THE GEOLOGY OF THE TROUT BAY NICKEL DEPOSITS
RED LAKE DISTRICT, NORTHWESTERN ONTARIO

by

Chester J. Kuryliw

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ABSTRACT

The study of the geology of the Trout Bay Nickel Deposits reveals a series of basic lavas and pelitic sediments of Keewatin-Timiskaming age that contain two types of mafic intrusions.

The older ultrabasic intrusion is long and narrow, it has been altered by dynamic metamorphism to a tremolite, antigorite, magnetite schist from a hornblendite. Dynamic metamorphism altered the copper nickel sulphides of the intrusion so that pyrrhotite was broken down to form pyrite, magnetite and sulphur; and the liberated sulphur migrated outwards from the stressed area and acted on magnetite to form pyrrhotite. With the breakdown of pyrrhotite, pentlandite coalesced into blocky masses to form the most abundant sulphide in the form of "augen" lenticles, and chalcopyrite migrated to the edges of augen. Metamorphism did not change the 4:1 nickel to copper ratio but greatly increased the nickel to sulphur ratio.

The younger basic intrusion consists of a differentiated lolopith-sill and related "outlier" gabbro intrusions. The differentiated sill has pyroxenitic, noritic and micropegmatite layers. Disseminated copper-nickel sulphides occur at the base of one outlier gabbro intrusion and the sulphides have a nickel to copper ratio of 2:1 but a low nickel to sulphur ratio. Medium grade contact metamorphic aureoles occur in pelitic rocks adjacent to the differentiated sill.

Late granitic intrusions of Kenoran age have intruded and deformed the Trout Bay rocks.

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A special note of thanks is due Mr. J. E. J. Fahlgren, General Manager and Executive Vice-President of the Cochenour-Willans Gold Mines Ltd., who permitted and encouraged this study.

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PART I

GENERAL INTRODUCTION

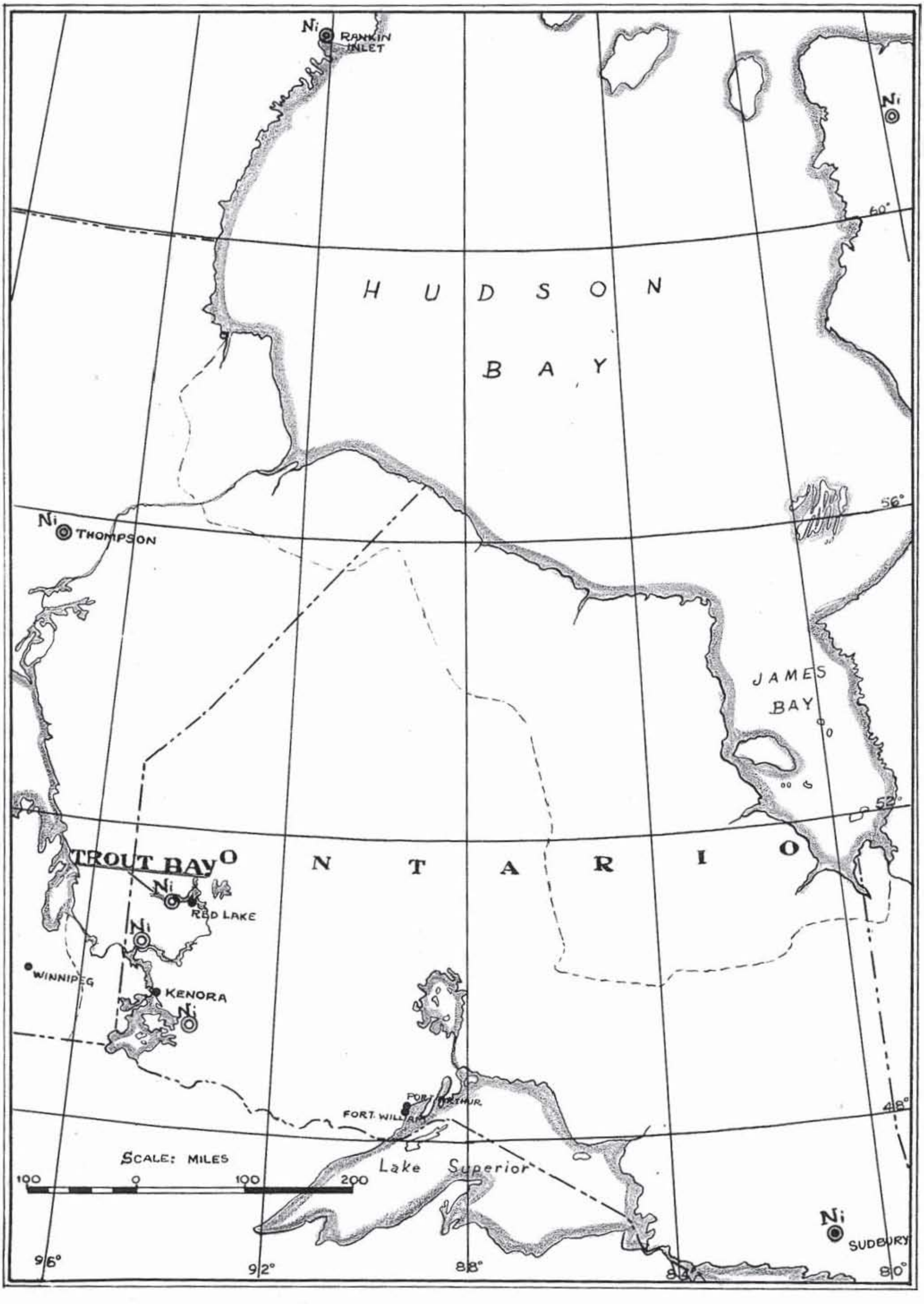

Figure 1. - LOCATION MAP

THE THESIS PROBLEMS

The objective of this study was primarily to gain information on the geology of the Trout Bay nickel occurrence. A better understanding of some of the puzzling aspects would materially assist in the concentration of exploration to the more worthy portions.

Some of the major problems worked on were:

(1) A microscopic study of all rocks to determine their general nature and composition along with some knowledge of their relative grade of metamorphism.

(2) The nature of the basic amphibolite intrusives, their composition, mineralogy and differentiation, if any, and their Cu-Ni sulphide mineralization.

(3) The nature of the ultrabasic amphibolite schist, including its possible origin, and the nature of its Cu-Ni sulphides with their peculiarly high Ni:S ratio.

(4) A study of the Cu-Zn-Pb-Ag sulphides and also the magnetite-rich iron formation.

GENERAL GEOLOGY OF THE RED LAKE DISTRICT, NORTHWESTERN ONTARIO

History

The first geologic survey of the Red Lake area was made in 1923 by E. L. Bruce of the Ontario Department of Mines. In 1926 E. L. Bruce and J. E. Hawley compiled the first good map of the area. In 1925 the first significant gold discovery was made and a staking rush ensued in 1926. The first producing mine, the Howey Red Lake, began production in 1930. During 1937-1941, H. C. Horwood of the Ontario Department of Mines completed a geologic survey and issued a plan of the Red Lake area; scale 1" = ½ mile. At the present time the six operating gold mines in the Red Lake Camp produce close to 500,000 ounces of gold per year.

Regional and General Geology of the Red Lake Area

The consolidated rocks of the Red Lake area are of Archean age. These rocks are covered in large part by a mantle of Pleistocene glacial drift, moraines, sand and clay. Recent accumulations of vegetable material and silt occur in swamps and muskegs.

H. C. Horwood divided the Precambrian complex into three main groups of rocks (see Table of Formations - Table 1): Keewatin, Timiskaming and Post-Timiskaming. The terms Keewatin and Timiskaming were chosen due to some general similarities to other rocks so named in other parts of the Canadian Shield.

TABLE 1

TABLE OF FORMATIONS - RED LAKE DISTRICT

(After H. C. Horwood)

QUATERNARY

Recent
Pleistocene

PRECAMBRIAN

- POST-TIMISKAMING
- ALGOMAN ?

Granite
----Intrusive contact----

Diorite, Hornblende diorite, Pyroxenite, etc.
----Intrusive contact----

Hybrid granites with assimilated rocks
----Intrusive contact----

Quartz feldspar porphyry, granodiorite porphyry
----Intrusive contact----

- LATE PRE-ALGOMAN ?

Feldspar porphyry
----Intrusive contact----

Quartz porphyry
----Intrusive contact----

- EARLY PRE-ALGOMAN ?

Howey Diorite
----Intrusive contact----

TIMISKAMING

Iron Formation

Paragneiss

Sediments

-----Unconformity-----

KEEWATIN

Granitized volcanic rocks

Iron formation

Sediments

Acid volcanic rocks

Intermediate to basic volcanic rocks

"Keewatin" Rocks

These are the most abundant rocks in the area. They are composed predominantly of intermediate to basic lavas and agglomerates. Tuffs and rhylitic to basaltic pillowed or variolitic lavas are common. In places flow layers are separated by beds of slaty or cherty pyritic iron formations.

Alteration of these volcanics is widespread, and variable. Carbonatization, silicification, steatitization, sericitization, chloritization, and amphibolization are all common, and in some localities intense.

All but one of the present producing gold mines in Red Lake Camp mine their ore from Keewatin host rocks.

"Timiskaming" Sediments

These sediments occur in wide variety, the most common being argillites, greywackes, slates, quartzites, and the variable cherty iron formations which may be rich in iron sulphides, ferromagnesian silicates or magnetite.

Significant gold occurrences have not been found in these rocks.

Post-Timiskaming Intrusions

---Early Pre-Algoman ?---

H. C. Horwood placed the Howey diorite in this group. Its hornblende content ranged from 25-50%. The remainder was chiefly labradorite.

---Late Pre-Algoman ?---

The sericitized quartz porphyry intrusions occur throughout the Keewatin-Timiskaming rocks of the Red Lake Camp. They precede gold ore introduction but in many cases appear to exert a beneficial control on ore localization. Haloes of silicification and sericitization are usually present. Some of the larger intrusions carry disseminated chalcopyrite, sphalerite and gold in brecciated portions.

---Algoman ?---

The Algoman encompasses a period of major igneous activity during which various granitic rocks were emplaced and now completely surround the volcanic and sedimentary complex of the Red Lake area. It is a generally held belief that gold mineralization in the area was derived from hydrothermal activity associated with these granites.

HISTORY AND PREVIOUS WORK DONE
LOCAL TO TROUT BAY NICKEL AREA

Location

The Trout Bay claim group and its nickel prospect are located in Mulcahy and Ball Townships about 15 miles due west of the town of Red Lake in northwestern Ontario. (See Location Map - Figure 1). The property is accessible by air, and by boat when in season. It is 12 miles from an all-weather road connected to the Trans-Canada Highway. The C.N.R. railroad is 102 miles by road from Red Lake. An Ontario Hydro Electric power line is located 3 miles to the north of the property.

History

1926 - 1956: Parts of this property have been staked and re-staked several times since the original gold rush to Red Lake in 1926. Past efforts were all concentrated in the search for gold. The latest publication by the Ontario Department of Mines (1940-41) on the Mulcahy Township indicated only the granite contact with "Keewatin" volcanics.

During the summer of 1956 the author, and Mr. J. E. J. Fahlgren, then Mine Manager of the Cochenour-Willans Gold Mine, and prospectors, examined some trenches for gold occurrences. The author recognized the "gabbroic" rock containing some Cu-Ni sulphides. The ground was then staked upon the approval of the Manager after a reconnaissance survey was made. The 160 claim group was then examined further. A grid of lines was planned and cut and an electromagnetic ground survey was carried out by McPhar Geophysics during the winter 1956-1957. The author completed a geologic mapping of the ground on a scale of 1" = 200' in 1957. Some diamond drilling and trenching were done to check the electromagnetic anomalies. A magnetometer survey was also carried out on the grid during that summer.

During the summers 1957-1959, prospecting, trenching and some diamond drilling were carried out which traced disseminated Cu-Ni sulphide mineralization in the gabbro intrusion for nearly a mile in length, but no deposit of commercial grade was located.

During the summer of 1960 search was concentrated more in the area of the numerous "outlier" intrusions. A self potential geophysical survey by D. Fisher located the amphibolite schist Cu-Ni deposit and the Cu-Zn-Pb-Ag deposit. Both of these occurrences were trenched and partly diamond drilled in the fall of 1960. The writer supervised the work that had been done during 1956-1961.

During the winter 1961-1962, a detailed magnetometer survey was completed on a grid spaced at 100 foot intervals to cover the amphibolite schist and magnetite iron formations. This is to be followed by detailed geologic mapping and diamond drilling of the unmapped amphibolite schist zone.

INFORMATION AND METHODS USED FOR THESIS

All accumulated data available were used in this study. These comprised:

(1) A plan of geologic mapping (1" = 200'), 1957, by the author.

(2) An electromagnetic survey (1" = 200').

(3) A magnetometer survey (1" = 200').

(4) The logs and assay results from diamond drill holes.

A systematic cross section sampling was made in preparation for this thesis (See Plan I in envelope). Ninety-six thin sections and forty-eight polished sections were made. Seven samples were selected for chemical analysis. Point count analyses were made of a number of thin sections to determine the mineralogic composition. The composition of plagioclase was determined for the differentiated gabbro intrusion by the Tsuboi method, which uses the refractive index of oriented grains to determine its composition. The composition of amphiboles was determined by a similar method after Parker, 1961, (Ref. 12).

Polished section examinations and statistical variation studies were made of the sulphide deposits. All thin sections were examined and studied for their petrographic character and significance. Literature pertaining to major topics was searched and studied, some of this information is used for comparative purposes in Part II. In Part III, the local geology of the Trout Bay nickel prospect is presented. In Part IV the findings of studies on sulphide deposits and economic geology are described and discussed.

P A R T II

REVIEW OF GEOLOGIC LITERATURE

between the direction of elongation of tabular and lensoid ultramafic intrusions and the trend of bedding or foliation of the enclosing rocks is highly characteristic. Although essentially concordant, the sill-like bodies both large and small, commonly transgress the bedding and thin and thicken in short distances. There is an almost constant association of alpine peridotites and serpentinite with geosynclinal sediments such as greywackes and cherts; and volcanic rocks such as basalts, spilites and keratophyres.

Commonly the ultramafic rocks become completely converted to magnesian schists as the climax of deformation develops. The banded fabric of some peridotites and serpentinites rendered conspicuous by parallel streaks rich in chromite or magnetite may also reflect deformation of the nearly or completely crystalline rock. Serpentine pseudomorphs after peridotite minerals indicate by their outlines the textures of the original igneous rock.

In many alpine serpentinites there is evidence of strong deformation synchronous with or post dating serpentinization of the parent peridotite. The serpentine mineral in most such rocks is antigorite. Associated with these antigorite serpentinites may be a considerable variety of antigorite-chlorite rocks, talc-tremolite-carbonate-schists; some of which represent original dykes of pyroxenite. The metamorphic influence of even large bodies of peridotite of the alpine type is usually slight.

LAYERED BASIC INTRUSIONS

A Reference to the Skaergaard Peninsula gabbro intrusion of Greenland, after Turner and Verhoogen, 1960 (Ref. 13).

The form of the Skaergaard intrusion was a steep sided funnel tapering downward with its axis plunging at 45°, its outcrops extend over an area of about 60 square Kilometers. There is a chilled border of about 30 Meters. The main mass of the intrusion shows a remarkable layered structure governed by three independent elements:

(1) Rhythmic Layering is due to variation in relative proportions of the following main constituents - plagioclase, clinopyroxene, orthopyroxene and olivine. Individual layers commonly show gravity stratification. The heavy ferromagnesians at the base, the lightest constituent, feldspar, concentrates towards the top. These layers maintain a gentle inward dip sharply discordant with the steeply dipping walls. The overall structure resembles that of a pile of saucers concave upward.

(2) "Cryptic Layering" of the whole mass is characterized by a steady change in the chemical composition of each of the four main mineral phases in a vertical sense passing upward through the mass. One encounters phases progressively enriched in the low temperature end members of solid solution series: pyroxenes and olivine become richer in iron and plagioclase richer in soda.

(3) "Igneous Lamination" - many of the rocks display a foliated or laminated structure except toward the top of the section, resulting from preferred orientation of tabular crystals.

Wager and Deer (Ref. 13) have put forward the hypothesis backed by strong evidence that...."Following the injection of a magma of more or less tholeitic composition, crystallization began near the roof, but the crystals were steadily transported downward by convection currents, and accumulated as a sedimentary crystal mush on the floor of the magma chamber. Gravitational settling of heavy dark minerals within the layer of mush carpeting the floor over a given period is responsible for the rhythmic layering so widely prevalent in the lower levels of the layered series. The intrusion is thus pictured as slowly solidifying from the base upwards".

THE SUDBURY INTRUSIVE AND THE DEPOSITION OF NICKEL

After H. D. B. Wilson, 1953 (Ref. 14)

The Sudbury norite is a massive uniform rock composed mainly of pyroxene or uralite and labradorite with only a weakly developed layering. A magnetite zone disseminated in the silicates occurs as a broad but well defined zone near the top of the norite. Overlying these are the transition zone and the micropegmatite.

The titaniferous magnetite zone on the south range of the Sudbury intrusion occurs in the norite a few hundred feet below the transition to micropegmatite, the magnetite is disseminated in the norite as a zone that may be as much as a thousand feet wide. The titaniferous magnetite zone at Sudbury is also an apatite-rich zone. It seems therefore that the titaniferous magnetite-ilmenite mixture now present in the magnetite band was precipitated from the magma entirely with the spinel-type structure, and ilmenite separated out as the solid slowly cooled.

The outer electron structure of Ni^{2+} is such that it preferentially enters a sulphide phase if a sulphide liquid separates from a silicate liquid. Mg^{2+} on the other hand, having a rare gas type of electron shell structure, should remain in the silicate phase if a sulphide phase separates. Nickel and magnesium which concentrate together in a crystallizing silicate melt will, therefore, be separated if a sulphide liquid separates from a silicate magma. This separation may take place either in a completely liquid stage or in a partly crystallized mixture as it has been determined experimentally that liquid iron sulphides will extract nickel from olivine crystals suspended in the melt. The physical relation of copper-nickel sulphide bodies to its related intrusion distinguishes these copper-nickel deposits from typical hydrothermal deposits. The most characteristic location for copper-nickel sulphide deposits is on the basal contact, that is, the bottom of the intrusion to which they are related in composition. This condition is found at Sudbury, Ontario; Alexo, Ontario; Rice Island, Manitoba; Yakobi Island, Alaska; and Insizwa, South Africa. The major control of the loci of nickel-copper deposits is at the basal contact of a magnesia-rich intrusion. Other controls such as downward embayments and fault structures are also important. The fault control of nickel-copper orebodies is peculiar in that the faults only control the ore in the immediate vicinity of the lower contact of the intrusion. It is obvious that nickel ore like chromite ore can be controlled by fault structure but both ore types are obviously not highly mobile at the time of their formation as they are not transported far from their parent intrusion, or in the case of nickel, from its embayment locus even along faults which control the ore at its actual emplacement.

Vogt has pointed out that some relationship exists between the size of a nickel-copper deposit and the size of the intrusion. In a basic intrusion, sulphide is still liquid when the silicate portion is solid or almost solid, and the sulphides may be moved along fractures in the direction of relief of pressure. The sulphides however are close to their freezing point and do not travel far from the parent intrusion as they are so quickly chilled by the wall rocks.

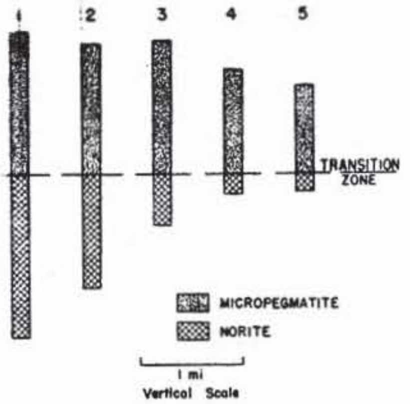

FIGURE 9.—COLUMNAR SECTIONS OF THE SUDBURY LOPOLITH

1. Creighton, 2. Gertrude, 3. Levack, 4. Nelson Lake, 5. Trill

be expected. These valleys and ridges may have characteristic plunges if they are controlled by fracture systems in the pre-existing footwall rocks. A new section of the Sudbury lopolith as shown in Figure 10 presents the structure as a funnel-shaped lopolith with layering not parallel to the lower contact. The bottom of the intrusion is composed of ultrabasic rocks, probably highly layered and possibly serpentinized.

Seismic studies of the Sudbury basin have been considered but have been rejected because tests showed that the norite is probably too similar to the granite basement rocks to show the contact seismically. This conclusion was based on the assumption of a norite bottom. If, however, the bottom of the lopolith is layered ultrabasic rocks, the possibilities of seismic studies of the lopolith should be reconsidered.

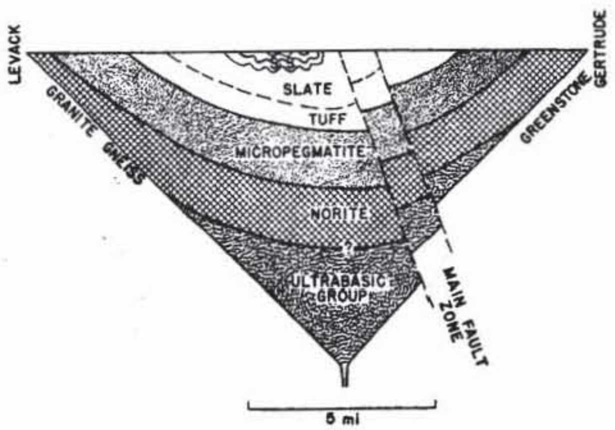

FIGURE 10.—DIAGRAMMATIC CROSS SECTION OF THE SUDBURY LOPOLITH FROM LEVACK TO GERTRUDE

cated in Figure 8 are shown graphically in Figure 9. The sections chosen are those which are least complicated by faulting. It is again apparent that the proportion of the rock types depends upon the location of the section—that is, the erosion level—and the structure of the bottom of the intrusion.

Because the Sudbury intrusion has the characteristics of other large lopoliths, it is suggested that it is not a folded sill but is a typical funnel-shaped lopolith probably with a feeder at the bottom.

The average 40- to 45-degree dip of the lower contact on the north and south ranges is likely to be maintained, but abrupt deepenings and shallowings resulting in valleys and ridges may

SUDBURY LOPOLITH AND THE SUDBURY BRECCIA

Figure 10 shows a problem of room since the footwall rocks must have been pushed aside to make way for the magma. More gently dipping lopoliths which are intruded into gently dipping sediments do not have such a serious room problem because much adjustment may take place along the sedimentary layers and by simple lifting of the overlying sediments. The Sudbury intrusion, however, is pictured as a steeply dipping funnel-shaped body intruded into massive Archean rocks. This intrusion could not take place without great adjustments which were the cause of the Sudbury breccia.

FIGURE 3.

GEOLOGY OF THE MCKIM MINE - SUDBURY, ONTARIO

(After Clarke and Potapoff, 1959 - Ref. 2)

The primary structural control of the McKim ore deposit, as with most nickel-copper deposits of Sudbury, is proximity of the outer (or basal) norite contact. Sudden deepenings or shallowings along the base of the norite intrusion are common (i.e. the Creighton embayment). Embayments are partly controlled by fracture systems in the pre-existing rocks. These embayments also are a common structural control on the location of nickel ore deposits.

Primary sulphides of the McKim orebody are pyrrhotite, pentlandite and chalcopyrite, with minor pyrite and the nickel arsenide, gersdorffite. Alteration of the primary sulphides has resulted in zones of limited extent of marcasite, pyrite and violarite.

The contact or main orebody occurs between the norite and foot-wall rocks very close to and in zones paralleling the norite contact. The orebody is composed of one large shoot and several smaller ones at its extremeties. The individual ore zones are irregular in that they follow the norite contact but in detail are irregular as their widths vary greatly within very short distances.

The footwall orebodies occur only in the lower levels and only in the granite.

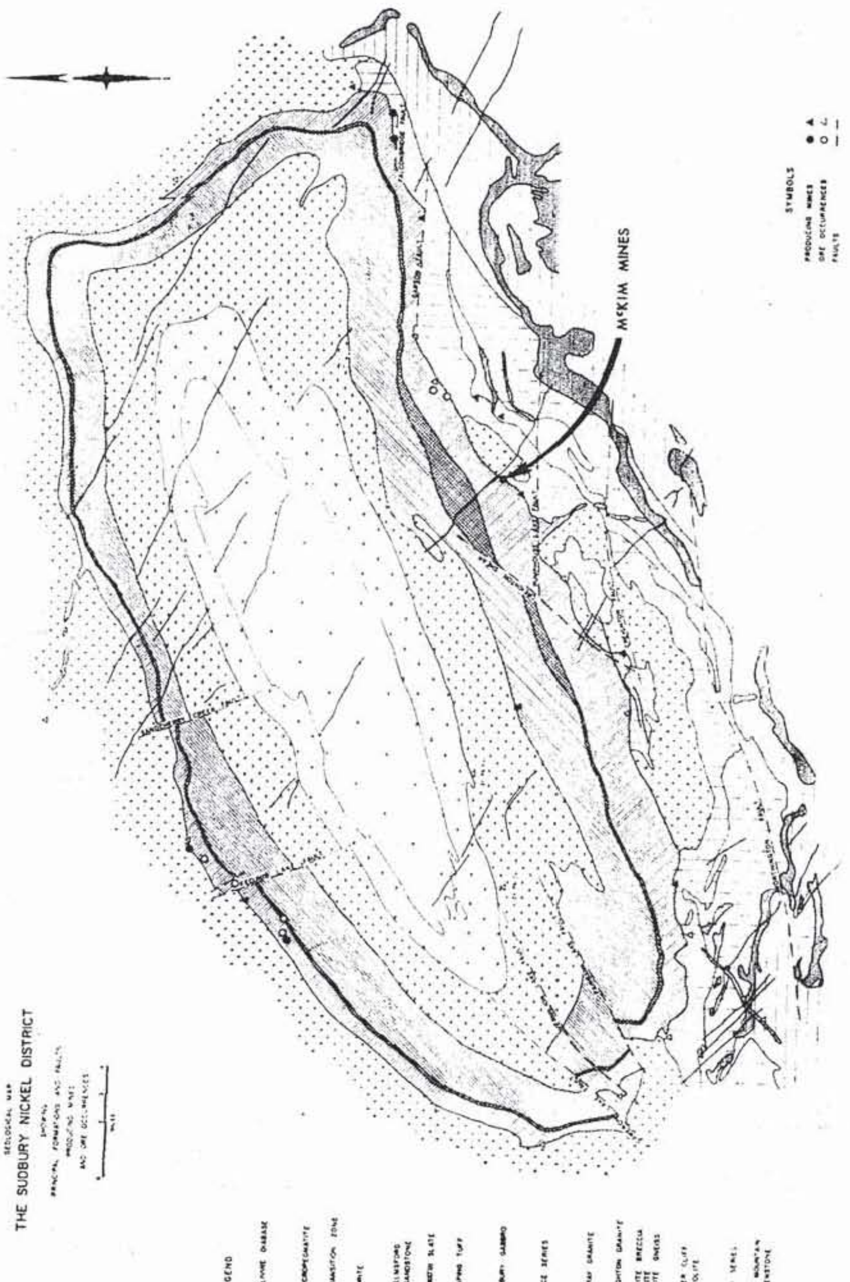
GEOLOGICAL MAP
THE SUDBURY NICKEL DISTRICT
SHOWING
PRINCIPAL FORMATIONS AND FAULTS
PRODUCING MINES
AND ORE OCCURRENCES
LEGEND
OLIVINE DIABASE
MICROPEGMATITE
TRANSITION ZONE
NORITE
CHELMSFORD SANDSTONE
ONWATIN SLATE
ONAPING TUFF
SUDBURY GABBRO
BRUCE SERIES
MURRAY GRANITE
CREIGHTON GRANITE
GRANITE BRECCIA GRANITE GRANITE GNEISS
COPPER CLIFF RHYOLITE
McKIM SERIES
ELSIE MOUNTAIN GREENSTONE
McKIM MINES
SYMBOLS
PRODUCING MINES
ORE OCCURRENCES
FAULTS

Figure 2

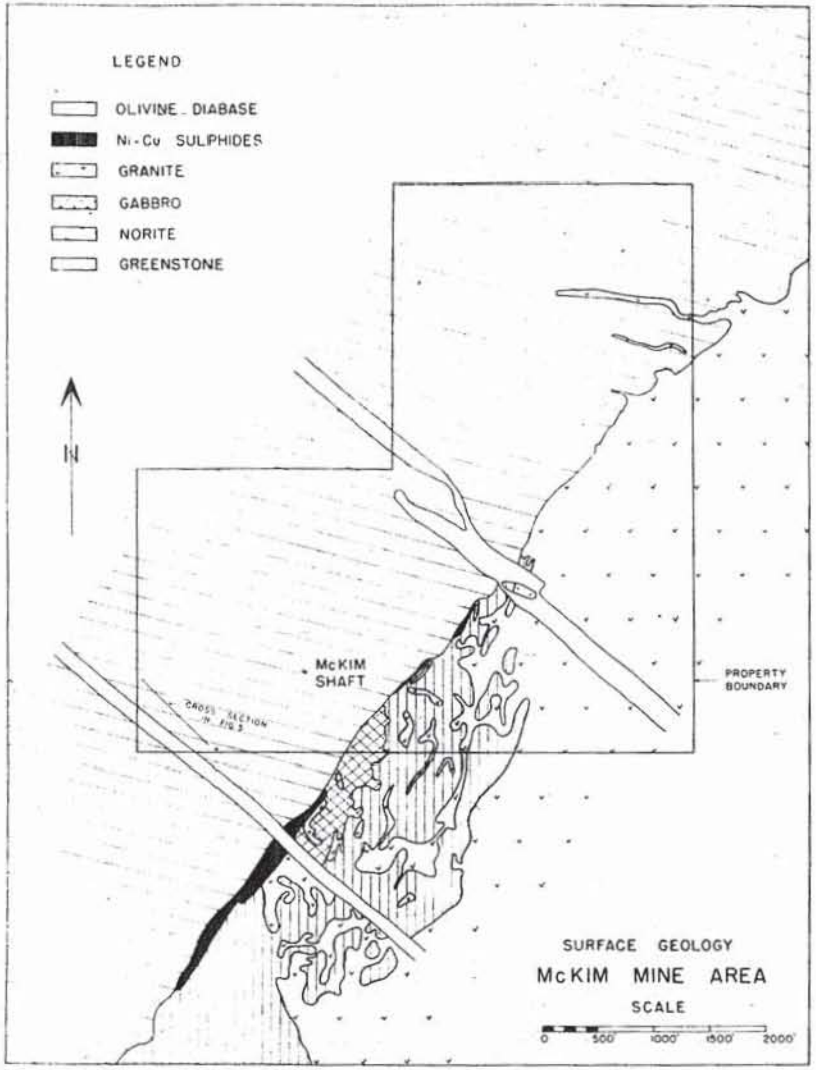

Figure 4. Geology Map of McKim Mine Area.

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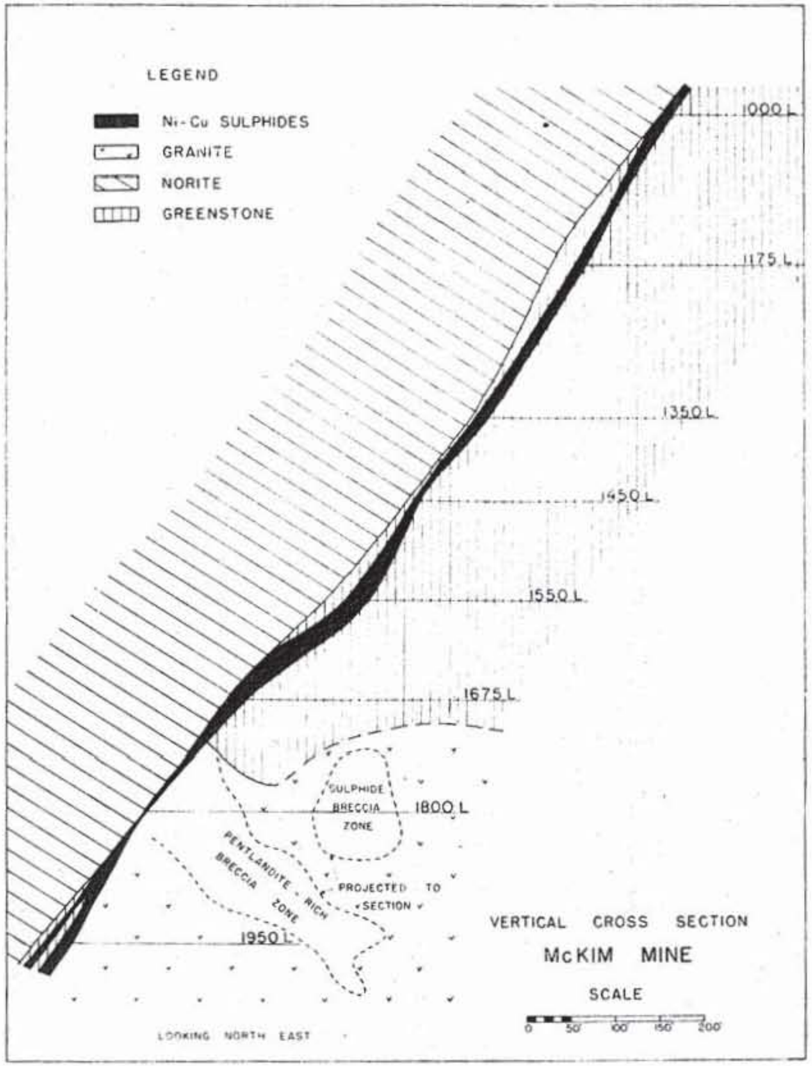

Figure 4A. Cross section showing dip of main ore and position of pentlandite-rich and foot-wall breccia ore.

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Types of Ore

(1) Sulphide Breccia Ore

This ore is composed of 80% nickel and copper sulphide minerals as a matrix containing fragments of gabbro, greenstone and norite. The sulphide is predominantly pyrrhotite.

(2) Massive Sulphide Ore

This ore occurs along the base of the sulphide breccia ore with the same sulphides but no rock fragments. This type also occurs as narrow stringers parallel to the contact, and as cross-cutting veins in the foot-wall rocks.

(3) Disseminated Pentlandite Breccia Ore

This type of footwall ore is not common in the Sudbury area. It is a disseminated pentlandite rich breccia with the matrix predominantly pegmatite. The disseminated zone contains only about 10% sulphides made up of 50% pentlandite, 30% pyrite, 20% pyrrhotite and almost no chalco-pyrite. The large proportion of pentlandite in the sulphides here is about ten times its concentration in the sulphides in the main ore zone.

Clarke and Potapoff state: "A theory to explain the pentlandite rich ore postulates that sulphide breccias existed only along the contact and when the granite intruded, large blocks of these sulphide breccias were rafted away from the norite contact into the footwall. Within some of these zones there was an abnormally high quartz carbonate content. The heat of the granite remobilized the sulphides with the result that, in the quartz carbonate rich zones, considerable volume of iron and sulphur was driven off leaving the nickel to re-crystallize mostly as pentlandite with lesser amounts of pyrite and pyrrhotite".

THE ERRINGTON CENTRE MINE - SUDBURY, ONTARIO

These copper lead zinc deposits lie at the contact of the Onwatin slate and Onaping tuff series that overlie the Sudbury intrusive. The slate and tuff have been much folded and faulted.

Sulphide mineralization of ore consists of chalcopyrite, sphalerite, galena, pyrite and minor pyrrhotite. The grade and ore reserves of the Errington deposit after 15% dilution (1954 estimates) are:

7,513,007 tons at 1.02% Cu, 0.75% Pb, 3.24% Zn,
1.49 oz. Ag, .017 oz. Au.

THOMPSON - MOAK LAKE

(After Wilson and Brisbin, 1961 - Ref. 17)

The Thompson-Moak Lake nickel belt lies along the root of a Precambrian mountain range of the island arc or alpine type. The ore deposits occur in serpentinized peridotite and in gneiss near peridotite. The sulphide mineralogy and sulphide ore textures are similar to those of other nickel ores. Pyrrhotite and pentlandite are the principal sulphide minerals, and pyrite, magnetite and chalcopyrite occur in lesser amounts. The ores are almost exclusively nickeliferous. Two origins for this ore were offered:

(1) An Igneous Origin - Solidification of peridotite intrusions containing a high sulphur content may have resulted in the low grade disseminated ores. A sulphide liquid segregated from a peridotite liquid may have been injected into the gneiss to produce the massive and stringer ore.

(2) A Metamorphic Origin - The mineralogy of the silicate gangue in the gneissic ore is typical of the almandine-amphibolite facies, sillimanite-almandine subfacies. Extensive metamorphism is prominent. Much of the iron formation is metamorphosed to medium grained banded mixtures of quartz, grunerite and magnetite. In many places more than half the magnetite has been converted to pyrrhotite. "The disseminated nickel-iron sulphides in the peridotite, and the pyrrhotite in the iron formation may have a similar origin. This origin is suggested in laboratory

experiments in which the presence of hydrogen sulphide will form nickeliferous pyrrhotite in peridotite and will convert magnetite to pyrrhotite in the temperature range between 400°C. and 650°C. at standard pressures". (Wilson, Brisbin, 1961 - Ref. No. 17).

"Gill (1960) has shown experimentally that sulphide minerals migrate readily along a temperature gradient at temperatures above 400°C. Such a process might explain the migration of the nickel-iron sulphides from the peridotite into the gneiss to form the gneissic ores regardless of whether the sulphides in the peridotite were igneous or metamorphic". (Wilson, Brisbin, 1961 - Ref. No. 17).

ON NICKEL SULPHIDES

THE PYRRHOTITE-PENTLANDITE Fe-Ni-S System

The intimate association of the major minerals pyrrhotite-pentlandite-chalcopyrite in Sudbury ores, strongly indicates their introduction together in one ore fluid. From this nickeliferous pyrrhotite solid solutions crystallized early and chalcopyrite later. Most, if not all, occurrences of pentlandite appear to be the results of progressive unmixing of the nickeliferous pyrrhotite up to and probably including the time of deposition of chalcopyrite and even longer during further cooling. (Hawley, 1962, P. 169-176 - Ref. No. 5).

The pyrrhotite-pentlandite textures indicate an exsolution or unmixing origin for the pentlandite. This is particularly evident where pentlandite lamellae lenses or veinlets and flames or brushes are contained within pyrrhotite grain boundaries. Coarse interstitial pentlandite passes into thin rims and partial rims about pyrrhotite grains. The bulk of the chalcopyrite crystallized from the same ore fluid as pyrrhotite after second generation magnetite and during and also after the sègregation of pentlandite from pyrrhotite. The bulk composition of Sudbury ores lies well to the left of the central cross section (Figure 5), so that $(Fe,Ni)_{1-x}S$ crystals form first in solid solution.

Kullerud demonstrated (1956 - Ref. No. 5) in his synthesis of the minerals of the Fe-Ni-S system (Figures 5 and 5A) that ore fluids attained a eutectic composition so that pyrrhotite and pentlandite

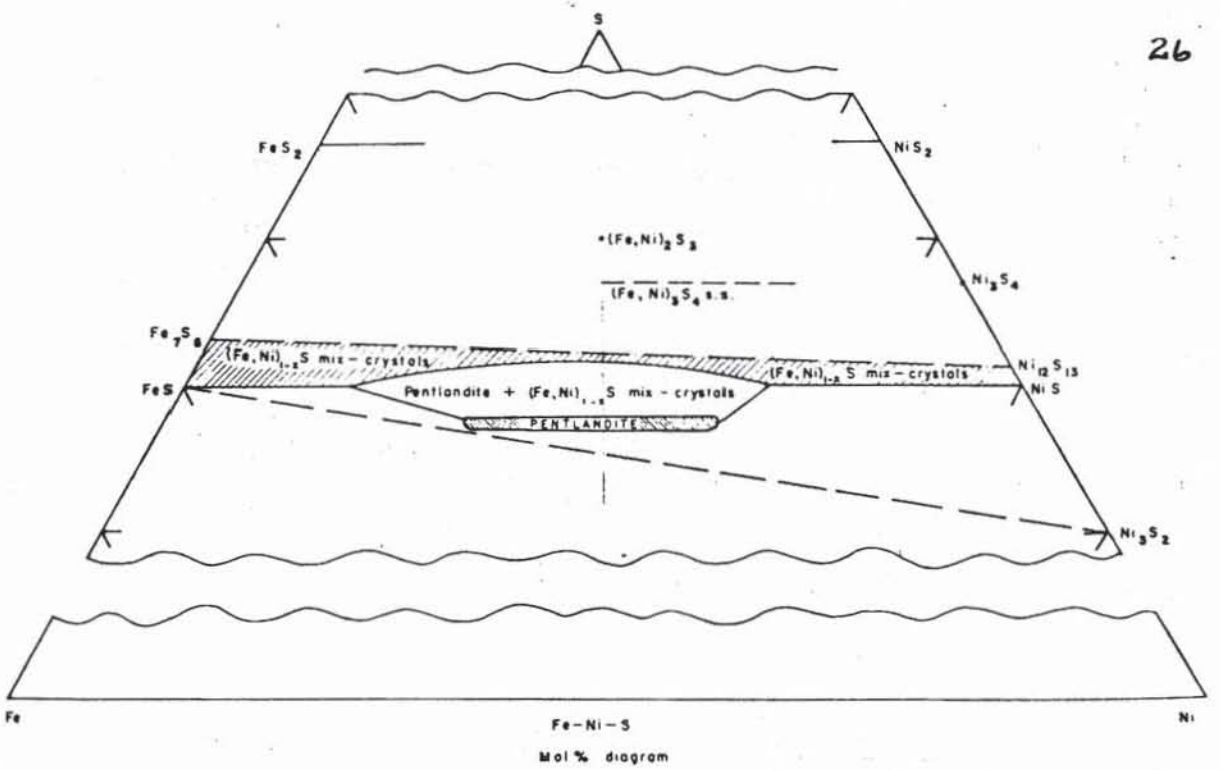


FIG. **5**. Sub-solidus phase relationships at 500° C for part of the Fe-Ni-S system, after Kullerud (1955 b), showing fields of "nickeliferous pyrrhotite" mix-crystals and pentlandite.

FIG. **5A** A vertical section in the Fe-Ni-S system along central line, Fe/Ni = 1/1, (after Kullerud), showing eutectic relations of nickeliferous pyrrhotite mix crystals and pentlandite.

crystallized simultaneously. Under equilibrium crystallization of liquids between D and C composition (Figure 5A) the remaining liquid will on cooling eventually attain the eutectic composition E, at which point pyrrhotite of D and pentlandite of C composition will crystallize together. Strong fractionation during crystallization might allow liquids on either side of these limits to also attain a eutectic composition. On the other hand it is equally clear that original liquids, richer in sulphur than D, and ranging from A to D in composition will yield, under equilibrium conditions (where early crystals can react with liquid), only crystals of a nickeliferous pyrrhotite solid solution of the same composition as the initial liquid, and pentlandite will only appear as an exsolved product when the composition line intersects the inclined solubility curve extending downward from D, as along the line GH.

The apparent absence of eutectic textures of pyrrhotite and pentlandite in Sudbury ores draws a conclusion that crystallization of the ore fluid must have occurred originally under rather constant partial pressure of sulphur and a sufficiently high sulphur content to maintain the total composition within the limits shown (Figure 5) by the field of $(Fe,Ni)_{1-x}S$ mix crystals.

On cooling of such mix crystals, Kullerud has further shown that nickeliferous pyrrhotites take up more sulphur, and in a closed system of constant composition this can only be obtained by the exsolution of the lower sulphur-bearing pentlandite $(Fe,Ni)_9S_8$.

Hawley and How (Ref. No. 5 - P. 173) have experimentally indicated that in a restricted system during a prolonged period of mineralization by fracturing and crushing of already solidified material, the bulk composition would move to a lower sulphur level and pentlandite would exsolve liberating some sulphur for the remaining pyrrhotite.

P A R T III

LOCAL GEOLOGY

of the

TROUT BAY NICKEL PROSPECT

TABLE 3

TABLE OF FORMATIONS

(Local to Trout Bay)

QUATERNARY

Recent - swamps and muskeg accumulations.

Pleistocene - glacial drift, sand and clay.

----Unconformity----

PRECAMBRIAN

Algoman ? (Kenoran ?)

(1) Quartz, feldspar porphyry dykes.

(2) Granite, gneissic granite.

----Intrusive Contact----

Early Algoman ?

(1) Differentiated amphibolite sill and related outlier intrusions.

(2) Amphibolite schist (serpentinized).

----Intrusive Contact----

Timiskaming-Keewatin

(1) Basic to intermediate volcanics with silicate and sulphide iron formation.

(2) Magnetite rich cherty iron formation.

(3) Agglomerate.

(4) Argillaceous sediments, silicate iron formation.

(5) Black sediments (graphitic hornfels).

(6) Andesitic to basaltic volcanics (amphibolitized).

THE LOCAL ROCK TYPES OF THE TROUT BAY NICKEL PROSPECT

THE KEEWATIN-TIMISKAMING GROUP

Basaltic Volcanics

This group of volcanic rocks is bounded to the S-W and S-E by the intruding granite and is overlain by the carbonaceous black sediments (See Plan I). They strike N-W and dip N-E. Their thickness varies from 1000 to 2000 feet depending on their outline with the intruding granite.

Petrographic examination of thin sections revealed that the rock has been amphibolized, poikilitic hornblende forming 50-60% of the rock with as much as 5% magnetite-ilmenite. A fine granular mosaic of plagioclase forms the major remaining interstitial mineral. Quartz forms up to 10% of some sections, where it is localized along micro-veinlets and vein filled fractures. Hence quartz is obviously introduced. Minor biotite, chlorite, epidote and carbonate are also present in some sections. The metamorphism of this rock essentially consists of amphibolization. A marked increase in amphibolization is evident with increasing proximity to the granite contact. The first 300 feet adjacent to the granite shows a marked increase in gneissosity, crystal size, and length to width ratio of the hornblende crystals. Further from the granitic intrusion, lavas are a fine grained amphibolite, with poikilitic hornblende as the main constituent.

Black Carbonaceous Sedimentary Rock

This sedimentary rock overlies the amphibolized basaltic flows. Intrusion of the large gabbro sill split the sedimentary formation so that one portion 50-150 feet wide occurs below the sill, and the other portion 100-300 feet wide occurs above the sill. This carbonaceous rock is an excellent electromagnetic conductor. It is covered in large part by lake or overburden, so outcroppings are rare.

A petrographic examination determined the following average composition of this rock: 45% quartz, 25% biotite, 10% sericite, 10% chiastolite, 7% graphite granules, 5% cordierite. Surface outcrops have a pronounced hornfelsic texture. Crystals of chiastolite, as much as 1 inch long, protrude in relief on outcrops, but relict banding is usually still recognizable. Some portions have been fractured, carbonatized and pyritized. Minor sphalerite occurrences are common in fracture-filled veinlets.

Argillaceous Sedimentary Rocks

This group of sedimentary beds vary in composition. The majority are pelitic and contain abundant alumina with relatively abundant iron, magnesia, and titanium. Potash and soda are relatively low.

A few narrow individual beds are quartzitic, graphitic, or cherty iron formations of iron silicates or iron sulphides. This series of sediments reaches a horizontal plan width of 1400 feet where undisturbed by intrusions. Contact metamorphic aureoles were produced in these sedimentary rocks by the heat conducted from the large gabbro sill intrusion. Adjacent to the amphibolite schist the predominant metamorphic effects are those caused by stress.

One bed of cherty, silicate iron formation has been mineralized with pyrrhotite, sphalerite and chalcopyrite near its contact with a graphitic, black sediment.

Agglomerate

A coarse agglomerate of andesitic to basaltic composition overlies the argillaceous sedimentary series. The agglomerate is about 200 feet thick and has been recognized in D.D. Hole No. 7 on line 12000'S. The fragments are angular, usually about 1 inch in diameter, but some occur up to 3 inches in diameter. The rims of the fragments are fine grained, chilled and altered.

Petrographic study of the agglomerate determined that the rock was andesitic to basaltic in composition. It has been amphibolized so that it now contains 55-65% fine amphibole (hornblende ?), 25% plagioclase, 2% magnetite-ilmenite, and numerous fine fractures which are filled with quartz, carbonate, coarse hornblende, and minor pyroxene. One thin section contained bedded sedimentary material that filled the matrix between two large pyroclastic fragments. The sedimentary material was composed of quartz, biotite and graphite granules. Thus volcanic activity and sedimentary deposition were probably contemporaneous in the locality.

Magnetite-Rich Iron Formation

The magnetite-rich iron formation overlies the argillaceous series of sediments and agglomerate, and it ranges from a few feet to 300 feet or more thick. It has not been mapped in detail. The intrusion of ultrabasic amphibolite schist has split the iron formation so that it now occurs above and below the schist. The iron formation has been severely contorted, drag folded, and discordantly intruded by "outlier" gabbro intrusives. This strongly magnetic bed contains 30-65% magnetite. Strong dipole effects give rise to strong magnetic and electromagnetic anomalies by geophysical surveys on this iron formation.

Petrographic examinations have determined the following composition for the iron formation: magnetite 30-65%, quartz 35-45%, amphibole-pyroxene 3-15%. Quartz forms a fine, equigranular mosaic texture which contains the silicates. Magnetite occurs in fine aggregates within bands that are similar in appearance to graded bedding (Refer to Figure 6).

Further work is planned to outline this iron formation by a detailed magnetic survey, by geologic mapping, and by correlation between diamond drill holes, to outline this key bed, for structural correlations.

Andesitic to Basaltic Lavas with Included Silicate Iron Formations

A wide belt of andesitic to basaltic lavas overlie the magnetite-rich iron formation and extends northeastwards in width up to Trout Bay of Red Lake. These lavas have been mapped only on a reconnaissance scale. Several types of interflow iron formations have been recognized. These include the silicate rich, magnetite rich, and iron sulphide rich cherty iron formations.

The Ultrabasic Amphibolite Schist

This ultrabasic intrusive rock has wedged apart and contorted the magnetite-rich iron formation into two sub-parallel bands. This schist is easily eroded and is generally covered by overburden except where it has been exposed by trenching. The amphibolite schist exposed in trenches has a strongly developed foliation formed by shearing stresses. The shearing developed bands rich in serpentine-amphibole which alternate with magnetite rich bands. Occurrences of sulphides in the rock are in the form of lenses and narrow veinlet-like bands along the foliation. The individual sulphide lenses have a streamlined "augen" or "tear drop" form. The down dip axes of sulphide lenses are about 2-3 times the strike lengths.

The chemical composition of two samples of amphibolite schist taken 1½ miles apart on strike are uniformly similar (Table 4), and high in magnesium, iron, alumina, and low in calcium and silica. The ultra-basic's intrusive origin is supported by the high magnesium-low calcium ratio.

TABLE 4

The CHEMICAL COMPOSITION of representative samples of the mineralized AMPHIBOLE-SERPENTINE SCHIST

CONSTITUENT	"FROG PIT" 12000'S-2400'E	"KELLY LAKE" 4800'S-2200'E
SiO_2	37.30	38.80
Al_2O_3	12.30	11.20
Fe_2O_3	7.35	5.45
FeO	9.50	9.48
MgO	19.08	21.24
CaO	3.50	6.60
Na_2O	0.33	0.20
H_2O (+,-)	3.92	3.80
CO_2	1.43	1.20
TiO_2	0.24	0.25
P_2O_5	0.12	0.14
S	2.98	1.46
Cu	0.38	0.19
Mn	0.15	0.17
Ni	1.20	0.55
Total	99.78%	99.73%

The average mineralogical composition as determined by the Rosiwal analyses are:

THE FROG PIT sample is tremolite-actinolite 60%, magnetite 10%, antigorite 25%, sulphides 5% - (pyrite, pyrrhotite, violarite, chalcopyrite).

THE KELLY LAKE pit sample mineral composition: tremolite-actinolite 65%, antigorite 20%, carbonate 5%, magnetite 7%, sulphides 3%.

The ultrabasic exposures studied along the cross section were strongly sheared and altered in the central portion, and progressively less sheared and altered towards their edges. A petrographic study was made across the ultrabasic on samples taken at intervals from diamond drill hole No. 5, 1960, which crosses the intrusion. The central portion of the amphibolite schist has the greatest development of antigorite, larger radiating knots and blades of tremolite and magnetite grain concentrations in bands and rings (Figures 8 and 9). At the perimeters of the strongly sheared centre antigorite is present in lesser amounts. Tremolite is predominant and occurs as smaller knots and blades. Magnetite concentrations occur predominantly as rings around relicts of unaltered hornblende and tremolite-antigorite. At the edges of the intrusion, hornblende relicts are common. Alteration of hornblende to tremolite, antigorite, magnetite and carbonate occur along the grain edges and fractures. Magnetite migrates and forms as an alteration product at previous hornblende intergrain boundaries (Figure 7).

Dynamothermal metamorphism has largely altered the ultrabasic rock from a hornblendite to an antigorite-tremolite-magnetite schist. The range of mineral composition is hornblende 0-20%, tremolite 35-70%, antigorite 5-45%, magnetite 7-20%, sulphides 2-7%, carbonates 1-10% and minor chlorite and plagioclase.

The Differentiated "Gabbro" Intrusion

This gabbro forms a sill or lopolith-like intrusion. A narrow bed of graphitic black sediments occurs both above and below the intrusion, evidence that it wedged its way into this fissile-bed without any notable replacement, assimilation, or stoping action. The gabbro was hot at the time of intrusion forming characteristic thermal metamorphic aureoles in the adjoining pelitic rocks.

This gabbroic intrusion is a layered basic rock. This is supported by its variations in: chemical composition (Figure 14 and Table 5), mineralogic composition (Figure 15), plagioclase composition (Figure 16), and amphibole composition (Figure 17). These lines of study indicate differentiation in the section taken across the amphibolitic gabbro intrusion. The chemical equivalent of amphibolite layers are: pyroxenitic base, central noritic portion, and micropegmatite-gabbro upper portion.

One peculiarity of differentiation within this intrusion is its essentially bimineralic composition, with the exception of micropegmatite and magnetite which increase near the top. Thus, this differentiation comprises a change in the composition of the hornblende and of the plagioclase isomorphous series. Deuteric alteration has been intense and has produced many fine actinolite blades which rim the edge of large crystals of hornblende, and grow as swarms and clusters in plagioclase (Figure 12). Relict structures of pyroxene or olivine were not recognized, so it may be assumed that the intrusive was originally a wet basic magma and that hornblende was the primary ferromagnesian mineral, or that the original ferromagnesian minerals were first metamorphosed and altered to hornblende then later uralitized.

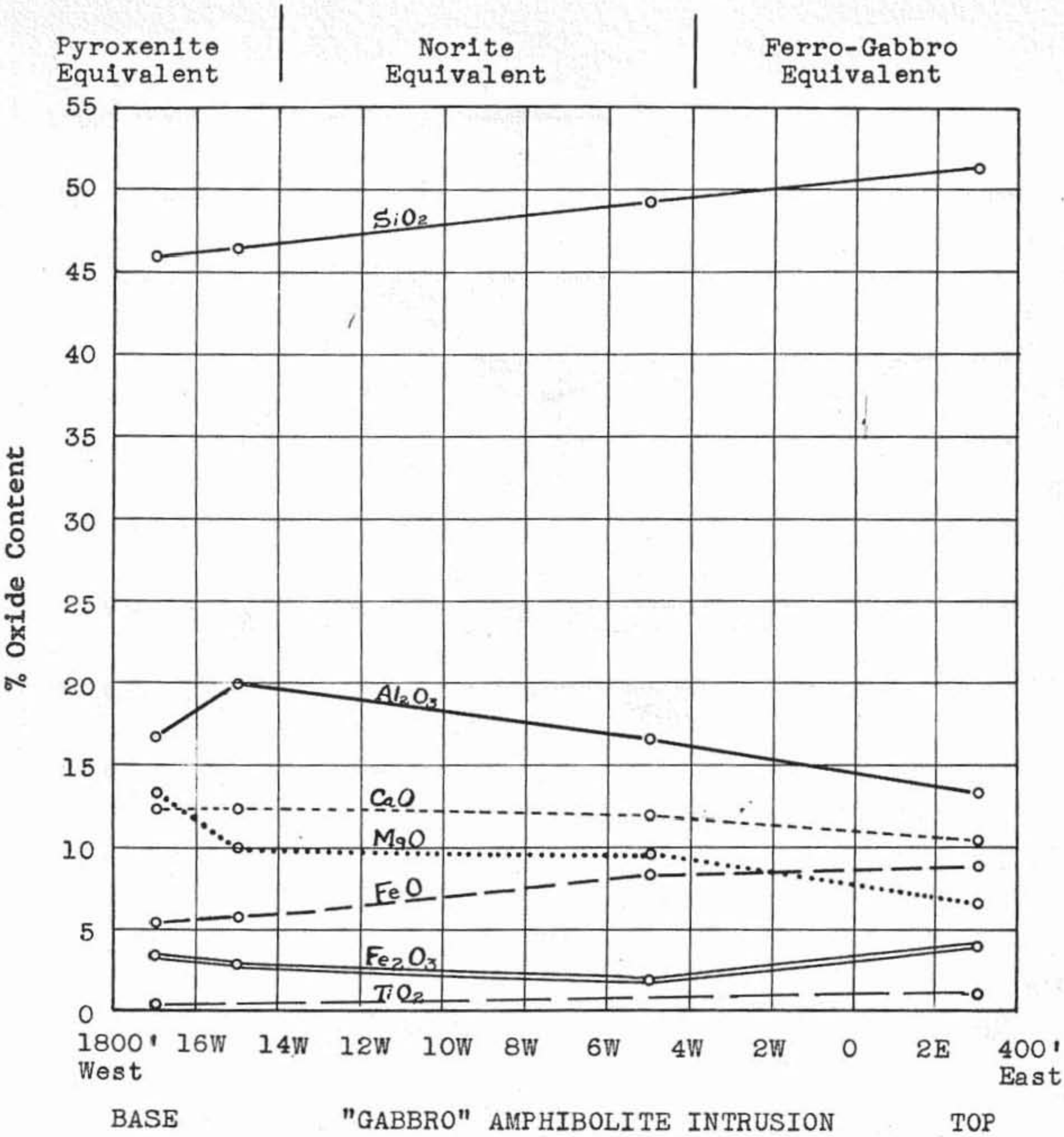


Figure 14.

The chemical composition variation diagram across the "gabbro" amphibolite sill intrusion at the Trout Bay nickel prospect.

NOTE: The gradual change from base to top indicates a possible differentiated layered basic intrusion. The higher MgO, CaO, Al_2O_3 and lower SiO_2, FeO, at the base and the higher SiO_2, FeO in the upper portion and lower MgO and CaO are significant.

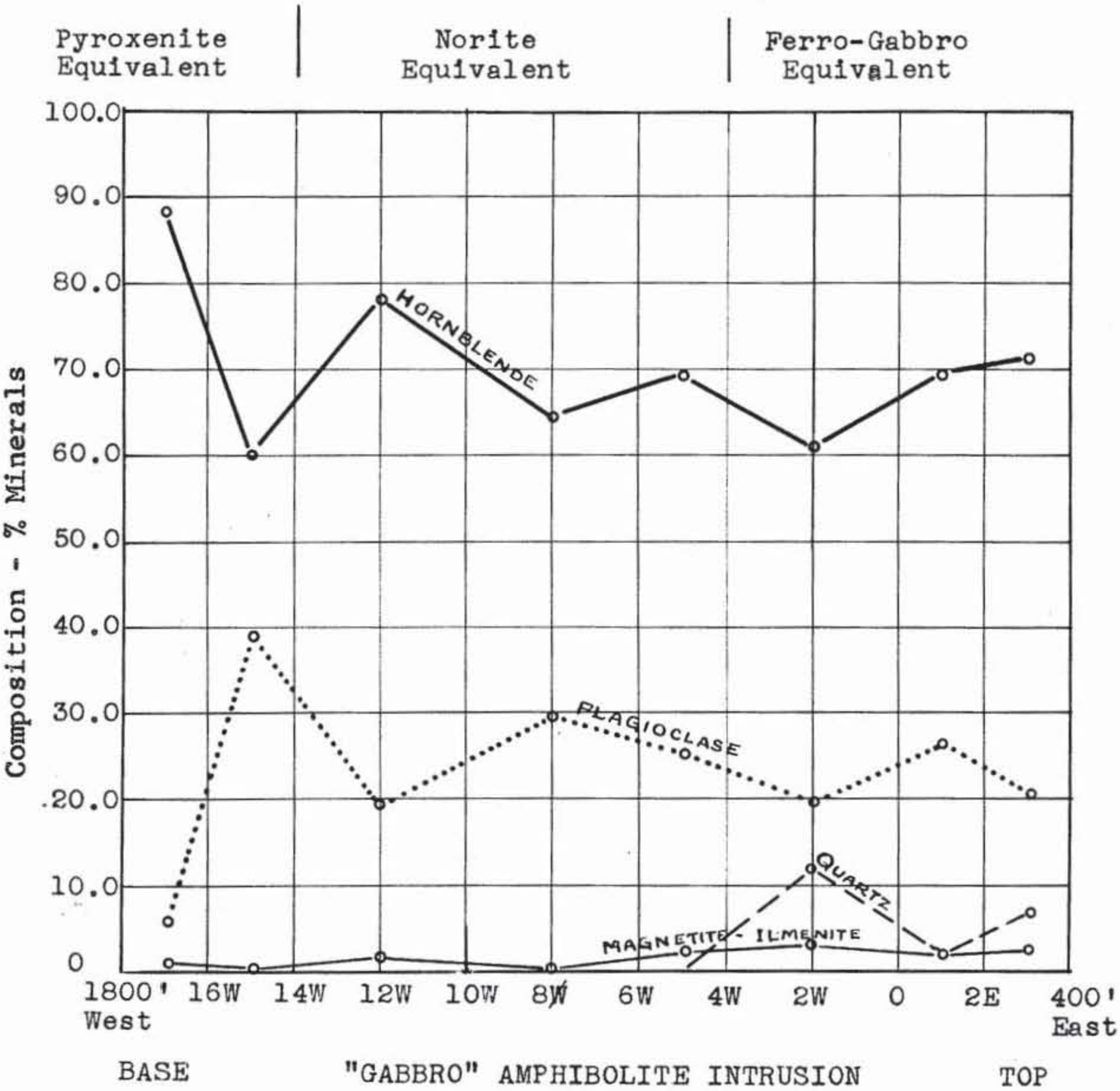


Figure 15.

The mineral composition variation diagram across the main "gabbro" amphibolite sill intrusion.

NOTE: The predominance of hornblende at the base of the intrusion, and the significant presence of quartz in micropegmatite in the upper portion along with the gradual increase in the magnetite-ilmenite content towards the top.

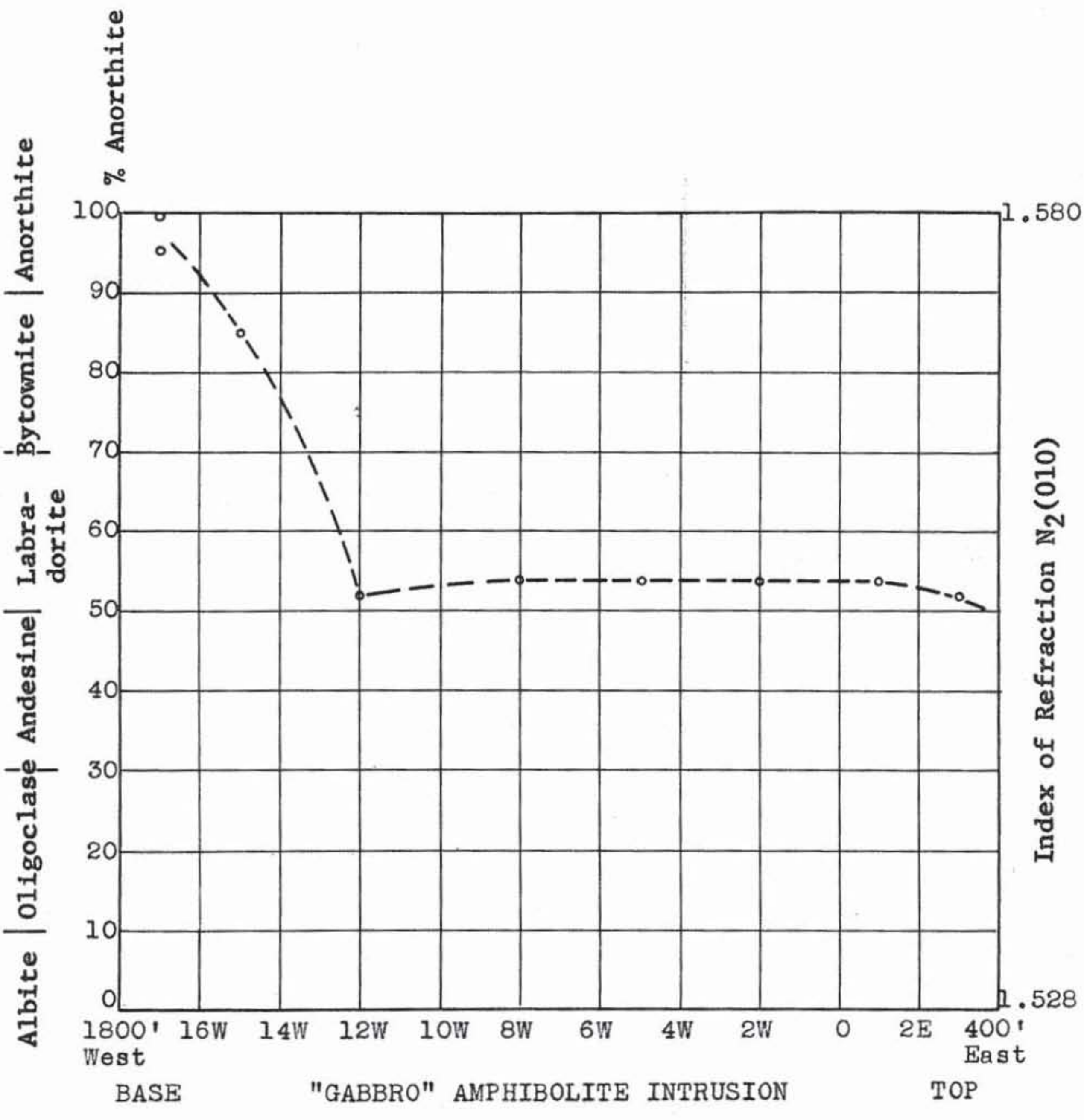


Figure 16.

The variation in plagioclase composition across the "gabbro" amphibolite sill intrusion.

The plagioclase composition was determined from the refractive index of grains which lay on the (010) cleavage (after the TSUBOI method and reference chart).

NOTE: The anorthite-bytownite composition at the base and the labradorite (An 54 - Ab 46) composition for the major part of the intrusion.

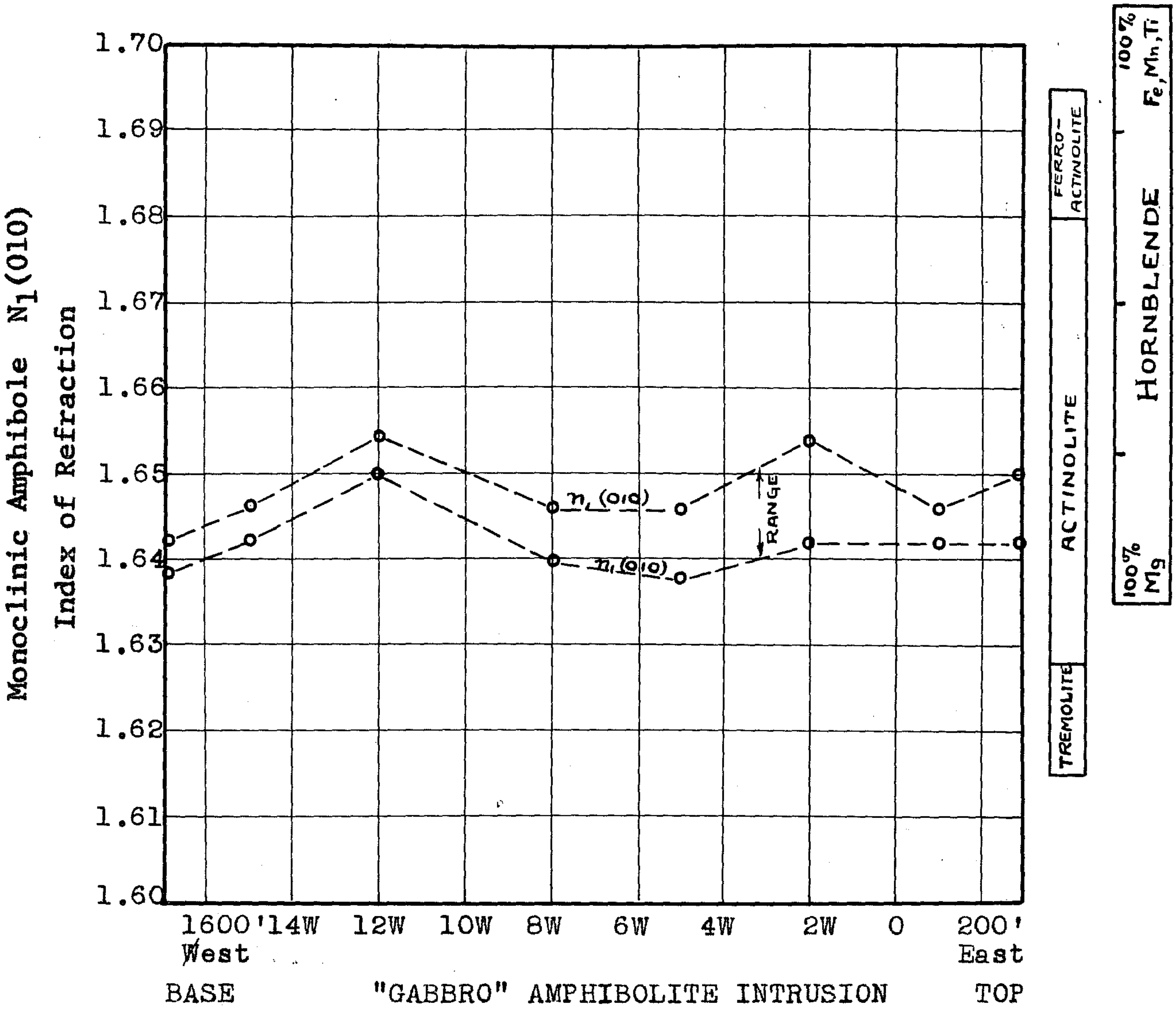


Figure 17.

A diagram of the variation in composition of monoclinic amphiboles across the "gabbro" amphibolite intrusion.

The amphibole composition was determined from its refractive index after the method and chart of Ronald B. Parker.

NOTE: There is a regular rise in the Fe/Mg ratio at the base, then it irregularily levels off in the same manner as the variation in plagioclase composition. The range in refractive index is due to the presence of both actinolite and hornblende. The greatest range in refractive index coincides with the most intense micropegmatitic and deuteric alteration.

The basal portion (pyroxenite equivalent composition) is composed almost entirely of hornblende. Calculations were made on the sample taken at 1700' West to determine chemical composition of its hornblende by combining its chemical analyses and mineral composition. This following result closely agrees with composition determined from refractive index determinations (Figure 17).

General formula for hornblende (after Berry and Mason):

$$(Ca, Na)_2 \left[(Mg, Fe^{2+}, Mn) \quad (Al, Fe^{3+}, Ti)_5\right] \; Si_8O_{22}\,(OH)_2$$

Ratio of Number of Atoms in Hornblende (1700' West-Sample):

$$(Ca_{10.9}Na_{1.1}) \left[(Mg_{18.3}Fe^{2+}_{3.5}Mn_{.05}) \quad (Al_{14.7}Fe^{3+}_{1.6}Ti_{1.7})\right] \cdot$$

$$\cdot \; Si_{10.2}O_{25.4}(O_{2.1}H_{2.1})$$

The hornblende above has a high Mg/Fe^{2+} ratio and a high Al to Fe^{3+} ratio. It is pale green in thin sections.

Towards the top of the sill the total iron increases in ratio with respect to Mg and Al respectively so that the hornblende becomes a darker green highly pleochroic type. Magnetite and ilmenite also increase, magnetite-ilmenite-rutile reach their greatest proportion at 600'-400'West which is at the top of the "noritic" composition layer.

Gabbro "Outlier" Intrusions

These gabbro intrusions appear to be genetically related to

TABLE 5

The CHEMICAL COMPOSITION of representative samples taken on Line 9800'S at intervals across the DIFFERENTIATED AMPHIBOLITE INTRUSION

CONSTITUENT	PYROXENITE 1700'W	PYROXENITE 1500'W	NORITE 500'W	FERROGABBRO 300'E
SiO_2	46.0	46.7	49.3	51.4
Al_2O_3	16.7	19.9	16.6	13.3
Fe_2O_3	3.5	2.84	1.89	4.0
FeO	5.2	5.64	7.21	8.9
MgO	13.2	9.88	9.55	6.6
CaO	12.2	12.23	12.06	10.5
Na_2O	0.7			1.7
H_2O (+,-)	1.5			2.18
CO_2	0.53			0.15
TiO_2	0.32			1.02
P_2O_5	0.13			0.27
S	0.12			0.10
MnO	0.13			0.18
Ni	Nil			Nil
Total	100.23	97.19	96.61	100.30

For mineralogical composition refer to Figure 15.

the differentiated gabbro sill. The chemical composition (Table 6) is similar to the average or noritic layer composition of the differentiated amphibolite (Table 5, third column). Mineralogically they are amphibolites, similar to the noritic layer in mineral composition, color, and pleochroism of the amphiboles. One large "outlier" intrusion (at 13200'S - 400'E) has disseminated primary copper-nickel-iron sulphides with exsolution textures at its base (Figures 26 and 27). This indicates that gravitational settling of the sulphides had taken place. The outlier amphibolite intrusions which cut across the amphibolite schist have been fractured, some of the fractures contain copper and nickel sulphides or serpentine (antigorite) (Figure 19). One outlier intrusion has a petrofabric that indicates rotation of the hornblende during crystal growth (Figure 18). An important age relationship would be established if it was proven that the rotation is related to the shear movements that produced the serpentinization of the amphibolite schist and at the same time the drag folds in the iron formation adjoining the amphibolite schist.

Granitic Rocks

The granitic rocks are part of vast granitic bodies of Archean age in the Canadian Precambrian Shield.

Such younger granitic rocks intrude and surround the older Trout Bay group of rocks on three sides. On line 17000'S the gabbro lopolith terminates against granite, and intrusive tongues of granite

TABLE 6

The CHEMICAL COMPOSITION of a representative sample taken from an AMPHIBOLITE OUTLIER INTRUSION

(Analysed for the main constituents only)

CONSTITUENT	9800'S - 600'E
SiO_2	48.3 %
Al_2O_3	16.5
Fe_2O_3	0.13
FeO	10.10
MgO	9.32
CaO	10.67
Total	95.02 %

The mineralogical composition of above sample from a Rosiwal analyses gave:

Hornblende 71.6%

Micropegmatite 12% (chiefly fine quartz)

Plagioclase 13.7%

Magnetite-ilmenite 2.7%

follow along regular jointing directions in the amphibolite, but obvious basification of the granite does not occur at the contact. It may be assumed that either stoping action of the granitic intrusion, or presence of strong convection currents in the intrusive granite, carried away evidence of any assimilated basic rock. The evidence of such a convection current in a mobile granitic melt would be important in the better understanding of the tectonic effects of the intrusion on the older Trout Bay rocks.

The granitic rock is a typical pink to grey coarse grained granite composed of about 30% quartz, 55% feldspars (which are chiefly zoned albite, oligoclase, pink microcline and orthoclase), 5% biotite, 3% chlorite, 3% muscovite, 1% sphene, 1% apatite, 1% pyrite.

METAMORPHISM - AMPHIBOLITE SCHIST

Most evidence from this study indicates that the amphibolite schist is an ultrabasic metamorphic derivative of an ultrabasic intrusion, most likely a pyroxene-olivine rock with a little plagioclase. Pseudomorphs of mixed tremolite, antigorite and magnetite have replaced original amphibole (hornblende ?) (Figures 7, 8, 9). Relicts of hornblende are still present in some pseudomorphs (Figure 7). A strong foliation parallels the contorted and drag folded bedding of adjoining magnetite iron formation. The mineral composition of amphibolite schist is not uniform across strike. The central portion is intensely sheared and altered, and contains the highest percentage of fibrous tremolite and antigorite. At the edges, amphibolite schist is mainly a mixture of fibrous tremolite and hornblende relicts, with minor antigorite, chlorite, and plagioclase. The weight of present evidence points to dynamic metamorphism being dominant in the formation of the amphibolite schist from original ultrabasic rock.

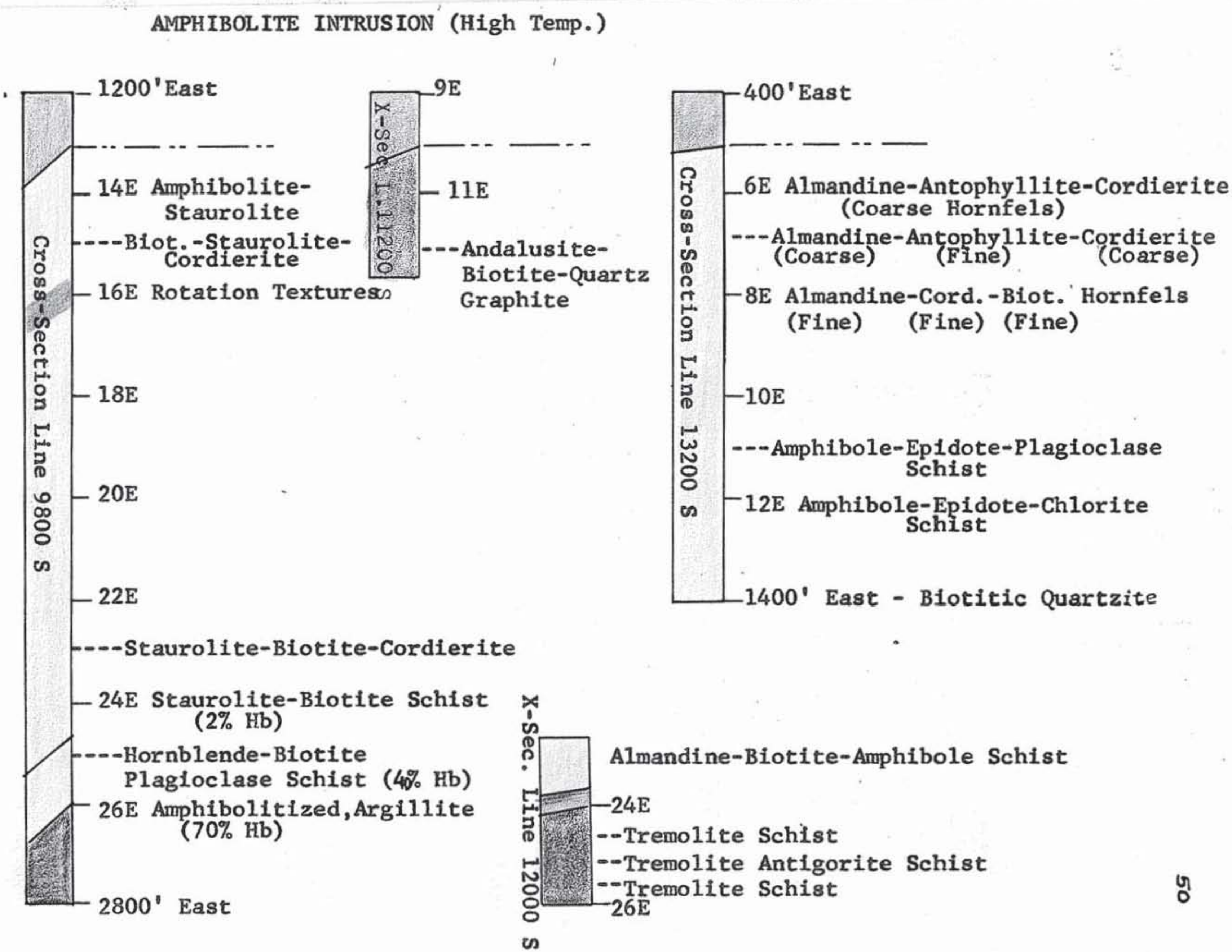
Wall rocks adjoining the amphibolite schist have not been sufficiently sampled and studied. However on line 9800'S, 2200'E - 2400'E (Figure 20) amphibole increases gradually with increasing proximity to the amphibolite schist. This raises the possibility of migration of magnesium into the wall rocks caused by the dynamic metamorphism. However, amphibolization of an originally more calcareous, argillaceous sediment would produce similar results.

METAMORPHISM - THE PELITIC SEDIMENTS

CONTACT METAMORPHISM AROUND THE DIFFERENTIATED AMPHIBOLITE INTRUSIVE

Volcanic rocks at the base of the differentiated amphibolite intrusion have been amphibolized but do not show obvious effects of thermal metamorphism, probably due to their chemical and mineralogic composition. The pelitic sediments above the intrusive on the other hand, show excellent progressive effects of thermal metamorphism (Figure 20). On line 13200'S (Figure 20), the anthophyllite-cordierite-almandine subfacies point to minimal load and fluid pressures. On line 9800'S (Figure 20), the presence of the staurolite-almandine subfacies almost certainly indicates dynamo-thermal metamorphism (Fyfe, Turner and Verhoogen, 1959 - Ref. No. 4).

Field map outlines of the argillaceous rocks provide evidence of pressures during the gabbro intrusions, since the argillaceous rocks have a restricted thickness on line 9800'S compared to the greater thickness of the same rocks on line 13200'S (Plan I). Thermal metamorphism is dominant on section line 13200'S where metamorphic minerals occur in aureoles to the main gabbro intrusion (Figure 20). Dynamo-thermal metamorphism is dominant on section line 9800'S.



METAMORPHISM OF ARGILLACEOUS SEDIMENTS

Figure 20.

STRUCTURE AND TECTONICS

The Trout Bay Timiskaming-Keewatin rocks and included basic and ultrabasic rocks are a remnant of older rocks that in plan protrude into the younger granitic rocks isolating them, so that, they can be studied without much reference to the general structural geology of the Red Lake district. The geologic plan of the Trout Bay prospect (Plan I) has the outlines and attitudes of the rocks marked as they now occur. In order to arrive at some concept of the structural geology, a reconstruction of the tectonic history from present evidence must be hazarded.

Reconstruction of Tectonic History

The Timiskaming-Keewatin group of oldest rocks have strong eugeosynclinal associations, as deduced from the nature and composition of the group (Krumbein & Sloss, P. 367 - Ref. No. 4). The sediments are carbonaceous shales, silty shales, argillites, siltstones and cherts. The volcanic rocks are essentially basic rocks. Periods of folding, uplift, erosion and deposition must have preceded the ultrabasic and basic intrusions, since, the author has mapped two major erosional angular unconformities within Timiskaming-Keewatin rocks at the Cochenour-Willans Gold Mine.

The first intrusion into Timiskaming-Keewatin rocks is represented by the ultrabasic amphibolite schist which now occurs irregularly along the magnetite-rich iron formation. The association of this ultrabasic intrusion with eugeosynclinal type sedimentary and volcanic rocks, together with its later deformation and serpentinization and lack of obvious thermal metamorphic aureoles, is suggestive of an alpine type ultrabasic origin.

A second period of intrusive activity is represented by the differentiated gabbro lopolithic sill and related gabbro outlier intrusions. Sedimentary rocks from 0'S to 9000'S (Plan I) appear to be less disturbed by the later granitic intrusions, so that their present attitude of northwesterly strike and northeasterly dip of 40° - 50° is probably the same attitude they had during the period of gabbro intrusions. Differentiated layering in the gabbro lopolith and gravitative settling of disseminated Cu-Ni sulphides accumulated at the base of the large gabbro outlier intrusion (line 13200'S, 400'E) supports this contention. The following evidence indicates that the gabbro lopolith was of magmatic origin: contact metamorphic aureoles occur in the sedimentary rocks above the lopolith; classical differentiated layering occurs in the sill; exsolution textures in copper-nickel sulphides and oxides occur at the base of gabbro sills; and micropegmatitic and deuteric alteration occur at the top. A black carbonaceous sedimentary bed was split by the lopolithic-sill intrusion and now occurs in changing thickness above and below the intrusion, however the sum thickness of split portions of the bed is generally similar in cross sections. This indicates that the intrusion did not materially assimilate or incorporate the rocks it invaded but forced its way up and along this highly fissile type of sediment. Sedimentary rocks which overlie the lopolith were intruded by "outlier" gabbros. These "outliers" are known to cut across the ultrabasic amphibolite schist, and, they contain rotation textures (Figure 18), which were apparently formed during their crystal growth and consolidation. Rotation textures in the outlier gabbro may have been caused by the last stages of dynamic metamorphism which drag folded the magnetite iron formation and which altered the ultrabasic rock to amphibolite schist. If such is the case, it may be concluded that dynamic metamorphism of the ultrabasic schist is related to the intrusion of the gabbros and their tectonics.

It is of interest to note that a study of the Geologic Plan (Plan I) shows that where the lopolith is widest on cross-section line 9800'S the sediments are narrowest. This implies greater compression of sediments to provide space for a greater thickness of intrusive. This is supported by the fact that the contact metamorphic mineral staurolite (which occurs instead of kyanite) is present not only where a medium range of metamorphic temperatures exist but where comparative pressure conditions are unusually high (Fyfe, Turner and Verhoogen, 1959, P. 164 - Ref. No. 4). In contrast, the greater thickness of the sedimentary rocks on line 13200'S imply that this abruptly narrower portion of the lopolith exerted a lesser compressive stress. This is supported by the presence of andalusite (variety chiastolite) and abundant cordierite-andalusite. Normally these minerals occur where the pressure factor is overshadowed by temperature factor in contact metamorphism (Fyfe, Turner and Verhoogen, 1959, P. 164 - Ref. No. 4).

The last evident major tectonic period is represented by the granitic intrusions which surround the area. Granitic intrusions surround Trout Bay Timiskaming-Keewatin rocks and their included basic intrusions on three sides. An examination of the Geologic Plan (Plan I) should take note of the regular change in dip of the sedimentary rocks from 40° northeasterly at the top northwest corner of the plan to 65° southwesterly at the southeast corner of the plan. Hypothetically, this change in dip may be attributed to the tectonics of a local rotational or tortional flow movement in the once molten granite, which surrounds the protruding remnant of older rocks. Rotation would have been in a clockwise direction when viewed in a vertical cross section (as along 17000'S) looking northwest, and by considering that the northwest end was in effect attached to the larger complex of Timiskaming-Keewatin rocks.

PART IV

ECONOMIC GEOLOGY

of the

TROUT BAY NICKEL PROSPECT

ECONOMIC GEOLOGY

1. COPPER-NICKEL-IRON SULPHIDES IN GABBRO INTRUSIONS

This mineralization occurs as disseminated sulphide blebs near and along the basal portion of a gabbro outlier intrusion. These sulphide blebs must have accumulated by gravitative settling from this rock of "noritic" composition, and then were frozen into their present locations. This occurrence is analogous in method of mineral accumulation to massive sulphide ores at the Sudbury norite contact (i.e. the McKim Mine). Sulphide blebs consist of pyrrhotite, pentlandite and chalcopyrite in an approximate volume ratio of 14:2:1 respectively. Excellent examples of exsolution textures exist where pentlandite exsolved from pyrrhotite (Figures 26, 27). Cooling of the sulphide mixture caused pentlandite to exsolve from pyrrhotite at a temperature range of 425° - 450°C (Hawley, Colgrove, Zurbrigg, 1943 - Ref. No. 6), so that pentlandite and chalcopyrite now occur as exsolution rims around the edge of sulphide blebs (Figure 26). Chalcopyrite always occurs next to the gangue, and its boundary with pyrrhotite or pentlandite is mutual. Exsolved pentlandite within the pyrrhotite occurs as intricate "feather" or "flame-like" patterns (Figure 27). This exsolution texture is very similar to Sudbury ores as described by Hawley, Colgrove and Zurbrigg, 1943 (Ref. No. 6). These exsolution textures in the sulphides indicate a primary sulphide with no obvious metamorphic rearrangement after cooling. Similar textures occur in the magnetite-ilmenite intergrowths (Figure 28).

The disseminated sulphide minerals form 5-10% of the rock at the base of the outlier amphibolite intrusion, located along the northeast shore of Fahlgren Lake. Some diamond drill intersections in this zone with their copper-nickel assays are shown in Table 7. The high pyrrhotite content of these nickeliferous sulphides would require about 40% total sulphides present in a deposit to contain about 1½% nickel. Such a deposit would be readily picked up by most geophysical methods, provided it occurred within the limiting depths for detection.

The Ni/Ni+Cu ratio frequency curve (Figure 31, P. 61) for this disseminated sulphide deposit gives a definite frequency peak. There is some general scattering in ratios that may be attributed to the fact that the sulphide droplets had not coalesced sufficiently to thoroughly mix the sulphides. This ratio scattering supports the view that no obvious metamorphic rearrangement of sulphides took place in this deposit.

TABLE 7

Cu-Ni ASSAY VALUES from some D. D. Holes
in the AMPHIBOLITE INTRUSION

D.D. Hole	Footage	Width(in ft.)	% Ni	% Cu
M - 1	29.3 - 44.0	14.7	.234	.60
M - 6	293.9 - 296.2	2.3	.26	.40
M - 15	65.9 - 70.9	5.0	.24	.17
M - 19	15.0 - 30.0	15.0	.55	.515
M - 20	9.1 - 25.0	15.0	.42	Tr
M - 25	105.0 - 110.0	5.0	.40	.20
M - 26	30.0 - 35.0	5.0	.40	.15
M - 33	930.0 - 940.0	10.0	.223	.125

TABLE 8

Cu-Ni ASSAY VALUES from D. D. Holes in
the AMPHIBOLITE SCHIST

D.D. Hole	Footage	Width (in ft.)	% Ni	% Cu	% Co	Precious Metals(oz.)
1960 #4	83.0 - 116.4	33.4	.615	.28		
	126.4 - 127.8	1.4	1.29	.70		
1960 #5	100.0 - 150.0	50.0	.55	.19	.04	.04
	151.4 - 153.5	2.1	.66	.17		
	155.0 - 156.9	1.9	.44	.09		
1960 #6	141.4 - 145.8	4.4	.71	.28		
	268.8 - 274.8	6.0	1.91	.41		

2. NICKEL-COPPER SULPHIDES IN THE AMPHIBOLITE SCHIST

Primary nickel-copper sulphides consist of pentlandite, chalcopyrite, pyrrhotite and pyrite. Supergene sulphides include violarite and marcasite as alteration minerals after pentlandite and pyrrhotite respectively.

The majority of sulphides occur in elongate lenticles parallel to the lineation in the amphibolite schist. Each lenticle's down-dip axial dimension is about one to three times its axial length along strike. Sulphide lenticles occur in streamlined forms that are most commonly blunted to the northwest and tail out along the lineation to the southeast. Some massive sulphides fill fractures which partly cross the lineation in the amphibolite schist (Trench at 12000'S - 2400'E, the "Frog Pit"). This physical form and occurrence of sulphides reflects at least partial remobilization during metamorphism. These sulphides have been studied by several different methods in an attempt to learn more about their unusually high nickel to sulphur ratio.

The deepest diamond drill hole intersection of sulphides in the amphibolite schist was first studied to determine the nature of sulphides free from supergene alteration. The following is a summary of the paragenesis of the sulphides as determined from a study of polished sections, thin sections, assay data, and elemental ratios. These results were related to the intensity of dynamic metamorphism as shown by the intensity of rock alteration and shearing. Details will follow this summary.

PARAGENETIC SUMMARY

(FOR SULPHIDES IN AMPHIBOLITE SCHIST)

1. PRIMARY SULPHIDES - pre-deformation

   Sulphides - pyrrhotite, pentlandite, chalcopyrite.

   Morphology - irregular.

   Pentlandite occurs as exsolution plate in pyrrhotite.

2. DYNAMOTHERMALLY METAMORPHOSED SULPHIDES

   Sulphides - pentlandite, pyrite, chalcopyrite.

   Morphology - sulphides occur as lenticles.

   Pentlandite coalesced into blocky masses.

   Primary pyrrhotite was broken down to form pyrite, magnetite and sulphur. Liberated sulphur migrated outwards to form pyrrhotite from magnetite.

   Chalcopyrite migrated to the edges of pentlandite lenses where it replaced pyrite, magnetite and gangue.

3. SUPERGENE-ALTERED SULPHIDES (near surface)

   Pentlandite altered to violarite.

   Pyrrhotite altered to marcasite (shredded).

PARAGENESIS - DISCUSSION

1. Primary Sulphides (Least Metamorphosed)

Sulphides, least metamorphosed and free from supergene alteration, occur in diamond drill hole No. 7, 1960, at a vertical depth of 550 feet. Pyrrhotite and chalcopyrite occur with mutual boundaries (Figure 30). Pentlandite occurs as exsolution blades in pyrrhotite and is subordinate to pyrrhotite in quantity. A primary origin for this sulphide assemblage is supported by the high iron to nickel ratio where dynamic metamorphism is less pronounced (Figure 34) from 97'.8 to 115'. Note also for the same location the Ni/Ni+Cu ratio shows some minor fluctuations away from the frequency peak (Figure 30). This is analogous to the slight variations from the frequency peak in the primary sulphides of the gabbro intrusion (Figure 31).

2. Dynamothermally Metamorphosed Sulphides

This study of sulphides in ultrabasic amphibolite schist, is concerned with the relative intensity of dynamic metamorphism as represented by the intensity of the shearing and alteration of the rock. The results are spatially related to a cross section of the schist from diamond drill hole No. 5, 1960. This sulphide deposit studied provides an excellent example of some effects of dynamic metamorphism on nickeliferous sulphides in an altrabasic schist.

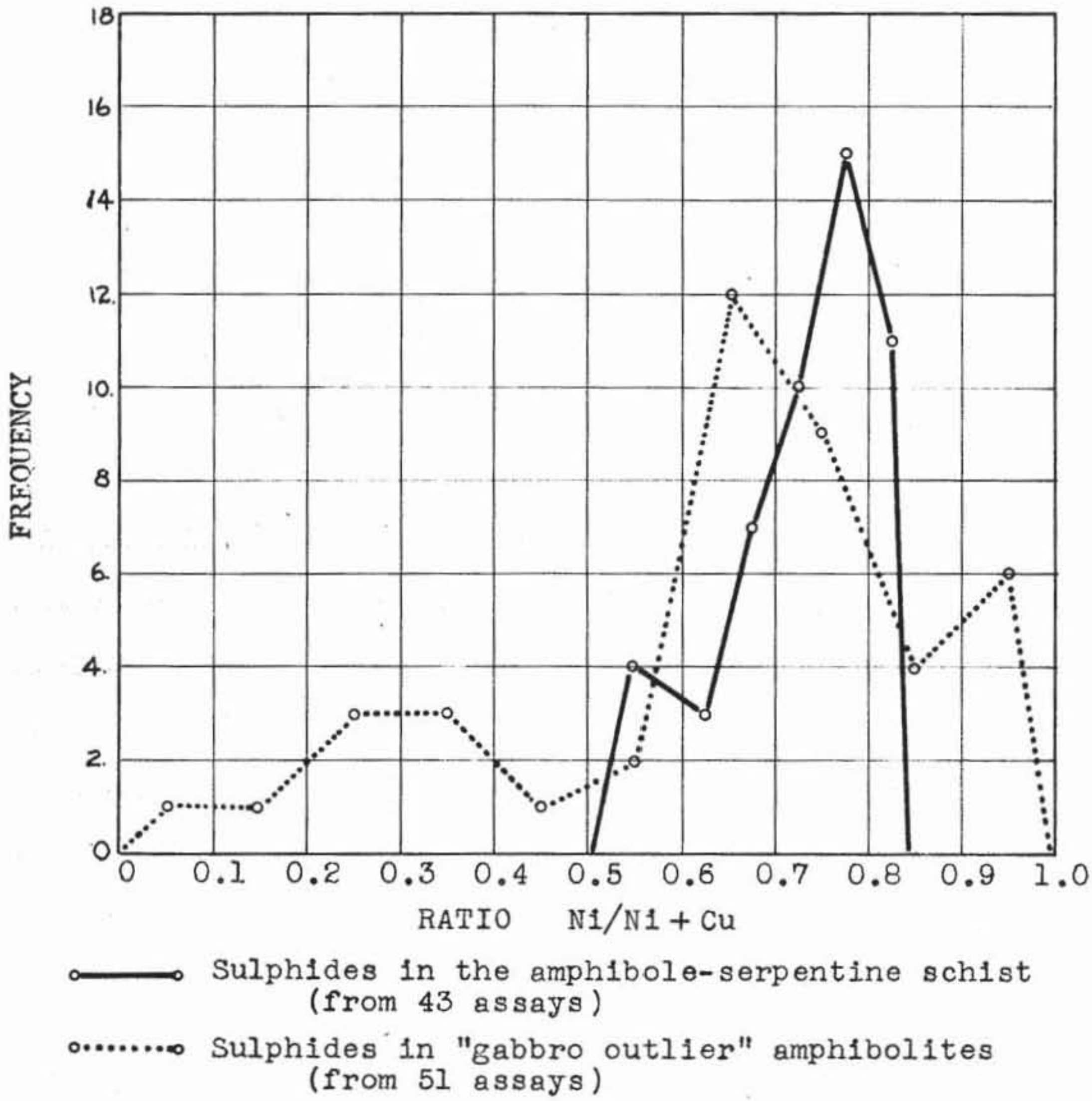


Figure 31.

<u>The frequency variation diagram</u> of the Ni/Ni+ Cu content for the two main types of nickeliferous sulphides present at the Trout Bay nickel prospect.

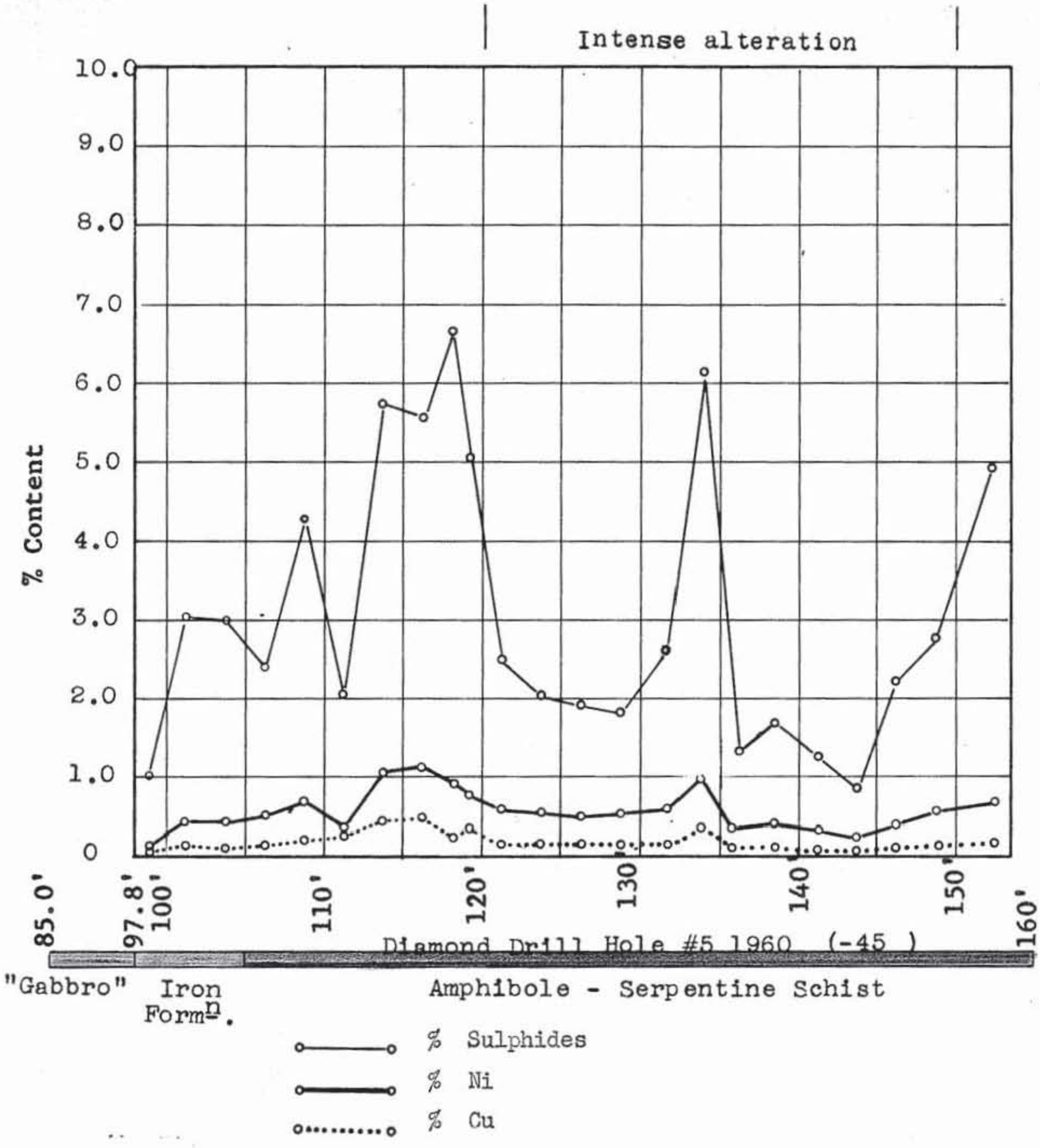


Figure 32

<u>CONTENT VARIATION DIAGRAM</u>

of

Sulphides and of Ni and Cu

along

Diamond drill hole #5 - which crossed the amphibolite schist at a mineralized and intensely sheared portion.

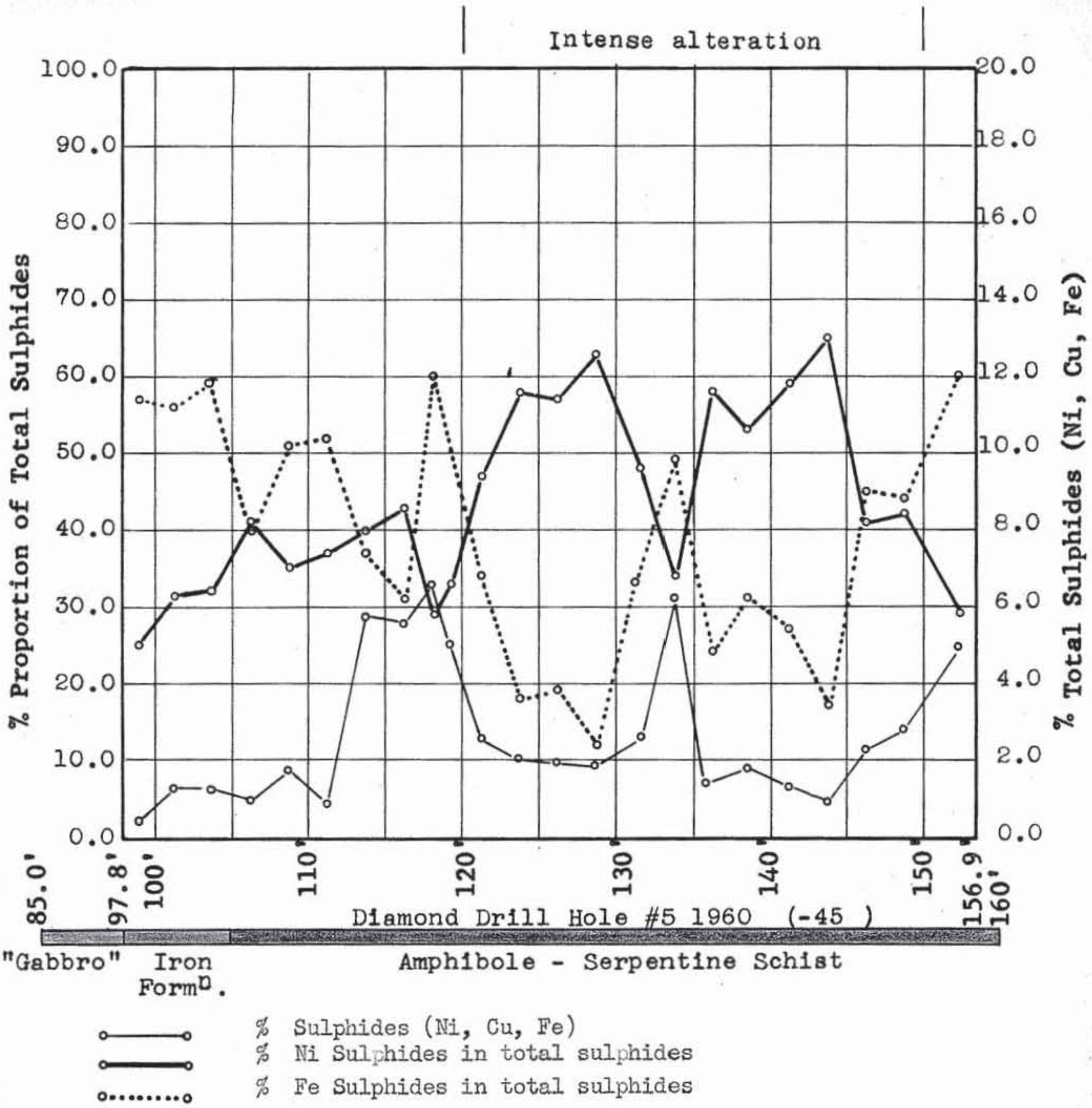


Figure 33

VARIATION DIAGRAM

of

Percentages Ni and Fe Sulphides to Total Sulphide Content

along

Diamond drill hole #5, which crossed the amphibolite schist at a mineralized and intensely sheared portion.

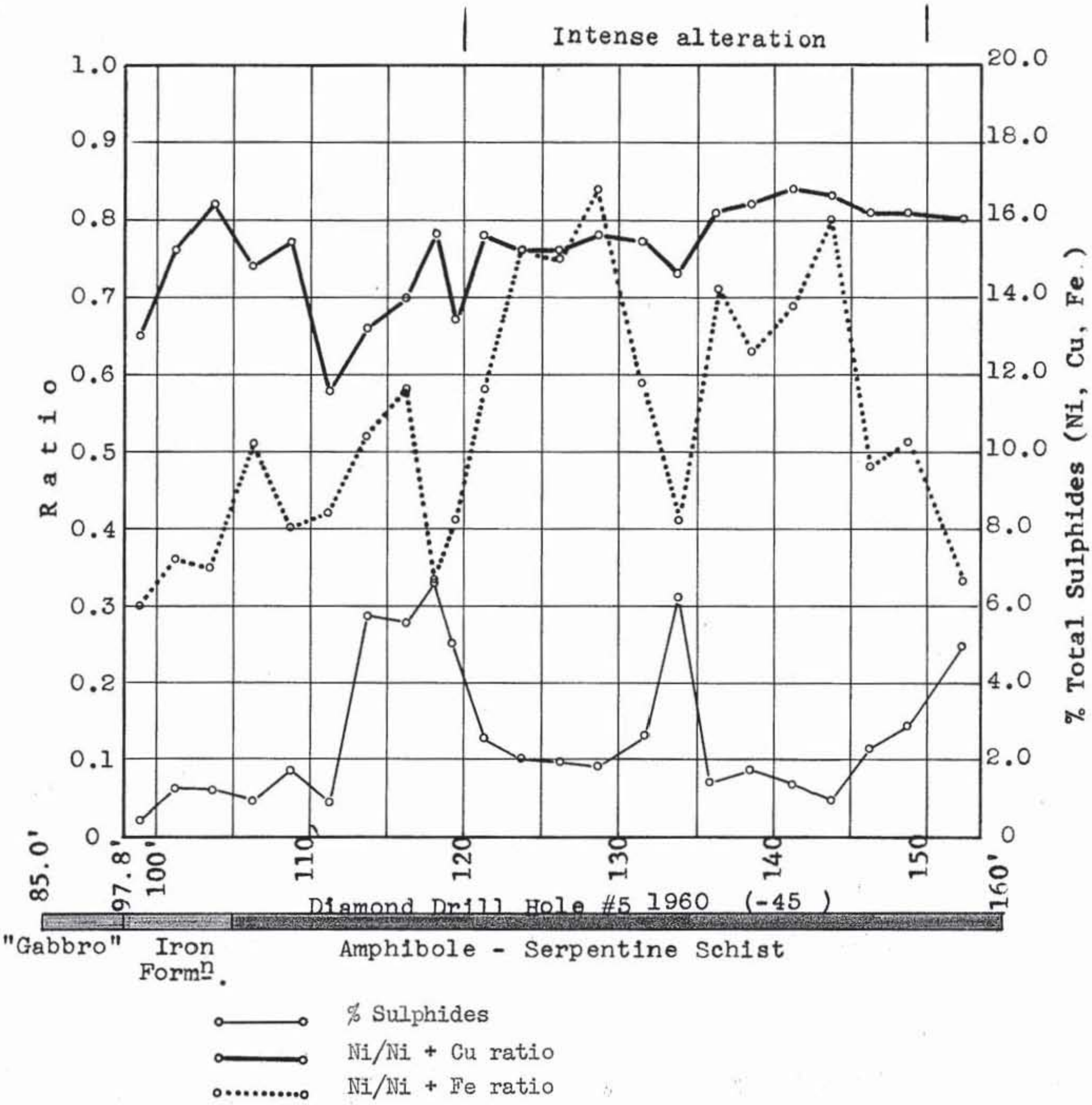


Figure 34

VARIATION DIAGRAM

of

Ni/Ni + Cu Ratios and Ni/Ni + Fe ratios

along

Diamond drill hole #5, which crossed the amphibolite schist at a mineralized and intensely sheared portion.

Ratios of Sulphides in Amphibolite Schist and Dynamic Metamorphism

The ratios of sulphides and their elements plotted on Figures 31, 32, 33 and 34 were derived from assays obtained for nickel, copper and sulphur. Polished sections of proportions of sulphide minerals assayed in diamond drill hole No. 5, 1960, were studied. Copper occurs in chalcopyrite, nickel in determined proportions of pentlandite and violarite, sulphur not combined with nickel or copper occurs combined with iron in determined proportions of pyrrhotite, pyrite and marcasite. Cobalt and platinum group metals would combine with comparatively little sulphur.

In Figure 31 the frequency variation diagram of the ratio Ni/Ni+Cu content for assays in a gabbro "outlier" of noritic composition forms a curve with a peak that indicates a Ni:Cu content of 2:1, this nickel to copper ratio is typical of sulphides associated with rocks of noritic composition (Table 2). Note the variation of some assays of higher or lower ratios of nickel to copper. This variation may be attributed to the isolation of disseminated grains of nickel-copper-iron sulphides that were frozen in place before collection and mixing of liquid sulphide droplets in the magma could take place to give a uniform composition. In the same figure, the nickel:copper ratio in the amphibolite schist is 4:1 as indicated by the high and restricted peak on the frequency curve. This high nickel to copper ratio is typical for rocks of ultrabasic composition (Table 2). The restriction of Ni:Cu ratios to a narrow range indicates that good mixing of the sulphides took place during formation of "augen" lenticles by dynamic metamorphism.

In Figure 32 the percent content of nickel, percent content of copper and the percent content of total sulphides of nickel, copper and iron are compared as curves and related to the intensity of alteration. The percent copper content curve follows the nickel content curve but is subdued by the ratio of nickel to copper. Intense alteration does not change the nickel to copper ratio, but it decreases the total sulphur content and increases the ratio of nickel to total sulphur 2 to 3 fold. The increase in ratios of nickel and of copper to total sulphides is due to the breakdown of pyrrhotite to magnetite, pyrite and sulphur by dynamic metamorphism. The liberated sulphur migrates from the stressed rock.

In Figure 33 the percent proportion of nickel sulphides (pentlandite, violarite) and the percent proportion of iron sulphides (pyrite, pyrrhotite and marcasite) are compared as curves to the total content of sulphide minerals. In the least altered rock from 97.8 feet to 115 feet the percent total nickel sulphides curve proportionately follows the percent total sulphides curve but in the intensely altered rock the percent nickel sulphides curve increases, whereas the total nickel sulphides content (the total sulphur content) decreases. Note, the percent proportion of iron sulphides to total sulphides is high in the least altered rock but low in intensely altered rock.

In Figure 34 the curves for the Ni/Ni+Cu ratios and Ni/Ni+Fe ratios are compared to the percent content of total sulphides. In the intensely altered portion, the Ni/Ni+Cu curve shows a fairly smooth curve of constant ratio, the curve in the less altered portion shows some minor fluctuations in nickel to copper ratio. This result indicates that metamorphism of the sulphides brought about a thorough mixing of copper and nickel sulphides. Note the Ni/Ni+Fe ratio curve generally increases with intensity of metamorphism.

Summary - Dynamic Metamorphism of Sulphides in Amphibolite Schist

The following conclusions are based upon studies of frequency and variation curve diagrams (Figures 31, 32, 33, 34; Pages 61 - 64) that were related to intensity of rock alteration due to dynamic metamorphism, supported by studies of polished sections of the copper, nickel and iron sulphide minerals (Figures 29, 30, 36, 37, 38, 39, 40; Pages 95 - 103).

Dynamic metamorphism altered the ultrabasic rock to tremolite, antigorite, and magnetite. It altered pyrrhotite to form pyrite, magnetite and sulphur. A result of these alterations is that the intensely sheared and altered portion of the amphibolite schist has a high content of magnetite, a low content of sulphur and pyrrhotite, a high ratio of nickel to sulphur, a nearly constant ratio of nickel to copper, and has pentlandite coalesced to form augen lenticles of larger grain size.

3. Supergene-Altered Sulphides

Pentlandite has altered to friable violarite, the alteration first having taken place along the edges of blocks of pentlandite (Figures 35, 40, 41). In surface trenches, the major proportion of pentlandite has altered to violarite. In diamond drill hole No. 5 (1960) at a vertical depth of 90 feet, about 1/3 of the pentlandite has altered to violarite. In diamond drill hole No. 7 (1960) at a vertical depth of 550 feet, violarite was not recognized.

Marcasite occurs as a shredded alteration product of pyrrhotite (Figures 40, 41). It occurs in proportion to the greater or lesser amounts of violarite present.

Pyrrhotite

Pyrrhotite is uncommon in sulphides of the intensely altered central portion of ultrabasic amphibolite schist. Dynamic metamorphism broke down the pyrrhotite into pyrite, magnetite and sulphur. Sulphur, liberated from the breakdown of pyrrhotite, migrated down the metamorphic gradient towards the less altered rock, where it reacted with magnetite to form new pyrrhotite (Figure 39). In less altered amphibolite schist new pyrrhotite occurs as an apparent replacement of magnetite devoid of other sulphides. Primary pyrrhotite with exsolved pentlandite occurs with chalcopyrite as irregular sulphide blebs in the least altered areas.

Pentlandite

Pentlandite is most abundant in "augen" lenticles of sulphides that have been intensely metamorphosed. The higher pentlandite content is due to the loss of pyrrhotite after it breaks down to pyrite, magnetite and sulphur. Pentlandite coalesced into "augen" and in some cases formed pentlandite-rich veinlets.

Pyrite

Pyrite formed from the breakdown of pyrrhotite, occurs around the edges and centre of pentlandite-rich lenticles as irregular grains. It is subordinate to pentlandite in volume.

Chalcopyrite

Chalcopyrite in intensely altered schist, occurs as an unevenly distributed to disseminated haloes around pentlandite-rich lenticles. The chalcopyrite replaces magnetite grains as narrow veinlets and as deep cusps, it also replaces gangue. The new pyrite in augen commonly contain small inclusions of chalcopyrite.

Ni/Ni+Cu ratios in sulphides of this dynamically metamorphosed amphibolite schist show a sharp frequency peak and a very restricted range (Figure 31). Normally such a restricted range would imply perfect mixing of the sulphides collected in some reservoir, but in this case, metamorphic mixing by partial mobilization of sulphides has brought about equilibrium. Note: in Figure 34 that the Ni/Ni+Cu ratio is slightly variable in the less altered portion 97'.8 - 120' and levels off to an almost constant ratio from 120' - 153' in the strongly metamorphosed portion. A relatively high Ni:Cu ratio of about 4:1 is in accordance with Ni:Cu ratios found in sulphides from rocks of such composition (Table 2). Metamorphism has performed the economically important and difficult metallurgical task of separating nickel and nickel sulphides from the pyrrhotite. This nickel sulphide concentration by nature has resulted in a sulphide that contains up to 60% nickel sulphides in the more metamorphosed portions (Figure 34).

3. THE MAGNETITE IRON FORMATION

Magnetic surveys have traced this iron formation for the full length of the mapped area. This rock is of considerable geologic value because it adjoins the mineralized amphibolite schist and is used as a stratigraphic marker bed. Iron content is variable, but occurs in the range of 29 - 38% (Table 9). The iron formation is relatively free of metallurgically difficult phosphorous, titanium or sulphur. Economically its grade is high enough for beneficiation and pelletizing, but widths, tonnages and distance to markets are adverse factors. If a large economic deposit of nickel ore can be located in the amphibolite schist, then the iron formation which occurs as wall-rocks to the nickel sulphide stopes, may become valuable as a by product iron mining operation.

TABLE 9

ASSAY VALUES for IRON from D. D. Holes
in the MAGNETITE IRON FORMATION

D.D. Hole	Footage	Width	% Fe	% Others
1960 #6	150.0 - 253.6	103.0	33.00	
	281.0 - 312.0	35.0	35.81	
M - 7	26.0 - 83.0	37.0	29.60	
M - 8	50.0 - 112.0	62.0	37.70	Cu - .04
				Ni - Nil
				SiO_2 - 27.77
				Cr - Nil
				S - .29
				P - .01
				Ti - .04

TABLE 10

ASSAY VALUES from D. D. Holes in the Cu-Pb-Zn-Ag
BASE METAL DEPOSIT

D.D. Hole	Footage	Width (ft.)	% Zn	% Cu	% Oz Ag	% Au
1960 x R-4	30.0 - 62.0	32.0		.809		
	34.0 - 54.0	20.0	9.89			
	38.0 - 62.0	24.0			.857	
1960 x R-5	65.5 - 104.1	38.6	3.45	.565	1.28	
	65.5 - 69.5	4.0				0.12

4. COPPER-LEAD-ZINC-SILVER DEPOSIT

This small deposit occurs exposed in a trench known as the "zinc pit" on line 10600'S at 2000'E (Plan I). Sulphides occur as replacement of a cherty silicate iron formation, near its contact with black carbonaceous shale. This deposit appears to be lensoid in plan, pipe-shaped in section and plunge northwards. Its plan dimensions are roughly 30' x 100'.

Mineralization consists chiefly of pyrrhotite, sphalerite and chalcopyrite with minor galena and marcasite. Marcasite is found as a supergene alteration of pyrrhotite. The mineralization is zoned. Sphalerite and galena occur only in the core which is as much as 20 feet thick, whereas chalcopyrite and pyrrhotite occur in equal amounts in both the core and in the rim. Values in silver from the few assays taken show no obvious relationship to any particular mineral in this deposit. Traces of nickel were not detected with normal assay methods. The metal contents are given in Table 10.

This deposit is of interest to geology because it occurs in a general geologic and structural association and location above the Trout Bay differentiated lopolith, analogous to the Errington-Vermilion deposits which occur above the Sudbury norite (Figure 2). This leads to some speculation that a consanguinous relationship exists between these base metal deposits and their underlying differentiated basic intrusions.

Textures of pyrrhotite exsolved in chain-like rings around grains of sphalerite (Figure 44) are of little use in establishing any temperature of formation for the deposit, because Kullerud has proven experimentally that pyrrhotite will exsolve from sphalerite at the wide temperature ranges of 138° - 894°C. (Edwards, 1954, P. 92 - Ref. No. 3).

5. ECONOMIC SIGNIFICANCES

(a) Nickel-Copper Sulphides in Amphibolite Schist

A detailed magnetometer survey and detailed geologic mapping of the amphibolite schist-iron formation zone are of vital importance. Metamorphic reorganization of these sulphides occurred, but the extent of sulphide mobilization and migration is not known. The most intensely sheared and metamorphosed portions may have so mobilized sulphides that a rich, nickel, sulphide pod may occur in some structural trap such as a sharp drag fold in iron formation, slightly removed from the strongest shearing. Such a high ratio nickel sulphide could conceivably run up to 20% nickel so that even a small pod of say 100,000 tons (100' x 300' x 20') would have the metal content of a million ton 2 percent nickel, orebody. Profit potential would be something like that of an 8 million ton 1½ percent nickel orebody.

Diamond drilling on widely spaced cross sections would greatly aid correlation and would help build up the structural picture. Structurally controlled, specific target drilling should locate economic deposits, if such exist.

(b) Nickel-Copper Sulphides in Gabbro Intrusions

The High pyrrhotite content Ni-Cu sulphides have been found at the base of an outlier gabbro intrusion. The footwall contact of the differentiated lopolith-sill amphibolite could conceivably contain valuable deposits in footwall depressions where the "noritic" layer rests on the black carbonaceous sediment and volcanics.

(c) Copper-Lead-Zinc-Silver Deposit

This small deposit has a good grade. If the corollary is accepted that this deposit is similar structurally to Sudbury's Errington-Vermilion deposits, then further exploration is warranted. Additional deposits may occur in sedimentary rocks that overlie the differentiated gabbro sill and may be located near carbonaceous black sediments, and along faults.

(d) Magnetite Iron Formation

The economic potential of producing iron ore from the magnetite iron formation is at present remote. It is of sufficiently good grade that all diamond drill core from it should be assayed for iron and carefully delineated by geologic mapping and correlation.

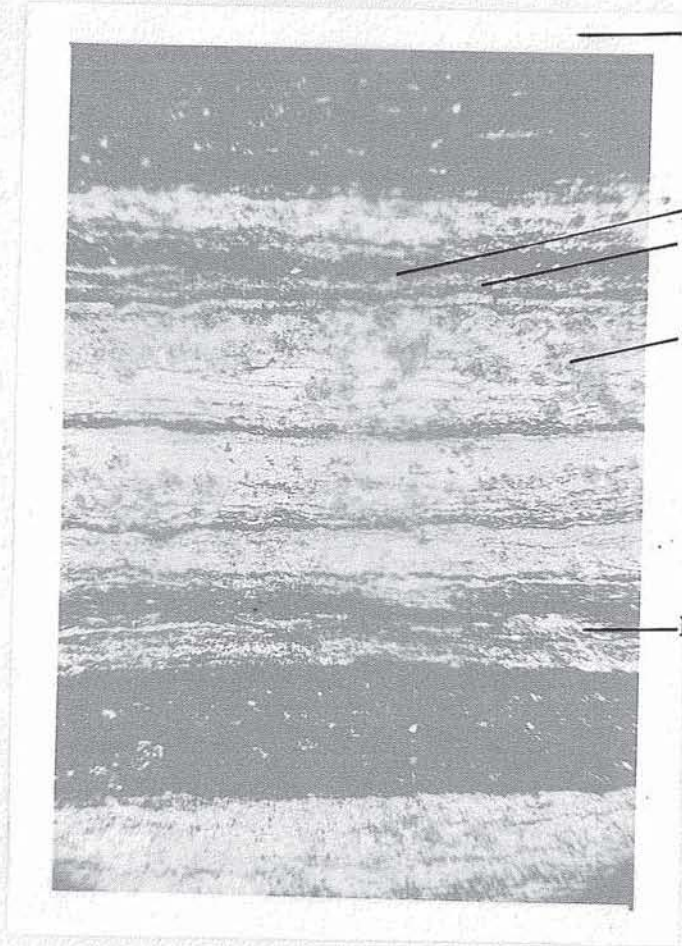


Figure 6.
X 20

Photomicrograph of a thin section of the magnetite iron formation taken from 10600'S - 2400'E.

NOTE: The "graded bedding" like appearance of banded grains of magnetite in the chert.

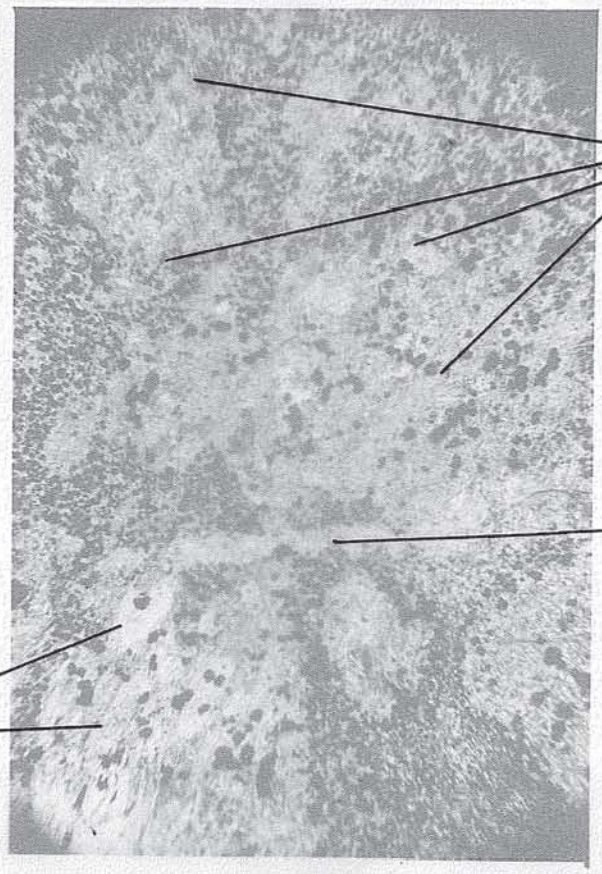


Figure 7.
X 20

Photomicrograph of a thin section of amphibolite schist taken from diamond drill hole #5 (1960) at 121 feet.

NOTE: Rings of grains of magnetite surround pseudomorphs of fine radiating clusters of tremolite-actinolite with antigorite; after amphibole (hornblende ?). A relict of hornblende is left only partly altered.

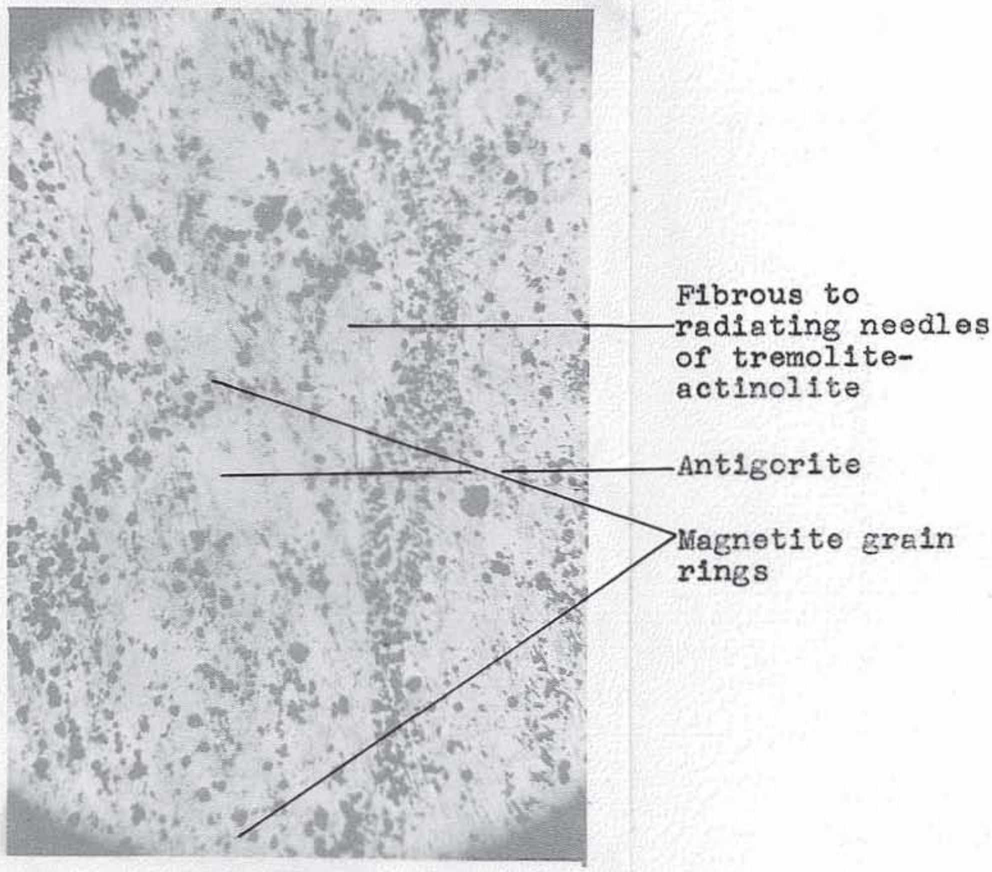


Figure 8.
X 60

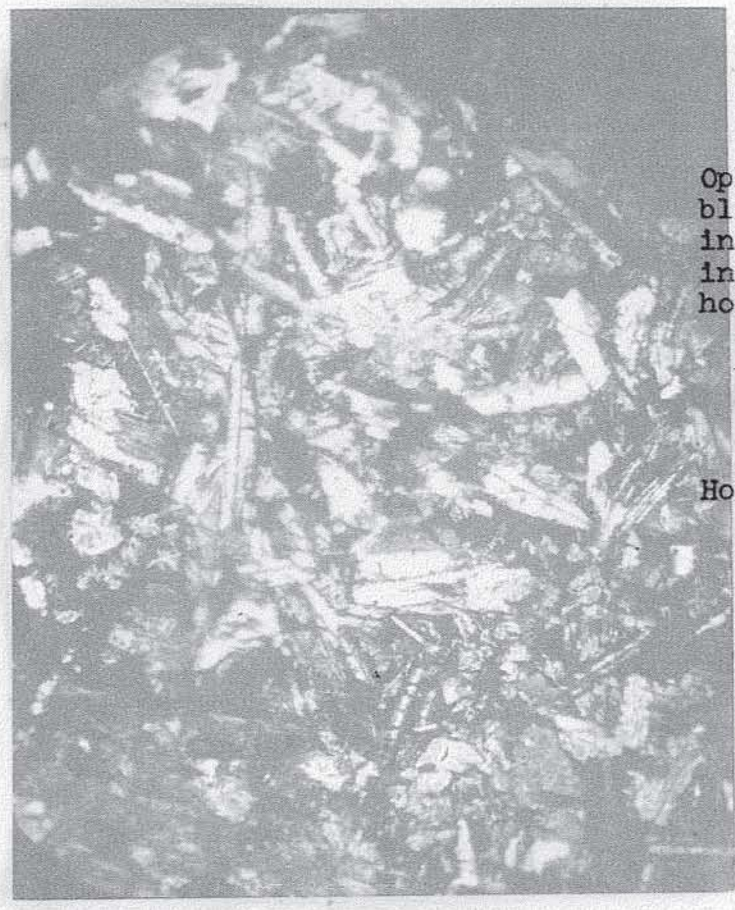
Photomicrograph of a thin section of amphibolite schist from diamond drill hole #5 (1960) at 132 feet.

NOTE: Rings of grains of magnetite outline pseudomorphs of amphibole completely altered to radiating clusters of tremolite-actinolite, antigorite and magnetite.

Figure 9.
X 50, X-Nicols

Thin section photomicrograph of amphibolite schist diamond drill hole #5 (1960) at 132' (12000'S - 2400'E).

NOTE: The texture of the tremolite-antigorite schist, magnetite and antigorite run in semi-parallel bands along the schist-gneiss lineation. Tremolite blades are partly aligned, and partly decussate.



Ophitic texture blades of plagioclase in a large encompassing grain of hornblende

Carlsbad twins of plagioclase, dark background is hornblende at extinction.

Hornblende

Figure 10.
X 20, X-Nicols

Thin section photomicrograph of amphibolite near base of lopolith-sill intrusion (Line 10400'S - 1500'W).

NOTE: The diabasic texture taken by blades of carlsbad twinned plagioclase (bytownite) set in a single large hornblende crystal.

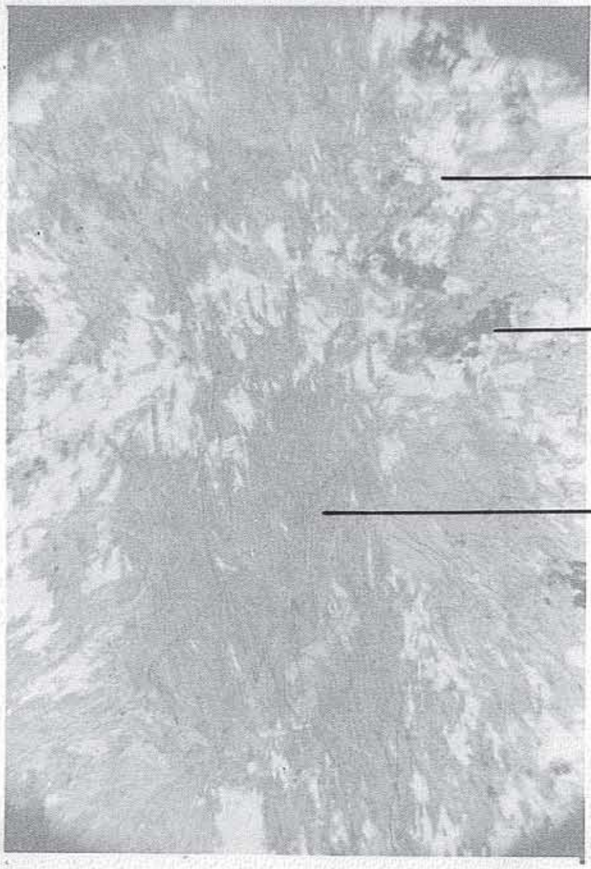


Figure 11.
X 20

Photomicrograph of a thin section from the differentiated amphibolite intrusion at 9800'S - 1200'W.

NOTE: The strained appearance and wavy cleavage of the large grains of amphibole.

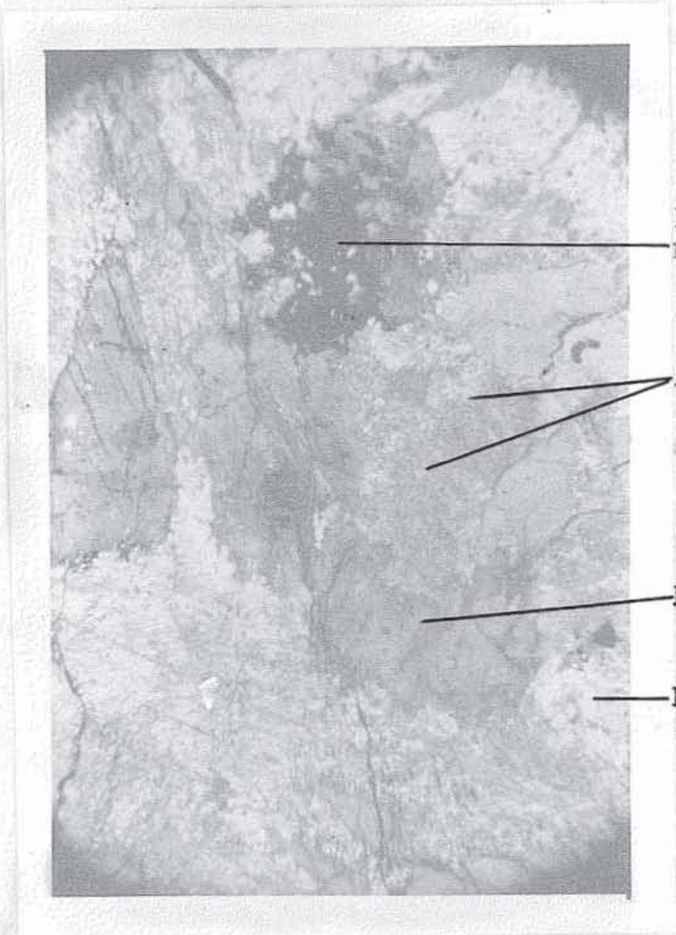


Figure 12.
X 20

Photomicrograph of a thin section from the main gabbro amphibolite intrusion at 9800'S - 2400'E.

NOTE: The heavy uralitic alteration indicated by the fine actinolite ? present in the plagioclase adjoining hornblende.

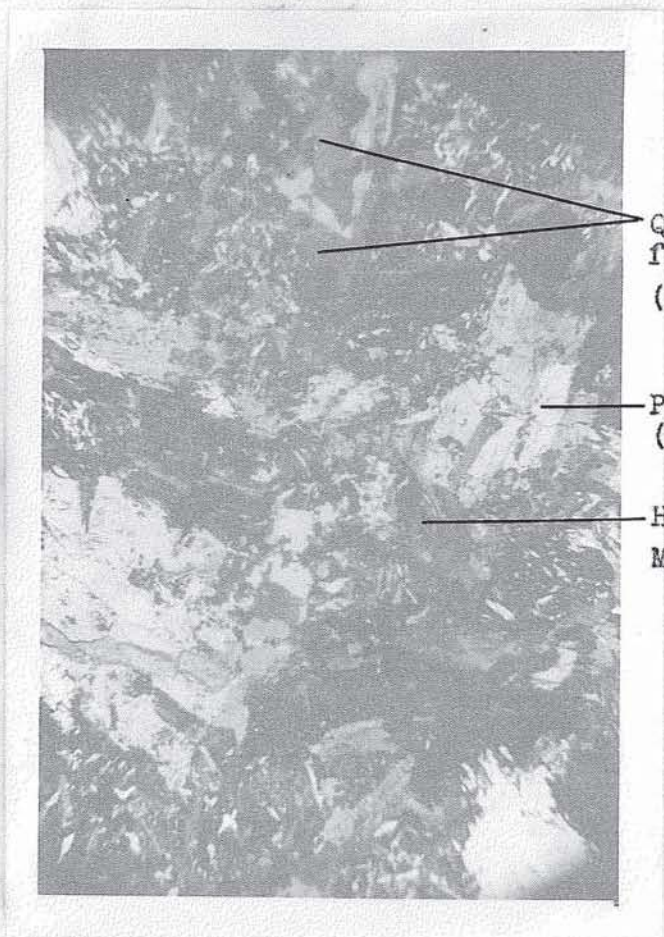


Figure 13.
X 20, X-Nicols

Photomicrograph of a thin section from the upper portion of the differentiated amphibolite intrusion at 9200'S - 300'E.

NOTE: The presence of micropegmatitic quartz in this upper portion of the intrusion.

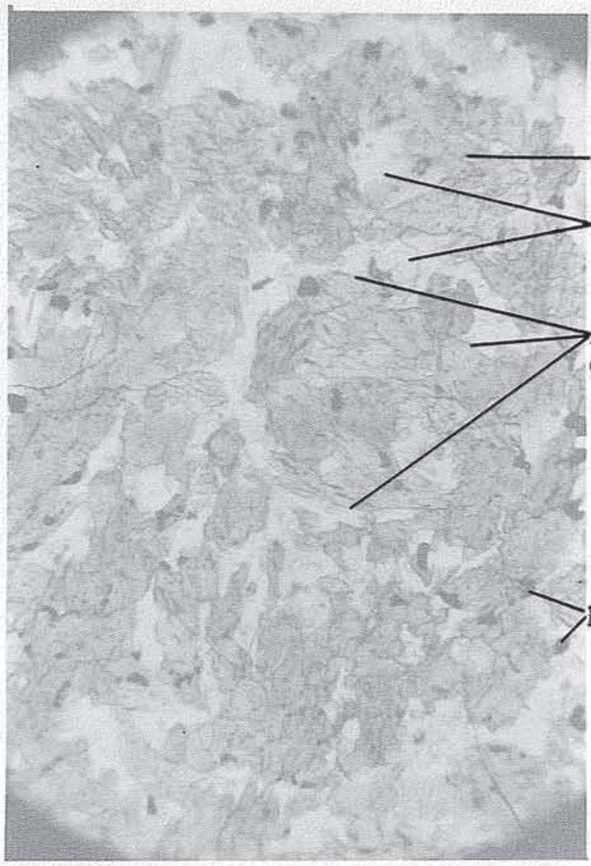


Figure 18.
X 60

Photomicrograph of a thin section from an "outlier" amphibolite intrusion at 9800'S - 2400'E.

NOTE: Dark green highly pleochroic hornblende is found to occur in many whorl or nebula like arrangements indicating rotation textures in this intrusion near the amphibolite schist.

Magnetite

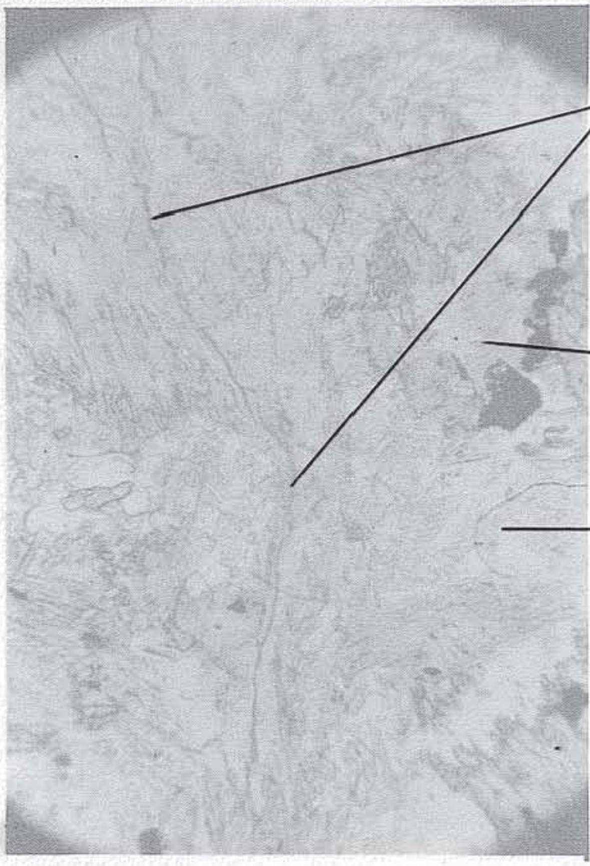


Figure 19.
X 60

Photomicrograph of a thin section of an "outlier" amphibolite intrusion from diamond drill hole #5 (1960) at 64 feet.

NOTE: Considerable fine fracturing occurs, some of these fractures are filled with antigorite without interruption across both hornblende and plagioclase.

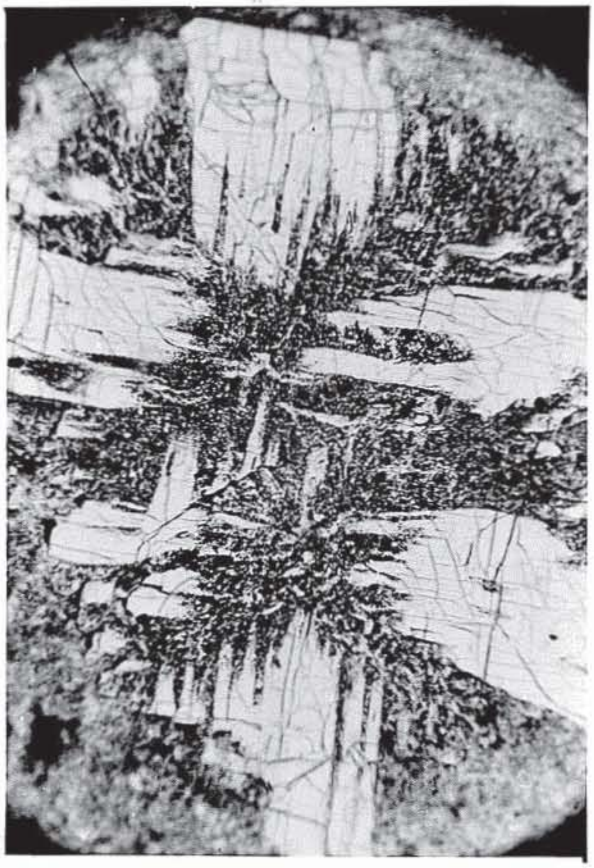


Figure 21.
X 20

Photomicrograph of porphyroblasts of andalusite (variety chiastolite) in the black sediment hornfels taken at 10600'S - 1200'E.

NOTE: The symmetrical inclusions of granules of graphite.

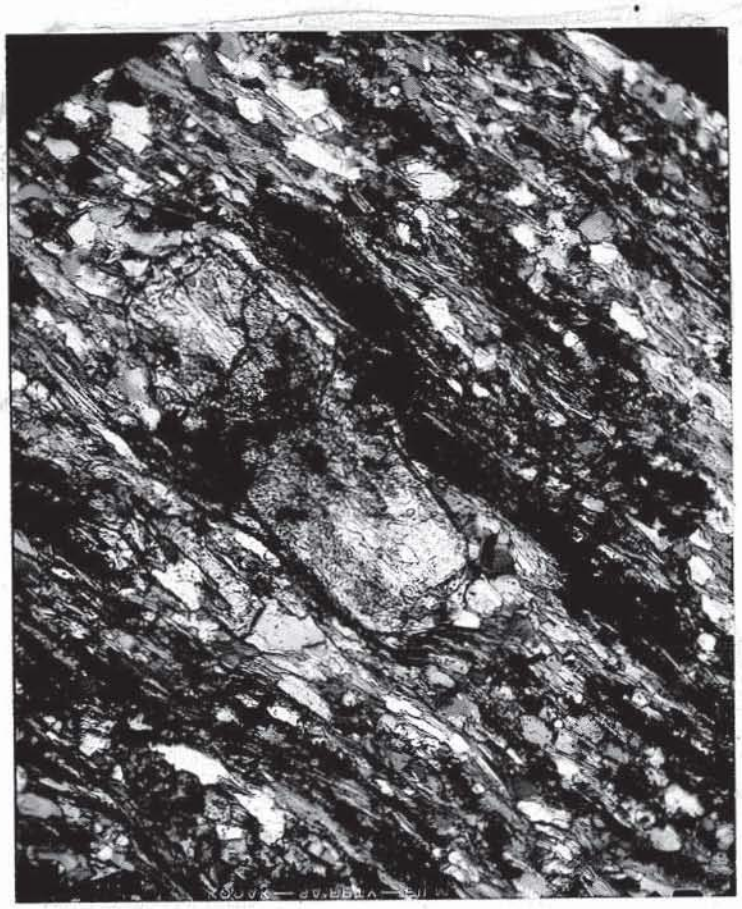
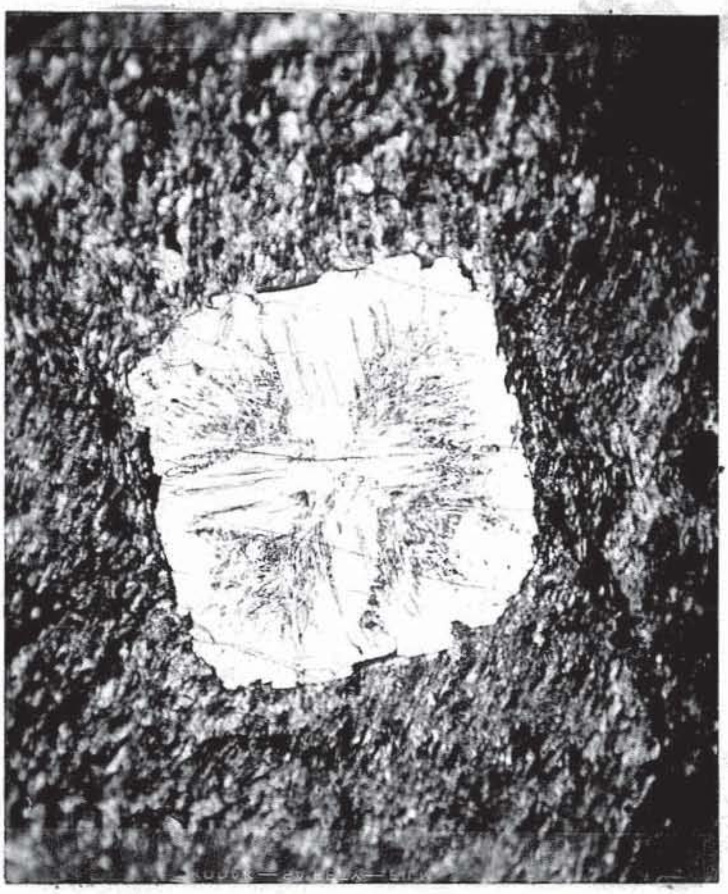


Figure 22.
X 50, X-Nicols

Thin section photomicrograph of staurolite schist from an altered argillaceous rock (Line 9800'S - 1500'E).

NOTE: The large twinned crystal of staurolite and its growth pattern as a porphyroblast wedging apart and bending the crystals of biotite with quartz in the matrix.



Crystal of garnet (almandine-spessartine) with symmetrical inclusions of Quartz.

Figure 23.
X 20

Thin section photomicrograph of metamorphosed argillite (Line 9800'S - 2100'E).

NOTE: The growth of the porphyroblast of the symmetrically zoned garnet crystal has by its force of crystallization growth, pushed aside and bent the blades of biotite in the ground mass of quartz, albite and biotite.

Sheaf-shaped group crystals of antophyllite

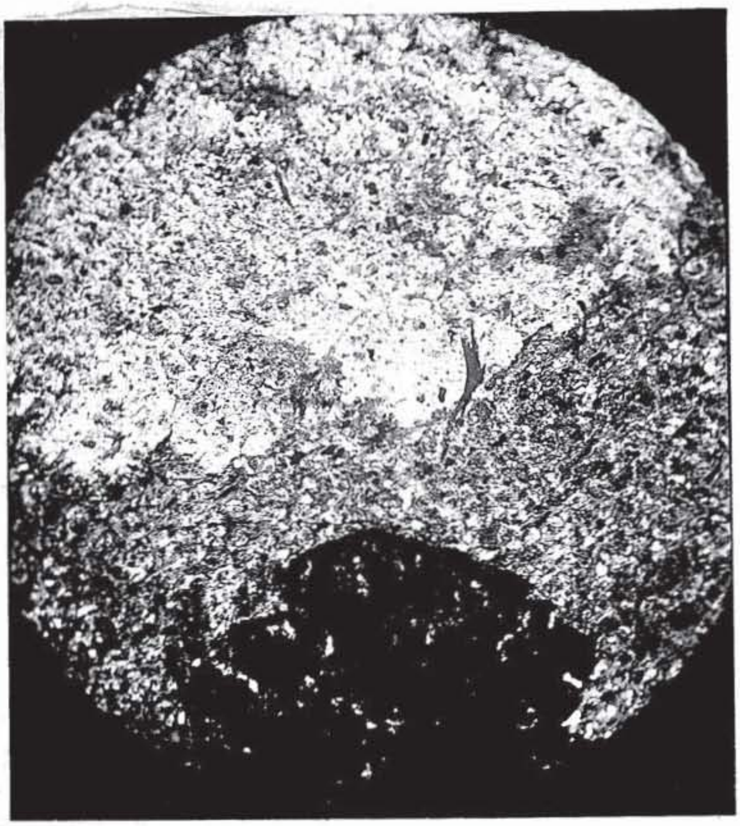
Cordierite (light areas)

Fine grained ground mass of quartz and biotite

Figure 24.
X 20, X-Nicols

Thin section photomicrograph (from Line 13200'S - 600'E).

NOTE: The characteristic minerals and hornfels texture of the thermally metamorphosed pelitic rock.



Light area - cordierite porphyroblast with inclusions of biotite and quartz

Fine quartz-biotite matrix

Dark area - garnet porphyroblast (almandine-spessartine)

Figure 25.
X 20, X-Nicols

Thin section photomicrograph of hornfels texture in pelitic sediments from (Line 13200'S - 800'E).

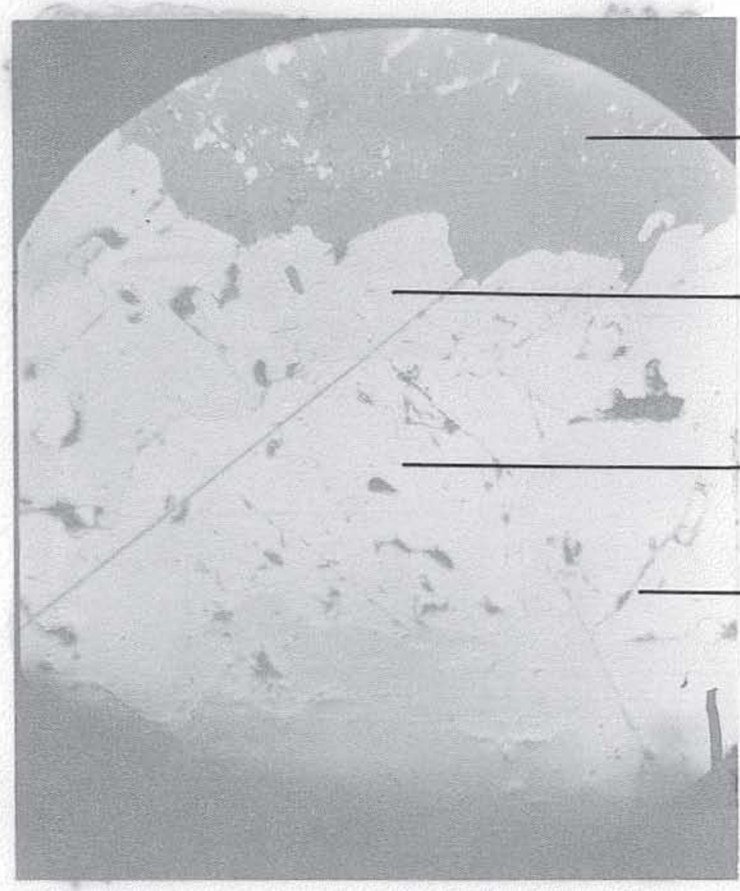


Figure 26.
X 30

Photomicrograph of a polished section of sulphides from the outlier amphibolite intrusion at 13200'S - 400'E. This photo covers part of the rim of an irregular bleb about 1/2 inch in diameter.

NOTE: The most common sequence is represented here: pyrrhotite with "feathery" pentlandite occurs in the central portion rimmed by pentlandite, then chalcopyrite, then gangue. The chalcopyrite-pentlandite boundary is mutual and sharp, the chalcopyrite-pyrrhotite boundary is irregular and in places feathery. This texture is a normal exsolution texture of pentlandite from pyrrhotite in primary sulphides. (Edwards, P. 108)

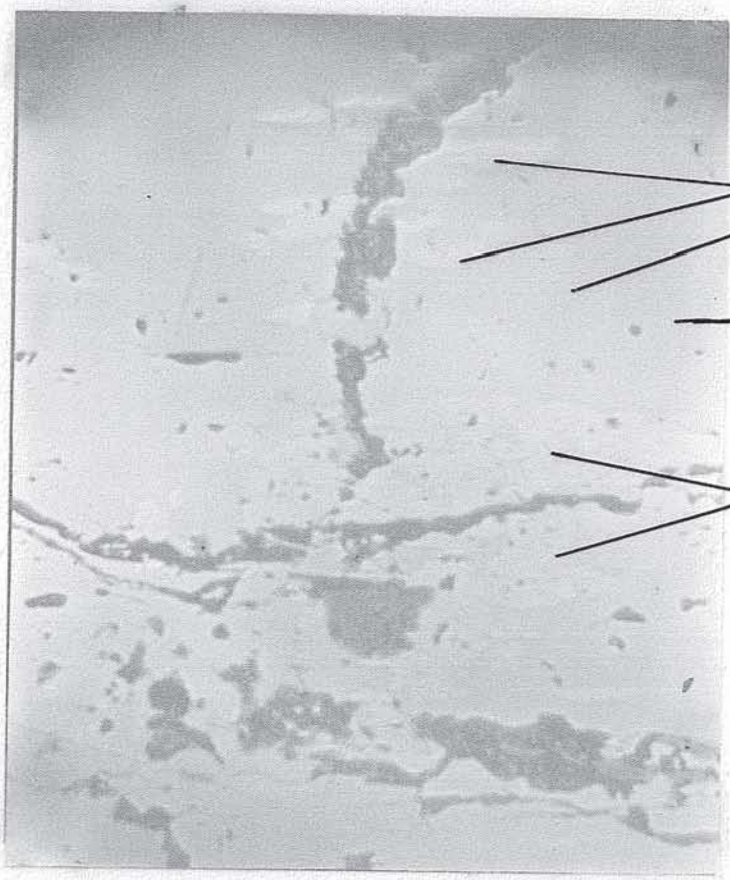


Figure 27.
X 150

Photomicrograph of a polished section of sulphides: the same one used in the previous Figure 26 but near the central part of the sulphide bleb.

NOTE: These "feathers" and "flames" of pentlandite have exsolved upon cooling from the pyrrhotite and are very similar to some of the primary sulphide ores at Sudbury.

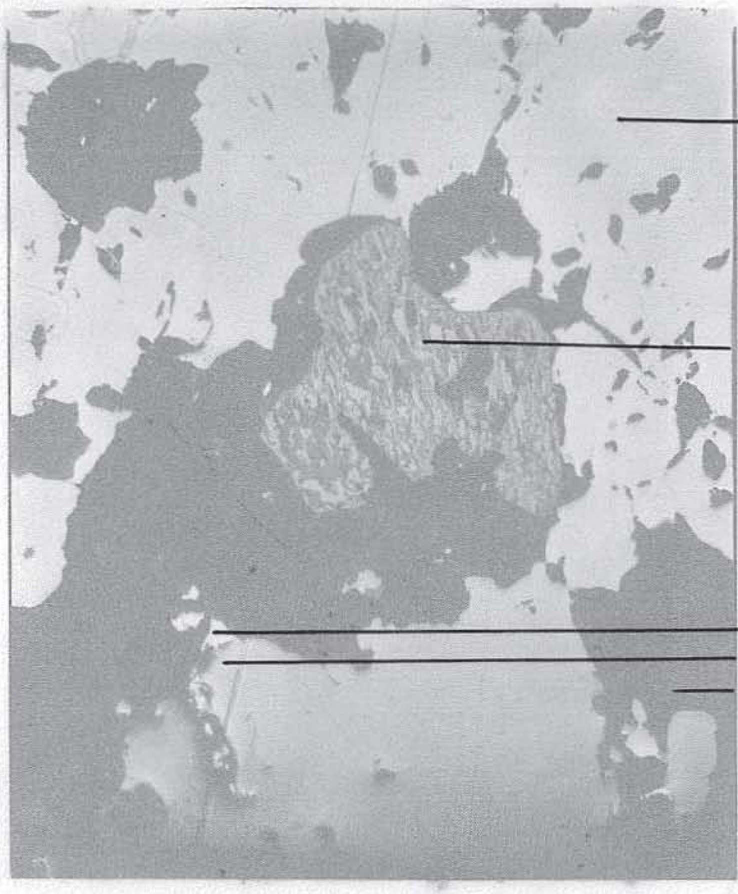


Figure 28.
X 150

Photomicrograph of a polished section from the "outlier" amphibolite intrusion at 13200'S - 400'E.

NOTE: The magnetite-ilmenite intergrowth texture resembles a eutectic intergrowth.

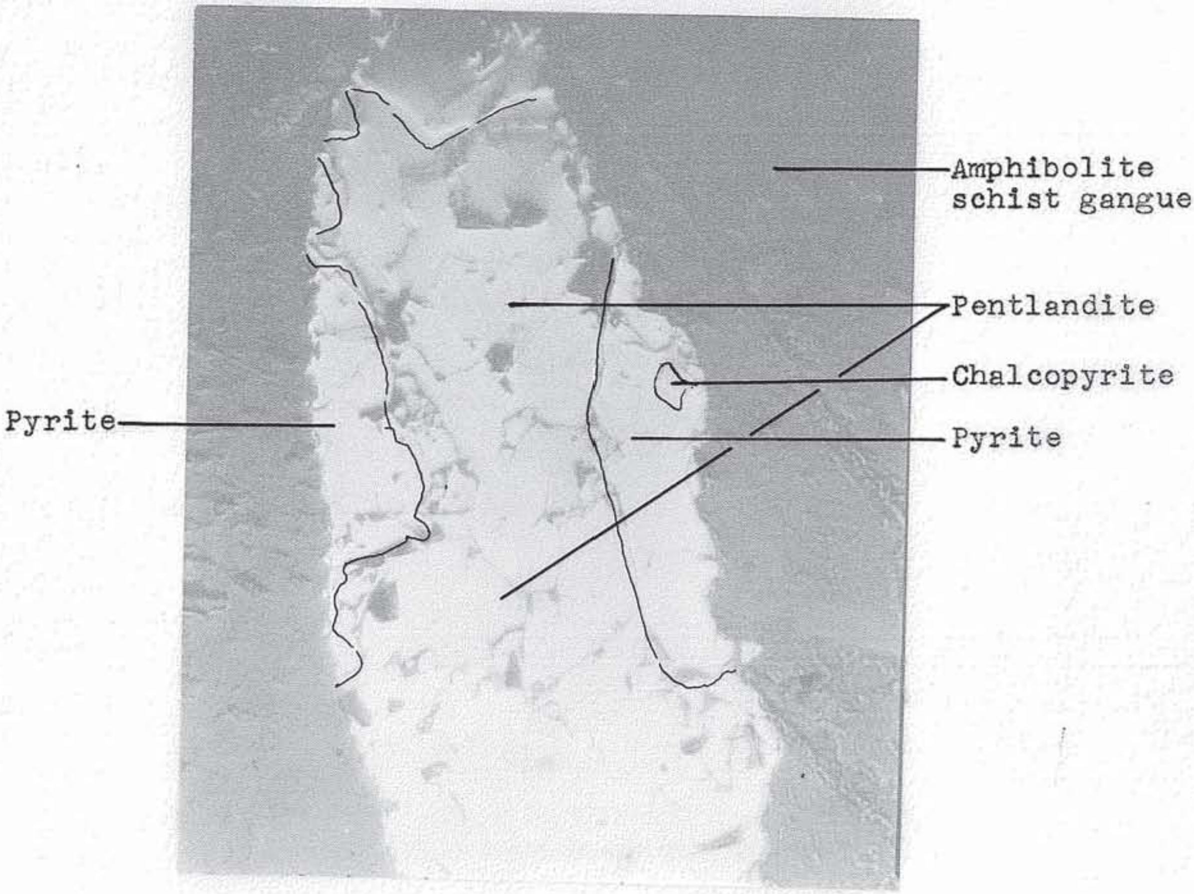


Figure 29.
X 30

Photomicrograph of a polished section of sulphides from diamond drill hole #7 (1960) at 824 feet. (550 feet below surface in the amphibolite schist)

NOTE: This lense-like bleb of sulphides appears to be unaltered by supergene action, fractured pentlandite is the main mineral present with some pyrite and minor chalcopyrite.

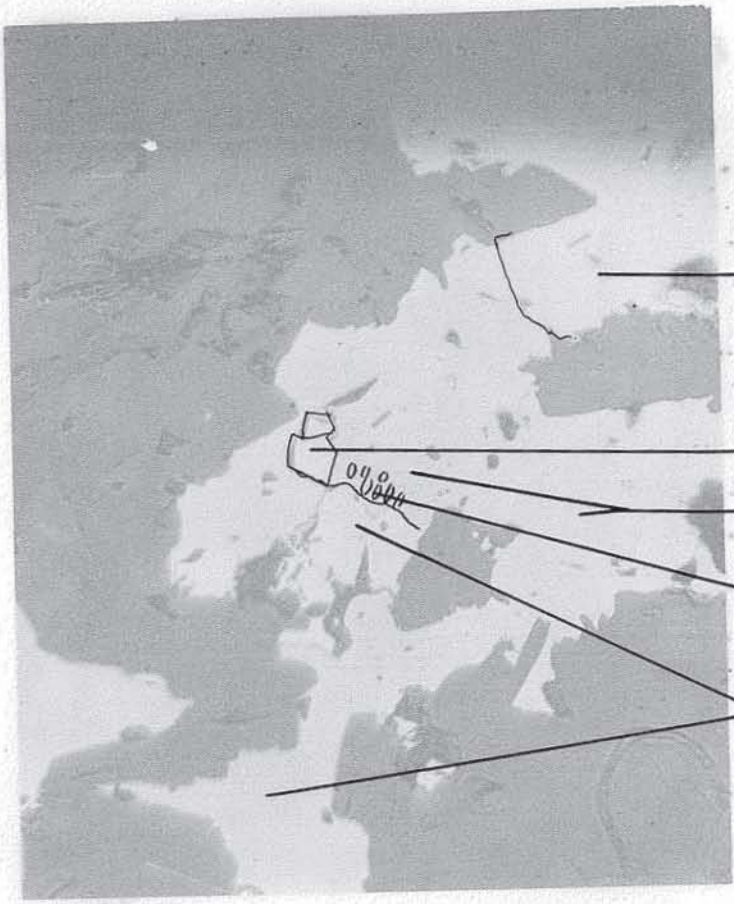


Figure 30.
X 50

Photomicrograph of a polished section of sulphides from diamond drill hole #7 (1960) at 824 feet. (550 feet below surface in amphibolite schist)

NOTE: Evidence of pentlandite exsolved from pyrrhotite in a feathery texture near the boundary between pyrrhotite and chalcopyrite - evidence that it is the primary sulphide. Also note - the cubes of pyrite present.

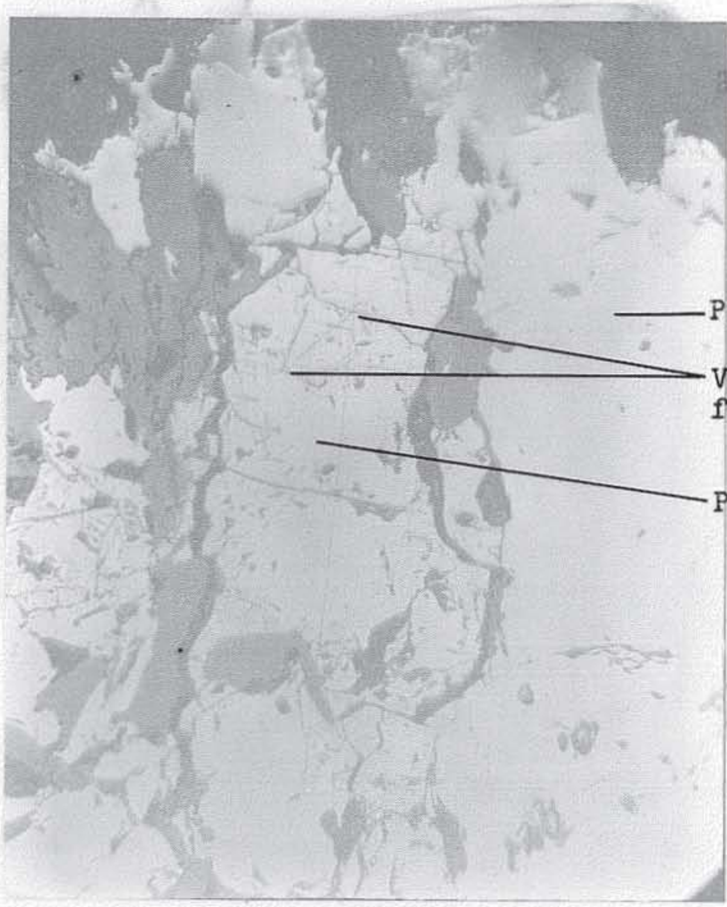


Figure 35.
X 50

Photomicrograph of a polished section of sulphides from a surface pit at 16600'S - 800'E on an island.

NOTE: The supergene alteration of pentlandite to violarite along fractures in the pentlandite.

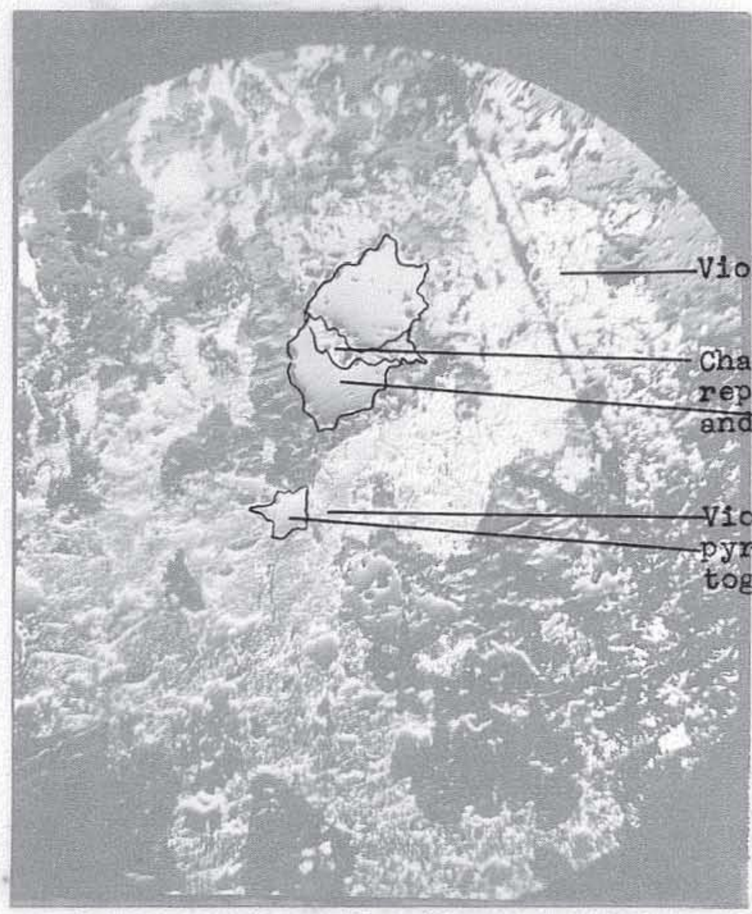


Figure 36.
X 30

Photomicrograph of a polished section of sulphide bearing amphibolite schist from the surface Kelley pit at 4850'S - 2200'E.

NOTE: The replacement of magnetite by chalcopyrite along fractures and the association of violarite with pyrite.

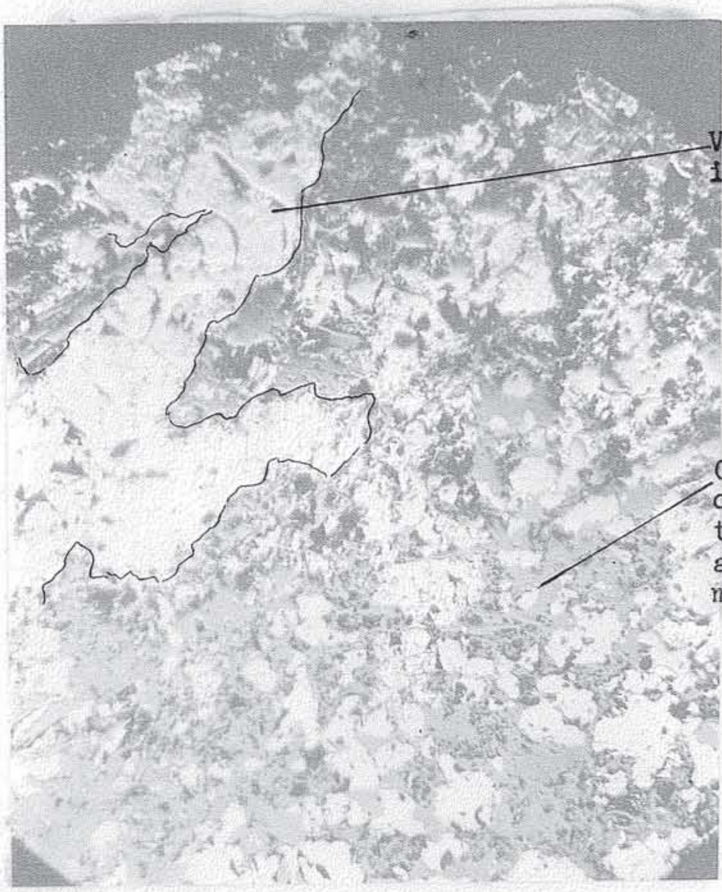
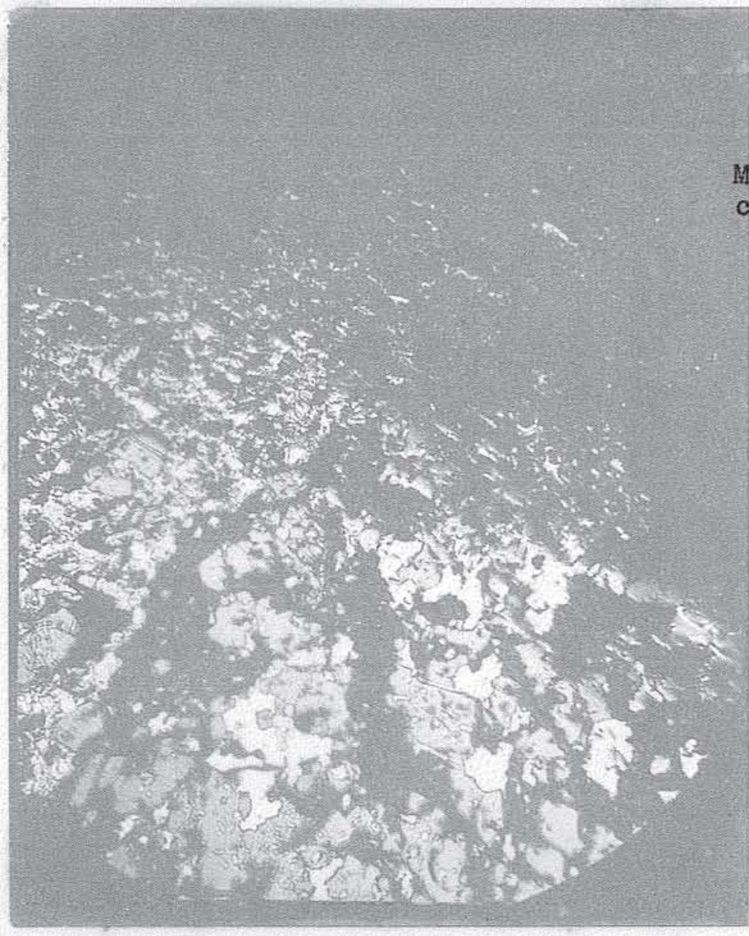


Figure 37.
X 30

Photomicrograph of a polished section of sulphide bearing amphibolite schist at the surface "frog pit" at 12000'S - 2400'E.

NOTE: Violarite occurs along the more massive sulphide veins or lenses with pyrite and marcasite, while chalcopyrite occurs adjoining the more massive sulphide in the gangue or replacing magnetite.



Magnetite
chalcopyrite

Figure 38.
X 30

Photomicrograph of a polished section of sulphide bearing amphibolite schist from the surface "frog pit" at 12000'S - 2400'E.

NOTE: The replacement of magnetite by chalcopyrite along fine fractures.

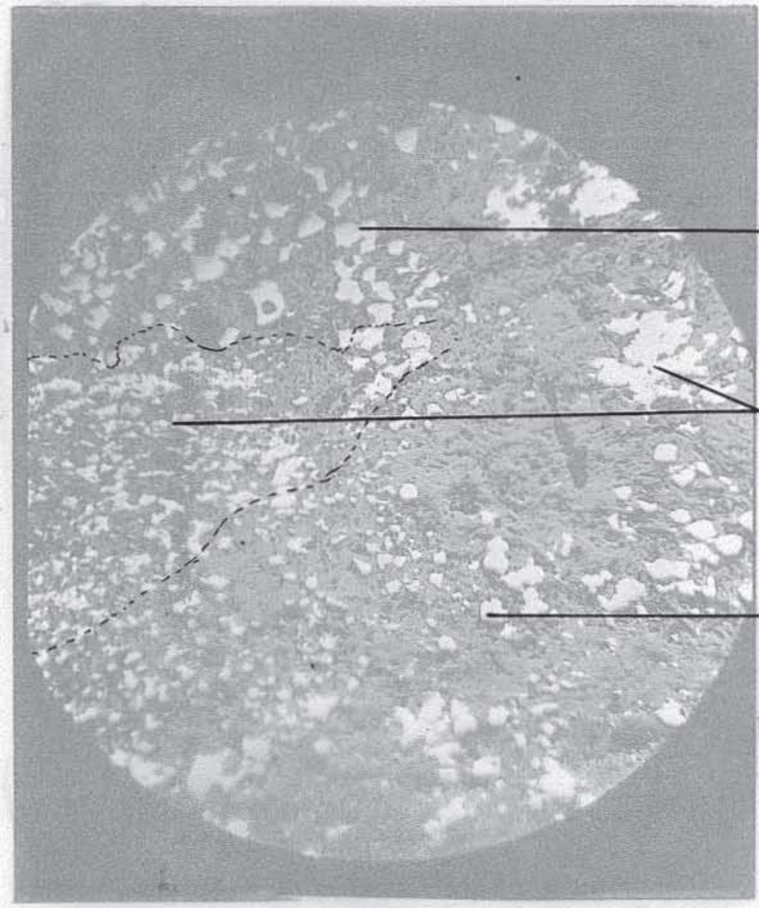


Figure 39.
X 20

Photomicrograph of a polished section taken from diamond drill hole #5 (1960) at 121 feet.

NOTE: This part of a pattern of sulphides which occur in a vein like band across a band heavier in magnetite. This pattern suggests replacement of magnetite by pyrrhotite and chalcopyrite.

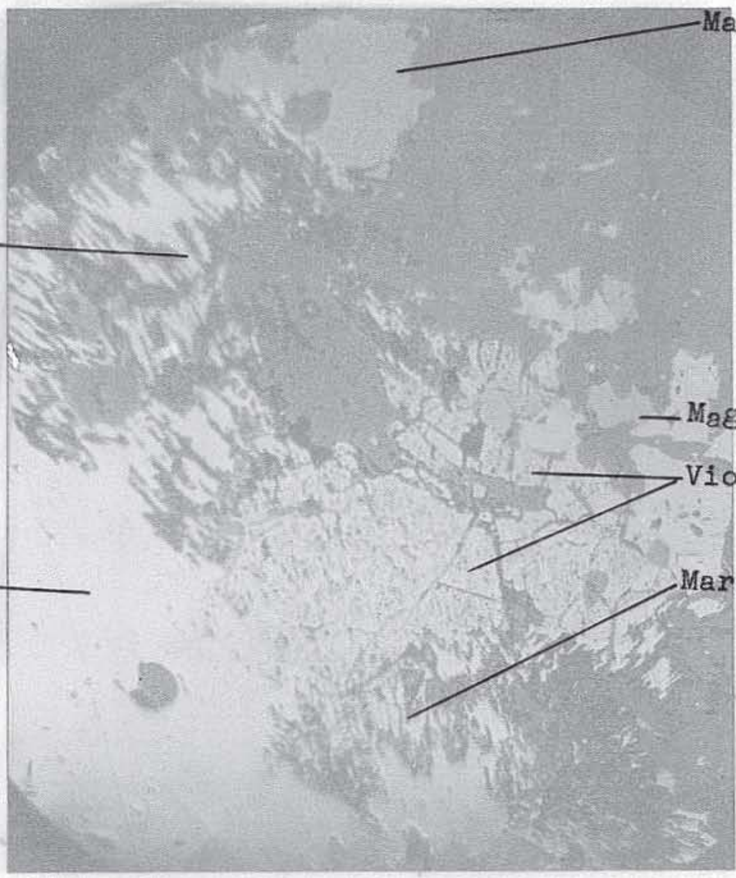


Figure 40.
X 50

Photomicrograph of a polished section of sulphides from diamond drill hole #5 (1960) at 132 feet about 90 feet below surface at 12000'S - 2400'E.

NOTE: Shredded marcasite formed as a supergene alteration of pyrrhotite. Violarite occurs as a pitted crumbly mineral with shrinkage cracks in a polygonal pattern typical of supergene alteration.

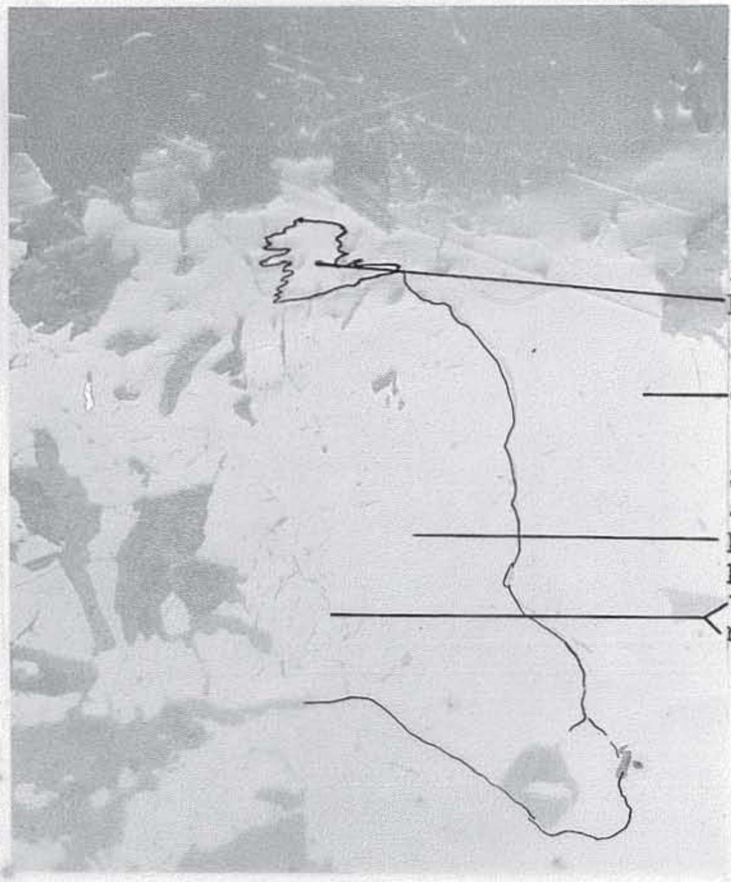


Figure 41.
X 50

Photomicrograph of a polished section of sulphide from diamond drill hole #5 (1960) at 132 feet about 90 feet below surface at 12000'S - 2400'E.

NOTE: Most pentlandite occurs as fresh pentlandite between pyrrhotite and chalcopyrite but some minor supergene alteration is present in incipient fractures forming violarite and marcasite from fractures in pyrrhotite-pentlandite.

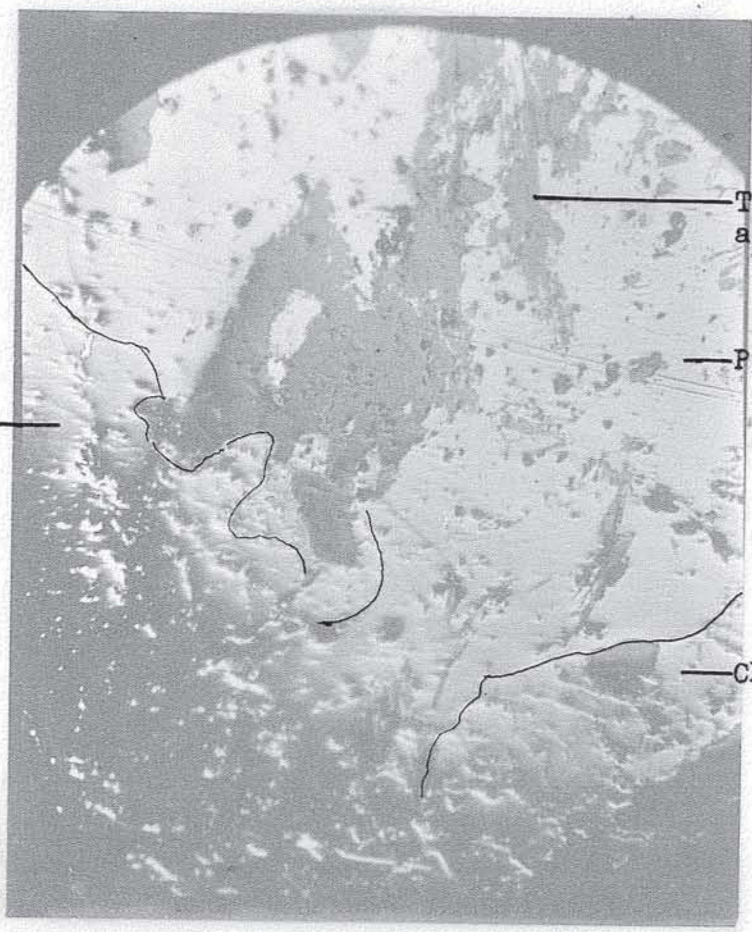


Figure 42.
X 50

Photomicrograph of a polished section of sulphides from the "zinc pit" 10600'S - 2000'E.

NOTE: Mutual boundary relations between chalcopyrite and sphalerite and between sphalerite and galena. Supergene marcasite alteration of the pyrrhotite has taken place along fractures in the pyrrhotite.

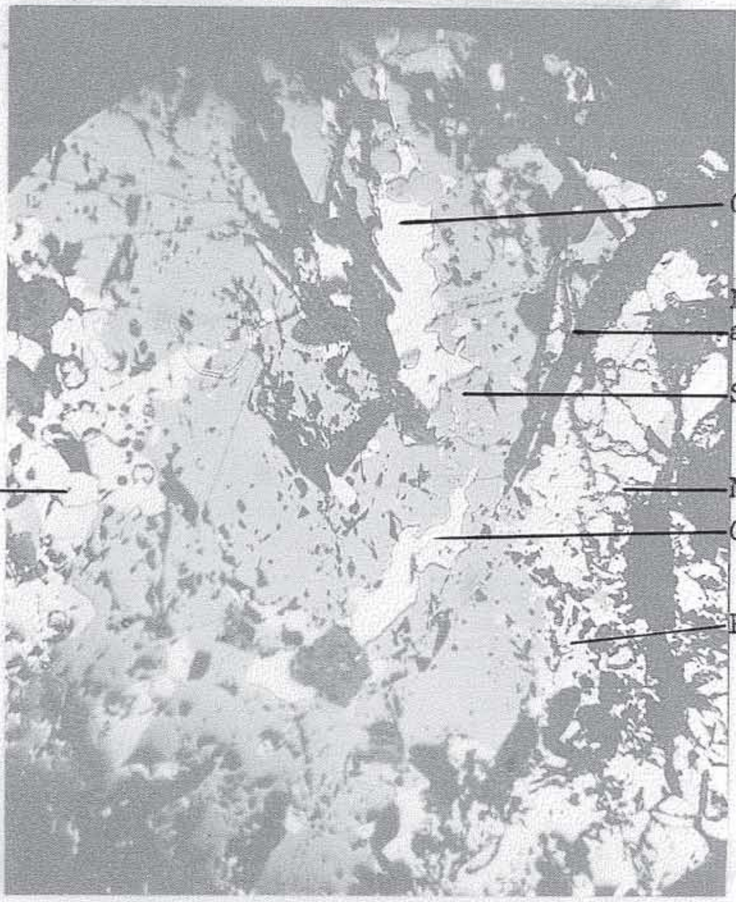


Figure 43.
X 30

Photomicrograph of a polished section from the "zinc pit".

NOTE: The mutual boundaries between pyrrhotite and chalcopyrite. The actinolite of the gangue has grown forcefully into the sulphides.

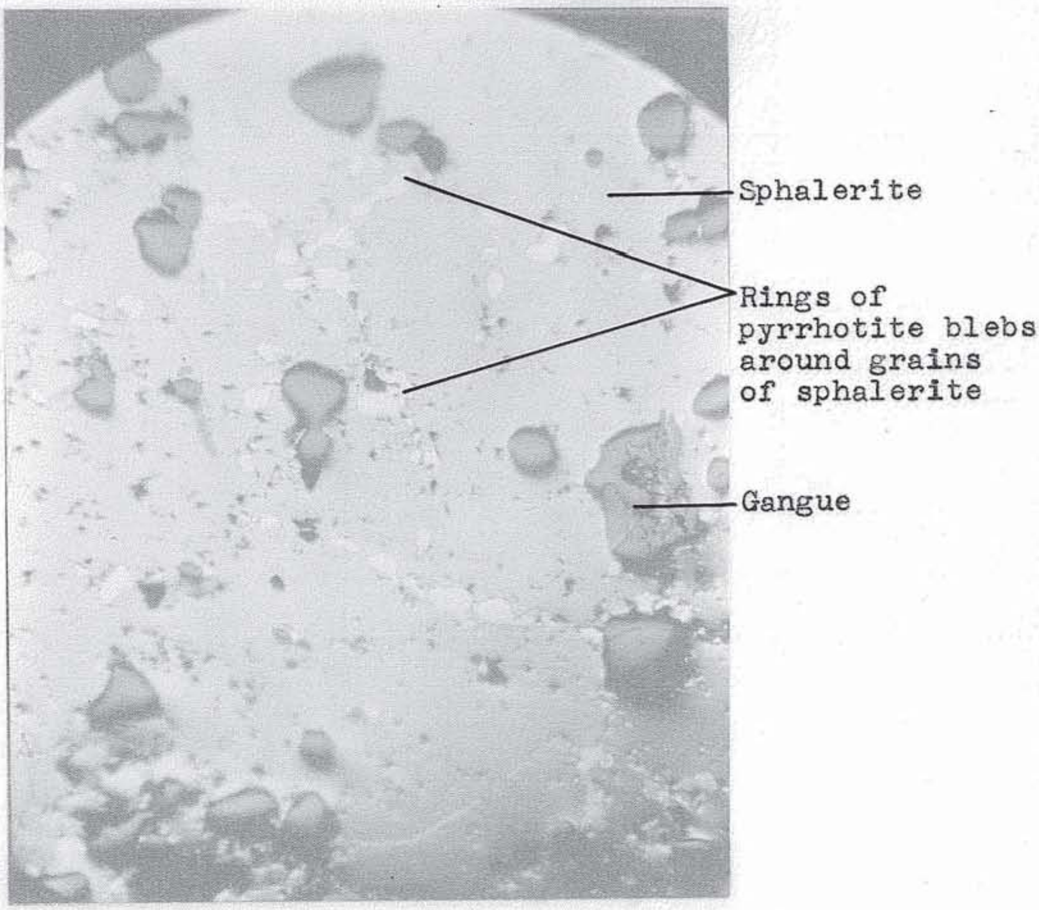


Figure 44.
X 50

Photomicrograph of a polished section from the "zinc pit".

NOTE: The ring like pattern of blebs of pyrrhotite around grains of sphalerite. This is a normal pattern exsolution texture for pyrrhotite exsolved from sphalerite upon cooling.

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