near the contact with the carbonate amphibolites. Closely spaced diamond-drill holes indicated about 1,500,000 tons of ore averaging 2.51% of lead, 8.16% of zinc, 0.036 ounces of gold and 5.76 ounces of silver. About 86,000 tons of ore containing 18% of zinc and $6.90 in gold and silver were also reported (1). A second zone of mineralization called the Longstreet zone similar to the first one and apparently connected to it, is found to the east in amphibolites. Diamond drilling however did not disclose any important ore body. The third zone is along the river where dissiminated sulphides occur in streaks in the limestone. One diamond-drill hole 3,000 feet east of the limestone reached that horizon and disclosed same mineralization indicating possible continuity.

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(1) Osborne, F.Fitz., Report under preparation.

Structural Relations of the Bowie Ore-Body.

The shape, attitude and relationship to the Country rock of the main ore-body known as the Bowie ore-body, were fairly well established by drawing vertical sections along lines of diamond-drill holes one-hundred feet apart, the holes being spaced one-hundred feet and in some instances being as close as fifty feet.

The ore-body is found to consist of a lenticular layer occurring almost entirely in the biotite and injected biotite gneisses at or near the contact with the overlying amphibolite. It is conformable in strike and dip with the gneisses, striking N 55° W and dipping between 25° to 30°E. Other small lenses and sheets are found also below and above or in the extension of the main ore body near the surface. These are usually associated with granitic lenses which they seem to replace.

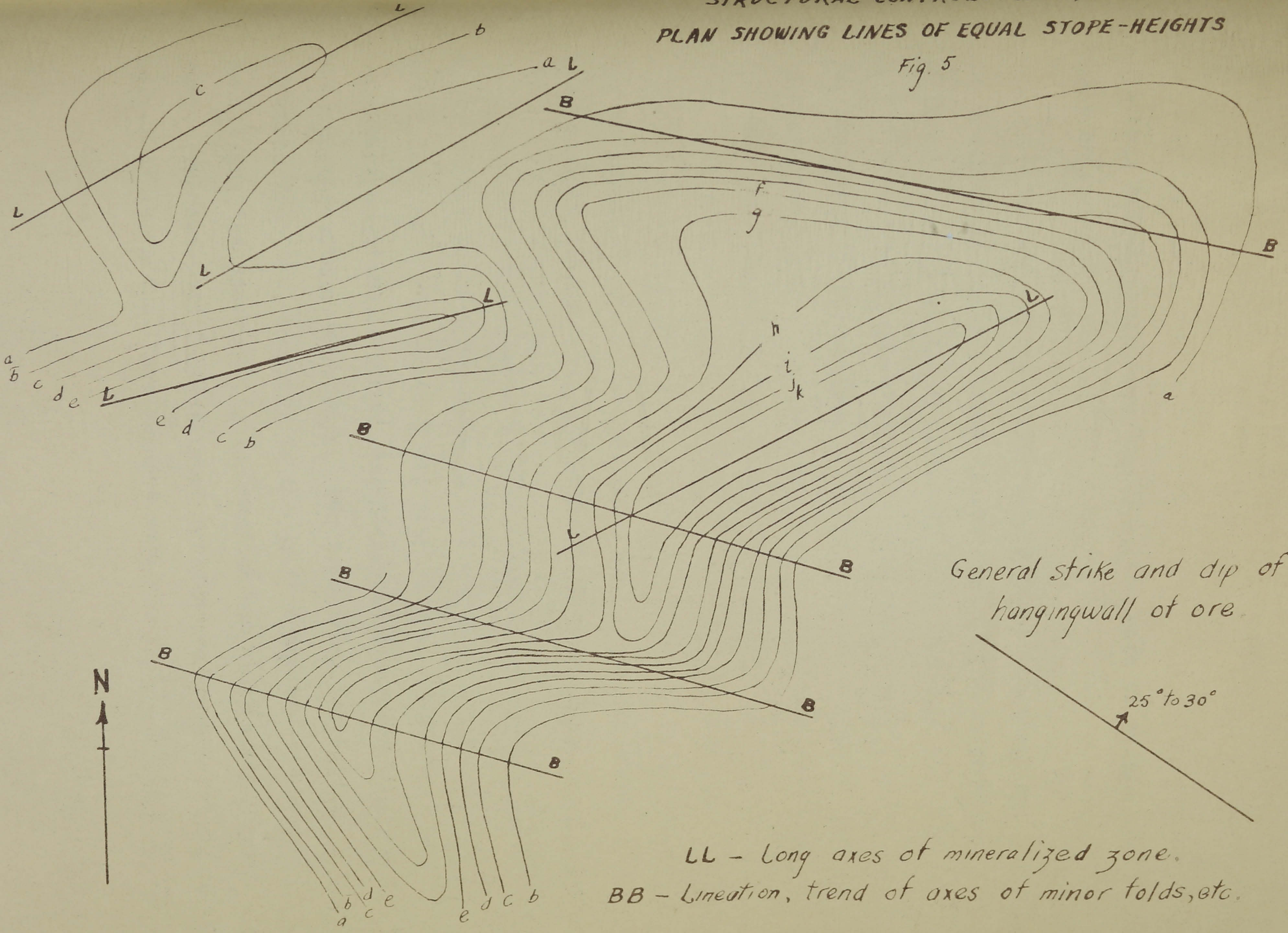
Minor ore-bodies to the north along this zone and showing the same conformity with the gneisses on surface are believed to have similar structural relations that the Bowie ore-body has.

The more important feature of the Bowie ore-body is the elongation in the direction N 65° E as shown by the

STRUCTURAL CONTROLS OF ORE SHOOTS

PLAN SHOWING LINES OF EQUAL STOPE-HEIGHTS

Fig. 5



General strike and dip of hangingwall of ore

LL – Long axes of mineralized zone.
BB – Lineation, trend of axes of minor folds, etc.

thickness contours map (see Fig. 5), the rake or plunge being about 25°.

The second important feature about the shape of the ore-body is the direction of the axes of the large warps, striking a little south of east. It coincides with the one of the same element of structure in the hanging-wall, with the long axes of the mineral and even with the strike of the diabase dyke. This direction observed to be fairly constant all over the island, is the direction of lineation. It is then justifiable to conclude that this direction does not coincide accidently with the lineation, but that the lineation was an important factor in the determination of the shape and possibly also the localization of the ore.

The distribution and the shape of the various rock units on the surface map seem to indicate that the rocks were acted upon by a tangential force resulting in a northeast - southwest compression force, that squeezed the rocks in a northwest-southeast direction. The tangential force is inferred from the convexity to the east of the massive amphibolite and the convexity to the west of the rocks of the ore zone. The ore-body is sandwiched between two irregular flat lenses of rocks that have escaped complete migmatization and striking at right angle to the hypothetic compressive stress. The plunge of the ore-body is in the direction of the force.

Apparently the amphibolites of the hanging-wall were quite plastic on account of the carbonates present and were less susceptible to injection than the biotite gneisses below. Most likely the difference of brittleness between the resulting two types of rocks was responsible for the location of a fracture at their contact which fracture was later filled by the ore-bearing solutions. The amphibolites being more plastic than the underlying gneisses further acted as an impervious wall preventing the escape of the mineralizing solutions so that the amphibolites can be considered as having played the most important role in the emplacement of the ore-body.

Ore and Gangue Minerals.

The ore consists of a medium-grained aggregate of sphalerite, pyrrhotite, marcasite, pyrite, galena, chalcopyrite, arsenopyrite, tetrahedrite and others in approximate order of abundance. Molybdenite is found in small amount. Native gold was reported, but usually gold and silver occur with the sulphides.

The gangue minerals consist of the following contact metamorphic silicates: cummingtonite, diopside, light coloured phlogopite and dark biotite. Calcite, dolomite and iron bearing carbonates are abundant. Scapolite, serpentine, chlorite and talc are found in small amounts. Some commercial ore occurs also in the country rock.

The sulphides are widely disseminated in the gneisses below the hanging-wall of the main ore-body. Near the contact with the hanging-wall they are concentrated into irregular undulating and branching bodies up to 70 feet of thickness of ore of commercial value with few thin sheets in the hanging-wall itself. In these bodies, the sulphides are irregularly distributed, being present as disseminated grains or massive lenses separated by almost barren quartz, calcite and leucocratic gneisses.

Paragenesis.

The paragenesis of the sulphides as determined by Moorhouse is the following: Pyrite (and arsenopyrite ?), sphalerite, pyrrhotite, galena, chalcopyrite, tetrahedrite. Marcasite replaces pyrite and pyrrhotite, its relation with the other sulphide is not known. Marcasite is always considered a low-temperature mineral of the supergene zone and its association with pyrrhotite, a high temperature mineral, is a peculiarity of this deposit. On the other hand, serpentine, replacing pyrrhotite, phlogopite and amphibole, and occurring also as veinlets cutting the other minerals and sulphides is found as rim around marcasite grains. Both marcasite and serpentine must be due to paulopost alteration.

The ore minerals replace all the other minerals, in preference the ferromagnesians to quartz and feldspar when occurring together. The age relation of the carbonate is not very clear, the contact-metamorphic silicates and the ore minerals are replacing carbonates either present originally in the gneisses or introduced by solutions. Osborne favors the second hypothesis. In the amphibolites, however, he believes that some of the carbonates are original but that the rest is younger than the silicates.

Pink pegmatites are common within the ore zone. The relation of these pegmatites with the contact silicates is not clear, but some sulphides replace the minerals of these pigmatites, so that the solutions producing granitization, contact silicates, pegmatites and ore might have been closely related to the pink granite, the only one younger than the regional metamorphism.

Type of Deposit.

The presence of high temperature minerals like pyrrhotite, pyrite, and arsenopyrite, in a gangue of contact metamorphic silicates like lime amphiboles, pyroxene, biotite, garnet and others, and the irregular shape of the ore-bodies are characteristic of high-temperature metasomatic deposits.

The widespread mineralization in the injected biotite gneisses and the presence of a zone of mineralization in the limestone along the river near the contact with the granitic migmatites indicate a close relation between the magmatic material introduced and the deposition of the sulphides.

SIMILAR DEPOSITS IN THE GRENVILLE SUB-PROVINCE OF THE CANADIAN SHIELD AND THE ADIRONDACKS OF THE UNITED STATES.

The Tetreault Mine, Notre-Dame-des-Anges, P.Q. (1)

Grenville garnet - biotite-sillimanite paragneisses make the bulk of the rocks of the ore that consists also of quartzites and limestone. The rocks are intruded by granite and grandiorite gneisses, amphibolite dykes and sills, and pegmatites.

The ore zone, about three thousand feet long, is along a narrow overturned syncline of Grenville paragneisses and limestone surrounded by migmatites and is associated with amphibolite dykes. The siliceous paragneisses were altered to cordierite-anthophyllite while the carbonates yielded tremolite and diopside (skarn rock) from replacement by solutions rising through a shear zone concordent with the axial plane of the fold. The principle metallic minerals are sphalerite, galena, pyrrhotite, and chalcopyrite. Tetrahedrite, stibnite, molybdenite, and arsenopyrite are of sporadic occurrence. The ore-bodies occur in calcium bearing silicates and to a minor amount in the cordierite-anthophyllite rocks.

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(1) Tetreault Mine, Montauban-les-Mines, Portneuf County, P.Q. by John J. O'Neill and F. Fitz. Osborne, Quebec Bureau of Mines, P.R. No. 136, 1939.

N.L. Wilson, *op. cit.*

The ore has replaced a band of limestone. The structure and the type of rocks were important factors in the formation of the ore bodies.

About 1,100,000 tons of ore have been mined of which 120,000,000 lbs. of zinc, and 40,000,000 of lead were extracted.

Long Lac Mine. (1)

The mine is located in Frontenac County, Ontario, about 42 miles northwest of Kingston. The rocks of the surrounding region are of the typical Grenville type and consist of crystalline limestone, quartzite, paragneisses and green schists, intruded by gneissic gabbro and diorite intruded in turn by granite.

The one occurs as lenses or is disseminated in a belt of coarsely crystalline limestone varying in width up to 400 ft. and 4,000 ft. in length dipping steeply and enclosed in gneissic diorite and gabbro.

The ore consists of sphalerite with varying amounts of pyrite, pyrrhotite and small quantities of galena and

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(1) Alcock, F.J., Zinc and Lead Deposits of Canada, Geol. Surv. Can., Eco. Geol. Ser. No. 8 , 1930.

chalcopyrite. The chief gangue is the calcite of the limestone but diopside, quartz and calcite veins are also associated with the ore.

F.J.Alcock considers that the deposit has an origin similar to the one of Calumet and Tetreault and that the solutions came from the intrusive granite intruded after the metamorphism of the limestone.

Renfrew Zinc Prospect. (1)

The deposit is located about thirty miles southeast of Pembroke in Renfrew County, Ontario. The rocks are Grenville sediments consisting mainly of limestone with tremolite and phlogopite. Bands of quartzites and sedimentary gneisses represent metamorphozed plastic beds in the limestone. With these rocks are associated amphibolites interbanded with or intruding the limestone. All the rocks are intruded by pink biotite granite and to a minor amount by pegmatites.

The ore occurs disseminated in the Grenville limestone and consists of sphalerite and galena with small amounts of pyrite and chalcopyrite. The gangue minerals are calcite, tremolite and diopside. Most of the ore is of low grade.

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(1) Alcock, F.J. op. cit., pp. 132-136.

It is a contact metamorphic deposit formed by excess of granite intruding limestones and accompanied rocks. It is similar to the one of Montauban.

The Balmat and Edwards Zinc Mine of the Adirondacks of United States. (1)

Balmat mine is 12 miles south of Edwards mine. The rocks of the district are all of pre-Cambrian age. The sedimentary rocks consist of garnet gneisses and limestone and the igneous rocks of gabbro, amphibolites, syenite and granite. The major feature of the structure is a dome slightly overturned.

At Balmat the ore-deposit is about three thousand feet long and consists in the replacement along bedding of an impure dolomite layer intercalated in a dominant limestone series. The ore minerals consist of sphalerite 19%, pyrite 18%, calcite 1.29% and accessories such as willemite, pyrrhotite and chalcopyrite. The gangue minerals are calcite and dolomite, garnet, diopside, tremolite, quartz and mica. Barite, anhydrite and gypsum are post-ore. The hydrothermal altercation minerals are talc from tremolite and diopside,

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(1) Brown, J.S., Structure and Primary Mineralization at Balmat Zinc Mine, Eco. Geol., vol. 31, No. 3, pp. 233-58, 1936.

and serpentine replacing the diopside.

The Edwards deposit is similar to the one just described. Brown believes that the solutions that form these ore-deposits were derived from an underlying igneous mass of pre-Cambrian granite.

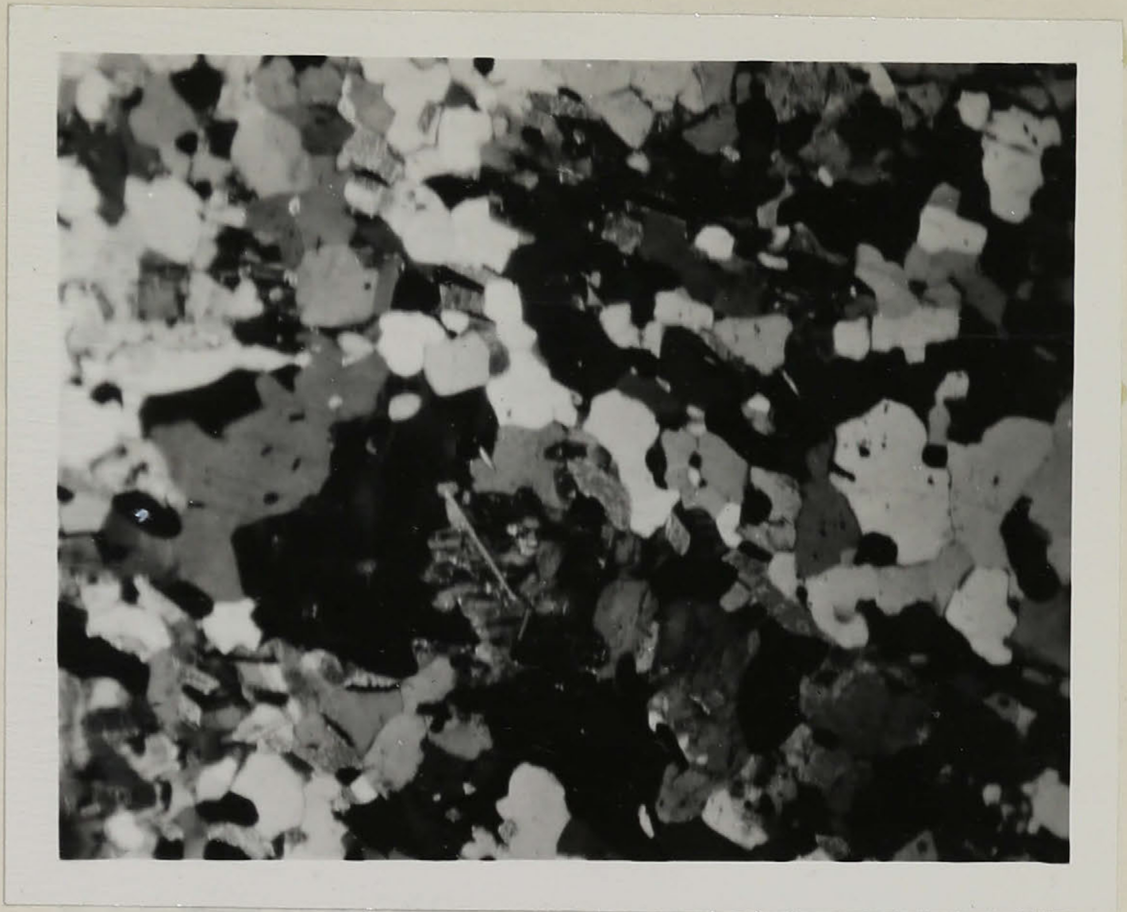


Fig. 1. x35
Texture of highly injected biotite gneiss. The predominating minerals are quartz and anorthoclase (a).

Fig. 2. x 108
Section showing the peculiar appearance of anorthoclase (cryptoperthite ?) under X nicols. The concave outline of the crystal suggests replacement by quartz.

Fig. 3. X 108

Injected biotite gneiss. Two crystals of anorthoclase ressembling microcline are shown at the bottom right and left of the picture. Grains of iron sulphides (black) are abundant.

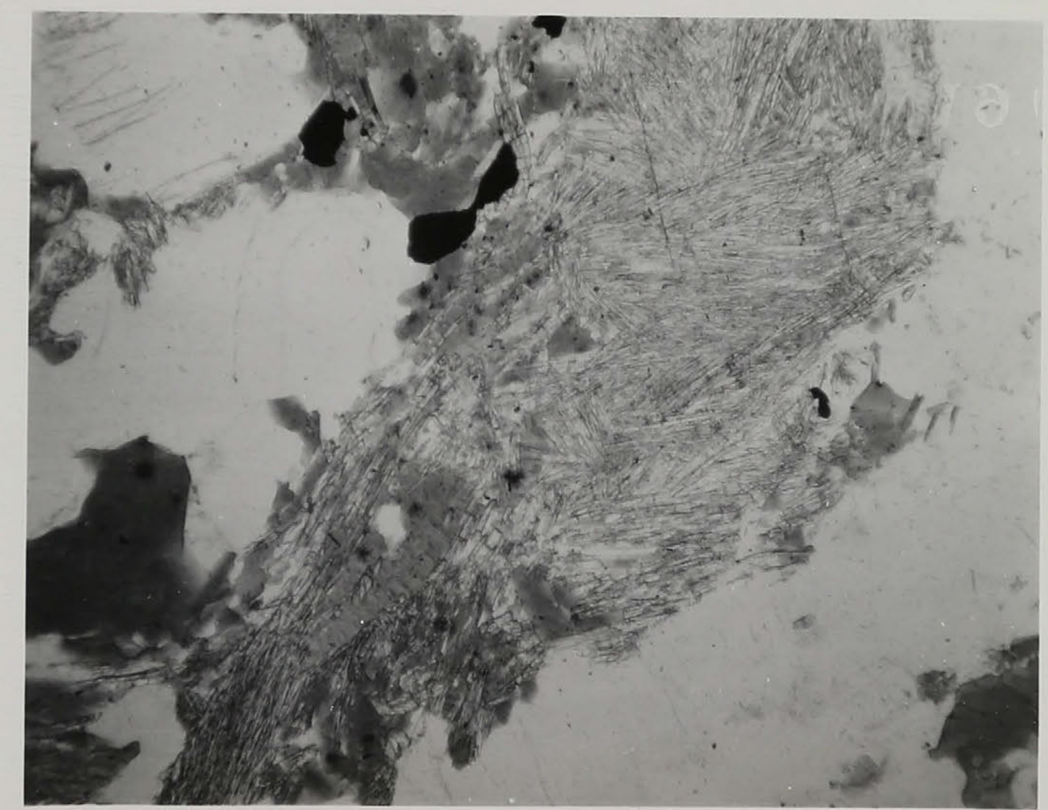
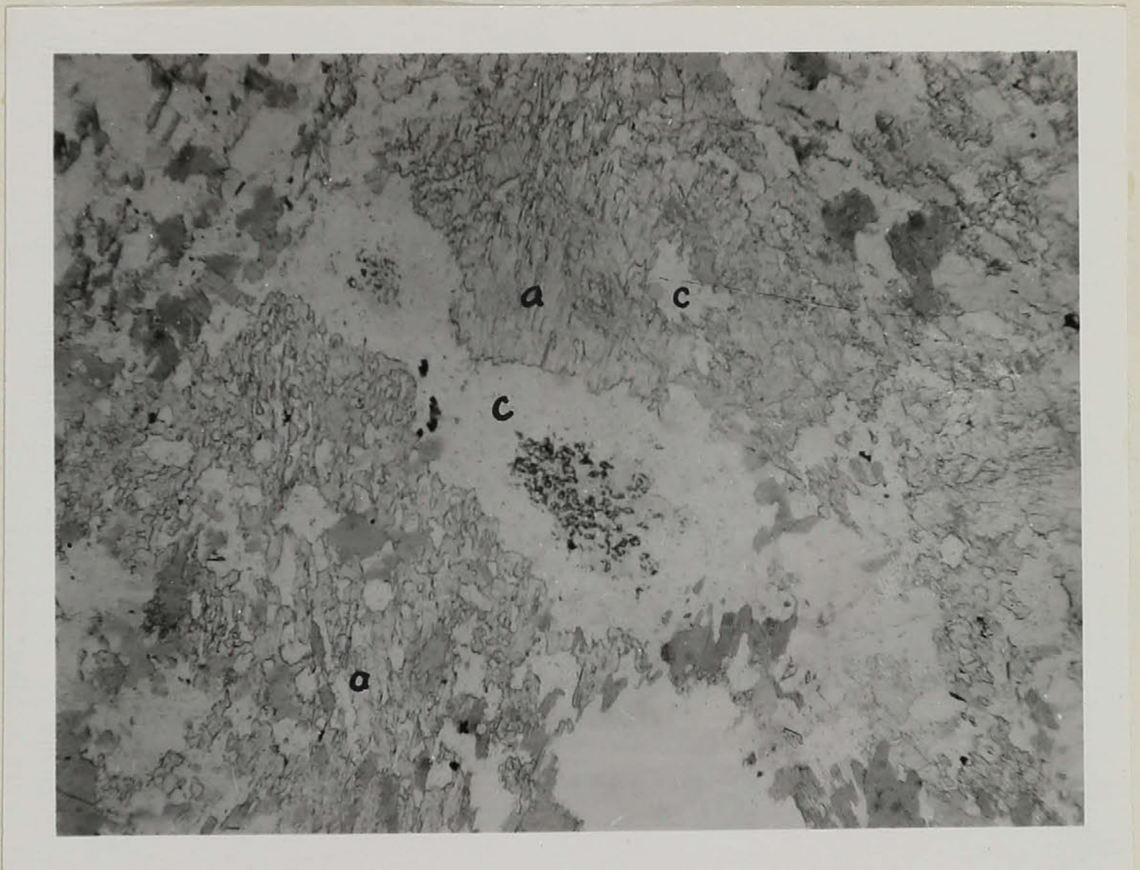


Fig. 4. X35

Bundle of sillimanite needles (fibrolite) replacing mica with numerous dark pleochroic haloes around small inclusions.

Fig. 5. X 108

Same as Fig. 4 (enlarged). One pleochroic halo (top right).



X 35

Fig. 6.

Eye structure in anthophyllite? - cordierite-biotite-plagioclase association with isotropic grains in the centre of the eyes. Anthophyllite (a), cordierite (c).

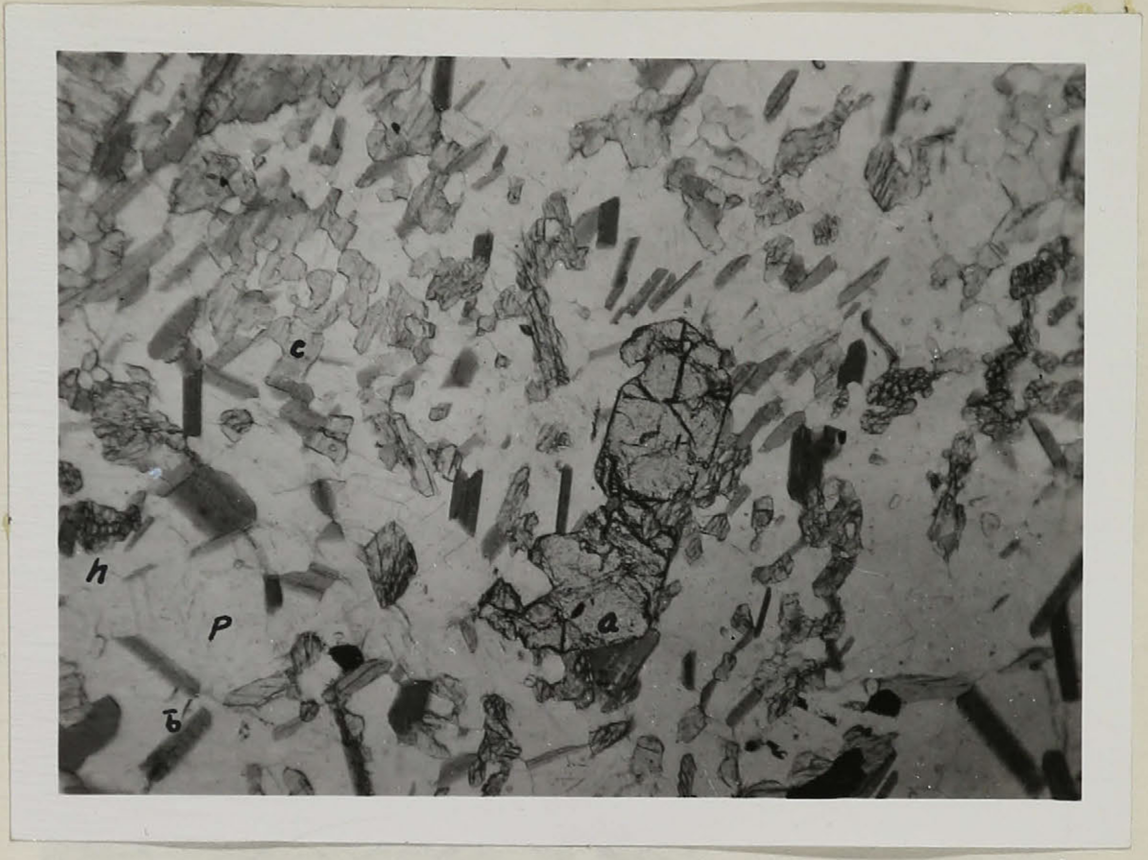


Fig. 7. X35
Typical texture of plagioclase (p) - cummingtonite (c) - biotite (b) - hornblende (h) - andradite (a) amphibolite.

Fig. 8. X108
Twinned crystal of cummingtonite with inclusions of plagioclase.

Fig. 9 . X 108

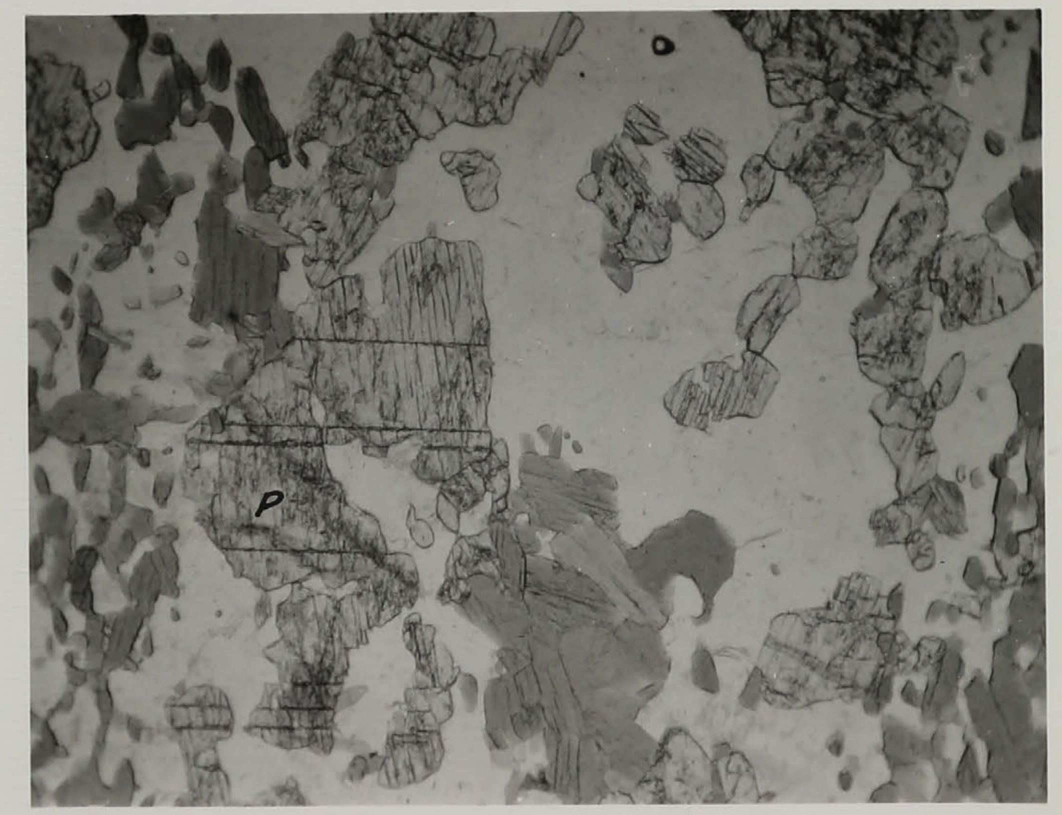
Hornblende replaced by cummingtonite. Two dark pleochroic green spots A and B with closely spaced parallel lines and same optical orientation, are left in the central part of the crystal.

Fig. 10. X108

Pyroxene (p) replaced by hornblende (h) in turn replaced by cummingtonite (c), the whole system replaced by plagioclase (white).

Fig. 11. X35

Section showing the typical texture of pyroxene and carbonate amphibolite. The minerals are pyroxene (p), carbonate (c), hornblende (h) and acidic andesine (a).



X35

Fig. 12.

Scapolite-bearing pyroxene amphibolite. A porphyroblast of pyroxene (p) with basal parting to the left, and small rounded grains of pyroxene (top right). The white mineral is scapolite, the third one is hornblende.

Fig. 13. X105

Section showing evidence of replacement of pyroxene (dark grey) by scapolite (white).

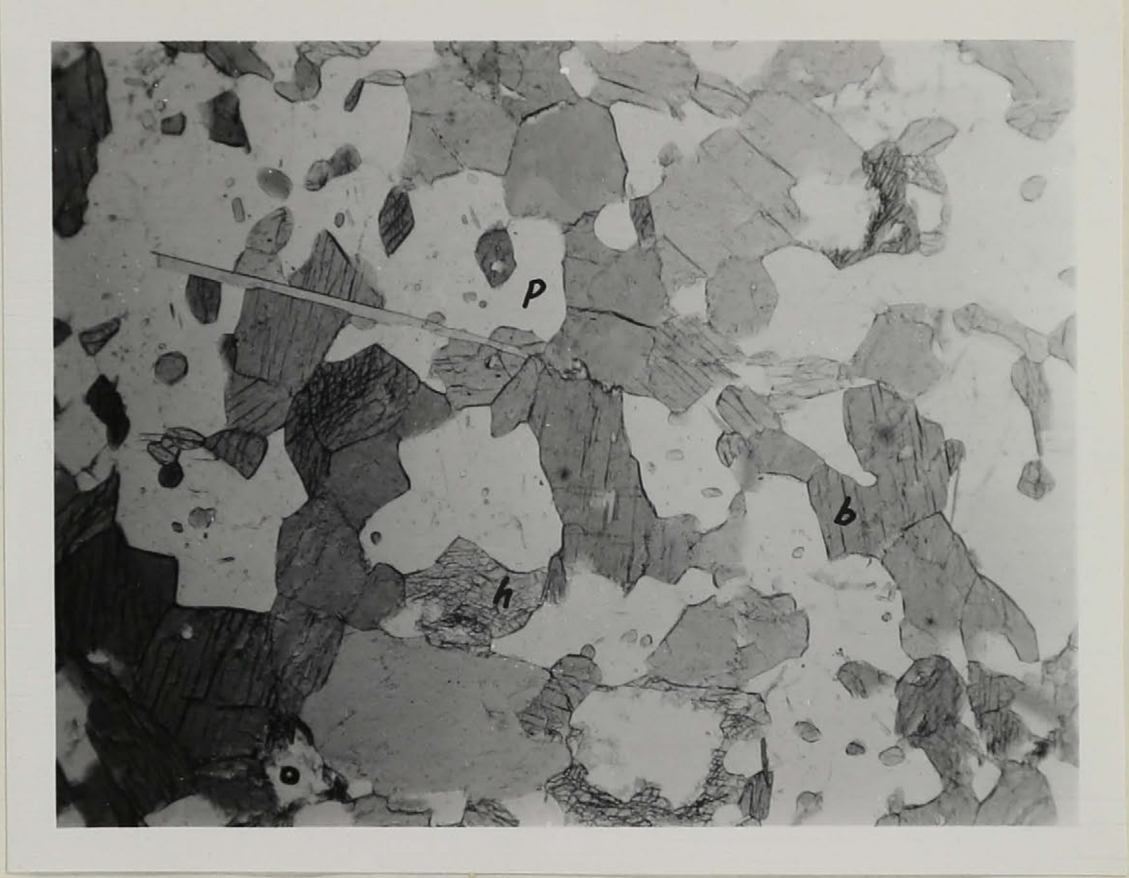


Fig. 14. X 35

Plagioclase-hornblende-biotite amphibolite with granoblastic texture. Plagioclase (p), hornblende (h), biotite (b).

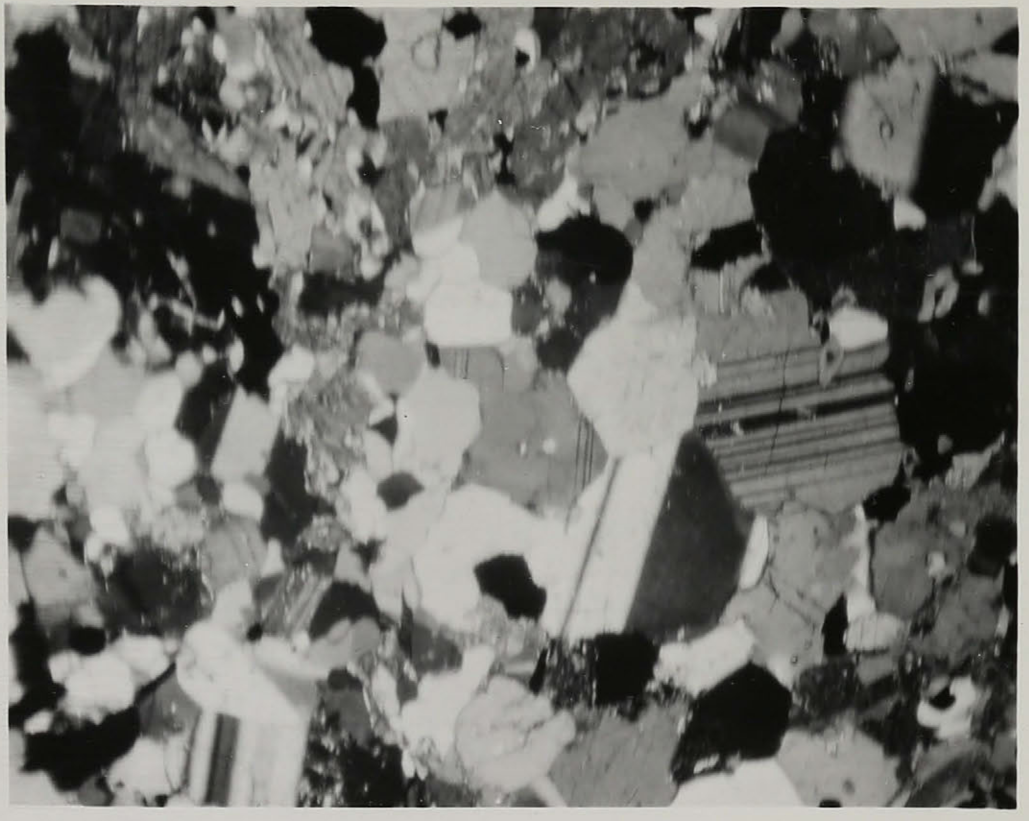


Fig. 15. x35

Typical texture of injected amphibolites overlying the pyroxene amphibolites of the hanging wall. The minerals are: plagioclase, quartz, pyroxene (top centre), carbonate, biotite, sphene, garnet and apatite.

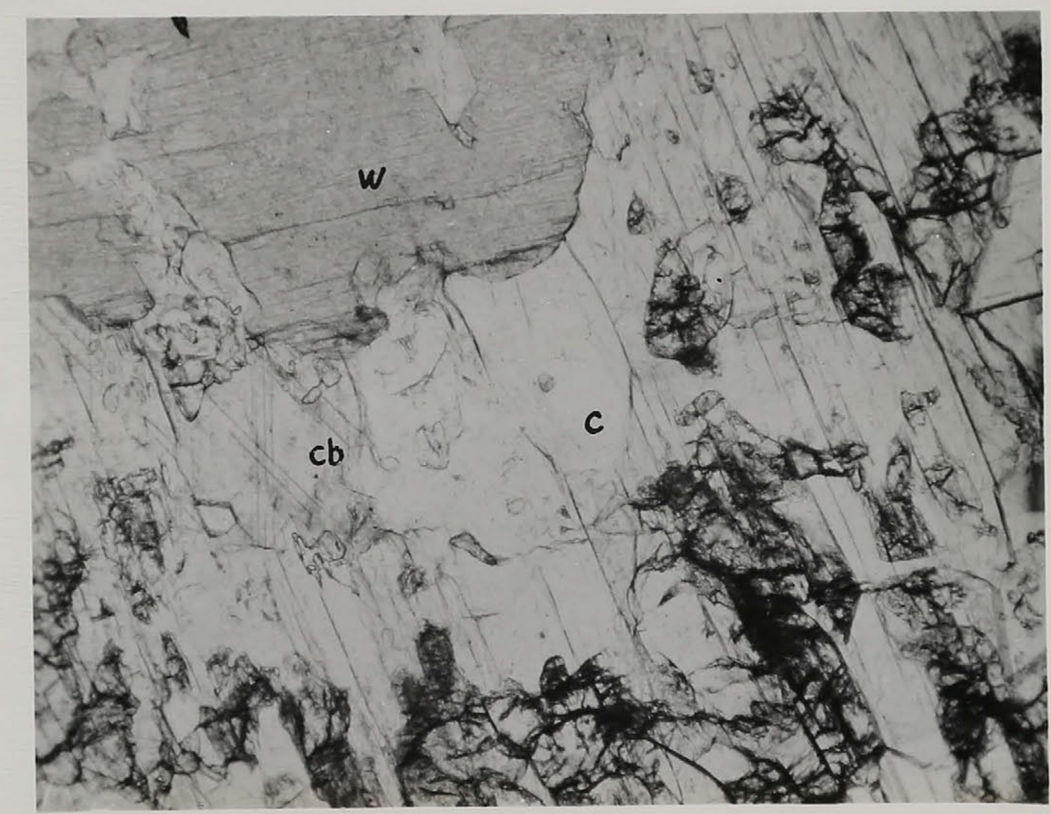


Fig. 16. x35

Wilsonite (w) untwinned cummingtonite (c), granular diopside (d) and carbonate (cb).

Fig. 17. x 35

Relation between anhydrite (a), diopside (d) and carbonate (c). The concave outline of carbonate crystals seems to indicate replacement by anhydrite.

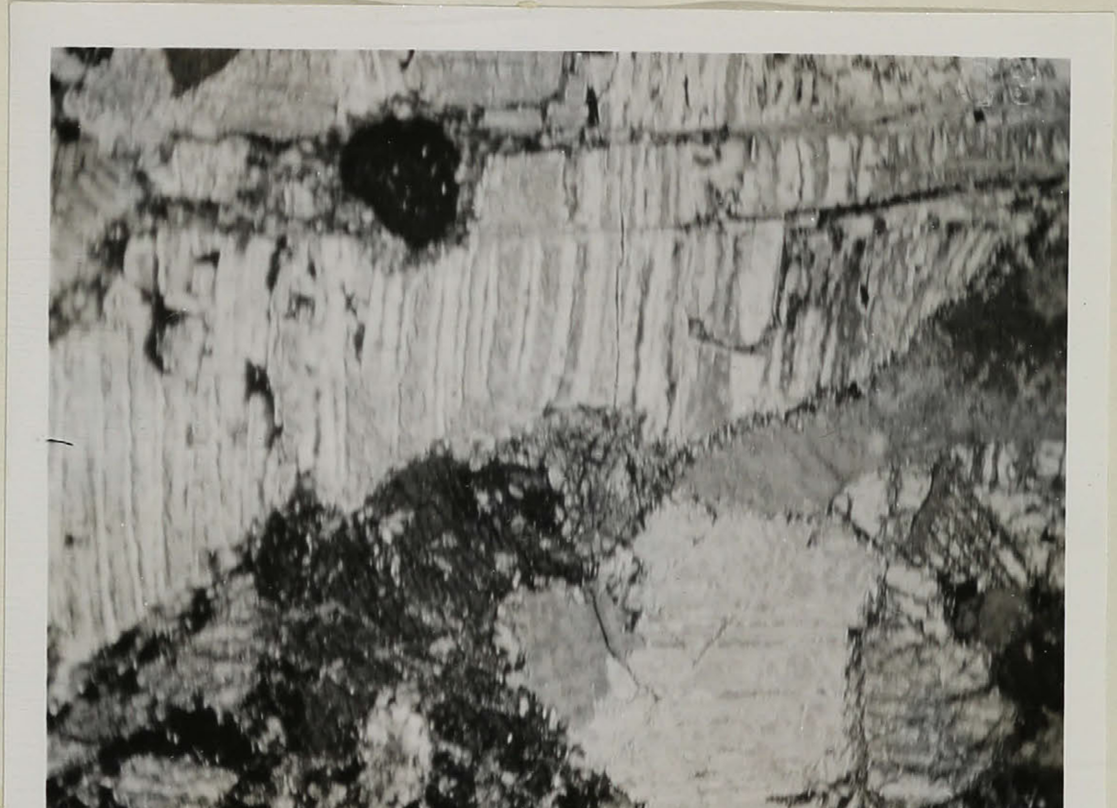


Fig. 18. x 35

Anhydrite replaced by gypsum forming rims around the former. Carbonate and pyroxene are also present. The peculiar appearance of anhydrite is apparently due to deformation of crystal in grinding X nicols.

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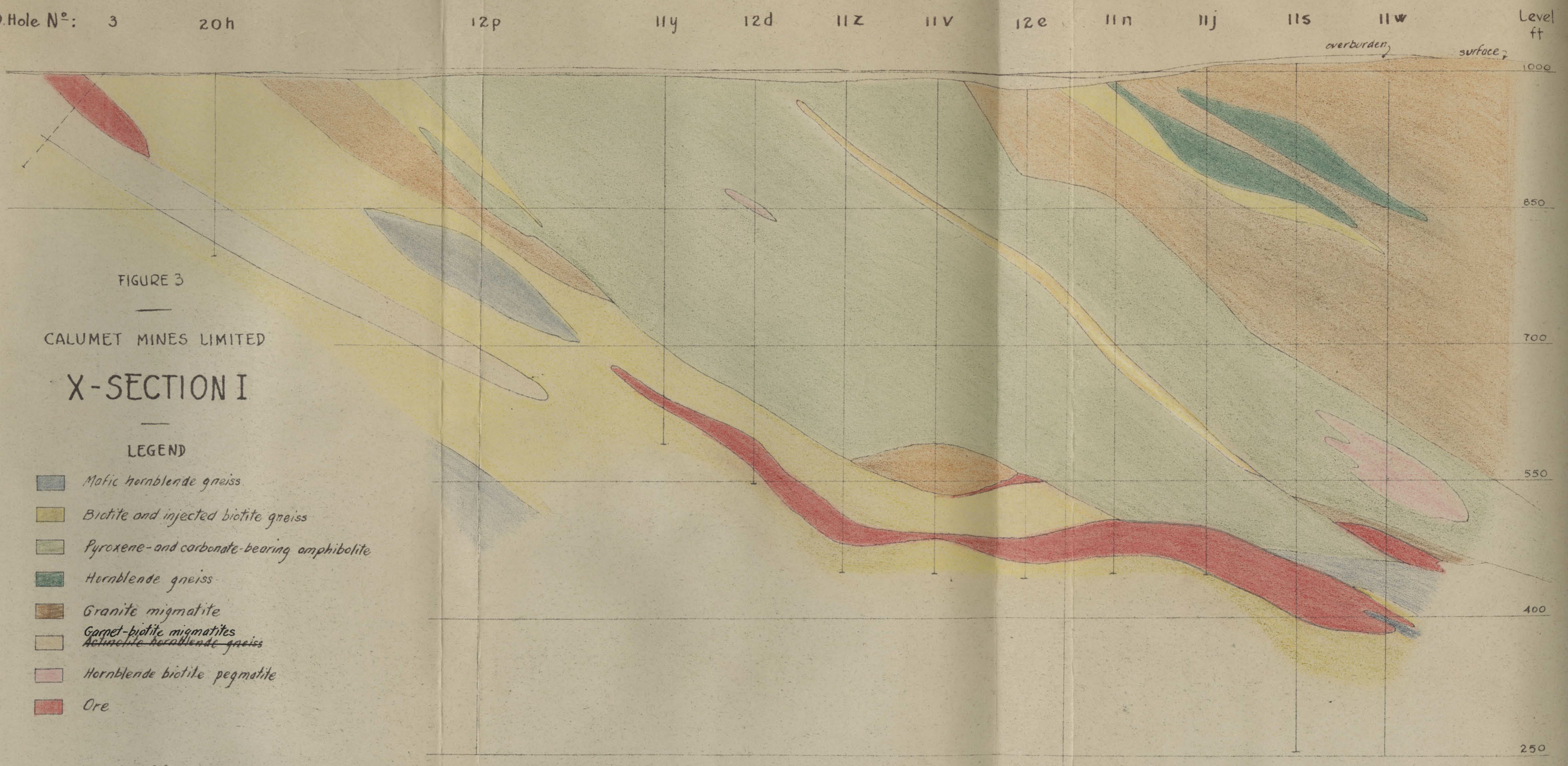

FIGURE 3

CALUMET MINES LIMITED

X-SECTION I

LEGEND

- ▨ *Mafic hornblende gneiss*
- ▨ *Biotite and injected biotite gneiss*
- ▨ *Pyroxene- and carbonate-bearing amphibolite*
- ▨ *Hornblende gneiss*
- ▨ *Granite migmatite*
- ▨ *Garnet-biotite migmatites* ~~*Actinolite hornblende gneiss*~~
- ▨ *Hornblende biotite pegmatite*
- ▨ *Ore*

Scale of feet

100 75 50 25 0 100 200

MINERALOGICAL COMPOSITION OF THE VARIOUS TYPES OF ROCKS
OF
CALUMET MINES LIMITED

(Figure 4)

BIOTITE AND INJECTED BIOTITE GNEISSES

Section N°	Quartz	Plagioclase	Anorthoclase	Biotite	Moscovite	Sillimanite	Apatite	Sulphides	Others
2	▭▭	☐ An_{33}	▭	☐				▭	
3	▭▭		▭	☐		☐		▭	Microcline?
4	▭▭		▭	☐		☐		☐	
5	▭▭	☐ An_{44}	▭	☐	☐	☐	☐	▭	Microcline?
6	▭▭		▭	☐	☐	☐		☐	
7	▭▭			☐	☐	☐	☐		
13		☐	☐	▭		☐	☐	▭	Hypersthene?
19	▭▭	☐ An_{19}		☐	☐	☐	☐	☐	Carbonate

CORDIERITE-BEARING ASSOCIATIONS

Section N°	Quartz	Plagioclase	Anthophyllite	Biotite	Cordierite	Sillimanite	Apatite	Sulphides
15	▭▭	☐		☐	☐		☐	☐
42	▭▭	☐ An_{20}		☐	☐	☐		☐
11		☐	▭▭	▭	▭		☐	☐

CUMMINGTONITE AMPHIBOLITES ± GARNET

Section N°	Quartz	Plagioclase	Cummingtonite	Biotite	Hornblende	Garnet	Apatite	Others
16	▭▭	☐	☐	☐			☐	Sulphides Carbonate
18	▭	▭ An_{46}	▭	☐	☐	☐	☐	Sulphides
20		▭ An_{11}	☐	☐	☐	☐	☐	"
22		▭▭ An_{37}	▭	☐	☐	☐	☐	.
14		▭▭ An_{30}	▭	☐		☐	☐	Serpentine
37		▭▭ An_{14}	▭	☐	☐		☐	
32		▭▭ An_{11}	☐	▭	☐		☐	
27		▭▭ An_{10}	☐	☐	▭		☐	Sulphides
25		▭	☐		▭▭		☐	Sulphides Carbonate
40		☐ An_{50}	☐	☐				▭▭ Actinolite
1		▭▭ An_{38}		☐		Sphene	☐	▭▭ Sulphides

NORMAL AMPHIBOLITES

Section N°	Quartz	Plagioclase	Hornblende	Biotite	Others
36	☐	▭▭ An_{30}	▭	☐	Carbonate Apatite
21		▭▭ An_{48}	▭	☐	Sulphides
17	☐	▭▭ An_{63}	▭▭	☐	Carbonate Apatite
34		▭ An_{35}	▭▭	▭	
28		▭▭ An_{33}	▭▭		Apatite

ANHYDRITE GYPSUM AND CARBONATE ROCKS

Section N°	Carbonate	Anhydrite	Gypsum	Tremolite	Diopside	Moscovite	Others
52	▭▭	☐		☐		☐	Sulphides
54	☐	▭▭	▭		☐		
55	▭		▭▭	☐	☐		Apatite
56	☐		▭▭	☐	☐		
51	☐	▭▭	▭	☐	☐		
58	▭▭		▭▭	Grains	Grains	☐	

MEDIUM-GRAINED CONTACT-METAMORPHIC ROCKS

Section N° 9	Biotite? ▭	Gedrite ▭▭	Zoisite ? ☐	Sulphides ☐			
45	Qtz ?	▭▭	Biotite ☐	Spinel ☐	Sulphides ☐		
10	Carbonate ▭	Chlorite ▭▭	Ore ☐				
50	Quartz ☐	Cummingtonite ▭▭	Wilsonite ▭	Diopside ▭	Carbonate ☐	Sphene ☐	Apatite ☐
53	☐	Plagioclase ☐ An_{20}	Biotite ▭▭	Sillimanite ▭	Apatite ☐	Sulphides ☐	
46	▭▭	☐ An_{16}	▭	▭	☐	☐	

AMPHIBOLITE-MIGMATITE COMPLEX

Section N°	Quartz	Plagioclase	Hornblende	Biotite	Pyroxene	Garnet	Sphene	Carbonate	Apatite	Sulphides	Others
39	☐	▭▭ An_{18}	☐		☐	☐	☐	☐	☐	☐	
33	▭	▭▭ An_{30}	▭	☐		☐			☐		
26	?	▭ An_{39}	▭		☐		☐	☐		☐	
24	▭▭	☐ An_{10}	☐	☐	☐	☐		☐	☐	☐	
44	☐	▭▭ An_{28}	▭					▭			
64	▭	▭▭ An_{40}	☐	☐				☐	☐	☐	
47		▭ An_{36}	▭▭ Actinolite						☐		
12	?	▭		▭▭						▭	Serpentine
35	▭▭	☐	hastingsite ☐	☐	☐	☐	☐		☐		Alter. of felds telds. To Scap

PYROXENE AND CARBONATE AMPHIBOLITES

Section N°	Plagioclase	Pyroxene	Hornblende	Biotite	Carbonate	Scapolite	Apatite	Sulphides	Others
23	☐ An_{40}	☐	▭	☐	▭	☐	☐	☐	Pinite
31	☐	▭	▭	☐	☐	☐	☐		
29	▭ An_{31}	▭▭	▭		☐	☐	☐	☐	Serpentine
30	☐ An_{50}	▭▭	☐	☐		▭▭	☐		
48	☐ An_{28}	☐	▭	☐	▭		☐		
62	▭ An_{47}	☐	☐		▭			☐	Epidote
63	☐ An_{32}	☐	☐	☐	▭▭		☐		
41	☐	▭▭	☐	▭			☐		
38	▭▭ An_{35}	▭		☐			☐	☐	Cummingtonite

LEGEND

▭▭	50% and over		Sulphides
▭	25% to 50%	▭	over 5%
☐	less than 25%	☐	less 5%

Pierre Mauffette

Pantograph reproduction of F. Fitz Osborne's map. Q.B.M.
Reduction two to one.

SURFACE MAP
CALUMET MINES LIMITED