

A STUDY OF THE SULPHIDES AND OXIDES OF THE NICKEL-
COPPER DEPOSITS OF LYNN LAKE, MANITOBA

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PART I

INTRODUCTION

GENERAL STATEMENT

The original discovery of the nickel-copper deposits of Lynn Lake, Manitoba, was made in 1941 by Sherritt-Gordon Mines Ltd. The discovery, made public in 1945, aroused intense interest and activity in the area and resulted in a new mining centre in the Precambrian.

This report consists of a brief introductory account of the Lynn Lake area in connection with a more detailed study of the mineralogy of the ore deposits and the heavy accessory minerals of the associated intrusive.

Location And Access

Lynn Lake is situated 150 miles north and slightly east of Flin Flon, Manitoba. Its location is shown in figure 1. The nearest railroad terminal lies 120 miles to the south at Sherridon, Manitoba. Sherridon is, in general, the base for operations in the Lynn Lake area. Principal access to the area is by means of aircraft. A winter road from Sherridon to Lynn Lake is used for freighting during the winter months. The water route from Sherridon to the Lynn Lake area is long and difficult and is seldom used.

Historical Account

The original discovery of nickel and copper sulphides in the Lynn Lake area was made in 1941 by Austin McVeigh prospecting for Sherritt-Gordon Mines Ltd. The discovery was not made public until

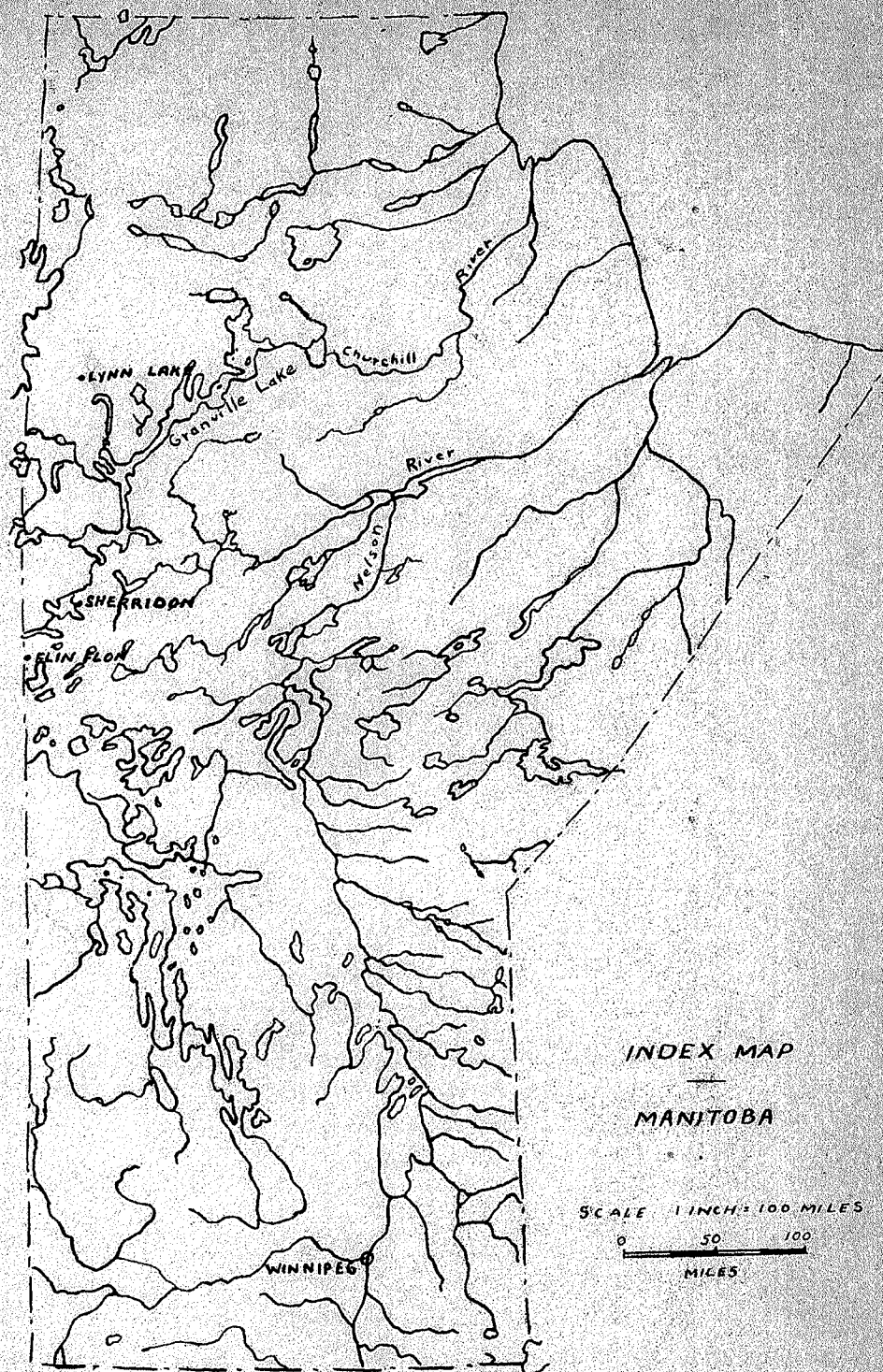


Figure 1. Index map of Manitoba showing the location of Lynn Lake.

1945. When released, this information aroused extensive interest and activity in the area. For the past five years prospectors and mining companies have engaged in extensive staking, exploration, geophysical surveys, and mapping in the Lynn Lake and adjoining areas. Government parties have mapped much of the territory.

Sherritt-Gordon holds all property on which sulphide deposits of any commercial importance have been located. An extensive geophysical and diamond drilling program carried out by this company located a total of five ore bodies concentrated in a relatively small area near the original discovery (map in pocket). To date more than 13 million tons of nickel-copper ore have been proved.

In 1948 shafts were collared at the 'A' and 'El' orebodies. At the time of writing the shaft at the 'A' orebody has been sunk to a depth of 1000 feet and underground development is proceeding.

Previous Work

Mapping of the Lynn Lake sheet on a scale of 1 inch to $\frac{1}{2}$ mile was carried out by J.D.Allan and issued by the Manitoba Mines Branch as report 46-2. Detailed mapping of the Lynn Lake intrusive on a scale of 1 inch to 250 feet was carried out by H. Hunter in 1949 as field work in connection with a thesis to be submitted to the Department of Geology at the University of Manitoba in 1950.

Theoretical studies of the Lynn Lake ore deposits are very limited in comparison with the extensive literature available on better known ore deposits of this type such as Sudbury. This is partially due to the fact that the exploration and development of the Lynn Lake ore deposits occurred within the last five years. As with new discoveries

in other localities the stress has been on exploration and development of the ore bodies. Another reason for the limited amount of literature has been lack of data on the ore deposits. Until recently when underground development began, data on the ore bodies was made available by diamond drilling.

Allan (2) made the principal contribution in the form of a petrographic and mineralogical study of the Lynn Lake intrusive and the associated ore deposits.

The Problem

The Lynn Lake nickel-copper deposits come under the classification of pyrrhotite-pentlandite-chalcopyrite concentrations associated with basic intrusives. In common with all ore deposits of this type the major problem is that of origin and emplacement of the ore minerals.

The original purpose of the laboratory investigations was to study the occurrence and paragenesis of the sulphides and oxides of the Lynn Lake nickel-copper deposits. As the work progressed it became apparent that the sulphides and oxides represented two separate problems rather than one as originally believed. The oxides were genetically related to the silicates rather than the sulphides. Accordingly, two separate lines of investigation were established. The first was a study of the minerals of the ore deposits. The second, which began as a study of the oxides, was extended to an investigation of the heavy accessory minerals of the Lynn Lake basic intrusive. The purpose of this investigation is, in part, to determine the value of heavy accessory minerals in possible identification and correlation of the

highly altered rock types and the association of heavy accessory minerals with the ore deposits. More generally, the investigation was designed to consider some of the problems of the occurrence of heavy minerals in basic rocks.

PART II

THE SULPHIDES AND OXIDES OF THE NICKEL-

COPPER DEPOSITS

REVIEW OF LITERATURE

The Lynn Lake ore deposits fall in the group of pyrrhotite-pentlandite-chalcopyrite concentrations associated with basic intrusives. In attempting to classify a new ore deposit it is common practice to compare it with similar occurrences that have been more extensively studied. Many examples of such deposits are described in the literature. All pyrrhotite-pentlandite-chalcopyrite occurrences possess certain general similarities but a controversy still exists among observers as to the method of emplacement of these sulphide deposits.

Pyrrhotite-pentlandite-chalcopyrite deposits are associated with basic rocks of the gabbro family and peridotite. The sulphides commonly lie in disconnected bodies at the base of the intrusive, often in depressions of the floor. Some deposits occur in the country rock along the contact of the latter with the intrusive. Many nickel-copper deposits are found at or near the margins of small norite or gabbro stocks. Where the basic intrusive is characterized by pronounced differentiation, the ore deposits occur within the intrusive.

The comparison of general characteristics of nickel-copper deposits may be extended to the mineralogy of the ore. Pyrrhotite,

pentlandite, chalcopyrite, and pyrite are the chief sulphides. Sperrylite, other sulphides, and gold are usually present. The oxides present are normally magnetite and ilmenite. With few exceptions the general paragenesis for the common ore minerals is: oxides, pyrrhotite, pentlandite, chalcopyrite and pyrite.

A voluminous literature is available on the mineralogy of the nickel-copper deposits. Detailed and painstaking investigations have been undertaken in all phases of the study of the ore minerals. A detailed description of the mineralogy of such deposits is necessary for an appreciation of the problems rising in connection with the ore minerals. Over and above the study of the paragenesis and textures of the minerals considered collectively, each mineral is a problem in itself. A large part of the extensive and varied literature therefore consists of more or less isolated studies of some particular phase of mineralogy.

To indicate more fully the nature of pyrrhotite-pentlandite-chalcopyrite occurrences and the principal theories of their origin a few typical deposits will be described in some detail. These examples are chosen on the basis of associated rock type and mode of occurrence of the sulphides as a representative cross section of nickel-copper deposits.

Prospect Hill, Litchfield Connecticut

The sulphide deposits of Prospect Hill are of little commercial importance but of great theoretical interest. A series of small basic intrusives are found in the Prospect Hill area. They

range in composition from granodiorite to peridotite with norites and pyroxenites predominating. Olivine norite, quartz norite and hypersthene pyroxenite are sulphide-bearing. Howe (18) attributes this great variety of rock types in a small area as due to extreme magmatic differentiation. Cameron (8) believes that separate intrusions occurred.

Six principal sulphide deposits are found in the intrusive. No systematic arrangement of the ores with respect to the intrusives is apparent. One deposit, occurring in quartz norite, occupies a marginal position in contact with the country rock. Two deposits adjoin large xenoliths. The fourth deposit lies along the brecciated margin of a mass of olivine norite at its contact with quartz norite. Two deposits occur in olivine norite.

The sulphides have a similar relationship with the associated rock types in all six deposits. They have an irregular distribution forming sparsely disseminated blebs, grains, streaks, and patches in the enclosing rock. Thin veinlets of sulphide cut the basic rock. The sulphides present in order of occurrence are pyrrhotite, pentlandite, and chalcopyrite.

Howe (18) concluded that the ore minerals are magmatic sulphides which separated out at an early stage in the cooling of the magma, but remained liquid until the silicates crystallized. He believed, however, that the sulphide veinlets in the silicates were formed by the replacement of the silicates.

Tolman and Rogers (39) found no evidence of any rearrangement of the ore minerals. They classify the veinlets as being of the

same age as the disseminated sulphides and all the ore minerals as late magmatic.

Cameron (8) believes the sulphides represent late differentiates from the magmatic reservoir from which the basic rocks originated. The sulphides therefore are genetically related to the basic intrusives but are not magmatic or late magmatic in the sense of being related to the period of crystallization of the basic intrusives. The deposits are epigenetic and are classified as high temperature hydrothermal.

Insizwa Range, East Griqualand and Pondoland, South Africa.

The nickel-copper deposits occur at the base of the largest of a series of gabbro and olivine norite sills. The sulphides are intimately mixed with the silicates and intrude the country rock to a limited extent. The silicates of the sill show no alteration in contact with the sulphides. Biotite is often intimately associated with the ore, either in the form of a discontinuous marginal selvage which separates the sulphide from the silicates, or as an envelope completely surrounding irregular blebs of ore. The sulphides appear to have crystallized after the biotite since they penetrate and replace the biotite along its basal cleavage.

In addition to the ores, a granite extract has been segregated along the base of the sill. This granitic extract occurs as a network of dikes varying from a fraction of an inch to a foot in thickness. The ore bodies are in general associated in an intimate manner with similar acid material indicating a genetic relationship.

Phemister (31) favored a hydrothermal origin for the sulphides because of the granitic extract and the location of the ore near the contact of the basic sill and the country rock.

Scholtz (34) believed that the ore separated from the magma and concentrated in the basal zone by gravitational differentiation to form pools in hollows and irregularities in the floor of the intrusive. The disseminated ore was formed by droplets of late arrival which were unable to penetrate the viscous crystalline mush at the base of the sill and eventually solidified. The biotite and granitic extract in contact with the sulphides indicate that the sulphides were associated with variable amounts of late magmatic products which, together with the ore, may be collectively referred to as constituting the ore magma. During the initial stages the drop in temperature was accompanied by an increase in the vapor tension (29,P.6) which rendered the ore magma an active intrusive. Cracks or fissures formed in the base or walls of a magma pool because of differential stresses developed along the cooling contact would immediately be filled by ore, late magmatic products, or a mixture of both. This provides an explanation of the common association of acid silicates with ore.

Norway

In Norway there are about fifty nickel-copper deposits which may be considered as a series of small scale models to illustrate the typical occurrence of pyrrhotite-pentlandite-chalcopyrite deposits. In many Norwegian deposits neither the ore nor the norite has suffered metamorphism and the geological relations are simple, making it possible to

select the characteristic features of this type of deposit. These deposits contribute a great deal to the understanding of the problems for they clearly indicate relationships not so evident in deposits of the same type in other localities.

The typical occurrence of the deposits is at or near the margins of small norite or gabbro stocks. The stocks are round or elliptical in outline, and some are funnel shaped in cross section. The individual intrusives are small, usually a few hundred feet in diameter. The amount of ore in each stock is roughly proportional to its size. The ore is found chiefly at the margins of the stocks, and to a minor extent as segregations within the norite or as impregnations in the schists and gneisses in which the norite intrusives are enclosed (Figs.2,3). The ore is further localized in the portions of the intrusive where marked differentiation has taken place.

The ore-bearing rock is a variety of norite, usually quartz norite, diallage norite or olivine norite. In a few localities it is extensively altered to uralite gabbro. Individual stocks have undergone extensive differentiation, especially in the vicinity of the ore bodies. All deposits are characterized by a similar differentiation. The basic segregations are mixtures of bronzite, olivine, hornblende, and biotite. The felsic products occur as masses of granite as well as streaks, dikes, and marginal veinlets of pegmatite and aplite. The margins of the stocks are often severely fractured and brecciated. Sulphides may cement these igneous breccias. The ores from the various deposits show the same group of minerals and the same paragenesis. The minerals in order of paragenesis are

magnetite, pyrrhotite, pentlandite, chalcopyrite and pyrite.

Tolman and Rogers (39) interpret the Norwegian deposits as follows: The more basic portions of the norite solidified by the sinking of crystals while the main mass of the rock crystallized as norite. Felsic dikes and masses were squeezed out as marginal segregates during a period of peripheral brecciation, which facilitated the concentration and escape of mineralizers from the deeper portions of the magma. Ore deposition occurred at a late stage and was preceded, accompanied, and followed by acid extracts. The evidence for this is the occurrence of ore as late minerals in felsic dikes which cut the main ore bodies.

Vogt (41) notes frequent occurrence of sulphides along cleavage planes and in cracks of some silicate grains and postulates an intrusion of molten sulphides into the solidified rock. Tolman and Rogers (39) believe that the sulphides were formed by the replacement of silicates under the influence of mineralizers. Since this process occurred in the late magmatic period and is not due to destructive pneumatolytic or hydrothermal stages, the deposits are still considered magmatic.

Vogt (41) regards the Norwegian deposits as magmatic segregations in gabbro or chemically analagous dike rock. He believes the nickel-copper deposits were not accompanied by pneumatolitic minerals. They appear to be formed from dry or almost dry melts. The molten sulphides were extremely fluid and often formed marginal injections or offset deposits which are commonly characterized by a brecciated nature.

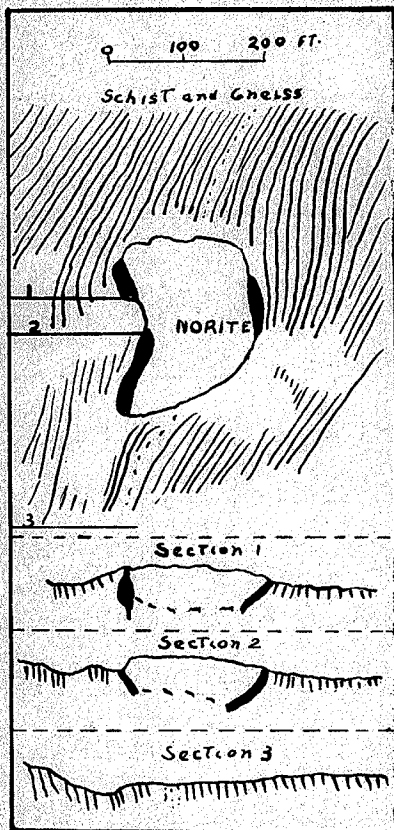


Figure 2. Meinkjar Mine, Norway. (After Tolman and Rogers, 39, p.47)

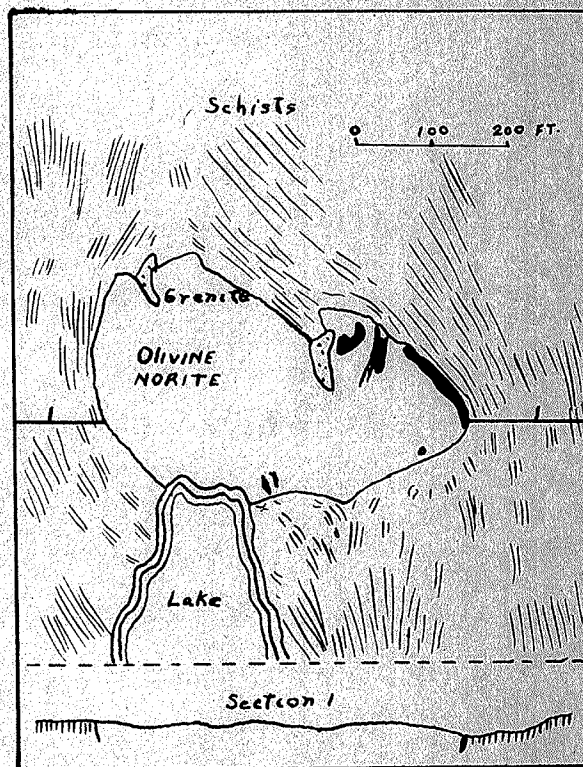


Figure 3. Erteli Mine, Norway (After Tolman and Rogers, 39, p.48)

Sudbury

General Geology - The dominant structural feature of the area is the Sudbury basin which is a spoon shaped trough, 36 miles long and 20 miles wide. The ore deposits occur at the base of a great sheet of "norite-micropegmatite" which outcrops in a great ellipse around the rim of the Sudbury basin. The sheet is of unusual regularity for an intrusive mass of its size and character. The norite is overlain by 9000 feet of tuffs, sandstones, shales and conglomerates dipping concordantly with it. Underlying the norite is a sedimentary series of great thickness with included older igneous intrusives. All rocks are Precambrian in age.

The norite intrusive consists of an outer rim of norite, a narrow transition zone, and an inner zone of micropegmatite. The nickeliferous pyrrhotite deposits are all found on the edge of the Sudbury basin and usually in the vicinity of the contact of the norite with the country rock.

Ore Deposits - Coleman (10) classifies the ore bodies into three main types.

(1) Marginal deposits - These are sulphide segregations at the base of the norite sheet. The sulphides become disseminated upwards and gradually grade into barren norite. The footwall is always a pronounced fissure along which brecciation, fracturing and later reconcentration of ore often occurs.

Faulted marginal deposits have suffered brecciation and faulting in their upper portions. The ore encloses the breccia. As chalcopyrite

is the more transferable of the sulphides it has entered the fissures to a greater extent than the pyrrhotite. In some deposits such as Carson and Crean Hill large amounts of quartz and carbonate are associated with the sulphides.

(2) Columnar offset deposits - The Copper Cliff mine is the most notable deposit of this type. It is a great cylindrical ore shoot varying from 50 feet to 200 feet in diameter. It extends to an unknown depth. It is in a gabbro dike which is traced to the norite a mile to the north. The ore consists of fragments of the dike rock cemented together by sulphides. Mineralization is confined to the dike.

(3) Parallel Offsets - The Frood-Stobie ore deposit is an example of this type of occurrence. It runs almost parallel to the edge of the norite sheet, but at a distance of from three quarters of a mile to one and one half miles to the south-east. The ore resembles that of a marginal deposit. The orebody is a long irregular sheet enclosing much brecciated rock. Disseminated ore near the surface grades into massive ore in pockets or depressions in the norite floor. Coleman (10), who studied the deposit before the discovery of the massive ore, believes the sulphides originally belonging to it have been drained off through a complex set of fissures to form the deposit. The Frood-Stobie deposit appears to have been a depression in the floor of the norite intrusive in which sulphides accumulated. Subsequent erosion isolated it from the main norite body.

There is evidence of hydrothermal deposition of ore and gangue minerals distinctly later than the main ore mass. Pyrite, marcasite, galena, sphalerite, and molybdenite are found in late veinlets

accompanied by quartz and calcite, often cutting the main ore bodies. Origin of the Sudbury ores - Not only are the pyrrhotite-pentlandite-chalcopyrite deposits of Sudbury the largest of their kind in the world, they are also the most extensively studied. A central theme runs through the voluminous literature on the subject - the origin of the deposits. Phemister (32) includes a brief historical review of the hypothesis of the origin of the deposits in a paper presenting the results of his own investigations. A short summary is of interest since it indicates the most prominent theories and the divergence of opinion based on observations of the same deposits.

The suggestion that the ores came from the norite was first made by Bell (5) in 1890. In 1897 Walker (42) presented evidence to show that the norite graded into micropegmatite towards the inner edge of the rim of the intrusive. He considered that the norite and micropegmatite were gravitative differentiates of the parent magma. This view was supported by Adams (1) who extended the hypothesis to include the ores as ultra-basic differentiates en situ from the norite-micropegmatite mass. Coleman (10) attempted to demonstrate the validity of Adams' hypothesis on the basis of more extensive observations. The theory that the ores are ultra-basic differentiates of the norite-micropegmatite was successively attacked by Dickson (11) Gregory (14) and Knight (22). These three observers showed that the sulphides had replaced the earlier silicates in some of the deposits. They postulated deposition of the ores by hydrothermal solutions which originated from the norite or a source common with the norite. In 1914 Howe (17) and in 1917 Bateman (4) postulated that the ores had

been injected as a sulphide melt which had originated by differentiation from the norite in a deeper magma chamber. The International Nickel Company favored a similar view in their 1920 report (20). Spurr (38) suggests that the sulphides were introduced as an ore magma independent in origin from the norite. Hoffman and Wandke (43) favored the hydrothermal replacement origin for the ores.

Phemister (32, P.49) classified the hypothesis of the origin of the Sudbury deposits into four groups. (1) The sulphides have formed by the settling of an immiscible sulphide melt from the norite. (2) After solidification of the norite, the sulphides have been injected in a molten condition, the separation into norite and sulphide having taken place in a magma chamber, presumably not far beneath the present site of the norite-micropegmatite. (3) The sulphides are hydrothermal replacements of the country rock and the solutions came either from the norite or from the same deep seated reservoir which was the source of the post-Sudburian igneous rocks of the district and (4) the sulphides are crystallizations from ore magmas which form independent members in the series of magmatic injections.

In his discussion of the origin of the Insizwa deposits Scholtz (34) states that much misunderstanding and unnecessary discussion have been caused because observers attempt to draw hard and fast distinctions between deposits of magmatic and hydrothermal origin instead of realizing that the two are simply stages of a common process.

Lindgren (23, p.807) points out that in a cooling magma when the concentrated and controlling gases instead of the straight melt become the dominating influence, the mode of deposition grades into

hydrothermal processes, In discussing the origin of the Sudbury deposits Lindgren believes that much of the difficulty in classifying ores as to their origin is owing to insufficient knowledge of how the processes of deposition differ, and in trying to limit the deposition to strictly one type or another.

GEOLOGY

General Geology (2,3)

The rocks of the Lynn Lake area are Precambrian in age. They consist of volcanic and sedimentary formations intruded by igneous rocks which range in composition from granite to gabbro. Most rocks are highly folded and metamorphosed.

The non-intrusive formations are grouped into two series:

(1) The Wasekwan series composed of volcanics and sediments unconformably overlain by (2) the Sickle series which is composed of sediments.

The following table summarizes the general geology:

Table of Formations (2)

Precambrian	Later Intrusives	Basic dikes; pegmatite, aplite; porphyry and felsite; granite, syenite, granodiorite, tonalite, diorite, gneissic varieties of above. Diorite, quartz, diorite, granodiorite, gabbro, amphibolite
	Intrusive Contact	
	Sickle Series	Arkose, greywacke, conglomerate; derived schists
	Post-Wasekwan Intrusives	Sheared granite gneiss porphyry
	Intrusive Contact	
	Wasekwan Series	Volcanics: basic to acid lava; breccia, tuff; derived hornblende schist and gneiss Sediments: quartzite, impure quartzite, greywacke, iron formation; derived mica schist and gneiss

Wasekwan Series

The Wasekwan series is made up of steeply dipping lavas, pyroclastics and sediments. "Greenstone" hornblende schist or gneiss is the predominant rock type. It is believed the original rock was probably a basalt which has since been strongly metamorphosed. Ellipsoidal and amygdaloidal structures are found in a few outcrops. The pillows are elongated and are believed to have been stretched. The amygdules are filled with quartz or calcite.

Volcanic breccia is exposed in several localities. The matrix of the breccia is similar to the basic flows. The fragments have an average size ranging from 1 to 2 inches and are well aligned. Most fragments have the same composition as the matrix but tend to be more fine grained. The breccias are believed to be flow breccias. Tuffs are interbedded with the flows in several localities.

The predominant sediments of the Wasekwan series are thinly bedded impure quartzites. In some localities they are interbedded with the volcanics.

Sickle Series

The Sickle series is a metamorphosed sedimentary formation consisting principally of fine grained quartz-mica schists. Interbedded with the schists are occasional conglomerate beds. They contain elongated fragments of quartzite, cherty material, amphibolite, granite gneiss, diorite, granite and quartz.

The lithology of the Sickle sediments indicate they were derived chiefly from the erosion of granitic rocks.

Sheared Granite Gneiss

Two bodies of granite gneiss occur to the south of Lynn Lake. These bodies are sill-like and conform with the bedding of the surrounding sediments. These two bodies represent an older granite intrusive into the Wasekwan, and have suffered the same deformation as that series.

Diorite, Gabbro, Amphibolite

Several bodies of basic intrusives occur within the area. The Lynn Lake intrusive, which contains the ore deposits, lies north and east of Lynn Lake. It is described in some detail in a following section.

One mile south of Lynn Lake lies a small intrusive which contains Sherritt-Gordon's "El" orebody. The rock is very similar to that of the Lynn Lake intrusive.

Another large body of gabbro occurs approximately 4 miles south of Lynn Lake. It is surrounded by younger granite. In general it is similar to the Lynn Lake gabbro. Several other small basic intrusives are found in the area.

Granite and Related Rock

A large part of the area is underlain by intrusives ranging in composition from granite to diorite. The granites intrude the associated volcanics and sediments. Some bodies of granitic rock range in composition from granite to diorite. In general the central portion of the intrusive is a granite grading into more basic rock towards the margin.

To the north of Lynn Lake occurs an area underlain by a complex of gneiss, schist and granite. Some outcrops are granite containing inclusions of gneiss or schist; others are gneiss or schist cut by granite or pegmatite dikes. The complex is believed to represent a zone not far from the original top of the granite intrusive.

Porphyry and Felsite

Several bodies of porphyry and felsite occur in the area. Some of these appear to be older than most of the intrusive rocks. However numerous felsite and porphyry stringers are encountered in diamond drill holes in the gabbro. This indicates two groups of different ages but a complete classification has not yet been made.

The Lynn Lake Basic Intrusive

Hunter (19) classified the rocks of the Lynn Lake basic intrusive into three types of uraltite gabbro which differ in grain size, type of amphibole, and amount and composition of the feldspar. The three types are designated as phases 'A', 'B', and 'C' respectively (map in pocket). Phase 'A' gabbro forms the west portion of the basic intrusive. Phase 'B' lies in a belt bordering phase 'A' to the east, south, and possibly to the north. The remainder of the intrusive is phase 'C' gabbro.

Phase 'A' gabbro is a medium grained, dark green to greyish-green, more or less massive rock - composed principally of labradorite and actinolite. Two outcrops of norite are located near the mine shaft. A diamond drill hole across the 'A' ore body on the 5th level cuts

through 250 feet of mineralized norite. Occasional small amphibolite and anorthosite bands up to six inches wide occur parallel to the lineation. Phase 'B' gabbro contains more feldspar and is less altered than phase 'A'. Phase 'C' consists of a medium to fine grained massive greenish-black rock with a less basic feldspar and less fibrous amphibole than phases 'A' and 'B'.

Hunter points out that it is not possible to state definitely that all the uralite gabbro of phases 'A' and 'B' was derived from norite but similarity of amphibole derived from enstatite and augite, and the amphibole in the uralite gabbro suggests this origin for at least a portion of the gabbro. He believes that the alteration of the intrusive body was caused by thermal metamorphism accompanied by moderate hydrothermal activity. The grades of alteration in the intrusive indicate that the source of metamorphism lies to the north and east of the basic intrusive. Extensive areas of granite, shown by Allan (3) to be younger than the gabbro lie about a mile from the Lynn Lake intrusive in the above mentioned directions. They are the suggested cause of the uralitization of the Lynn Lake gabbro.

Hunter concludes that the three gabbro phases indicate differentiation into an acidic portion represented by phase 'C' and a more basic portion represented by phases 'A' and 'B' which were further differentiated into the more mafic phase 'A' and the more felsic phase 'B'. Combining the petrography with a study of the lineation of the silicates of the intrusive Hunter postulates the following stages in the history of the intrusive body:

1. Differentiation of a body of basic magma into three zones.

2. Intrusion of phase 'A' and phase 'B' gabbro, probably contemporaneously with differentiation taking place en situ.

3. Intrusion of phase 'C' gabbro, probably after consolidation of the phase 'A' and 'B'.

Location and Description of the Ore Bodies

The Lynn Lake nickel-copper deposits consist of five ore bodies. Four of these, the 'A', 'B', 'C' and 'E' occupy a narrow, irregular zone which lies in phase 'A', 400 to 800 feet from the contact of the intrusive body and roughly parallel to it. Their position and general outline are shown in the map in the pocket. The 'El' ore body is located in a small basic plug about 7000 feet south of the Lynn Lake intrusive. Its position is shown in figure 4. The ore bodies are covered by overburden; the 'B' ore body lies beneath Lynn Lake.

The ore bodies are roughly lenticular in plan and elongated parallel to the west contact of the intrusive. They range from 300 to 500 feet long, and from 60 to 250 feet wide. They are irregular in section but maintain approximately their same dimensions to a depth of 1000 feet which is the general limit of diamond drilling to date. They cannot be outlined accurately as sharp contacts between the ore and the surrounding rock are rare. The outer limits of the ore bodies will be determined largely by the cut-off grade of the ore, which is made up of massive and disseminated sulphides. In most places the ore grades from disseminated to massive to disseminated across the ore bodies which in most cases contain several centres of massive ore. The latter contains grains of silicates

throughout, which in some places gradually increase in quantity and the massive ore grades into disseminated ore. Figures 5, 6, 7, 8, are lateral sections of some of the ore bodies drawn up from diamond drill records and made available through the courtesy of Sherritt Gordon Mines Ltd. They indicate the size, shape and general nature of the deposits.

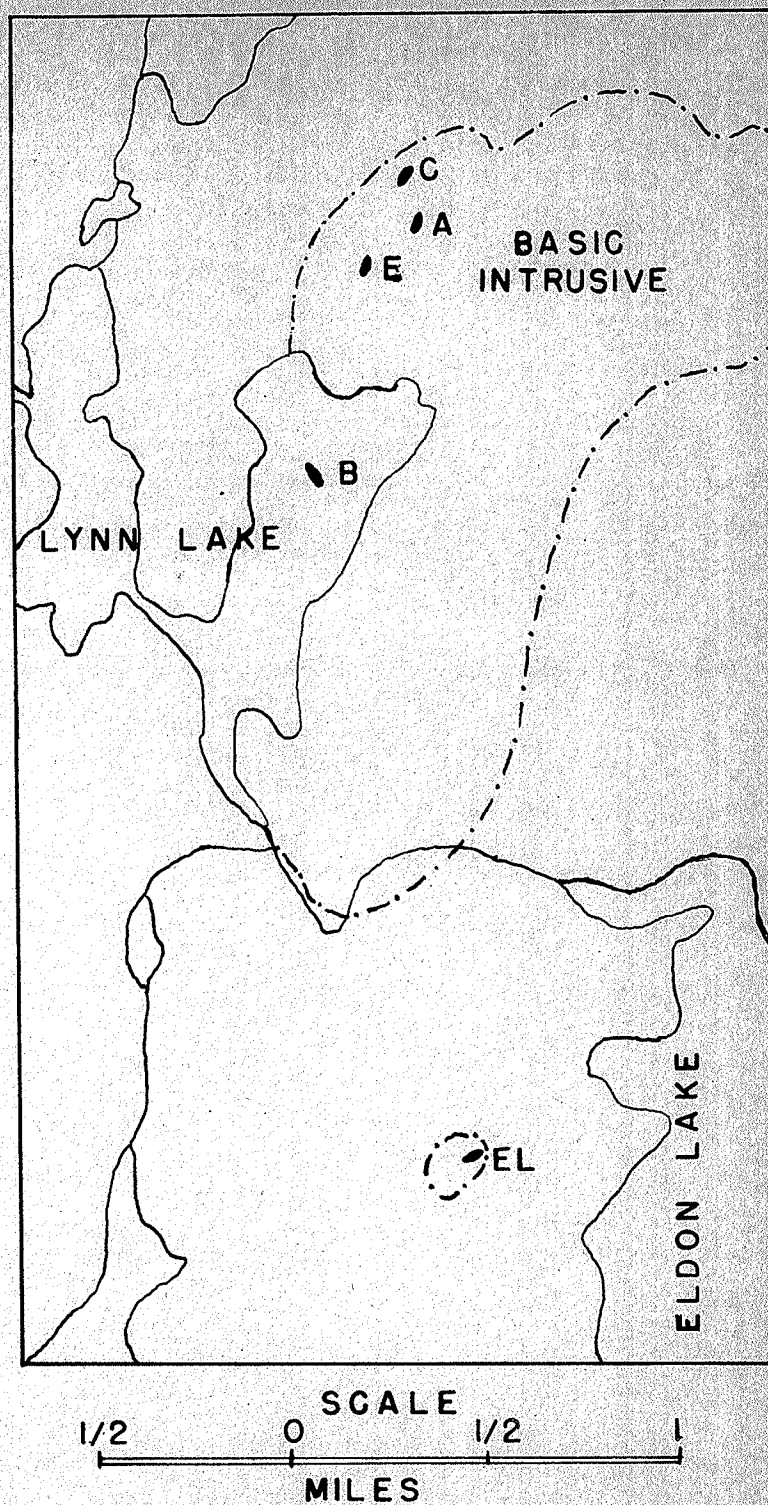


Figure 4. Approximate location of the nickel-copper ore bodies.
(Courtesy of J.D.Allan(2))

MINERALOGY OF THE ORE

Method of Study

Available for the laboratory investigations were diamond drill core and underground specimens obtained from exploration and development work carried out by Sherritt Gordon Mines Ltd. The specimens represented a minimum of one section at 20 foot intervals across each ore body. Samples from different depths in each ore body were available. In collecting the suites of ore, special care was taken by Sherritt-Gordon Mines Ltd. and H.E.Hunter to include not only a cross section of specimens from the ore bodies, but also several samples of the various types of ore encountered, such as mineralization associated with acid dikes, shear planes etc. A more detailed study of the upper 'A' ore body was possible because a cross section of specimens was available from the newly developed 1000 foot level. The suite of ore minerals included several samples from a barren pyrrhotite deposit in the vicinity of the ore bodies and specimens from the 'El' ore body representing ore at a depth of more than 2000 feet. The alteration of the ore under the influence of weathering was studied in specimens of drill core which had been exposed to the elements for five years. The location of all specimens was accurately indicated in drill plans and sections across the ore bodies made available through the courtesy of Sherritt-Gordon Mines Ltd.

Polished sections were made of representative samples of each ore body and ore type. The adjacent faces of saw cuts of many sections of drill core were mounted as polished sections and thin sections

respectively. This made it possible to examine both the opaque and non-opaque mineral relations in essentially the same section. Staining the polished sections facilitated the identification and study of the sulphides. The technique is described in a latter section.

The appearance and relations of the ore minerals noted in the examination of the polished sections are described below. These relations will be discussed in connections with observations and theories in the literature regarding similar sulphide deposits. Finally an attempt will be made to classify the ore deposits from the conclusions reached in the study.

General Megascopic Description

The Lynn Lake nickel-copper deposits consist of massive and disseminated sulphides in a gabbro intrusive. Pyrrhotite is the predominant mineral. Associated with it are pentlandite and chalcopyrite with minor amounts of magnetite, ilmenite, picotite, pyrite, and sphalerite. The sulphides vary from fine to coarse grained with sharp alteration of the two phases in some places. The nickel content of the fine grained pyrrhotite is generally lower than that of the coarse grained variety. The deposits of barren pyrrhotite in the basic intrusive are fine grained. However there are notable exceptions to this rule. The massive high grade ore of the upper 'A' ore body which assays up to 10% nickel is made up of fine grained sulphides.

Usually chalcopyrite is closely associated with pyrrhotite but in some places it is segregated in disseminated masses or forms a thin coating on surfaces of shear or fracture planes. For this reason the

nickel to copper ratio of the ore is not constant. In all occurrences pentlandite is intimately associated with pyrrhotite. It occurs as stringers through the latter mineral which may enlarge locally into small irregular masses. Some boundary zones have sharp contacts between massive sulphides and the enclosing gabbro or amphibolite. A band of pentlandite up to one quarter of an inch wide commonly marks the contact. Similar bands of pentlandite give some of the massive high grade ore a streaked appearance.

Magnetite

Magnetite occurs as subhedral to anhedral grains distributed throughout the host rock with no apparent relation to the ore deposits in which it is a minor constituent. Individual grains of magnetite are disseminated in the basic intrusive and, less frequently, in the sulphides.

When in contact with the sulphides, the magnetite is invaded or corroded by them. This is especially prominent in the case of chalcopyrite as the corrosion of the magnetite appears to be more advanced in contact with it than the other sulphides. A few small, isolated patches of magnetite were observed in the pyrrhotite. However, most magnetite grains are anhedral masses occupying the space between crystals of silicates. Small tongues of magnetite project between grains of feldspar and amphibole indicating that magnetite crystallized late.

Magnetite appears to be early in relation to the sulphides and late in relation to the silicates. It was not deposited with the

ore minerals but appears to have crystallized as a late accessory mineral from the original intrusive.

Ilmenite

The occurrence of ilmenite is similar to that of magnetite and it shows the same relations to the sulphides as the latter mineral. Many ilmenite grains are euhedral rod-like crystals, which in many cases have irregular, corroded edges in contact with silicate minerals. Anhedral ilmenite grains appear to be interstitial to the silicates, occupying spaces between the latter and curving around feldspar lathes.

Ilmenite appears to have started solidifying early, with crystallization continuing after solidification of the silicates so that a large portion of the ilmenite came down at the same time as the magnetite.

Picotite

Numerous grains of picotite or chrome-spinel were observed in a highly sheared border of a fine grained basic dike which was heavily mineralized with disseminated sulphides. When isolated for an X-ray powder photograph* it was found to constitute about 5% of the specimen. No other occurrence of picotite was noted in the ore deposits. It occurs in subhedral, roughly circular grains, many of which possess an ex-solution texture of small ilmenite rods oriented along octahedral planes. Irregular blebs of ilmenite in the picotite grains have a

* Courtesy of Dr. R. B. Ferguson

tendency to be aligned in a similar manner. Numerous islands of pyrrhotite are present in the picotite grains and appear to corrode the latter. Some islands have one straight edge, possibly against a cleavage plane. Many of the large blebs of pyrrhotite in the picotite have pentlandite associated with them. The borders of picotite grains are extensively corroded by pyrrhotite and chalcopyrite. Picotite therefore appears to be earlier than the sulphides. It also contains pits and corroded edges in contact with the silicate minerals. A thin section revealed that the silicates had been almost completely altered to biotite so that the relationship of picotite to the original silicate minerals is indeterminate.

Nickelian Cobaltite

A few sections of core taken from a diamond drill hole near the 'A' ore body contained small quantities of a disseminated silver-white sulphide. Microchemical analyses gave a strong nickel test and a cobalt test which was partially masked by the nickel. An X-ray powder picture* identified the mineral as cobaltite. Because of the strong nickel test it was classified as nickelian cobaltite. It was not observed in contact with other sulphides.

Pyrite

Pyrite is present in small quantities in most of the ore specimens examined. It occurs as grains up to one-eighth of an inch across, and as veinlets, stringers and areas of massive pyrite. Some grains

* Courtesy of Dr. R. B. Ferguson

are well developed and show cubic crystal faces. They are particularly abundant on mineralized surfaces of shear planes or fractures but also occur in mineralized acid dikes and in massive and disseminated phases of the ore. Corroded islands of pyrite are frequently observed in the pyrrhotite (Plate 1, figure 1). Pentlandite forms pits and carries in subhedral pyrite grains. Fractured pyrite grains with matching walls contain chalcopyrite as a fracture filling mineral (Plate 1, figure 2).

Most of the pyrite in the ore is in contact with pentlandite. Bands or streaks of the latter mineral seen in hand specimens along contacts or in the massive ore are found to be made up largely of pyrite when examined under the microscope. Pyrite-pentlandite intergrowths (Plate 1, figure 4) are common in the pentlandite bands. They consist of a fine lace-like network of pyrite and pentlandite which grades into massive pyrite in one direction and massive pentlandite in the other. Stringers of pyrite cut the network. Pyrite often occurs as veinlets or partial rims around pyrrhotite grains with a few corroded remnants of pentlandite in contact with the pyrrhotite. Stringers of pyrite cut through pyrrhotite, pentlandite, and chalcopyrite (Plate 1, figure 3). In some specimens there is massive replacement of pyrrhotite in which grains of the latter mineral are completely replaced by pyrite which advances in needle-like projections along cleavage planes. The initial stage of this process is observed in many places as long narrow blades of pyrite in contact with the gangue minerals or the walls of a fracture and advancing along cleavage planes in the pyrrhotite.

The relationships described above suggest that two ages of pyrite are present. The well developed grains appear to be early whereas the relationships of the stringers, veinlets and masses of pyrite indicate that it is the latest mineral of the sulphide deposits. These relationships will be discussed in a later section.

J.D.Allan (2), in his study of the Lynn Lake area, sent a sample of pyrite to Dr.F.G.Smith of the University of Toronto. Dr. Smith tested it on the "pyrite geo-thermometer" (37) which indicated a temperature of deposition of 470°C .

Pyrrhotite

Pyrrhotite is the predominant mineral of the ore deposits. It varies from strongly magnetic to non-magnetic. In polished section the individual grains are not visible but under crossed nicols the various sizes and orientations of the grains are clearly seen owing to strong anisotropism. The grains are irregular in form and interlock, or are bordered by pentlandite and chalcopyrite. In some grains the 0001 parting is visible.

Pyrrhotite corrodes and penetrates the silicate minerals, especially along cleavage planes, often displacing cleavage fragments. Isolated islands of pyrrhotite often occur in silicate grains. In many specimens pyrrhotite contains corroded islands of magnetite and pyrite.

Staining for five minutes with the solution used to stain pentlandite brings out the structure of the pyrrhotite grains. The staining technique is described in a later section. In some specimens

twinning is present as wide straight edged bands or lens shaped lamellae which extinguish in different directions under crossed nicols.

Many pyrrhotite grains are not homogeneous but are composed of two phases, one as partial rims, lenses or lamellae in the other. The two phases may be distinguished in some well polished sections due to a slight difference in hardness. Different orientation of the lamellae serves to distinguish them under crossed nicols. They are also brought out by staining as mentioned above. The lamellae vary from regular and linear to irregular and flame-like. They tend to be concentrated at the margins of grains or around inclusions and are parallel to the direction of the 0001 parting of the grain.

Strongly magnetic and non-magnetic pyrrhotite separated in the course of the investigation of the heavy accessory minerals were mounted in bakelite as polished sections. Examination before and after staining failed to reveal any apparent cause for the variation in magnetic properties.

Pentlandite

Pentlandite was observed in all ore specimens examined except mineralized quartz veins. All occurrences of pentlandite are closely associated with pyrrhotite. Small patches or grains of the former mineral are in contact with the outer boundaries of masses of disseminated pyrrhotite. In contact with silicates it corrodes and replaces them. Pentlandite forms irregular masses which taper into stringers or a partial network structure, or die out as a flame-like structure in massive pyrrhotite (Plate 11, figure 1). The pentlandite

stringers differ from ordinary veinlets in that they are not straight but are gently curved and taper out to a sharp point in massive pyrrhotite. Under crossed nicols the pentlandite stringers are observed to be between pyrrhotite grains and do not invade them (Plate 11, figure 2). In some places rims of pentlandite around pyrrhotite grains form a network structure. In some of the massive sulphides or along sharp sulphide host rock contacts, pentlandite is concentrated into wide bands adjacent to which the pyrrhotite is barren. Many pyrrhotite grains, especially in the massive ore, contain tiny blades, lenses, or flames of pentlandite which are isolated in the grains or project into them from an included remnant of a silicate mineral or boundaries of the grain. These forms are usually parallel to each other, often occurring along a barely visible line which is believed to be a crystallographic direction of the pyrrhotite grain which contains them (Plate 11, figures 3 and 4).

Most boundaries between pyrrhotite and pentlandite are smooth with no evidence of replacement. However, some of the contacts of wide stringers, or irregular masses of pentlandite with the pyrrhotite tend to be irregular. In some specimens small patches or islands of pyrrhotite occur in the pentlandite. Most of them tend to be circular but a few are irregular in shape. The cleavage of some of the islands of pyrrhotite has the same orientation as the cleavage of the pyrrhotite grain immediately adjoining it across the surrounding pentlandite. This strongly suggests some replacement of pyrrhotite by pentlandite.

Pentlandite is distinguished from pyrrhotite by a lighter color

and a strong octahedral parting. In specimens with an even polish, the color difference between pyrrhotite and pentlandite, although distinguishable, is not great. Under these circumstances the relationship between the two minerals is observed with difficulty. Many minor occurrences of pentlandite are missed entirely. This difficulty was overcome by staining. The method of "Selective Tri-descent Filming" developed by A.M. Gaudin (12) was found satisfactory. For filming the sulphides, a hydrochloric acid-chromic oxide-water solution is used. It is prepared by mixing together 2.5 gms. CrO_3 , 20 ml. 12 N HCl, and enough water to make up 100 ml. of solution which is allowed to age half an hour before use.

The following technique was used for staining: The specimens were rinsed in a thin stream of alcohol to remove any oil from the surface. They were then placed face upwards in a beaker and covered with staining solution. They were allowed to remain in the solution at room temperature for five minutes, immediately rinsed in running water and dried in an air blast. Pentlandite appears bright blue, pyrrhotite is stained to a bronze color. The colors of pyrite and chalcopyrite are not affected. Pentlandite films at the same rate regardless of the orientation of the grains. The mineral relations are brought out clearly by this method of staining and many features such as fine intergrowths, barely visible before filming, become distinct.

Chalcopyrite

Chalcopyrite occurs as small irregular patches in other sulphides,

large segregated masses, or surface coatings on some fracture planes of the basic intrusive in the vicinity of the ore bodies. It is more abundant in the disseminated sulphides than in the massive ore. It is weakly anisotropic under polarized light.

Chalcopyrite cross-cuts and embays oxides, silicates and other sulphides except sphalerite and late pyrite. In the disseminated ore the most common occurrence of chalcopyrite is in fine particles in contact with the outer borders of pyrrhotite disseminations. The chalcopyrite-pyrrhotite boundaries in most places vary from mutual to broad, shallow embayments of chalcopyrite in pyrrhotite. Chalcopyrite stringers project between grains of pyrrhotite but some cut across grain boundaries or penetrate the latter mineral as a straight edged veinlet indicating possible control by the cleavage of the pyrrhotite grain. Corroded islands of pyrrhotite are found within chalcopyrite. Many boundaries of the latter mineral with pentlandite are mutual and give no indication of the relative ages of the two minerals. Some contacts consist of wide, gentle embayments of chalcopyrite in pentlandite. Corroded islands of pentlandite occur in the chalcopyrite. In some specimens stringers of chalcopyrite cut pentlandite.

The structure of chalcopyrite is revealed by etching for twenty seconds with a solution made up of 2.5 cc concentrated HNO_3 , 4 cc concentrated HCl , 10cc H_2O and a small quantity of KClO_3 (33, p.348).

Etching indicated that some of the chalcopyrite contained multiple twinning which were made up of two intersecting sets of twin lamellae in some places. The twinning was also visible under crossed nicols. The chalcopyrite grains are irregular and vary in size from

coarse to fine grained. No cubanite was observed in the chalcopyrite.

A grey mineral occurring as long, thin oriented rods or short stringers with irregular boundaries were observed in some specimens of chalcopyrite. The rods are oriented in two directions approximately at right angles to each other. They cross the grain boundaries of the chalcopyrite. They are extremely small and are best observed under an oil immersion lens. Not enough physical properties could be obtained to identify the mineral.

Sphalerite

Traces of sphalerite were observed in some specimens associated with large concentrations of chalcopyrite. It occurs in small rounded blebs in chalcopyrite and as small particles in contact with grains of the latter mineral. In a few places there is a slight indication of sphalerite corroding chalcopyrite but along most contacts the two minerals form mutual boundaries. A few small corroded islands of silicate minerals and pyrrhotite were observed in blebs of sphalerite. Contacts of the latter mineral with other sulphides were not seen. In the barren pyrrhotite, sphalerite is more abundant than in the ore deposits and is not as closely associated with chalcopyrite. Traces of sphalerite were observed in some mineralized stringers of quartz and feldspar porphyry in which it is present near the sulphides as small islands in the gangue minerals which it corrodes.

Violerite

Violerite was observed in a few specimens and was confined to

pentlandite in all occurrences. It is present in some specimens of mineralized coarse grained amphibolite and some highly sheared mineralized zones to a maximum depth of 400 feet. Violerite occurs as a dull purplish stain in fractured areas of pentlandite masses. Although it is not completely confined to the fractures, the quantity of the mineral present is proportional to the amount of fracturing of the pentlandite, and appears to be an alteration product of the latter mineral. Most violerite patterns in pentlandite are irregular and appear to be controlled principally by fractures in the latter mineral. However, occasional regular triangular patterns and parallel straight bands across pentlandite masses suggest alteration along crystallographic planes of the pentlandite grains.

Violerite is limited both in extent of distribution and the number of occurrences. It is best studied under an oil immersion lens. Specimens of drill core that have been exposed to weathering for five years show a more extensive development of violerite than more recent drill core specimens from zones in the ore bodies favorable for its formation.

Paragenesis

The observations noted above indicate the following paragenesis for the ore deposits. Magnetite and ilmenite are distributed through the ore and host rock and were probably formed during crystallization of the basic magma. Ilmenite began to form early but finished crystallizing with magnetite after the silicates had completely solidified. Picotite appears to be an accessory mineral associated with a

basic dike. It is earlier than the sulphides and secondary silicate minerals.

The ore deposits were formed subsequent to the solidification of the gabbro host rock. The sulphide minerals appear to have formed at approximately the same time with some overlapping deposition. Pyrite was the first mineral to form as euhedral to subhedral crystals, followed by pyrrhotite and pentlandite. Pentlandite is later than pyrrhotite. Chalcopyrite formed later than the above sulphides although there are indications of slight overlapping deposition with pentlandite. Sphalerite was deposited later than the chalcopyrite. Pyrite in the form of large irregular masses or stringers appears to be later than all the other sulphides. Violentite is an alteration product of pentlandite due to weathering of the latter mineral. The relationship of nickelian cobaltite to the other sulphides is not known.

DISCUSSION OF MINERAL RELATIONS

In the previous section the mineral relations observed in specimens from the Lynn Lake deposits were described and a simple paragenesis was postulated. These relations will now be discussed more fully in connection with observations and theories presented by several authors regarding similar relationships in the same type of sulphide deposits, which have been the subject of much discussion and disagreement.

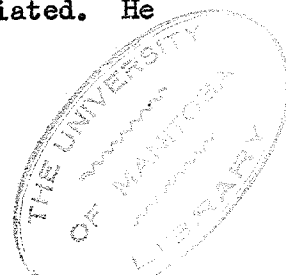
Pyrite

The description of pyrite in the previous section indicates two ages of deposition in the Lynn Lake ores. It appears to be the first sulphide surrounded and corroded by later sulphides, and also the last sulphide replacing and veining pyrrhotite, pentlandite and chalcopyrite.

Cameron (8, p.671) described euhedral to subhedral pyrite grains in pyrrhotite, and pyrite veinlets obviously younger than chalcopyrite in the nickel deposits of Prospect Hill, Connecticut.

Tolman and Rogers (39, p.33) came to the conclusion that late pyrite veins cut all the sulphides in ore specimens from Sudbury and Norway. They believed that euhedral pyrite in some of the deposits was of the same age as the veins, and all the pyrite was therefore post-ore in age.

Schwartz (35) studied pyrrhotite from 86 occurrences, describing its relations to the other sulphides. The Lynn Lake deposits would belong to his group in which pyrite and pyrrhotite are associated. He



pointed out (p.31) that although one might logically expect pyrite to form later than pyrrhotite when the two are associated, descriptions of most deposits of this type indicate that pyrite is the earlier in origin. Pyrrhotite ore from Fierro, New Mexico contains pyrite which occurs as early subhedral crystals partly replaced by pyrrhotite, and less commonly as veinlets of pyrite that cut all other minerals, suggesting two generations. He noted that a similar relationship prevails in some specimens from pyrrhotite veins in the Homestake mine. He describes ore from the Potosi claim, Santa Elulua, Mexico, which contains two generations of pyrite, the latest generation of which is considered to be supergene.

Paige (30, p.29) also studied the ores of the Homestake mine. He described veinlets of pyrite later than the pyrrhotite cutting pyrite grains of the first generation.

Graton (13, p.89) described pyrite veinlets in chalcopyrite at Bisbee. He believed that the pyrite was earlier than the chalcopyrite and explained the paragenesis of the two minerals as follows: Pyrite replacing the country rock along veinlets was overtaken by chalcopyrite which in places completely replaced the country rock that formed the walls of the pyrite veinlets, thus completely surrounding the pyrite. Since pyrite and chalcopyrite had originated from a common source and one followed the other closely they were reasonably well in equilibrium with each other or with the solutions from which they were deposited. The appearance within the chalcopyrite portion strongly suggested that younger veinlets of pyrite cut through chalcopyrite, but when studied in relation to the country rock, where this remained,

the process described above was indicated. Graton terms this relationship "Antecedant Veining".

The foregoing review of literature suggests three possible explanations for the occurrence of pyrite in the Lynn Lake ore deposits: (1) The pyrite may all be early. Veinlets and other occurrences of apparently late pyrite may be explained by antecedant veining or a subsequent redistribution of the pyrite. (2) All the pyrite may be late. (3) There are two generations of pyrite.

The writer cannot visualize the process of antecedant veining described by Graton (13, p.89) as a controlling process in the formation of disseminated ore which makes up the principal part of the ore deposits. Antecedant veining also does not satisfactorily explain the consistent and abundant association of pyrite with pentlandite in the most common occurrence of the latter mineral as bands and stringers or networks around pyrrhotite grains. The formation of the extensive fine intergrowths of pentlandite and pyrite by antecedant veining appears highly improbable. There is no evidence to indicate or support a subsequent redistribution of early pyrite to a greater extent than the other sulphides.

The possibility that all pyrite is late is not feasible in view of the evidence of early pyrite such as euhedral to subhedral grains of this mineral corroded by the other sulphides, or chalcopyrite filling fractures in pyrite grains as previously described.

Further study may reveal additional evidence to support other theories, but present observations indicate an early generation and a late generation of pyrite in the Lynn Lake ore deposits.

Pyrrhotite

In pyrrhotite of the Lynn Lake ore no apparent connection was observed between the magnetic properties and the two phases of the mineral. According to Michener (25) the magnetic properties of pyrrhotite are controlled by the sulphur content which varies from $\text{Fe S}_{1.10}$ to $\text{Fe S}_{1.17}$. At the composition $\text{Fe S}_{1.135}$ the mineral becomes ferromagnetic.

Twinning in pyrrhotite was encountered and discussed by several observers. Scholtz (34) showed that twinned pyrrhotite in the Insizwa deposits was confined to narrow brecciated zones along the contact of the intrusive and the country rock. Schneiderhohn (33) believes twinning in pyrrhotite is rare and unimportant and any such translation can almost invariably be attributed to stress.

Non-homogeneous pyrrhotite was described by Cameron (8) in ore from Prospect Hill, Connecticut. Van der Veen (40) describes and illustrates similar inhomogeneous pyrrhotite from Norway. He believes that the structure represents exsolution due to some sort of transformation dependant upon the temperature and the ratio of iron to sulphur in the pyrrhotite. Schneiderhohn (ref. Van der Veen; 40) had previously attributed this structure to twinning. Ramdohr (ref. Van der Veen; 40) suggested that the lamellae were formed by segregation of FeS from a sulphur-rich iron sulphide.

In his detailed description of the Insizwa ore deposits Scholtz (34, p.151) distinguished the two phases of the inhomogeneous pyrrhotite as α -pyrrhotite and β -pyrrhotite; α -pyrrhotite being the principal component forming the matrix and β -pyrrhotite the minor component

forming the lamellae. He showed that the physical properties of the two components were slightly different. α -pyrrhotite was slightly harder and showed different interference colors under crossed nicols than β -pyrrhotite. On a polished surface the lamellae may be regular and linear, sinuous and lenticular, or irregular and flame-like, and may vary considerably in thickness. The lamellae are parallel to the 0001 parting and appear to be lenticular bodies flattened in that direction. Where lamellae intersect they thin out at the contact. They tend to be concentrated around inclusions and at the margin of grains. Scholtz observed that the "flames" of secondary pentlandite appeared to be almost invariably confined to the β -phase, and from this suggested a double exsolution process by which, at a high temperature, any nickel in the pyrrhotite induced the separation of the β -component, and with further cooling the β -component became unstable and exsolution of pentlandite took place. He believed that the β -pyrrhotite probably still contains some nickel in solid solution. Microchemical tests indicated the presence of nickel but were considered inconclusive.

Chalcopyrite

N.W. Buerger and M.J. Buerger (7) found and described twinning in chalcopyrite from Pike Hill Mine, Corinth, Vermont. They described two types of twin lamellae and designated them as grid twins and echelon twins. They determined that the grid and the polysynthetic echelon twinning lamellae are along the sphenoid (111) planes. They believe both types of twinning are secondary, caused by plastic

deformation and suggest that the exsolution of cubanite from chalcopyrite may have been the cause of the stresses which produced the twinning.

It was noted in a previous section that some chalcopyrite occurred as large segregated masses or surface coatings on fracture planes of the basic intrusive in the vicinity of the ore bodies. Regarding similar occurrences in the Insizwa deposits Scholtz (34,p.206) believes the ore separated from the magma as a mass and began to cool.

"After the crystallization of the pyrrhotite and some pentlandite in the larger accumulations of ore, these sulphides appear to have existed in a state of unstable equilibrium with the still liquid copper-rich residuum. The squeezing out of such copper-rich residues, or their migration in directions of reduced pressure under their own inherent intrusive power, owing to high vapour pressure, would result in the formation of ore bodies greatly enriched in chalcopyrite".

Pyrrhotite-Pentlandite Relations

A voluminous literature is available on pyrrhotite-pentlandite-chalcopyrite deposits in various parts of the world. Many explanations of the observed mineral relations have been suggested which indicates a great divergence of opinion among observers.

Buddington (6) studied pyrrhotitic ores from Alaskan mineral deposits and concluded that pentlandite was part contemporaneous with pyrrhotite and in part crystallized later than pyrrhotite. Kerr (21) concluded that pentlandite cut pyrrhotite in Alaskan mineral deposits. Lindgren and Davy (24) concluded that pentlandite had followed and replaced chalcopyrite and pyrite in the ore from the Key West mine Nevada.

Campbell and Knight (9), who were among the earliest investigators of the Sudbury deposits, concluded that all the pentlandite was later than the pyrrhotite. Wandke and Hoffman (43,p.186) shared a similar view. Tolman and Rogers (39) concluded that the sulphides of the Sudbury ores were deposited one after the other in the order pyrrhotite, pentlandite, chalcopyrite, the later minerals replacing the earlier indicating deposition by mineralizing solutions. They interpreted the minor flame-like inclusions of pentlandite within the pyrrhotite as second generation pentlandite due to a minor late rearrangement of the sulphides.

Howe (17) put forward an explanation which marked the trend of many subsequent hypotheses. He concluded that the pyrrhotite-pentlandite relationships of the Sudbury ore deposits were better explained by the nearly simultaneous cooling of the different sulphides that had previously separated as distinct mineral compounds, non-miscible, though still molten.

Scholtz (34) believed in simultaneous cooling of the sulphides. He postulates that a condition of limited miscibility set in at the freezing point of pyrrhotite, so that most of the nickel separated in the form of pentlandite more or less contemporaneously with the pyrrhotite, which held a certain amount of nickel in solid solution. This nickel later exsolved as pentlandite on further cooling. He concludes that although both minerals appear to have separated more or less simultaneously, pentlandite continued to crystallize after the pyrrhotite had completely precipitated.

Van der Veen (40) examined Sudbury ores and concluded that

pentlandite had existed in solid solution in pyrrhotite but that during slow cooling had almost completely segregated into rims around the pyrrhotite grains. He compares this texture to network textures of metals in which two phases separate by exsolution in the solid state. He goes on to say that if the temperature drop is too rapid, part of the new phase will be prevented from gathering in the network on the boundaries and will crystallize within the grains along crystallographic, cleavage or twin planes, forming a crystallographic texture. This explains the origin of the flakes, flames, or blade-like inclusions of pentlandite in pyrrhotite. Van der Veen concludes that pentlandite and pyrrhotite seem to separate in the solid state at a relatively high temperature at which diffusion is rapid so that generally complete separation takes place.

Several authors discuss the problem of whether or not nickel is retained in solid solution in pyrrhotite at low temperatures. Dickson (11) found that by repeated finer grinding and magnetic separation, the nickel content as determined by chemical analysis continued to decrease. From this he concluded that all the nickel in pyrrhotite is present as fine exsolution pentlandite.

Newhouse (27) conducted a series of experiments with sulphide melts. He constructed an equilibrium diagram and produced minerals and textures similar to natural occurrences of pyrrhotite and pentlandite. He showed that with rapid cooling pyrrhotite could retain 13% Ni in solid solution. Solid solutions containing more than 13% Ni broke down into pyrrhotite and pentlandite on cooling. He believes that in slow cooling in nature probably all the nickel would be exsolved as pentlandite. Newhouse noted that the network texture of Sudbury ore is far

from perfect and varies considerably in appearance from metallographic exsolution textures. He found some evidence of liquid immiscibility in melts with high nickel content and proposed that in the presence of other substances such as water and sulphur, liquid immiscibility of pyrrhotite and pentlandite might be extended into the range of nickel content of natural ores. He concludes that pentlandite formed later than pyrrhotite, but was introduced into the ore deposits at the same time since there is no evidence of replacement of pyrrhotite by pentlandite, and that during cooling the two sulphides separated as immiscible liquids. He believed that the early formed pyrrhotite crystals may have existed in a pentlandite liquid until the temperature dropped to about 870°C when pentlandite would start to crystallize. The small blebs of pentlandite within pyrrhotite crystals in ores are similar to exsolution pentlandite formed by the breakdown of solid solutions prepared in the laboratory.

Hewitt (16) performed a series of heating experiments on Sudbury ore using Newhouse's equilibrium diagram as a basis for his study. He determined that the pentlandite stringers around pyrrhotite grains went entirely into solid solution in pyrrhotite between 425°C and 450°C and assumed that temperature was probably close to the unmixing temperatures. By slow cooling from 800°C pentlandite exsolved again, forming rims around pyrrhotite grains. These results agree rather well with Newhouse's determinations of the solubility of pentlandite in pyrrhotite. Hewitt also observed that the unmixed pentlandite contained oriented lathes of pyrrhotite visible at high magnification, a relation which is rarely noted in natural material. Hewitt concluded that small pentlandite grains around pyrrhotite, and lenses within pyrrhotite grains are

products of unmixing, but that the larger masses of pentlandite are probably produced from a field of immiscible liquids.

Hawley, Colgrove and Zurrbrigg (15) determined the equilibrium diagram in part for the Fe-Ni-S system. They point out that their experiments have a bearing only on ores formed from melts. An experiment to test Newhouse's theory of immiscibility for iron and nickel sulphides yielded negative results and from it they conclude that all cooling curve data can be interpreted as indicating a peritectic reaction between early crystals of FeS and a nickel rich liquid to form pentlandite as an end member of a solid solution series at about 870°C . Thus in a cooling ore melt, pyrrhotite crystals will first appear, the liquid will become progressively richer in nickel as the temperature decreases, and at the temperature of the peritectic reaction the remaining nickel-rich liquid will react with some of the pyrrhotite giving rise to pentlandite, which could fill in around the pyrrhotite and so show later age relations. Their experiments showed that under certain circumstances the early crystals of pyrrhotite would float in the residual liquid, reaction would be incomplete, and crystallization differentiation could take place so that the separated liquid might yield pure pentlandite. In no case could pyrrhotite form later than pentlandite from the same melt. As the mixture of pyrrhotite and pentlandite crystals cools further, pyrrhotite can contain less nickel, and pentlandite is exsolved. Similarly pyrrhotite may be exsolved in the pentlandite crystals. In an exceptionally rich pentlandite ore the observers found a natural pyrrhotite solid solution containing 1.88% Ni, thus opposing the idea that all pyrrhotites will completely

exsolve nickel as pentlandite under natural cooling conditions. They recognized that higher percentages of sulphur may change the manner of crystallization, but they believed that the results obtained would explain some of the textural relations shown by natural pyrrhotite and pentlandite.

With regard to the Lynn Lake ores, Allan (2,p.95) believes that the observed pyrrhotite-pentlandite relationships indicate that the ratio of pentlandite to pyrrhotite in the ore is not constant, that pentlandite was deposited independantly of pyrrhotite, and that there was some replacement of pyrrhotite by pentlandite.

Allan (2,p.104) lists the following observations from his experimental work on the Lynn Lake ore:

1. Pentlandite does not form a true network texture around pyrrhotite as would be expected if it formed by exsolution.
2. Most pyrrhotite-pentlandite boundaries are smooth, but some show embayments suggesting replacement of pyrrhotite by pentlandite. Also small crystals of pyrrhotite occur within larger masses of pentlandite.
3. Some crystals of pyrrhotite are not in contact with any pentlandite and some pentlandite in silicates is not in contact with any pyrrhotite.
4. The ratio of pentlandite to pyrrhotite in the ore varies considerably.

Allan argues that his observations seem sufficient to indicate that the pentlandite formed in some other way than by exsolution from pyrrhotite solid solution. The small pentlandite structures within

pyrrhotite are believed to be the result of exsolution in the solid state. He believes that primary pentlandite must have been deposited at a temperature below that at which it would be taken into solid solution in pyrrhotite. He states that if the above conclusions are correct then there is considerable doubt that the pyrrhotite-pentlandite relations seen in the Lynn Lake ore are the result of deposition from a melt. It seems easier to conceive that the sulphides were deposited from solutions, at temperatures considerably below their melting points. Pyrrhotite containing a small amount of nickel in solid solution was the first to form. At much the same time pentlandite was deposited, but it was somewhat later as it is more or less interstitial to the pyrrhotite and replaces it to some extent. During the cooling a small amount of secondary pentlandite was formed by exsolution of the pyrrhotite.

The writer agrees with Allan's observations with one slight modification. Allan notes that some pentlandite in silicates is not in contact with any pyrrhotite. Although the observation is true this form of occurrence is rare. If we take into consideration the fact that mineral relationships are studied in a plane surface with the third dimension obscured, this relationship is further reduced in importance so that it is no longer a reliable diagnostic feature.

To the above listed observations the writer wishes to add his own as follows:

1. In the massive sulphides pentlandite forms many irregular masses which taper into a stringer or partial network structure, or die out as a flame-like structure in massive pyrrhotite. The stringers

lie between pyrrhotite grains and do not invade them.

2. Along many sharp contacts of massive sulphides and wall rock a band of massive pentlandite up to one quarter of an inch wide occurs.

3. In the massive sulphides of the 'A' ore body, bands or streaks of pentlandite ranging up to one quarter of an inch wide are abundant in the ore. The massive pyrrhotite between these bands or for an appreciable distance on either side of the latter may contain a few traces of pentlandite but is usually barren.

The writer believes that the irregular masses of pentlandite in pyrrhotite may contain some primary pentlandite, but they are also partially made up of pentlandite exsolved from pyrrhotite. This is indicated by the irregular masses tapering into a stringer or partial network structure, or dying out as a flame-like structure in the massive pyrrhotite. The stringer or partial network structure of pentlandite is strongly suggestive of an exsolution texture. It is generally accepted by most observers that the flame-like structures previously described are due to exsolution. The bands and streaks of pentlandite are produced by exsolution from pyrrhotite at a relatively high temperature at which diffusion would be rapid. Because of its position near the middle of the ore body the massive ore would cool slowly, thus favoring more complete segregation of both exsolved and primary pentlandite. The barren pyrrhotite on either side of the pentlandite bands indicates segregation. This process would also explain the variation of the pyrrhotite-pentlandite ratio for the ore.

Evidence indicating replacement of pyrrhotite by pentlandite will be discussed in a later section pending a description of the ore

types and a discussion of sulphide-silicate relationships. The latter feature is most prominent in shear zones where there is evidence of deposition from hydrothermal solutions.

In a previous section observations were listed indicating that chalcopyrite was in part deposited contemporaneously with the pentlandite. The writer believes that if the above evidence and conclusions are correct they indicate that the sulphides were deposited more or less as a mass and began to cool simultaneously.

Violerite

Violerite is considered as an alteration product of pentlandite. Since its principal occurrence was in highly sheared zones in which its development was very limited, in comparison to drill core weathered for five years, it appears to be caused by weathering of the pentlandite.

Michener and Yates (26) studied drill core of primary sulphides exposed and weathered at the surface for at least 25 years. They noted that the first sign of alteration in the core is the development of violerite along cleavage cracks in the pentlandite and that violerite always formed within the limits of the pentlandite grains. Towards the completion of this stage the pyrrhotite begins to develop cracks in which limonite is deposited. These gradually widen. At this point the pentlandite is all replaced by violerite which starts to leach out.

The oldest drill core from Lynn Lake, after five years of weathering was still well within the first stage of alteration described by Michener and Yates. As development of the Lynn Lake deposits progresses it would be of interest to determine the maximum depth in the shear zones at which traces of violerite are found. The deepest occurrence observed by the writer was 400 feet.

ORE TYPES

Several varieties of ore are present in the Lynn Lake deposits. All types have megascopic features in common. Pyrrhotite and chalcopyrite are visible where present. Veinlets or grains of pentlandite can rarely be recognized on a broken surface but can be distinguished on the relatively smooth side of drill core by its lighter color and stronger parting. Bands or streaks of pentlandite in the massive ore are readily distinguished while pyrite occurring in these bands is finely distributed and difficult to observe being partially masked by pentlandite. The paragenesis and mineral relationships of the sulphides are similar in all occurrences with certain features more pronounced in some types than in others. Gangue minerals such as carbonate, quartz, and sphene are associated with some occurrences of the ore minerals. Several varieties of ore are recognized as follows:

1. Massive ore.
2. Siliceous ore.
3. Disseminated ore.
4. Sulphides associated with dikes and stringers.
5. Sulphides associated with fractures and shear zones.

Massive Ore

The massive ore is composed of sulphides varying from fine to coarse grained with sharp alteration of the two phases in some places. Traces of silicate minerals and carbonate are present which in some places increase in quantity so that the massive ore grades into disseminated ore. In the medium to coarse grained ore the sulphides vary

from subhedral to anhedral interlocking grains. Concentrations of pentlandite in the fine grained ore give the specimens a streaked or banded appearance. The predominant mineral is pyrrhotite with minor pentlandite and pyrite. The massive sulphides have a low chalcopyrite content.

Siliceous Ore

Siliceous ore was encountered on the 1000 foot level of the 'A' ore body where it appears to occur as fragments in massive ore. It is made up of fine grained silicates containing a heavy dissemination of sulphides in minute specks. The predominant sulphide is pyrrhotite with minor pentlandite and chalcopyrite. In some specimens chalcopyrite is segregated in broad disseminated masses.

Fine grained quartz is the principal silicate mineral with minor carbonate and sphene. The sulphides occur in blebs interstitial to the quartz which it corrodes to a limited extent. Many blebs of sulphide are completely surrounded by carbonate. In some places sulphides spread along the outer boundaries of the latter mineral. Small islands of carbonate occur in the sulphides.

Quartz and sphene are the earliest minerals followed by carbonate and finally sulphides. No strain shadows were observed in quartz.

Disseminated Ore

The most abundant ore type in the Lynn Lake deposits consists of sulphides disseminated in uralite gabbro and amphibolite. Disseminated sulphides grade into massive ore towards the centre of the

ore body and into barren rock towards the margin, the boundary of the ore body being determined by the cut-off grade. Numerous small sulphide stringers are associated with the disseminated ore.

Many large blebs of sulphides in uralite gabbro have a few grains of quartz associated with them. Some blebs are partially or completely surrounded by a wide rim of brown biotite (Plate III, figure 2). In many specimens the sulphides penetrate the biotite rims along cleavage planes. All biotite in the basic rocks is not associated with sulphides, but in many places forms as an alteration product of hornblende. Some blebs of sulphide have partial rims or grains of carbonate or sphene associated with them.

Sulphides replace all silicates of the uralite gabbro to a greater or less degree. They corrode feldspar to a limited extent. They fray the ends of amphibole needles, corrode the grains, displace the cleavage fragments, and penetrate the grains along cleavage planes (Plate III, figure 3). They intrude enstatite and augite. In some places sulphides appear to be more or less interstitial to the silicates and in others appear to replace the silicates (Plate III, figure 1). In some specimens containing abundant feldspar which is only slightly replaced, or in specimens containing broad disseminated masses of chalcopyrite which does not attack the silicates to the same extent as pyrrhotite, the sulphides are interstitial. The sulphides in norite specimens are interstitial to the silicates. Hunter (19) noted that in the less altered phases of the gabbro, sulphides are interstitial to the silicates. The amount of penetration and replacement of the silicates by the sulphides increases with the amount of alteration of the silicates.

Sulphides Associated with Dikes and Stringers

Minor dikes and stringers associated with the ore bodies are generally mineralized. The composition of the stringers vary from acidic pegmatite and felsite to more basic feldspar porphyry and amphibolite. The dikes vary from thin, sharply defined stringers to broad areas of dike material with gradational boundaries which in some places partially assimilate the intruded rock. The relationship of the sulphide minerals are similar to those of the other ore types except for quartz veins which do not carry pentlandite.

Small stringers of sulphides run through the quartz veins, following around the grain boundaries. The edges of quartz grains in contact with sulphides are irregular, and in many places small corroded islands of quartz occur in the sulphides. In some specimens the edges of the quartz grains are crushed, with isolated blebs of sulphides disseminated in the crushed zones. Quartz is not crushed along sulphide veinlets but many grains show wavy extinction indicating strain (Plate IV, figure 1).

The mineralized pegmatite consists principally of orthoclase and contains a fracture system indicated by a more or less regular pattern of narrow amphibole veinlets. The sulphides form irregular disseminations and small stringers in the orthoclase with no apparent control by the fracture system, and replace both orthoclase and amphibole. The orthoclase is heavily kaolinized indicating deposition of the sulphides by hydrothermal solutions (Plate IV, figure 4).

Many irregular, mineralized felsitic zones have poorly defined

boundaries with the enclosing rock. They are made up of quartz and carbonate penetrating uralite gabbro. The carbonates are coarse grained and have polysynthetic twinning. Many quartz grains show strained extinction. In some specimens the gabbro is crushed along the margin of the veinlets. The sulphides form stringers through quartz and carbonate or are disseminated in the crushed zones. They replace carbonates and silicates (Plate IV, figure 3).

The feldspar porphyry stringers are made up of feldspar phenocrysts in a matrix composed of quartz and feldspar of the same composition as the phenocrysts, which were determined by the statistical method to be andesine. Some feldspar grains have bent albite twinning indicating deformation; the edges of some grains are crushed. Sulphides occur as blebs or veinlets replacing the silicates along the crushed zones (Plate IV, figure 2).

Sulphides and carbonates penetrate amphibolite dikes along fractures. The opposite walls of the sulphide veinlets do not match, and islands of amphibolite occurring in wide portions of the veinlets indicate replacement of the amphibolite by sulphides. Irregular islands of carbonates are present in the wide portions of the sulphide stringers. This may indicate complete replacement of the carbonate by sulphides in narrow portions of the stringer.

All occurrences of sulphides in dikes appear to be later than the dike minerals. The brittle dikes appear to have been fractured by stresses in the basic intrusive and thereby formed convenient channels for the sulphides.

Sulphides Associated with Fractures and Shear Zones

The mineralized shears of the Lynn Lake ore deposits may be classified into two types; shear zones in which the rock is crushed and altered, and shear planes or fractures which are clean breaks in the rock along which movement may or may not have taken place, but was not accompanied by crushing or alteration. In the crushed and altered zones the sulphides occur as disseminations or stringers replacing the silicate minerals. Some of the stringers are fractured or displaced, indicating disturbance along the zones after emplacement of the sulphides.

Many shear and fracture planes are coated with sulphides which, in some specimens where chalcopyrite predominates, may also be disseminated in the wall rock for a short distance from the surface. The sulphide coatings vary from a surface veneer to one-eighth of an inch in thickness. Some are composed principally of chalcopyrite with minor pyrrhotite, pentlandite, and traces of sphalerite. Chalcopyrite coatings generally tend to be thin veneers. The thick surface coatings consist predominantly of pyrrhotite with early and late pyrite, minor chalcopyrite and pentlandite, and in many specimens are accompanied by carbonate and minor quartz which may form a layer between the sulphides and wall rock.

The mineral relationships of the sulphides are in general, similar to those in other ore types, but with a slightly modified pyrrhotite-pentlandite relationship. Typical pentlandite textures as described in a previous section are present but there is a relatively higher occurrence of pentlandite in the form of large irregular masses

in the pyrrhotite. The contact with pyrrhotite tends to be irregular. Many small islands of pyrrhotite occur in the pentlandite. Most of the islands tend to be circular but a few are irregular in outline. The cleavage of some of the islands has the same orientation as the cleavage of the pyrrhotite grain immediately adjoining it across the surrounding pentlandite. This strongly suggests some replacement of pyrrhotite by pentlandite.

Thin sections cut normal to the shear surfaces coated with chalcopyrite show that the amphibole and feldspar of the uralite gabbro were highly altered to muscovite and sericite respectively (Plate III, figure 4). Sulphides penetrate muscovite grains along cleavage planes or flatten out against the straight edge of the grain indicating they were later than muscovite. Sericite and muscovite suggest high temperature hydrothermal alteration and therefore a hydrothermal origin for the sulphides. A hydrothermal origin is also suggested by a decrease in the amount of sulphides as the distance from the shear plane increases.

Similar sulphide relationships in the shears and shear zones, and in mineralized dikes and stringers indicate that the same stresses fractured the dikes and the intrusive body, with common subsequent mineralization. Similar ore minerals and mineral relationships indicate a genetic relationship of all ore types and possibly one period of mineralization.

Barren Pyrrhotite

Some holes drilled into geophysical anomalies of phases 'B' and 'C' of the Lynn Lake intrusive encountered massive to disseminated

barren pyrrhotite. This mineral is fine grained and contains traces of chalcopyrite and sphalerite. The trend of these barren deposits is northeast in contrast to the northwesterly trend of the ore. They follow a different fracture system and because of their close resemblance in texture and composition to other barren northeasterly striking pyrrhotite bodies in the Lynn Lake Area, they are considered to be unrelated to the ore bodies.

SULPHIDE - SILICATE RELATIONSHIP

Observations of sulphide-silicate relationships were noted in connection with the description of the ore bodies, mineralogy of the ore, and classification of ore types. In this section the more or less isolated observations are compiled and discussed.

The massive ore contains traces of carbonate and a few silicate grains which are predominantly long needle-like crystals of amphibole. Sulphides fray the ends of the amphibole crystals, corrode the grains, displace cleavage fragments, and penetrate the grains along cleavage planes. They appear to be later than the silicates.

In the siliceous ore, sulphides occur as small masses disseminated in fine grained quartz with minor sphene and carbonate. There is little evidence of replacement, the sulphides fill in between silicate grains and appear to be interstitial. No strained extinction was observed in the quartz. These observations along with the more or less massive occurrence of the siliceous ore indicate that the sulphides were present when the silicate mass began to crystallize and were the last minerals to solidify.

Disseminated sulphides grade more or less into massive ore towards the centre of the ore body and into barren rock towards the margin, although in many places this sequence is irregular. Disseminated ore consists of grains or irregular masses of sulphide grains disseminated in the host rock. Many large blebs of sulphide have a few grains of quartz associated with them, or are partially or completely surrounded by a wide rim of brown biotite. The sulphides often

penetrate the biotite rims along cleavage planes. Some blebs have partial rims or grains of carbonate or sphene associated with them.

Sulphides replace all silicates of the uralite gabbro to a greater or less degree. They corrode feldspar to a limited extent. They fray the ends of amphibole needles, corrode the grains, displace the cleavage fragments, and penetrate the grains along cleavage planes. They intrude enstatite and augite. In some places sulphides appear to be more or less interstitial to the silicates and in others appear to replace the silicates. In specimens containing abundant feldspar which is only slightly replaced by sulphides, or in specimens containing broad disseminated masses of chalcopyrite which does not attack the silicates to the same extent as pyrrhotite, the sulphides are interstitial. The sulphides in norite are interstitial. Hunter (19) noted that in the less altered phases of the gabbro the sulphides are interstitial to the silicates. The amount of penetration and replacement of the silicates by the sulphides increases with the amount of alteration of the silicates. He believes the alteration of the intrusive body was caused by thermal metamorphism accompanied by moderate hydrothermal activity due to the intrusion of granite bodies in the Lynn Lake area. The above observations indicate that all the disseminated sulphides were originally interstitial and underwent varying amounts of subsequent rearrangement under the influence of the agents which metamorphosed the host rock.

In mineralized dikes and stringers the sulphides are late, penetrating the dikes as veinlets along minute fractures, or disseminated along crushed zones. In amphibolite dikes carbonate preceded the sulphides along the above mentioned channels. Felsite dikes have the same

composition as siliceous ore. The mineralized pegmatite is made up of disseminated sulphides replacing heavily kaolinized orthoclase, indicating mineralization by hydrothermal solutions.

Sulphides coat the surfaces of fractures and shear planes, and in some specimens where chalcopyrite is the predominant sulphide, sulphides are disseminated in the country rock for a short distance from the surface. Thin sections cut normal to the surface show that the amphibole and feldspar of the uralite gabbro are highly altered to muscovite and sericite respectively, which suggests high temperature hydrothermal alteration and therefore a hydrothermal origin for these sulphides. In many specimens in which pyrrhotite and pyrite are the predominate sulphides, carbonate and quartz form a layer between the sulphides and the wall rock.

The writer believes the above observations indicate that in all occurrences the sulphides are later than the silicates and were accompanied by small quantities of mineralizers or mineralizing solutions. The latter are indicated by the following observations: Traces of carbonate occur in the massive ore. In the siliceous ore sulphides were the last minerals to solidify from a mass composed of quartz, sphene, carbonate and sulphides. Blebs of sulphides associated with grains of quartz or sphene or surrounded by rims or partial rims of biotite or carbonate, all of which are not constituent minerals of the uralite gabbro, were observed in the disseminated ore. Carbonate in sulphide veinlets cutting through amphibolite stringers, and quartz and carbonate layers between sulphides and the wall rock along shear planes indicate mineralizing solutions associated with the sulphides.

ORIGIN OF THE DEPOSITS

The Lynn Lake deposits fall in the group of pyrrhotite-pentlandite-chalcopyrite concentrations associated with basic intrusives.

Scholtz (34, p. 141), in classifying the Insizwa deposits stated:

"Any theory which attempts to account for the genesis of the ore should not only be in harmony with the facts disclosed by the study of the associated silicates, but also with the geology and petrology of the intrusion as a whole".

Allan (2, p.113) concluded that the Lynn Lake ore bodies are in the class of high temperature hydrothermal replacement deposits. He points out the presence of granite in the area younger than the basic intrusives and states that even if there is a genetic relation between the sulphide ore and the basic intrusives, it seems possible to conceive that the intrusion of the granite later than the basic intrusives may have opened up channels or provided the energy which caused the sulphides to be moved from the original magma chamber into their present position.

The study of the Lynn Lake ore deposits has led to several observations and conclusions which have been noted and discussed in previous sections and are listed below for reference:

1. Four ore bodies occupy a narrow, irregular zone which lies in the most basic phase of the Lynn Lake intrusive 400 to 800 feet from the contact of the intrusive with the country rock. The 'El' ore body lies in a small gabbro stock. No major structural control for the location of the ore bodies has yet been determined.

2. Sharp boundaries between the sulphides and host rock are

rare. In most places the ore grades from disseminated to massive to disseminated across the ore bodies which in most cases contain several centres of massive ore.

3. Two outcrops of norite occur near the mine shaft. A diamond drill hole across the 'A' ore body on the 5th level cuts through 250 feet of mineralized norite. Hunter (19) has presented evidence to indicate the possibility that all the uralite gabbro of phases 'A' and 'B' was derived from norite.

4. The sulphides solidified later than the silicates of the basic intrusive.

5. In the less altered phases of gabbro, sulphides are interstitial to silicates. The amount of penetration and replacement of the silicates by the sulphides increases with the amount of alteration of the silicates.

6. The Lynn Lake ore deposits are genetically related to one another and represent one period of mineralization with some subsequent readjustment.

7. The sulphides were accompanied by small quantities of mineralizers or mineralizing solutions.

8. Dikes and stringers were formed earlier than the sulphides occurring within them.

9. The principal sulphides were deposited in the order pyrrhotite, pentlandite, chalcopyrite. Pentlandite is largely interstitial to pyrrhotite; chalcopyrite replaces the other sulphides.

10. A large part of the pentlandite in the ore formed by exsolution from pyrrhotite. In the massive fine grained ore there is a marked segregation of pentlandite into bands or irregular streaks.

The observations noted above indicate that the sulphides are magmatic products formed by the solidification of a basic magma. They were the last minerals to solidify. Since the ore bodies are genetically related to the basic intrusive, they are classified as the magmatic segregation type.

Several methods of segregation of magmatic ores are postulated in the literature. Vogt (41) postulates liquid immiscibility of sulphides in a cooling magma and subsequent settling to the floor of the intrusive due to gravity. Scholtz (34) believes the nickeliferous deposits of the Insizwa range segregated under the influence of gravity. Tolman and Rogers (39) describe a magmatic deposit at Engels, California and minor deposits in Norway in which the sulphides occur as lenses or tabular ore shoots situated in the highly differentiated basic portion of the intrusive. Howe (18) describes sulphide deposits at Prospect Hill, Connecticut, which occur within intrusives characterized by extreme magmatic differentiation. Newhouse (28) suggests deforming pressure or gas pressure as the cause of segregation of the sulphides. Tolman and Rogers (39), in their study of Norwegian deposits, conclude that the sulphides, along with felsic dikes or masses and acid secretions, were squeezed out as marginal segregates by the crystallization of the basic magma.

The hypothesis of segregation due to gravity and subsequent injection appears best to explain the observations noted in connection with the Lynn Lake deposits. On the basis of the observations of Vogt (41) and Tolman and Rogers (39) who have shown that in Norwegian deposits the quantity of ore is proportional to the size of the intrusive,

the quantity of sulphides in the Lynn Lake intrusive appears to be too high for the size of the stock. Hence the sulphides must represent segregation from a larger volume of gabbro or norite than is indicated by the dimensions of the Lynn Lake intrusive. This along with the elongated pipe-like shape and vertical attitude of the ore bodies and their present location some distance from the contact indicates they are not in the position where primary segregation took place and suggests an injection of the Lynn Lake mass to its present position from a greater depth. This late magmatic injection included movement of both the liquid sulphides and adjacent crystallizing silicate melt, and took place at a time when the melt was sufficiently viscous to support the sulphides in their present position. The altered norite between the ore and the country rock was due to flowage of the mass during which the silicate melt completely enclosed the sulphides during the movement. The silicates enclosing the ore bodies represent that portion of the silicate melt adjacent to the sulphides at the time of their primary segregation. Phase 'B' of the Lynn Lake intrusive presumably represents some of the original silicate melt from a slightly higher level of the magma reservoir. In accordance with the above hypothesis the ore deposits would be classified as late magmatic injection deposits.

Several types of mineralized dikes and stringers of different origins are associated with the basic intrusive. The amphibolite dikes are phases of the gabbro. The felsite and porphyry dikes may represent late differentiates from the gabbro magma, altered inclusions of quartzitic sediments in the intrusive, or they may be genetically related to the granite in the area. The pegmatite dikes are probably a phase of the granite.

Many small mineralized felsic and acid stringers represent mineralizers associated with the sulphides being of similar composition as the siliceous ore and disseminated ore associated with quartz and carbonate. After the mineralized sulphides were segregated and began to cool, unmixing began. In the initial stages the drop in temperature was accompanied by an increase in the vapor pressure, thus rendering the more volatile mineralizers an active agent (Niggli, 29) which would penetrate cracks and fissures formed by differential stresses in the cooling intrusive. Later stresses of the cooling intrusive may have fractured the brittle dikes before the sulphides were completely solidified, and residual mineralizing solution from the crystallizing sulphides followed the channels of the fractured dikes, shear zones and shear planes.

In all cases the dikes and stringers were formed earlier than the sulphides occurring within them. They were mineralized by two possible methods. If genetically related to the basic intrusive they may have been mineralized by the process described above. Dikes and stringers genetically related to the granite, and metamorphism due to the granite could cause redistribution of the sulphides resulting in the mineralization of intersecting dikes. This possibility is illustrated by the mineralized pegmatite.

Scholtz (34) in discussing the origin of the Insizwa deposits states that much misunderstanding and unnecessary discussion have been caused because observers have attempted to draw hard and fast distinctions between deposits of magmatic and hydrothermal origin instead of realizing that the two are simply stages of a common process.

SUMMARY OF CONCLUSIONS

The sulphides were deposited in the order pyrrhotite, pentlandite, chalcopyrite. Much of the pentlandite was formed by exsolution from pyrrhotite.

The Lynn Lake ore deposits fall in the group of pyrrhotite-pentlandite-chalcopyrite concentrations associated with basic intrusives. The sulphides are magmatic products formed by the solidification of a basic magma, and were the last minerals to solidify. Primary segregation of the sulphides took place at depth by liquid immiscibility, the liquid sulphides settling to the floor of the magma chamber under the influence of gravity. Subsequently the sulphides and the overlying magma, both still in the fluid state, were subjected to earth movements which injected them upwards into their present position. During this movement the flowage of the basic magma brought about the complete enclosure of sulphides by the gabbro. The Lynn Lake ore deposits are therefore classified as "late magmatic injection deposits". They differ from other deposits included in this group by having a portion of the adjacent magma injected along with the liquid sulphide mass.

PART II

HEAVY ACCESSORY MINERALS OF THE LYNN LAKE BASIC INTRUSIVE

INTRODUCTION

Relatively new in geological research is the correlation of similar rock types by means of heavy accessory minerals. One of the principal trends of this work has been the correlation of granitic rocks using zircon as the key mineral. To the writer's knowledge no attempts have been made to apply the method of heavy accessory minerals to the correlation of basic rocks. Although predicated by Newhouse (28) in connection with his study of the opaque minerals of igneous rocks, the possibilities of this method have not yet been determined.

The original purpose of the laboratory investigations was to study the occurrence and paragenesis of the sulphides and oxides of the Lynn Lake nickel-copper deposits. As the work progressed it became apparent that the oxides were genetically related to the silicates rather than the sulphides. The oxides were distributed throughout the host rock with no apparent relation to the ore deposits. Two separate lines of investigation were accordingly established. The study of the oxides was extended to an investigation of the heavy accessory minerals of the Lynn Lake intrusive.

Throughout the remainder of this report heavy accessory minerals will be referred to as "heavies" and the minerals of low specific gravity as "lights".

The investigation was designed to consider the occurrence of heavy accessory minerals associated with basic rocks. The heavies

were identified and their relative proportions across an intrusive noted. The contribution of the heavies to the petrography of the basic intrusives was evaluated, their value in determining a method of emplacement and their use in correlation of the intrusive bodies was studied.

The Lynn Lake intrusive has been divided into three phases of uralite gabbro based on feldspar composition and extent of alteration of the original mineral constituents. Basic dikes cut the intrusive. Both composite intrusion and differentiation have been suggested as possible explanations of the three phases. Paucity of outcrops and the highly altered nature of the gabbro make it difficult to confirm either hypothesis.

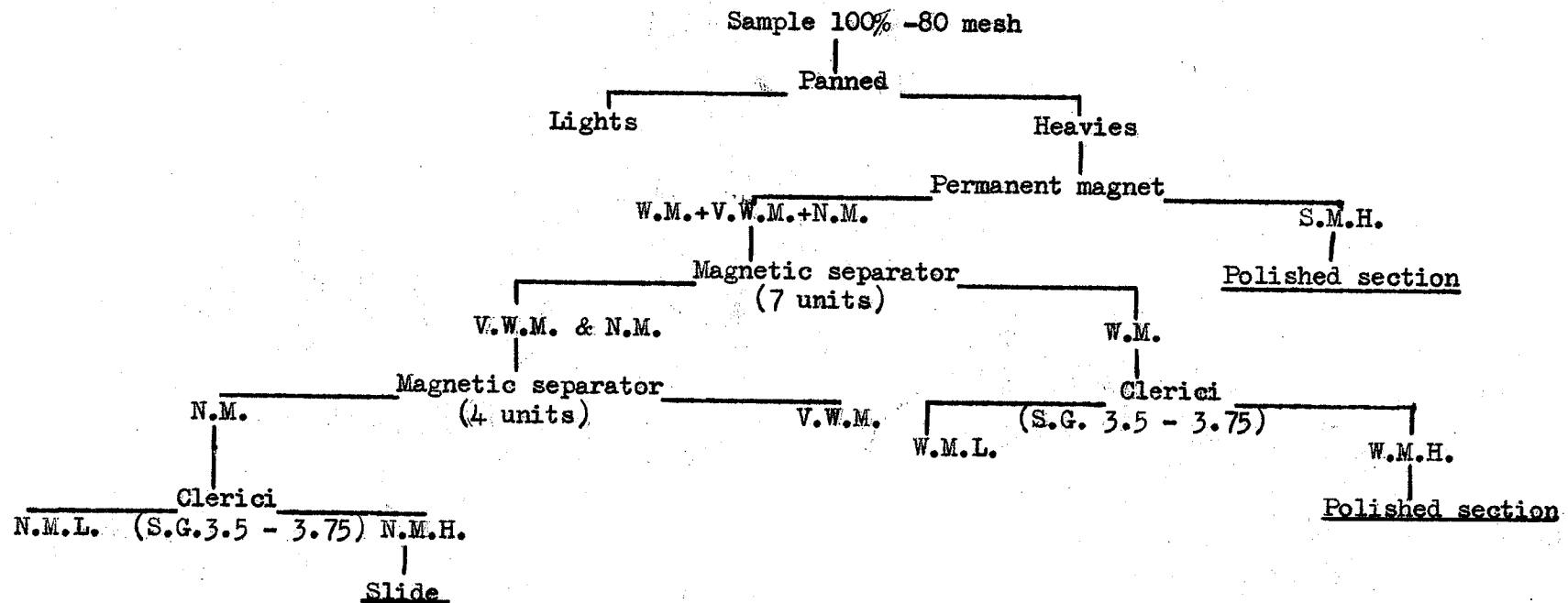
More specifically, the purpose of the investigation was to determine the value of the heavies as applied to the petrographic problems of the Lynn Lake intrusive. The identification of the heavy accessory minerals was of interest from a petrographic standpoint. A check was made of the possibility of the heavies supplying evidence of the origin and emplacement of the intrusive.

A suite of heavy accessory minerals was compiled for each rock type. Individual grains of each mineral were examined and tabulated on the basis of distinctive or possible diagnostic features. In this manner the suites were compared quantitatively and qualitatively. With this data a comparison of the heavies of phases 'A', 'B', 'C' and the basic dikes of the uralite gabbro was possible and consideration was given to the possibility of distinguishing between them by this method. A check was made on the possibility of a unique set of heavies or peculiarities of any one heavy accessory mineral associated with the sulphides or sulphide bearing phase of the gabbro.

TABLE OF SPECIMENS

No.	ROCK TYPE	WEIGHT
2	Uralite gabbro phase A	333 gms.
6	" " " "	365 "
7	" " " B	455 "
8	" " " "	535 "
9	" " " "	265 "
11	" " " C	95 "
4	" " " "	100 "
12	" " " "	82 "
1	Mineralized amphibolite	560 "
13	" "	320 "
3	Basic dike	258 "
5	" "	81 "
10	" "	215 "

FLOW SHEET FOR HEAVY MINERAL SEPARATION



Abbreviations:

- S.M.H. - Strongly magnetic heavies
- W.M.H. - Weakly magnetic heavies
- V.W.M.H.- Very weakly magnetic heavies
- N.M.H. - Non-magnetic heavies

METHOD OF STUDY

Specimens

Representative specimens of the various rock types were chosen from the barren parts of the intrusive to avoid contamination by sulphides of the ore deposits. The largest specimens available were used to obtain a reasonable concentration of heavy accessory minerals. Duplicate specimens of each rock type were obtained from different outcrops where possible. The specimens are listed in the table of specimens and their locations are shown in map in the pocket.

Separation

The specimens were mechanically crushed and pulverized to 100% -80 mesh. The procedure for isolating the heavies was divided into three steps: (1) Panning (2) Magnetic separation (3) Gravity separation; as indicated in the flow sheet of heavies.

1. Panning - The samples were panned with water in a prospector's gold pan. This process eliminated the finely crushed material and a portion of the lights which were principally feldspar, quartz and mica. The efficiency of this operation depends upon the skill with which the panning is performed. The lights were therefore not completely separated from the heavies by this method. The lights were discarded. The heavies were dried and separated on the basis of the magnetic properties of the constituent minerals.
2. Magnetic Separation - After panning and drying the heavy minerals were

separated according to their magnetic properties. They were separated into the following portions: (a) Strongly magnetic (b) weakly magnetic (c) very weakly magnetic (d) non-magnetic. The separation was based on arbitrary standards. The strongly magnetic minerals consisted of that portion which could be removed with a permanent horseshoe magnet. The weakly magnetic and very weakly magnetic portions were minerals removed by an electro-magnetic separator with pole distance of seven units and four units respectively. The non-magnetic minerals remained after the magnetic separations.

3. Gravity Separation - Gravity separation was carried out by means of clerici solution whose specific gravity ranged from 3.40 to 3.75. This range of specific gravity was chosen to keep amphibole with the lights. Amphibole was particularly abundant and would have made the examination of the heavies tedious if drawn off with that portion. The specific gravity of apatite is 3.20. Therefore it also remained with the lights and was not considered. Previous workers have shown that the distribution of apatite in a rock may vary considerably over a very short distance and is therefore of little value as a diagnostic mineral in correlation.

A separatory funnel was used for the separations. The rock sample was poured into a funnel slightly more than half full of clerici. The clerici was then swirled to prevent bunching of the sample and to ensure each grain being wet by the solution. The heavies were allowed to settle for ten minutes, then drawn off and freed from the clerici with a filter funnel and suction pump. The heavies were then rinsed and dried. The lights were filtered from the clerici in

a similar manner. Because of its high cost, complete recovery of the clerici solution was attempted throughout the separations.

Gravity separations were carried out on the weakly magnetic, very weakly magnetic and non-magnetic portions. The strongly magnetic heavies were isolated with a permanent magnet and were mounted without a gravity separation.

Mounting

Examination with the binocular microscope showed that the strongly magnetic heavies and the weakly magnetic heavies were opaque minerals. For further study they were mounted in bakelite as polished sections. The non-magnetic heavies were mounted in slides for identification of the silicates.

Before gravity separation, under the binocular microscope the very weakly magnetic minerals were seen to consist principally of amphibole. Gravity separation yielded very small to negligible quantities of heavy minerals which consisted of weakly magnetics and non-magnetics dragged down as impurities in the original magnetic separation. The study of the very weakly magnetic heavies was therefore not pursued.

Microscopic Examination

The polished sections of the strongly magnetic and weakly magnetic concentrates were systematically examined by means of a traversing stage mounted on the microscope. Each grain of oxide was examined and the properties tabulated.

In his study of the oxides of the Duluth gabbro Schwartz (36) etched his specimens in hot concentrated hydrochloric acid to bring out any possible structures not otherwise visible in the grains. Using control specimens of ilmenite and magnetite this method was checked and it was found that etching with hot concentrated hydrochloric acid for five minutes gave the best results. When etched under these conditions ilmenite retains the bright lustre of its polish, whereas magnetite assumes a dull black appearance.

After the systematic examination of the strongly magnetic and weakly magnetic heavies they were etched as described above and re-examined as a check on the former observations.

The non-magnetic heavies were mounted in slides for the identification of the silicates. A microscopic examination of the sulphides in the strongly magnetics showed that they were non-diagnostic. A similar study of the sulphides of the non-magnetics would serve no purpose and was therefore omitted.

RESULTS

The heavy mineral investigation was not conducted on a precise quantitative basis. Material was lost in the crusher and pulverizer. When mounted in polished sections for microscopic examination an indeterminate number of grains were completely buried in bakelite. Some of the ilmenite observed in connection with the study of the paragenesis of the ore minerals occurred in minute rod-like grains which may have been lost in pulverizing and panning because of their small size.

A rough quantitative determination is desirable however, and can be indicated, if the limitations are borne in mind. The weight of the original specimen was accurately determined. Since all specimens underwent a standard procedure in crushing, pulverizing, separation, and mounting, it may be assumed that they suffered approximately the same percentage loss of material, including heavy accessory minerals. The table of results should therefore not be interpreted as absolutely accurate on a quantitative basis but accurate enough for comparison purposes.

Observations

(a) Strongly Magnetic Heavies - The minerals in the strongly magnetic portion were pyrrhotite, magnetite and ilmenite. Steel from the pulverizer was present as an impurity and was ignored. No distinctive features were noted in the pyrrhotite from the various rock types.

Magnetite occurred as isolated grains of the pure mineral or as grains consisting of intermixed magnetite and silicates. The grains

of intermixed magnetite and silicates were due to silicates clinging to small anhedral magnetite grains or irregular masses of magnetite penetrating the silicates. The amount of magnetite in each grain varied from a trace to pure magnetite. Exsolution texture was not observed in the magnetite of the various rock types. Etching for five minutes in hot concentrated hydrochloric acid confirmed this observation. The magnetite grains varied from smooth to heavily pitted. In some grains the pits had a tendency to be aligned, probably along cleavage planes. Quantitatively the magnetite content was not constant from one gabbro dike to another. The magnetite content also varied from one phase of the intrusive to the other. Phase 'C' had the highest magnetite content followed by phase 'B' and phase 'A' respectively as shown in the table of results.

A few grains of ilmenite were present in the strongly magnetic portion. The occurrence and properties of the ilmenite were similar to those described for the magnetite.

(b) Weakly Magnetic Heavies - The weakly magnetic heavies with one exception were made up entirely of ilmenite. The weakly magnetic portions of mineralized amphibolite contained some pyrrhotite. Ilmenite occurred as large anhedral grains which varied from smooth to heavily pitted. In some grains the pits had a tendency to be aligned. No exsolution texture was observed in the ilmenite grains of the various rock types. Etching with hot concentrated hydrochloric acid confirmed this observation. Etching brought out or accentuated the cleavage of many ilmenite grains. The quantitative occurrence of ilmenite was similar to that described for the magnetite of the

TABLE OF RESULTS

	PHASE "A"		PHASE "B"		PHASE "C"			DIKE ROCKS			MINERALIZED AMPHIBOLITE		
	STRONGLY MAGNETIC HEAVIES												
SPECIMEN NO.	2	6	7	8	9	11	4	12	3	5	10	1	3
Pure magnetite grains	6	6	30	39	36	129	117	132	162	37	16	7	2
Grains comp. of mag. & silicates	5	7	4	11	9	18	24	12	95	16	11		
Pure ilmenite grains	1	2	1	3	3	3	12	1	20	4	3	2	1
Grains comp. of il. & silicates							6		6				
Pyrrhotite	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
	WEAKLY MAGNETIC HEAVIES												
Pure ilmenite grains	30	35	2700	2400	2600	3900	3300	3600	>5000	800	300	18	22
Pyrrhotite												X	X
	NON-MAGNETIC HEAVIES												
Pyrrhotite	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Pyrite	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Chalcopyrite	X	X	X	X	X	X	X	X	X	X	X	X	X
Bornite									5				
Zircon			3						3				
Sample in grams	300	300	300	300	300	300	300	300	300	300	300	300	300

EXPLANATION: XXX - Large quantity
 XX - Medium quantity
 X - Small quantity

strongly magnetic portion, that is highest in phase 'C' with successively lower amounts in phases 'B' and 'A' respectively.

(c) Non-Magnetic Heavies - The non-magnetic heavies consisted principally of sulphides which were pyrrhotite, pyrite and chalcopyrite. Traces of pentlandite were observed in a few pyrrhotite grains. One specimen (number 3) contained a few grains of bornite. A few zircons were found in two specimens. Usually one or two grains of a clear, colorless anhedral silicate were present in each portion. This silicate was not positively identified. The number of grains was too small to be of any diagnostic value. They may have been silicates of low specific gravity dragged down as impurities in the gravity separation.

Table of Results

The table of results was recalculated from the original grain count and established on the basis of a 300 gram sample, the average weight of specimens used. Where counts were not made a check mark (x) indicates the presence of that mineral.

Discussion of Results

With the exception of the mineralized amphibolite the sulphides found in the specimens are considered to be accessory minerals with no direct connection with the mineralization which produced the ore bodies. No distinctive features of any diagnostic value were noted in the sulphides of the various rock types.

Newhouse (28) believes that the variations in the opaque oxides of basic igneous rocks are sufficiently diagnostic to form

an important part in heavy mineral correlation work. Schwartz (36) describes and illustrates several types of exsolution textures in the oxides of the Duluth Gabbro. The laboratory investigation of the heavies of the Lynn Lake intrusive was centred around the oxides.

The grains of mixed magnetite and silicates were due to silicates partially surrounding small anhedral magnetite grains, or irregular late magnetite penetrating the silicates. If a gravity separation had been carried out as well as the magnetic separation, a large part of these grains would have been eliminated. This occurrence therefore was not diagnostic in itself. It was tabulated because it served to give a more accurate estimate of the amount of magnetite present.

The magnetite grains varied from smooth to heavily pitted with a tendency in some grains for the pits to be aligned, possibly along cleavage planes. This could not be used as a diagnostic feature since the pitting could be due to a large extent to features such as orientation of the grain in the mount and the polish of the section. The only diagnostic feature is a quantitative one. This is discussed in connection with the table of results.

A few grains of ilmenite occurred in the strongly magnetic portion; the majority being in the weakly magnetic fraction. A few grains of silicates dragged out as impurities during the separation, were present in the strongly magnetic portion. The same applies to the few ilmenite grains found in the strongly magnetic fraction.

Pitting similar to that in the magnetite grains was observed in the ilmenite. The diagnostic value of ilmenite is similar to that of magnetite which was discussed above.

Three zircons were observed in the non-magnetic portion of two specimens. They were not abundant enough to be used as a diagnostic mineral. The colorless unidentified silicate mentioned above also falls into this category.

The table of results indicates that the only diagnostic feature of the heavy accessory minerals in distinguishing the various rock types is a quantitative one.

Ilmenite is the predominant oxide. Newhouse (28) observed that ilmenite was usually the dominant oxide in gabbros and allied rocks. This holds true for the Lynn Lake intrusive.

A quantitative determination of magnetite and ilmenite indicates that the concentration of these minerals is uniform within the phases but varies considerably from one gabbro phase to another. Phase 'C' has the highest oxide content followed by phase 'B' and phase 'A' respectively. The oxide concentration decreases from the least basic to the most basic phase. The ratio of ilmenite to magnetite shows a corresponding decrease.

The gabbro dikes show no consistency in oxide content among themselves or in relation to the main intrusive. Specimen 3 has a high oxide content whereas specimen 10 is the opposite in comparison with the phases of the main intrusive body.

Applied to the petrographic study of the intrusive the distinctive oxide concentrations tends to confirm the existence of the three phases. The oxide concentration and ilmenite-magnetite ratio may be used as additional data in the petrographic classification of highly altered rocks of the intrusive.

No light is thrown on the problem of the origin of the gabbro phases, that is, whether they are due to composite intrusion or differentiation. The suites of heavies for each rock type are very similar except for the amount of oxides present. The possibility that this indicates a common magma or common source of magma for the various phases of gabbro and dikes of the intrusive body may be mentioned. This investigation represents a new field of study in which criteria and validity of diagnostic features have not yet been established. The origin and relationship of other basic intrusive bodies may be postulated on the basis of exsolution textures if they are present. More work is required on this method of investigation.

The table of results indicates that the basic dikes are not associated with any one phase of the intrusive since these conditions would demand similar concentrations of oxides for each dike. The zircons found in specimen 7 of phase 'B' and in the specimen from a basic dike suggest the latter originated from phase 'B.' However zircons are not sufficiently abundant to confirm this possibility.

SUMMARY OF CONCLUSIONS

1. The oxides are the only heavy accessory minerals of diagnostic value for correlation purposes in the Lynn Lake basic intrusive.
2. The oxide content is uniform within each phase of the gabbro but varies from one phase to another, which tends to confirm the existence of three distinct gabbro phases in the Lynn Lake intrusive.
3. The concentration of the oxides decreases from the least basic to the most basic phase. The ratio of ilmenite to magnetite shows a corresponding decrease.
4. The oxide content of the basic dikes associated with the intrusive varies from one dike to another. This indicates that the dikes are not of the same age and did not originate from the same phase of the intrusive.

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PLATES AND ILLUSTRATIONS

PLATE I

PYRITE

- Figure 1. Corroded islands of early pyrite (white) in pyrrhotite (grey). X80.
- Figure 2. Grain of early pyrite (white) corroded by chalcopyrite (grey) and silicates (black). The matching walled fractures of the pyrite grain are filled with chalcopyrite. X170.
- Figure 3. Late pyrite (white) veining and replacing pyrrhotite (grey) and pentlandite (light grey with pitted surface). X85.
- Figure 4. Late pyrite (white) forming a replacement intergrowth texture with pentlandite (light grey). X94.

PLATE I

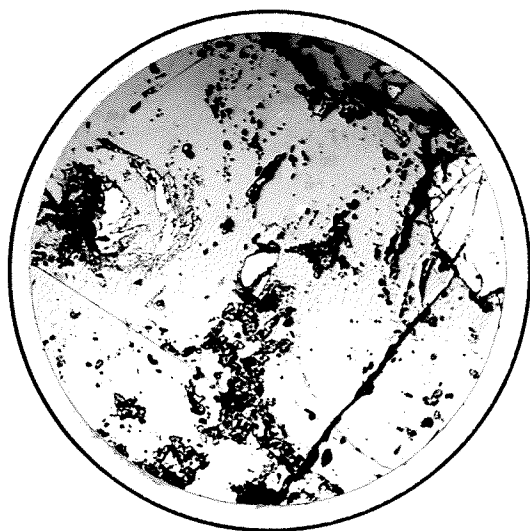


Figure 1. Polished section
406-255.5. X80.



Figure 2. Polished section
406-255.5. X170.



Figure 3. Polished section
U-6-0. X85.

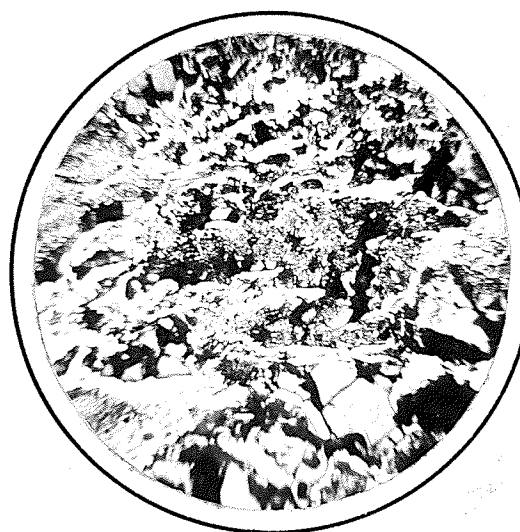


Figure 4. Polished section
U-4-0. X94.

PLATE II

PYRRHOTITE - PENTLANDITE RELATIONSHIP

- Figure 1. An irregular mass of pentlandite tapering into a partial network structure along the borders of pyrrhotite grains. Note that the pentlandite veinlets are gently curved around the pyrrhotite grains and taper out into massive pyrrhotite. Pentlandite, white; pyrrhotite, dark grey; silicates, light grey. Stained. X93.
- Figure 2. Pentlandite forming a partial network structure around pyrrhotite grains. Pentlandite, white; pyrrhotite, grey; silicates, black. Stained. X94.
- Figure 3. Flames of pentlandite projecting into massive pyrrhotite from an included silicate grain. Pentlandite, white; pyrrhotite, grey; silicate, black. Stained. X170.
- Figure 4. Blades and flames of pentlandite (white) projecting from a fracture into massive pyrrhotite (grey). Note the parallel orientation of the pentlandite blades along crystallographic planes of the pyrrhotite. Stained. X230.

PLATE II

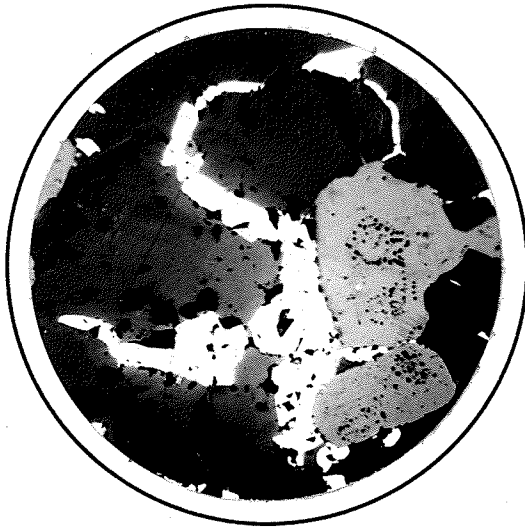


Figure 1. Polished section
U-6-O.Stained.X93.

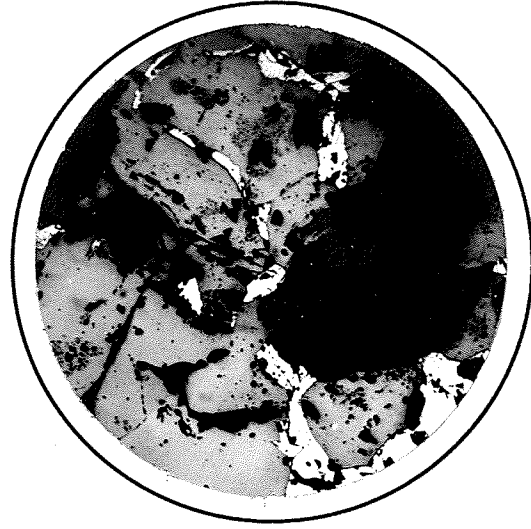


Figure 2. Polished section
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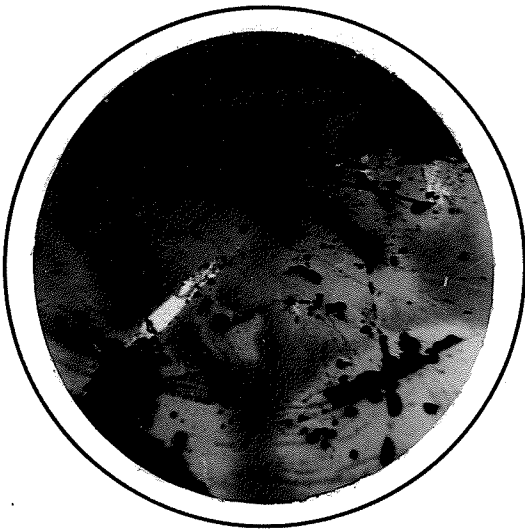


Figure 3. Polished section
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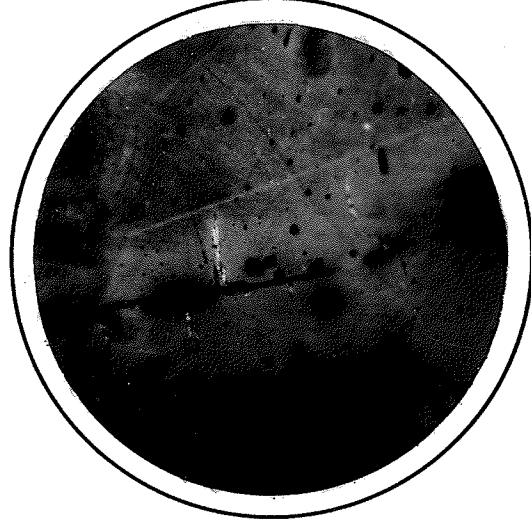


Figure 4. Polished section
U-4-O.Stained.X230.

PLATE III

SULPHIDE - SILICATE RELATIONSHIP

- Figure 1. Interstitial sulphides in mineralized amphibolite. Sulphides, white; silicates, grey. X35.
- Figure 2. Blebs of sulphide partially surrounded by biotite in medium grained gabbro. Sulphides, black; biotite, dark grey; amphibole, light grey; feldspar, white. X10.
- Figure 3. Mineralized uralite gabbro. Sulphides (black) replace silicates (grey) and penetrate amphibole grains along cleavage planes. X10.
- Figure 4. Thin section cut normal to a shear plane coated with chalcopyrite. Sulphides (black) corrode and replace highly altered silicates (grey). X10.

PLATE III

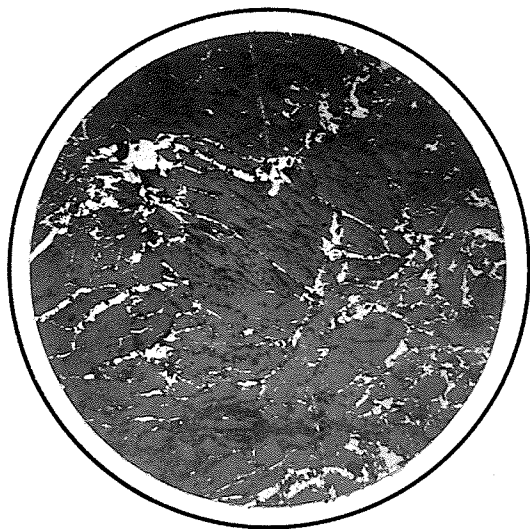


Figure 1. Polished section
U-9-0. X35.

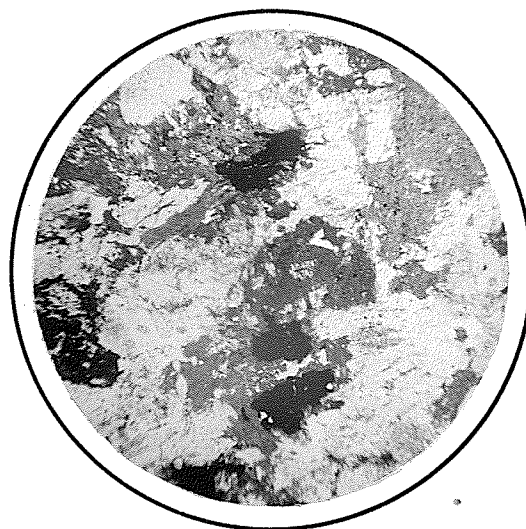


Figure 2. Thin section
299-544. X10.

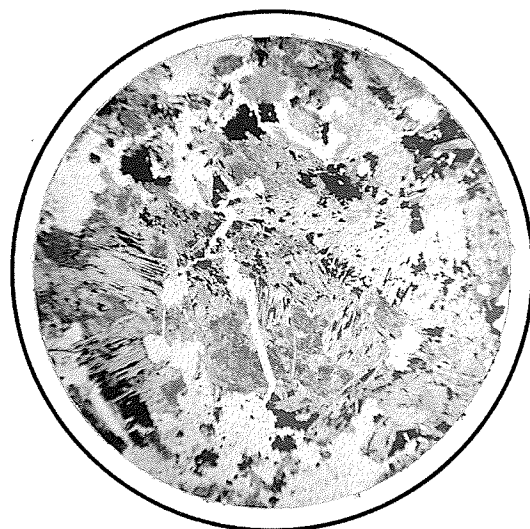


Figure 3. Thin section
U-14-0. X10.

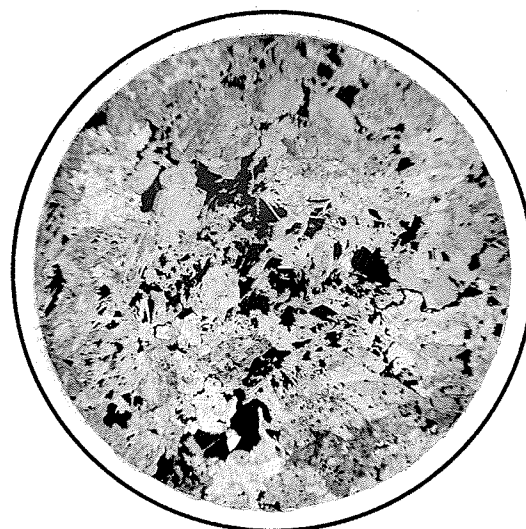


Figure 4. Thin section
U-23-0. X10.

PLATE IV

SULPHIDES ASSOCIATED WITH DIKES AND STRINGERS

- Figure 1. Mineralized quartz stringer. Veinlets of sulphides penetrate and corrode the quartz. Disseminated sulphides occur along crushed zones. Note the strained extinction of the quartz grains adjacent to the sulphide veinlet. Sulphides, black; quartz, grey. Crossed nicols. X10.
- Figure 2. Mineralized feldspar porphyry stringer. Sulphides penetrate and replace silicates along crushed zones. Sulphides, black; feldspar, cloudy grey; quartz, grey to white. Crossed nicols. X10.
- Figure 3. Mineralized felsic dike. Sulphides penetrate and corrode the dike minerals. Note the polysynthetic twinning of the carbonate and the strained extinction of the quartz. Sulphides, black; carbonate, grey with polysynthetic twinning; quartz, grey to white. Crossed nicols. X10.
- Figure 4. Mineralized pegmatite. Sulphides corrode and replace orthoclase. Note the heavily kaolinized orthoclase indicating deposition of the sulphides from hydrothermal solutions. Sulphides, black; orthoclase, cloudy grey. X10.

PLATE IV



Figure 1. Thin section
48-494. X nicols.
X10.

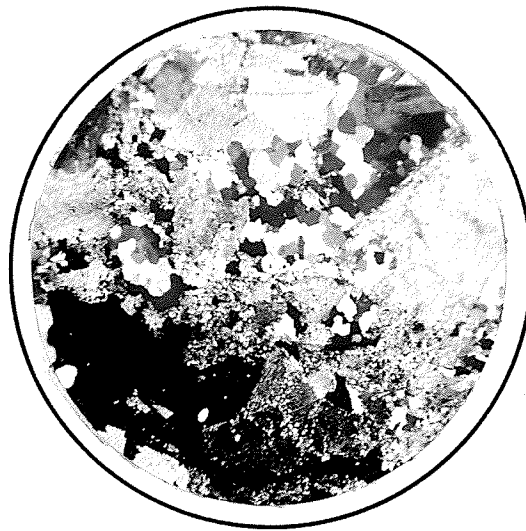


Figure 2. Thin section
51-997. X nicols.
X10.



Figure 3. Thin section
406-258. X nicols.
X10.

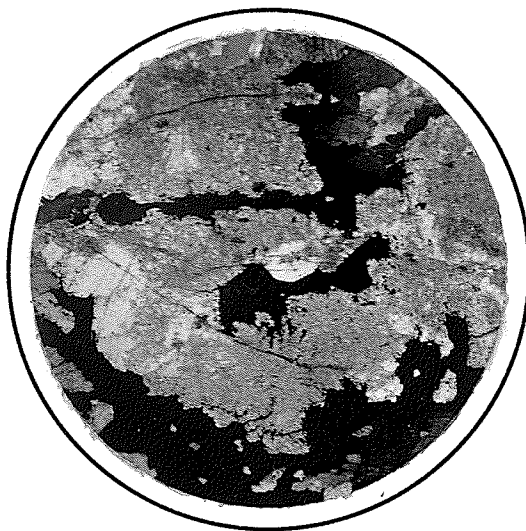

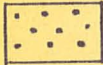
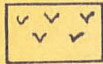
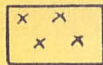
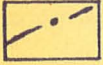


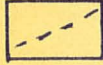


Figure 4. Thin section
U-8-0. X nicols.
X10.

LEGEND

-  HEAVILY DISSEMINATED TO
MASSIVE SULPHIDES
-  FINE GRAINED GABBRO, DIKES,
OR VOLCANIC INCLUSIONS
-  GABBRO
-  AMPHIBOLITE

SYMBOLS

-  ORE OUTLINE TO INCLUDE ZONES
OF LIGHTER DISSEMINATION OF SULPHIDES
-  FAULT AND SHEAR ZONE
-  DIAMOND DRILL HOLE
-  GEOLOGICAL CONTACT



SHERRITT GORDON MINES LTD

LYNN LAKE PROPERTY

LATERAL SECTION OF

"A" ORE BODY

ALONG LAT 39650

SCALE 1 IN.=100 FT.

Figure 5.

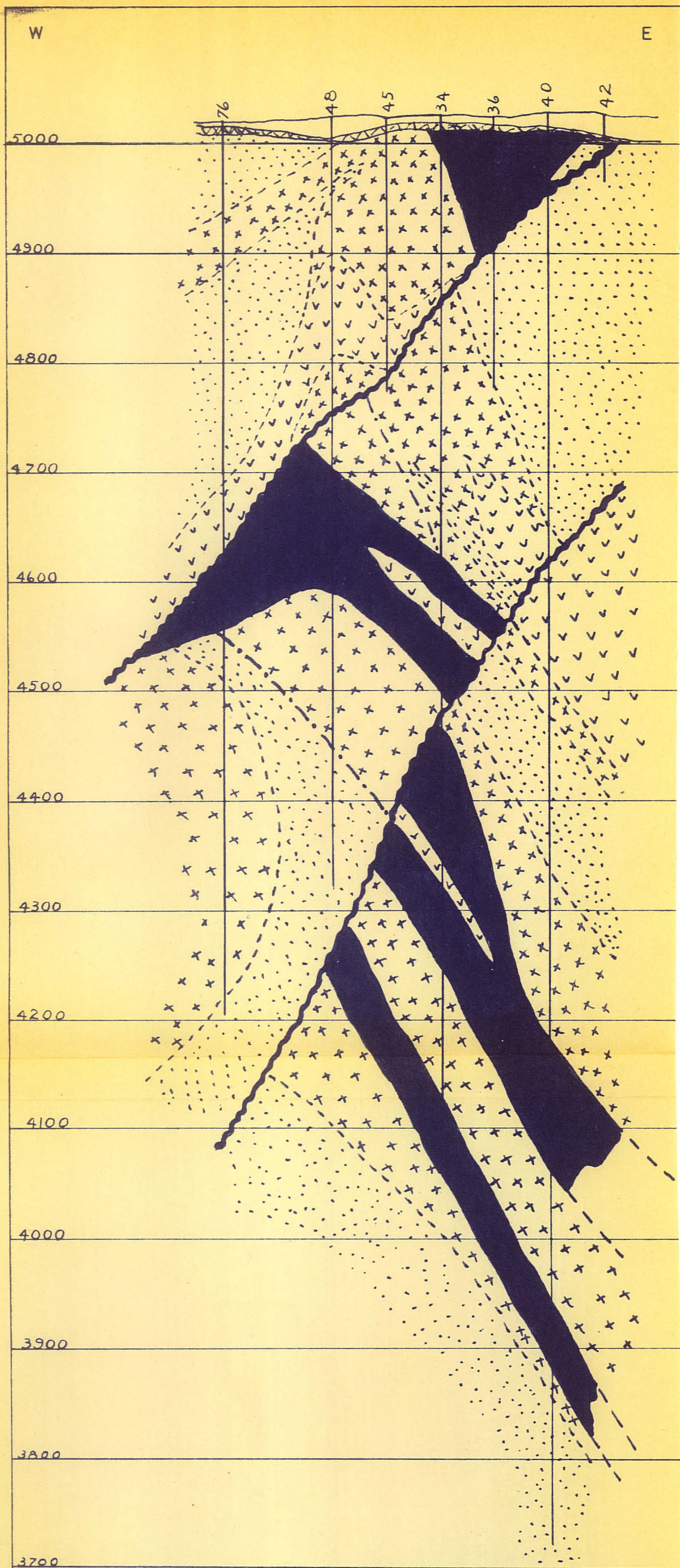


Figure 5.

LEGEND

 HEAVILY DISSEMINATED TO
MASSIVE SULPHIDES

 FINE GRAINED GABBRO, DIKES,
OR VOLCANIC INCLUSIONS

 GABBRO

 AMPHIBOLITE

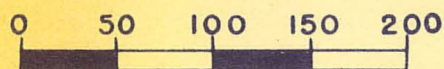
SYMBOLS

 ORE OUTLINE TO INCLUDE ZONES
OF LIGHTER DISSEMINATION OF SULPHIDES

 FAULT AND SHEAR ZONE

 DIAMOND DRILL HOLE

 GEOLOGICAL CONTACT



SHERRITT GORDON MINES LTD

LYNN LAKE PROPERTY

LATERAL SECTION OF

"B" ORE BODY

ALONG LAT 35800

SCALE 1 IN.=100 FT.

Figure 6.

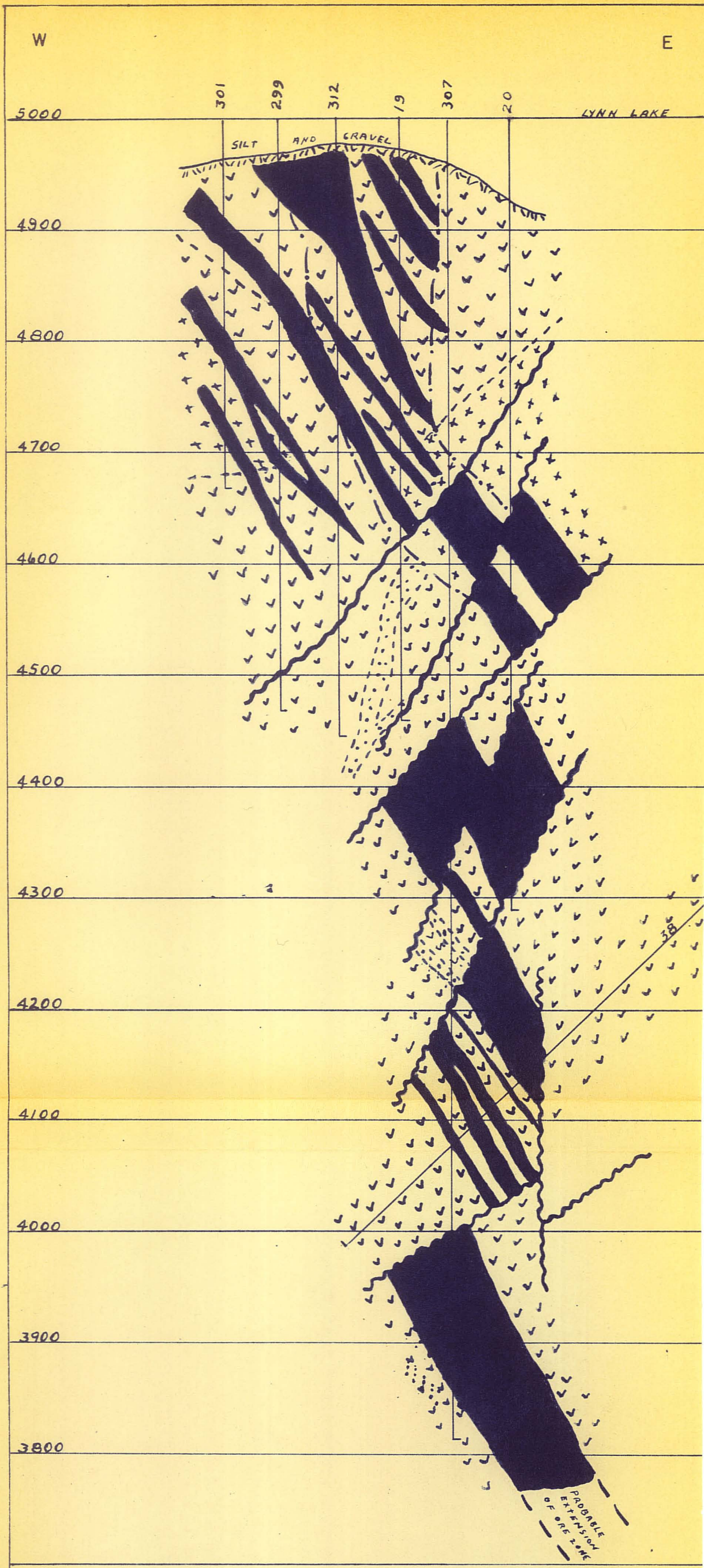



Figure 6.

LEGEND

 HEAVILY DISSEMINATED TO
MASSIVE SULPHIDES

 FINE GRAINED GABBRO, DIKES,
OR VOLCANIC INCLUSIONS

 GABBRO

 AMPHIBOLITE

SYMBOLS

 ORE OUTLINE TO INCLUDE ZONES
OF LIGHTER DISSEMINATION OF SULPHIDES

 FAULT AND SHEAR ZONE

 DIAMOND DRILL HOLE

 GEOLOGICAL CONTACT



SHERITT GORDON MINES LTD

LYNN LAKE PROPERTY

LATERAL SECTION OF
"E" ORE BODY

ALONG LAT 38850

SCALE 1 IN.=100 FT.

Figure 7.

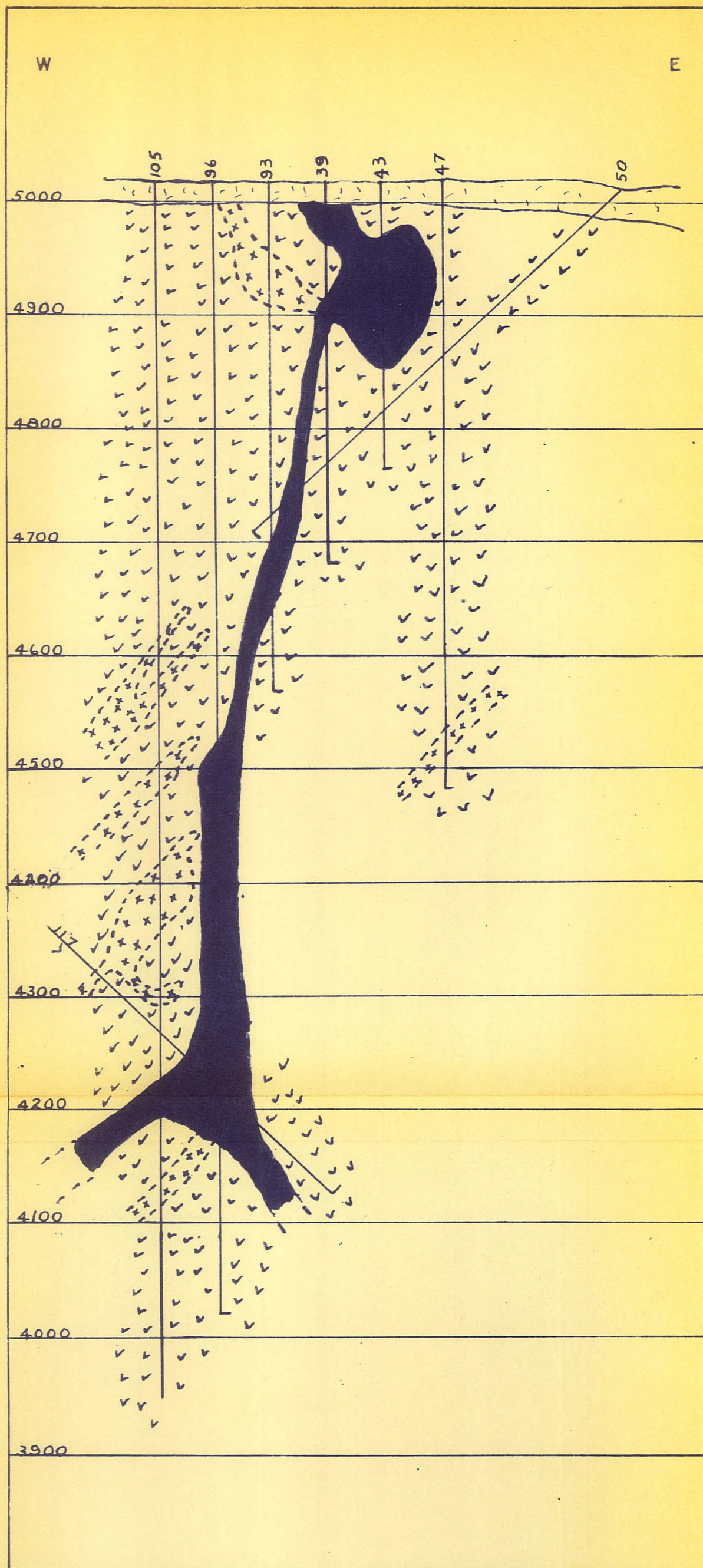


Figure 7.

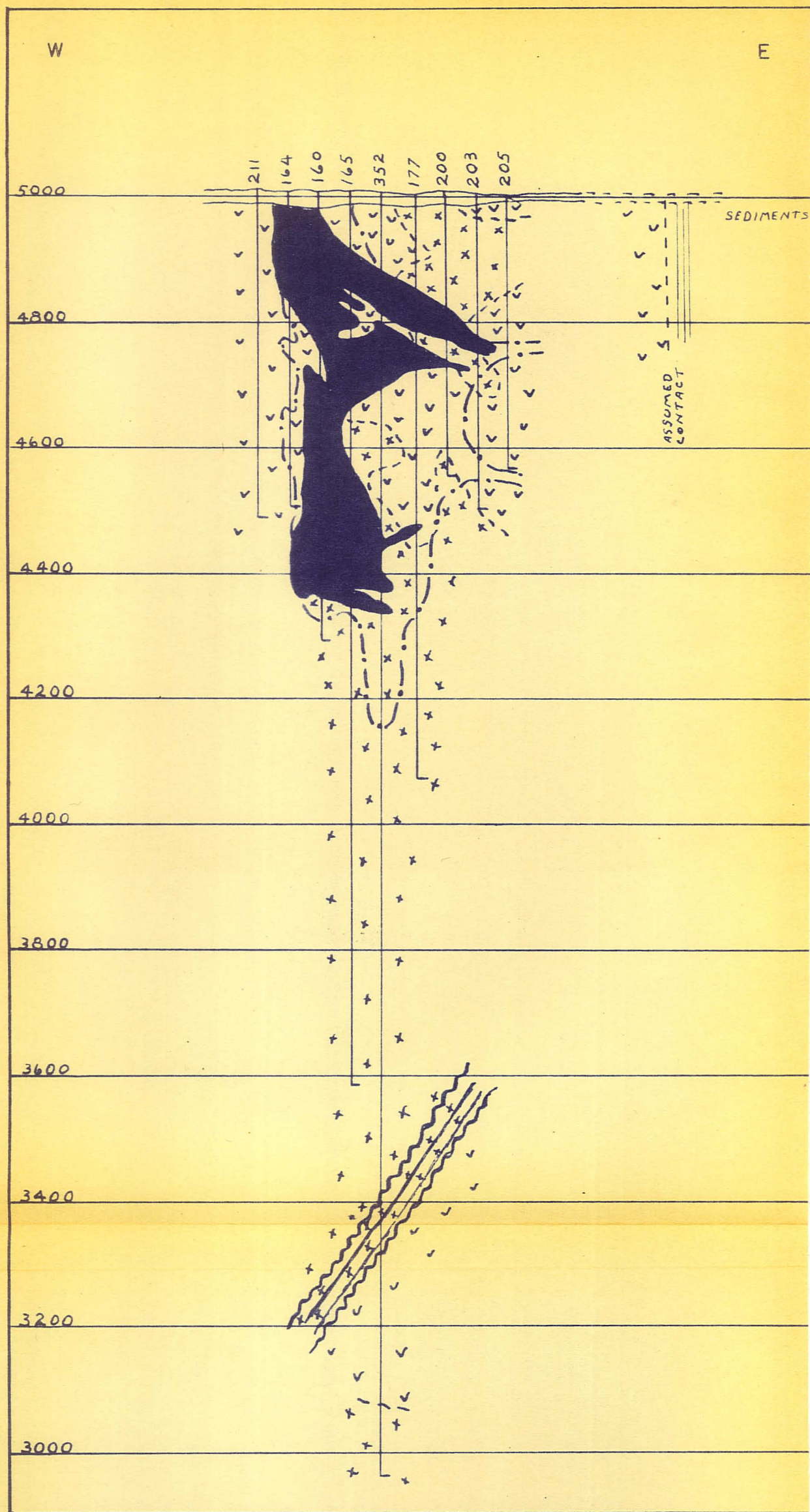

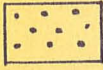
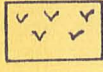



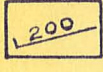



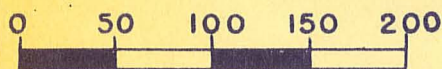
Figure 8.

LEGEND

-  HEAVILY DISSEMINATED TO MASSIVE SULPHIDES
-  FINE GRAINED GABBRO, DIKES, OR VOLCANIC INCLUSIONS
-  GABBRO
-  AMPHIBOLITE

SYMBOLS

-  ORE OUTLINE TO INCLUDE ZONES OF LIGHTER DISSEMINATION OF SULPHIDES
-  FAULT AND SHEAR ZONE
-  DIAMOND DRILL HOLE
-  GEOLOGICAL CONTACT



SHERRITT GORDON MINES LTD

LYNN LAKE PROPERTY

LATERAL SECTION OF

"EL" ORE BODY

ALONG LAT 29100

SCALE 1 IN.=200 FT.

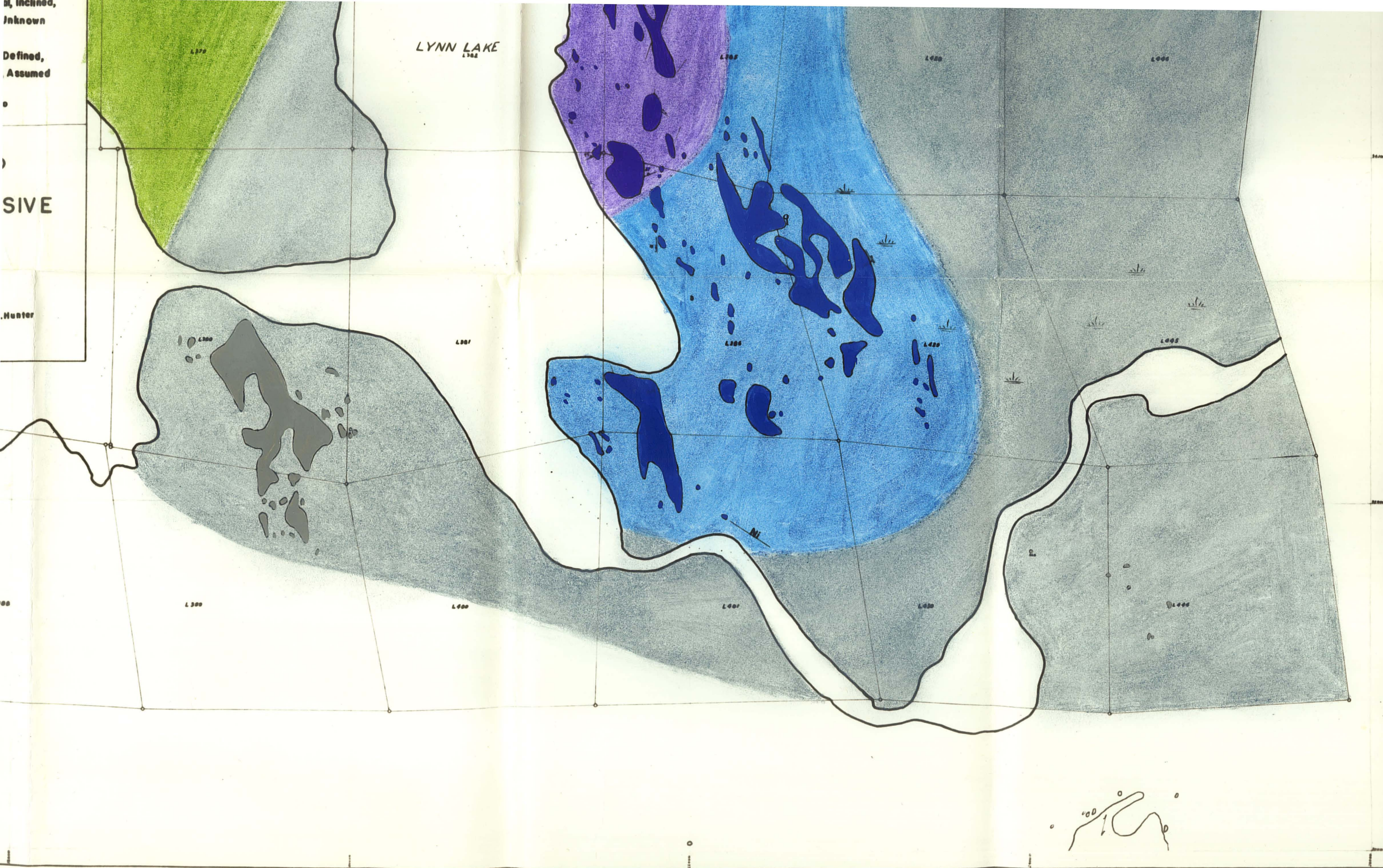
Figure 8.

at, inclined,
known
Defined,
Assumed

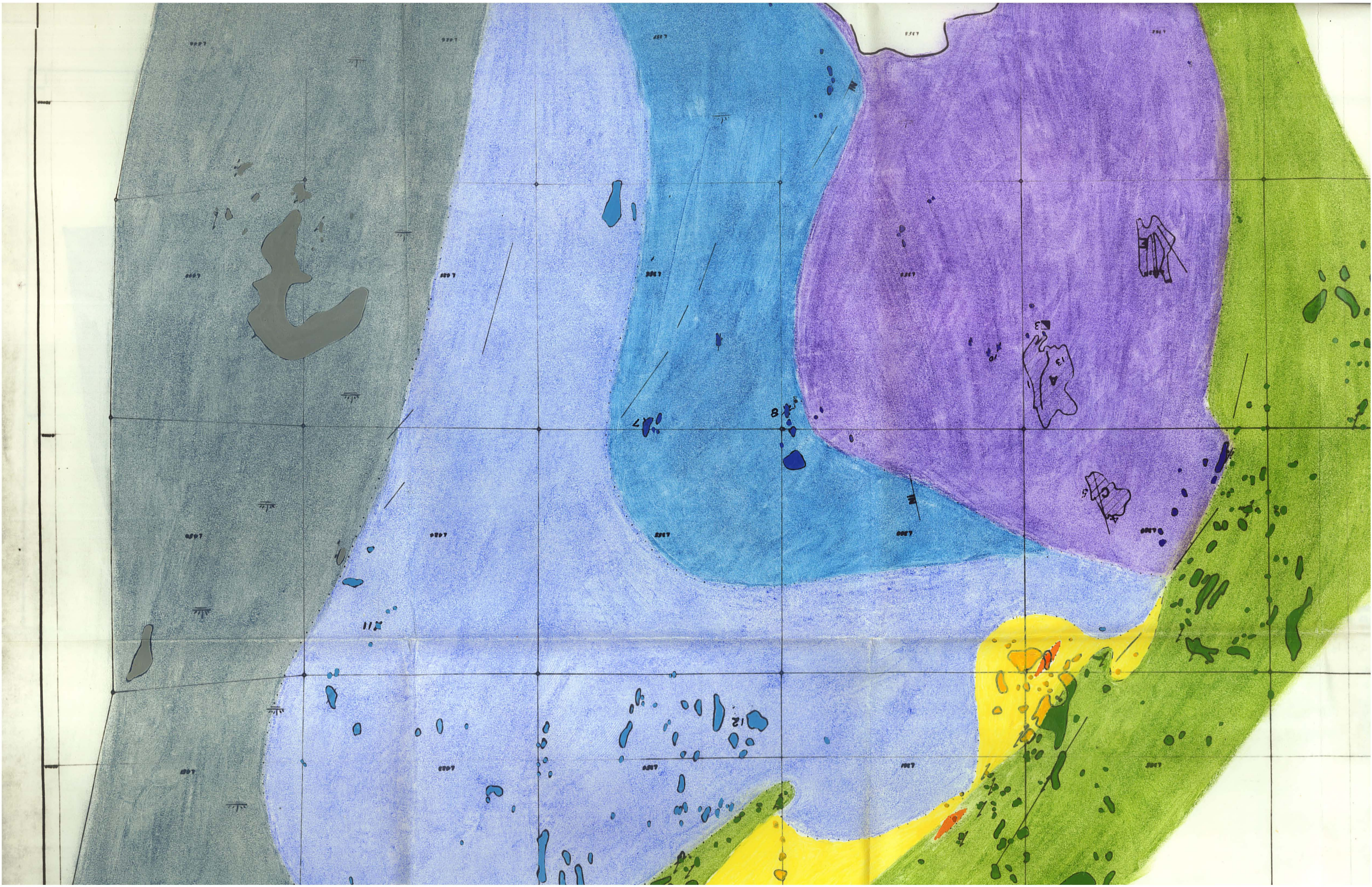
SIVE

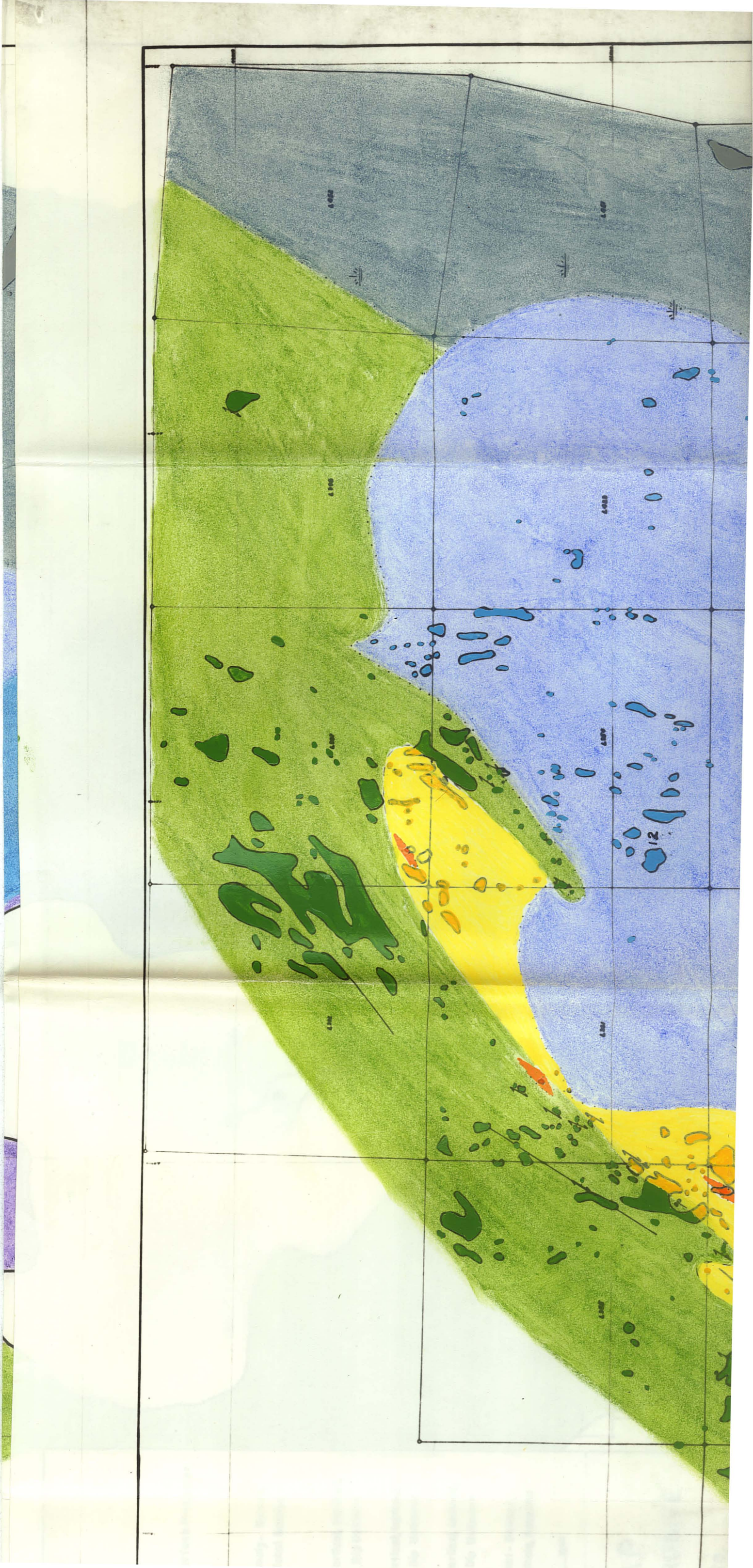
Hunter

LYNN LAKE
L 302





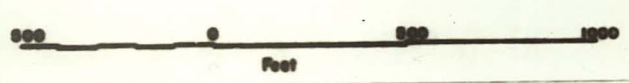




WASEKWAN-POST-SICKLE

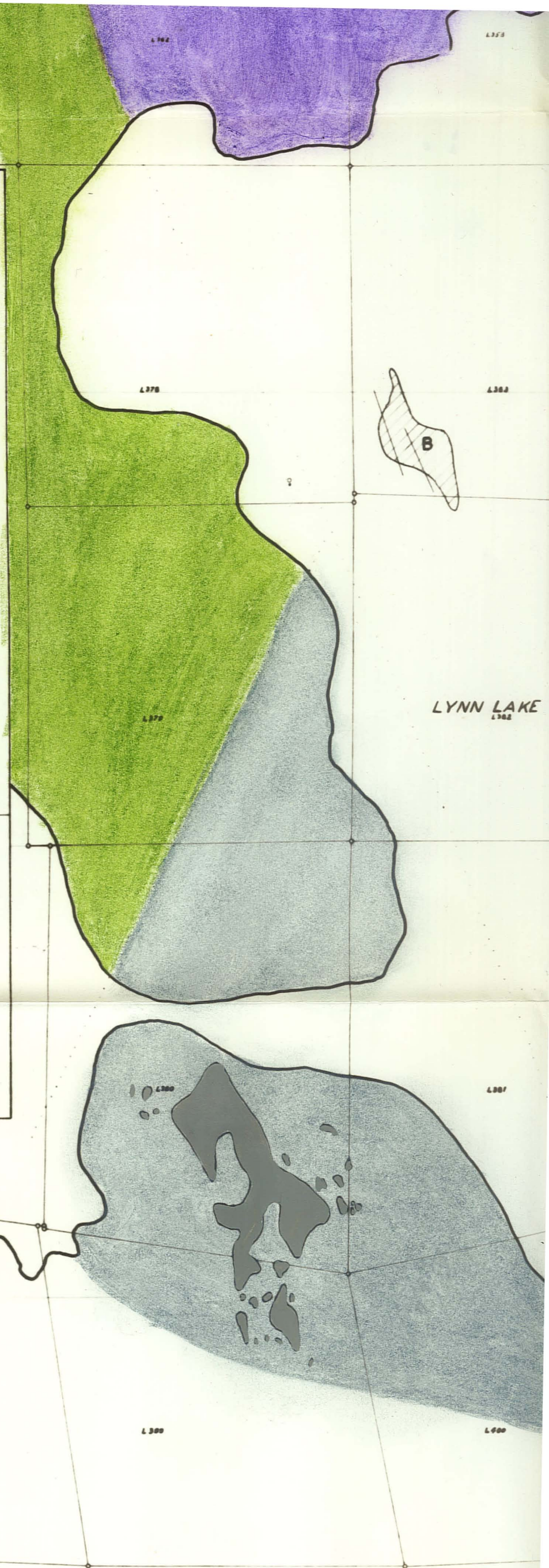
— LEGEND —

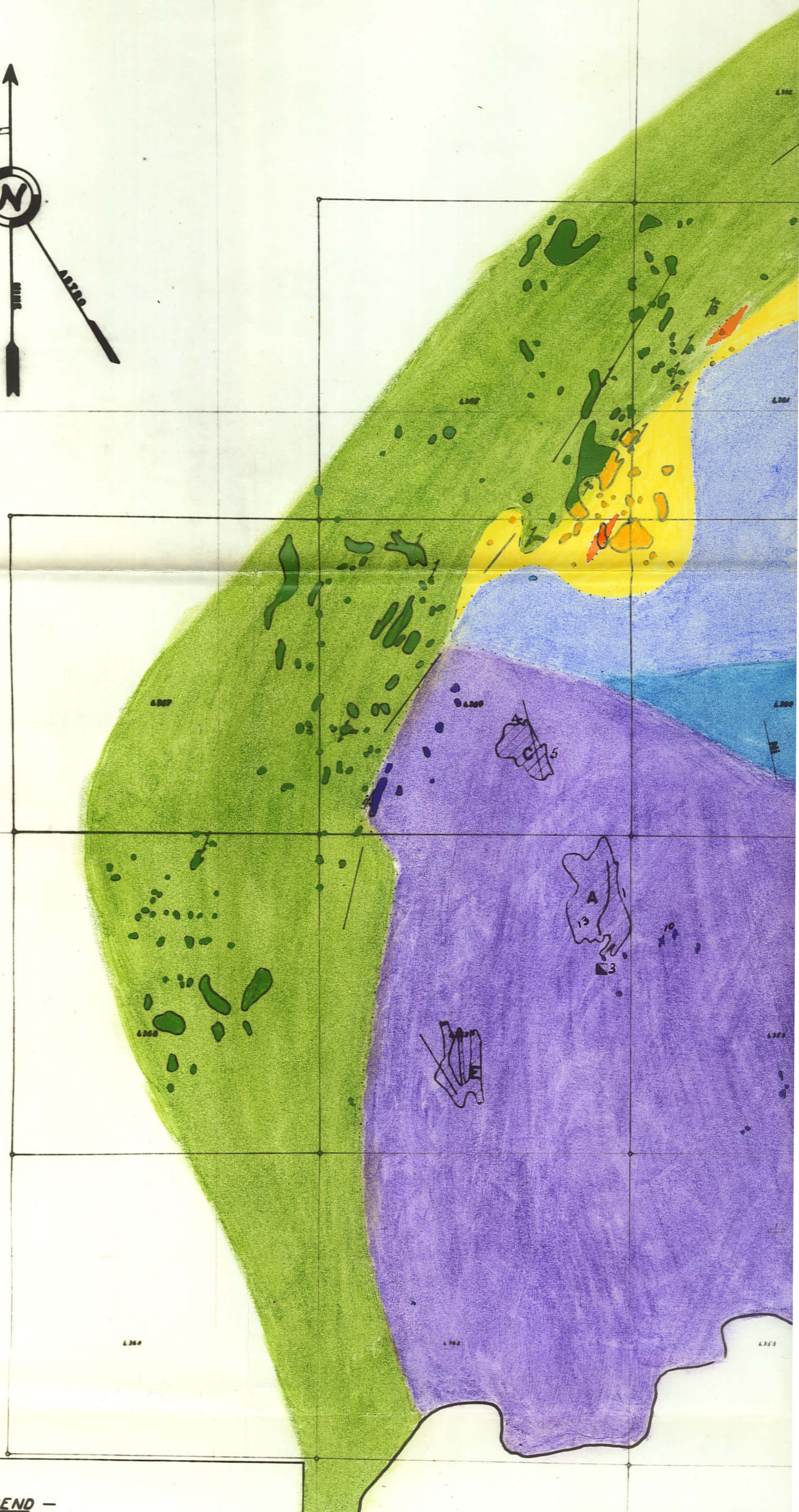
- | | |
|--|--|
|  Acid Intrusives |  Outcrop |
|  Basic Dykes |  Ore Body - Surface Projection |
|  Uralite Gabbro Phase C |  Mine Shaft |
|  Uralite Gabbro Phase B |  Magnetic Anomaly - Barren, Nickel Bearing |
|  Uralite Gabbro Phase A |  Swamp |
|  Sediments |  Schistosity - Vertical, Inclined, Dip Unknown |
|  Altered Volcanics |  Lineation - Vertical, Inclined, Dip Unknown |
|  Volcanics |  Shear Zone - Vertical, Inclined, Dip Unknown |
| |  Geologic Contact - Defined, Approximate, Assumed |



GEOLOGICAL MAP
LYNN LAKE BASIC INTRUSIVE
SHERRITT GORDON MINES LTD.

Geology by H.E. Hunter
April 1950





- LEGEND -