A STUDY OF THE COPPER-NICKEL-ZINC DEPOSIT OF BIRD RIVER MINES CO. LTD., SOUTHEASTERN MANITOBA.

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ABSTRACT

The "Ore Fault" copper-nickel deposit of Bird River Mines Ltd. contains an anomalous high amount of zinc mineralization. The small area containing the "Ore Fault" deposit is a faulted block containing metasedimentary and metavolcanic rocks of the Bird River Greenstone Belt and a sill-like body of ultramafic rock. The eastern part of the fault block is in sheared contact with a granite intrusion. The western part of the fault block is bounded by the 'ore fault' which also displaces the Bird River sill.

Copper-nickel ratios and copper-nickel-zinc values suggest a copper-zinc mineralization overlapped by a separate copper-nickel mineralization.

Copper-nickel ratios favour a magmatic origin for the copper-nickel mineralization. The host rocks appear to be ultramafic rocks which occur as small bodies in the deposit area. The copper-zinc plot does not correspond to a typical copper-zinc deposit which may be partly the result of mixing of the two proposed mineralization periods.

Sulphur isotope techniques were helpful in ascertaining a possible origin for the nickel and zinc mineralization. The sulphur isotope ratios obtained suggest that the nickel has a magmatic origin and the sphalerite does not have a sedimentary origin. The zinc mineralization could have originated from the mafic volcanic rock or the granite.

It is suggested that the products of two different mineralization periods were mixed by a later deformational or intrusive event.

FRONTISPIECE

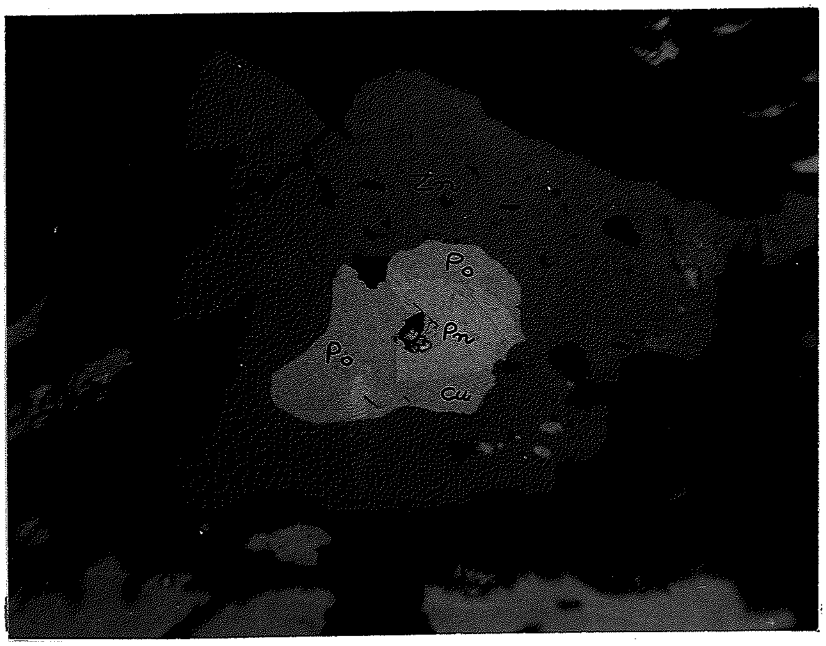

PLATE O: Copper, nickel, and zinc minerals occurring together in the "Ore Fault" deposit.
Po = pyrrhotite, Pn = pentlandite,
Cu = chalcopyrite, Zn = sphalerite.
X 100.8

This thesis is dedicated to my wife Jude.

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CHAPTER 1

INTRODUCTION

1.0 THE THESIS

The "Ore Fault" copper-nickel deposit contains an anomalous high amount of zinc mineralization. Copper-nickel-zinc deposits are uncommon and, e.g., are not included in the natural compositional groups of ore deposits (Wilson and Anderson, 1959).

The purpose of this thesis is to determine whether the zinc mineralization is originally associated with the copper-nickel mineralization or related to a separate event.

1.1 LOCATION AND ACCESSIBILITY

The "Ore Fault" Group of Bird River Mines is in southeastern Manitoba, 15.3 miles west of the Ontario-Manitoba Provincial border (lat. 50°28'40"N. and long. 95°30'W.).

The property is accessible by road from Lac du Bonnet, Manitoba. The road into the property joins the Cat Lake Road from the east 0.9 miles north of the Cat Lake Road and Bird Lake Road intersection.

1.2 HISTORY OF THE DEPOSIT

Copper-nickel mineralization in ultramafic rock was first discovered in 1953 when limited diamond drilling was undertaken on what was then called the Luckey Boy prospect. Mr. John Donner, who has been active in the area since 1930, staked this group in 1967 and contracted for a long wire Afmag Survey over the property. The survey defined a number of conductive zones, which were subsequently drilled. Each of the conductors drilled was found to be mineralized. Further surface stripping uncovered the north and south mineralized pits (see map in folder).

The area is included in Memoir 169, Canada, Department of Mines and Resources, Mines and Geology Branch, 1938; "Geology and Mineral Deposits of a Part of Southeastern Manitoba", by J.F. Wright. This report describes the regional geology of the area as well as the known mineral deposits.

The area is also included in the Province of Manitoba Mines Branch Publication 49-7 by G.D. Springer: "Mineral Deposits of The Cat Lake-Winnipeg River Area, 1950", which describes the regional geology of the area. This publication was written prior to the discovery and drilling of the Luckey Boy prospect (Ore Fault group).

The Province of Manitoba Mines Branch Publications 51-3 by J.F. Davies, "Geology of the Oiseau (Bird) River Area, 1952", is the first publication to specifically mention the Luckey Boy (Ore Fault) deposit. This paper refers to the original trenches found east of the existing surface exposures. Pyrrhotite, pyrite and chalcopyrite are the sulphide minerals noted in this report. The province of Manitoba Mines Branch Publication 54-1 by J.F. Davies, "Geology and Mineral Deposits of the Bird Lake Area, 1955", is similar to the previously mentioned Manitoba publication 51-3. The mapping for the report is at a scale of 1 inch = 1000 feet.

S. Karup-Möller and J.J. Brummer, (1971) reported on the area southeast of the "Ore Fault" deposit dealing with the copper-nickel deposit of Dumbarton Mines Limited.

The Manitoba Mines Branch is currently re-mapping the area including the Ore Fault property at a scale of 1 inch = ¼ mile.

1.3 FIELD WORK AND ACKNOWLEDGMENTS

In October, 1970 and June, 1971 the author spent several weeks mapping and sampling the Ore Fault property. Two maps with the following scales were compiled: 1 inch = 10 feet (in folder) and 1 inch = ¼ mile (P. 6).

The author wishes to acknowledge the assistance rendered to him by Dr. H.D.B. Wilson, who suggested the problem and gave guidance and criticism during the study. Thanks are also due to Dr. D.T. Anderson, who acted as my supervisor; Dr. A.C. Turnock, who helped with petrographic studies; and Mr. K. Ramlal, chemist of the Department of Earth Sciences, University of Manitoba, who provided the chemical analyses.

A very special vote of thanks is due to Mr. John Donner, the Property Manager of Bird River Mines Co. Ltd., who kindly allowed the author to map and sample the deposit, and examine the core and assay data.

The author also wishes to thank his colleagues at the University of Manitoba for many stimulating discussions and arguments which helped to clarify points of contention arising during this study. This appreciation is specifically extended to P.K. Seccombe who helped extensively with the sulphur isotope studies. Dr. R.H. Betts of the Chemistry Department (University of Manitoba) kindly made available the mass spectrometer for the sulphur isotope measurements.

CHAPTER 2

REGIONAL GEOLOGY

2.0 GENERAL STATEMENT

The regional geology of the area is described in J.F. Davies (1955). This report includes the deposit area, but does not refer to the area immediately to the west of the deposit (Figure 1).

The area to the west of the deposit is not adequately covered by previous reports. The author has therefore mapped the area which surrounds the deposit (Figure 2), at a scale of 1 inch = ¼ mile to tie in the geology with the work done by J.F. Davies and S. Karup-Möller and J.J. Brummer (1971).

2.1 REGIONAL GEOLOGY

Intermediate to basic metavolcanic and metasedimentary rocks of the Bird River Greenstone Belt underlie the greater portion of the map area. These are intruded by the Bird River Sill which is composed of sill-like bodies of gabbro and ultramafic rocks. The Bird River Greenstone Belt and the basic intrusions have been invaded in turn by large bodies of granitic rock. The granitic rocks are intruded by younger diabase dykes.

The Bird River Greenstone Belt appears to have been folded into a syncline whose axis lies within the sedimentary rocks of the group. Consequently, the sedimentary rocks overlie the lavas. Some of the rocks of the Bird River Greenstone Belt have been intruded by granite and numerous dykes and sills of pegmatite intrude the Bird River Greenstone Belt in the southeastern part of the area.

Faulting has affected all of the rocks of the region. Several easterly strike faults have been recognized, and probably others are present. Traverse faults, striking north-northwest, are abundant in the Bird Lake Belt.

Deposits of base metal sulphides are closely associated with

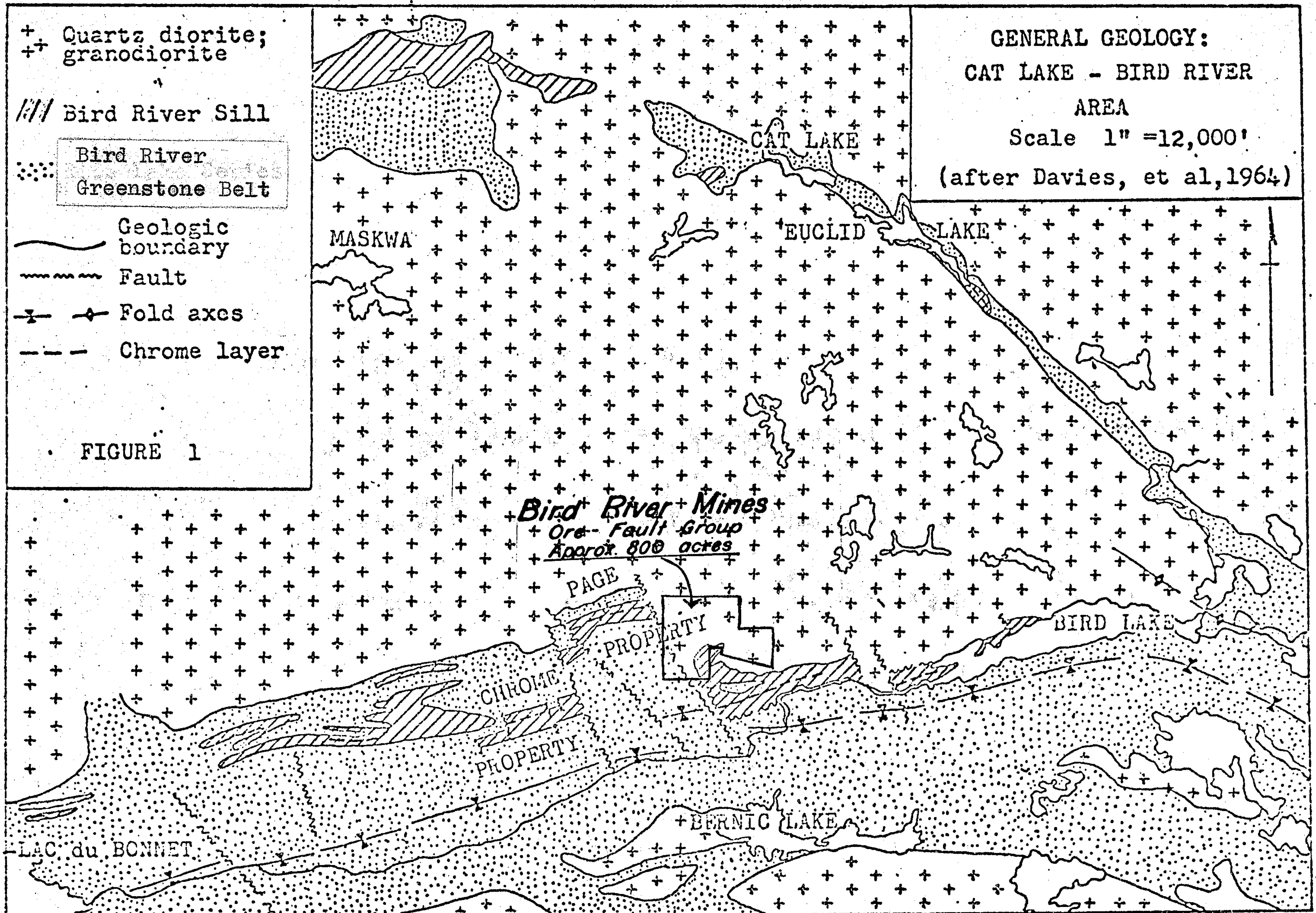

Quartz diorite; granodiorite
Bird River Sill
Bird River Greenstone Belt
Geologic boundary
Fault
Fold axes
Chrome layer
GENERAL GEOLOGY: CAT LAKE - BIRD RIVER AREA
Scale 1" =12,000'
(after Davies, et al,1964)
CAT LAKE
MASKWA
EUCLID LAKE
Bird River Mines
Ore- Fault Group
Approx. 800 acres
PAGE PROPERTY
CHROME PROPERTY
BIRD LAKE
BERNIC LAKE
LAC du BONNET

FIGURE 1

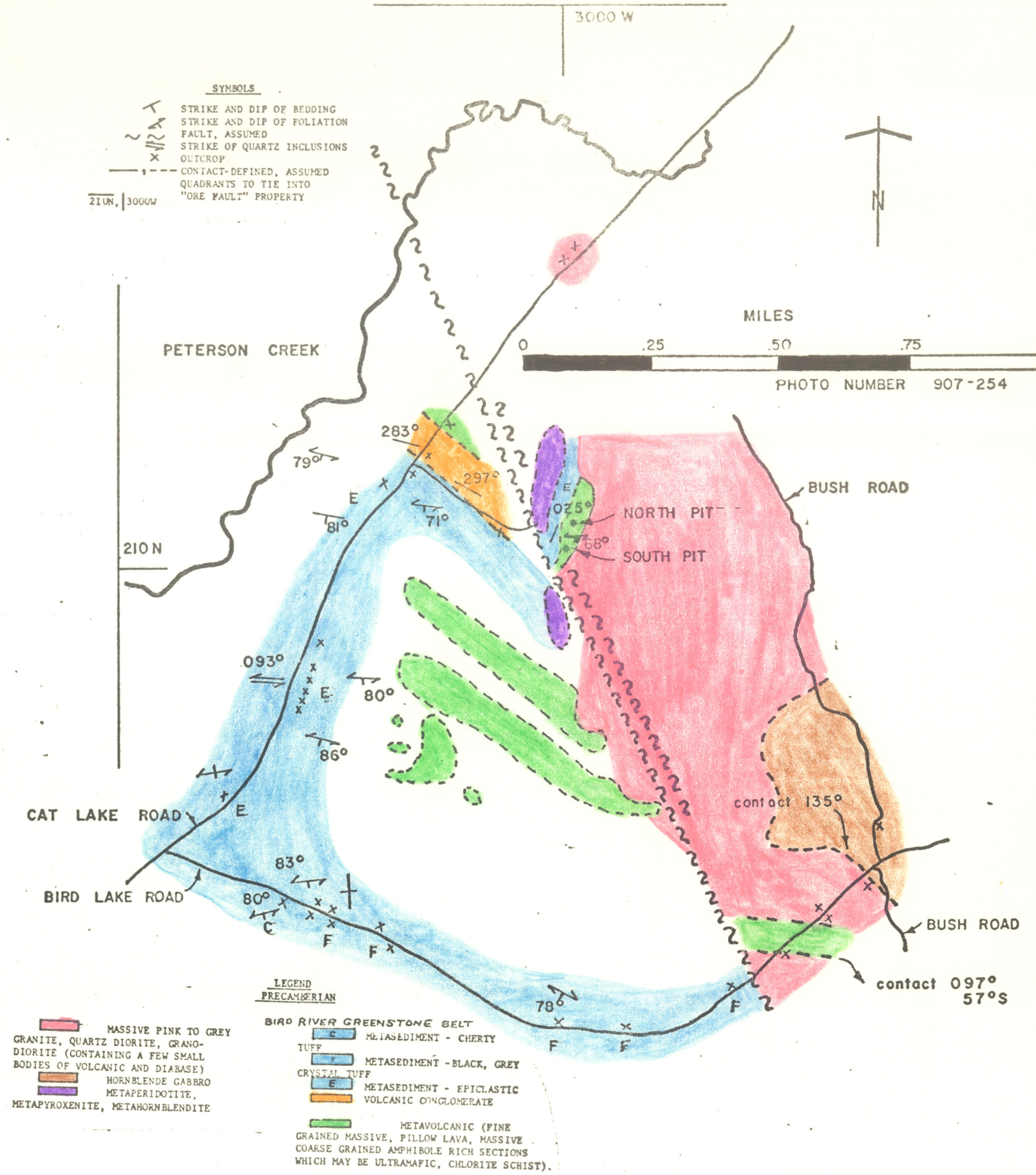


FIGURE 2: Regional Geology in the immediate area of the Ore Fault Deposit (~~after H.D.B. Wilson, 1952~~). The ultramafic body is outlined on the basis of data from drill cores, magnetic maps and surface mapping.

ultramafic, metavolcanic, and gabbroic rocks, and apparently occur along or near the contacts of these rocks with the granite. Chromite occurs near the top of the metaperidotite portion of the Bird River complex.

The accompanying table of formations (Table 1) indicates the classification of rocks within the area. In accordance with a previous interpretation for the area to the west (Davies, 1952, p. 6) all the rocks in the present area are considered Archaean in age.

2.1.1 BIRD RIVER GREENSTONE BELT

Rocks of the Bird River Greenstone Belt, occupying a belt three to four miles wide along Bird River, are flanked on both sides by granitic intrusions.

The lavas, andesite and basalt, and derived schists occur on the north and south sides of the belt; the central band consists of clastic sedimentary rocks - arkose, greywacke, tuff, and quartzose schists.

The volcanic and sedimentary rocks contain irregular bands of light - to dark-coloured, fine-grained siliceous rocks.

2.1.1.a Andesite

Narrow bands of massive andesite occur north of Bird River. In general, the lavas north of Bird River are less altered than those in the south part of the area.

The massive, fresh-looking, andesite, such as that occuring north of Bird River, is a fine - medium-grained, dark green to dark grey rock which is exposed in hummocky outcrops as much as 50 feet high. Some of the medium-grained varieties resemble fine-grained gabbro but flow features such as pillow structures and flow contacts, can be found in some places in the andesite.

2.1.1.b Greywacke, tuff, quartz-mica schist

The rocks of this unit constitute the lower members of the sedimentary portion of the Bird River Greenstone Belt. They are in contact with the southern volcanic belt but have not been observed in contact with the volcanic rocks north of the Bird River.

The different rock types in this unit are a fine-grained, dark brown, thinly laminated schistose greywacke, a fine grained,

TABLE 1
TABLE OF FORMATIONS
(after J.F. Davies, 1955)

<table>
<tr><td colspan="2">Recent
and
Pleistocene</td><td>Glacial clay and sand</td></tr>
<tr><td colspan="3">Great Unconformity</td></tr>
<tr><td rowspan="5">A
R
C
H
A
E
A
N</td><td rowspan="3">Intrusive
Rocks</td><td>Trap, diabase
Pegmatite dykes and sills
Granite, granodiorite, quartz diorite</td></tr>
<tr><td>Intrusive Contact</td></tr>
<tr><td>Hornblende gabbro
Peridotite, pyroxenite, hornblendite</td></tr>
<tr><td></td><td>Intrusive Contact</td></tr>
<tr><td>Bird River
Greenstone Belt</td><td>Silicified rocks
Arkose
Greywacke, tuff, quartz-mica schist
Andesite, basalt, derived schists</td></tr>
</table>

brown knotted cordierite schist, a fine to medium grained dark grey to black greywacke and schist, a dark green tuff and a fine to medium grained brown quartz mica schist.

2.1.1.c Arkose

Arkose occupies the central part of the sedimentary section of the Bird River Greenstone Belt and stratigraphically overlies the greywacke and related rocks. Thin beds of arkose are interbedded with some of the greywacke, and similarly, beds of greywacke commonly are interstratified with the unit mapped as arkose.

Two distinct textural types of arkose are readily distinguished; one is fine to medium grained, the other is coarse grained. Both types range from light to dark grey. The weathered surfaces of these rocks usually have a light brownish or orange cast.

2.1.1.d Silicified Zones

Cream, dark grey, or black, fine-grained siliceous chert-like rocks form several bands within the sedimentary portion of the Bird River Greenstone Belt. Two bands occur partly or wholly within the volcanic sequence. Some of the siliceous rocks exhibit thin delicate banding, others are entirely massive. Parts of some bands are coarser grained and have a sugary texture.

Davies (1955) states that there is evidence in some places that these fine-grained siliceous rocks are actually silicified greywackes, arkoses and lavas. Both the texture and structure of the siliceous rocks can be directly related to the rocks with which they are associated.

2.1.2 INTRUSIVE ROCKS

2.1.2.a Bird River Sill

Ultramafic rocks commonly underlie the gabbro in the Bird River Sill. This is true of the ultramafic-gabbro sill west of the "Ore Fault" property. This relationship, however, is complicated in places. It is probable that, in addition to the normal ultramafic-gabbro complex, separate gabbro intrusions occurred, which may account for the irregularities found in parts of the sill.

The ultramafic rock is soft, medium-grained, dark green to black; in places massive, elsewhere schistose. The weathered surface is dark green or reddish brown. Schistose ultramafic rock is soft and friable on surface. The minerals are all secondary; no relicts of the original constituents were found. In the sections examined, fibrous serpentine and tremolite made up the bulk of the rock. These minerals form a felted aggregate with chlorite, carbonate, and magnetite.

The gabbro section of the sill is composed of various phases differing in grain size and proportions of amphibole and plagioclase.

The ultramafic-gabbro complex is of special interest because of the chromite and copper-nickel sulphide which it contains.

2.1.2.b Granitic Intrusive Rocks

The Bird River Greenstone Belt and the basic intrusions are bounded on the north by a large mass of granitic rock. Other granitic bodies invade the volcanic rocks south, southeast, and west of Bernic Lake (southeast of the "Ore Fault" property). The edges of the granitic intrusions trend parallel to the regional structure.

Davies (1955), describes two types of granitic rocks; an altered grey granodiorite and a pink granite with a fresh appearance. The granodiorite is composed essentially of plagioclase and quartz with 10 to 20 per cent ferromagnesian minerals, usually biotite, and in places, hornblende. The massive pink granite is composed mainly of quartz, microcline, and biotite; it may also contain small amounts of albite or oligoclase.

Other phases, which range in colour from grey to pink, and can be distinguished only under the microscope, contain varying proportions of microcline and albite or oligoclase. Such rocks have been classified as granodiorite and quartz monzonite.

2.1.2.c Pegmatite

Pegmatite intrusions are common in the southeastern part of the area. These bodies occur as pegmatite dykes, sills and irregular bodies.

The pegmatite is of two types, microcline pegmatite and albite pegmatite. No direct evidence was found indicating the derivation of the pegmatite from any particular granite body in the area.

These dykes and sills range from a foot or less up to several hundred feet wide, and from a few tens of feet to as much as a mile in length. Remnants of country rock, lavas or sediments, commonly occur within the pegmatite bodies.

The pegmatite intrudes both the volcanic and sedimentary rocks of the Bird River Greenstone Belt.

2.1.2.d Diabase - Trap

A number of dark green or black fine to medium grained diabase and trap dykes, striking in a northwest direction, cut the granite north of Bird River. In addition to those which exhibit intrusive relationships, there are irregular areas of andesitic and gabbroic rocks in the granite. These are shown as andesite and gabbro on the map but little evidence relates them to the gabbro and andesite of the main volcanic belt. One of these irregular areas contains the "Ore Fault" deposit.

The diabase consists of amphibole and andesine in varying amounts. Some sections contain about equal quantities of amphibole and andesine, in others amphibole may form 75 per cent of the rock. Diabasic texture occurs in some specimens.

2.1.3 STRUCTURAL GEOLOGY

2.1.3.a Folding

The volcanic rocks and the rocks of the Bird River sill, in the north part of the area, dip and face towards the south. The volcanic rocks in the south-central part of the area face north. The volcanic rocks therefore form a syncline, the center of which is occupied by the overlying sedimentary rocks. The location of the synclinal axis is not known precisely, but it lies within the sedimentary rocks.

The sedimentary rocks all dip steeply southward at angles of 75 to 85 degrees, indicating that the south limb of the syncline is overturned. Schistosity in the lavas and sediments is generally parallel to the bedding. There are also indications of some local minor tight folding.

2.1.3.b Faulting

A major northwest trending fault is located near the "Ore

Fault" deposit. This fault has caused the Bird River sill, which trends east-west to be displaced a considerable distance (Davies, 1952). One section is located north and west of the "Ore Fault" deposit. The gabbro-peridotite intrusion located southeast of the "Ore Fault" deposit is the other part of the Bird River sill which has been faulted southward. However, the major northwest fault which caused the displacement does not come in contact with this peridotite and gabbro intrusion because of pre-fault intrusion of granite and east-west post-granite faulting (Figures 1 & 2).

The post-granite nature of faulting is well illustrated by the faults west and north of Bird Lake. A large number of north-northwest faults cut the granite. Most are visible as distinct lineaments on aerial photographs, and generally can be seen on outcrops of the granite. Some of these faults dip steeply eastwards, others are essentially vertical.

The large fault which displaces the Bird River sill is located approximately 165 feet west of the "Ore Fault" deposit (south pit). It is not exposed on surface, however. The author believes that the deposit area is related to this fault or perhaps to another fault just east of the main fault and trending in the same direction.

CHAPTER 3

DETAILED GEOLOGY

3.0 GENERAL STATEMENT

The table of Formations (Table 1) in Chapter 2 is valid for this discussion on detailed geology. A volcanic conglomerate unit should be added to the Bird River Greenstone Belt. The area immediately surrounding the "Ore Fault" deposit has been mapped at a scale of one inch equals ¼ mile (Figure 2). The area including the surface exposures of the "Ore Fault" deposit has been mapped at a scale of one inch equals 10 feet (large map located in the back folder).

3.1 DETAILED GEOLOGY

Fine grained black to dark green metavolcanic rocks occur in the deposit area. Metasedimentary rocks are observed in two varieties: volcanic conglomerate, and epiclastic metasedimentary rocks.

The small area containing the "Ore Fault" deposit is a faulted block containing metasedimentary and metavolcanic rocks of the Bird River Greenstone Belt and a sill-like body of ultramafic rock. The fault block is bounded on the southeast, east, and north by a granite intrusion. The western part of the fault block is bounded by the 'ore fault' which also displaces the Bird River sill. The deformation in the surface exposures of the "Ore Fault" deposit can possibly be explained by the proximity to the acid intrusion and also to the 'ore fault'.

The sulphide mineralization in the "Ore Fault" deposit is contained in a series of shears on the surface (large map in folder) and at depth. The massive nickel mineralization appears to be related to the amphibole rich metavolcanic rock in the deposit area. The amphibole rich rock could possibly be an actinolitic hornblendite ultramafic rock.

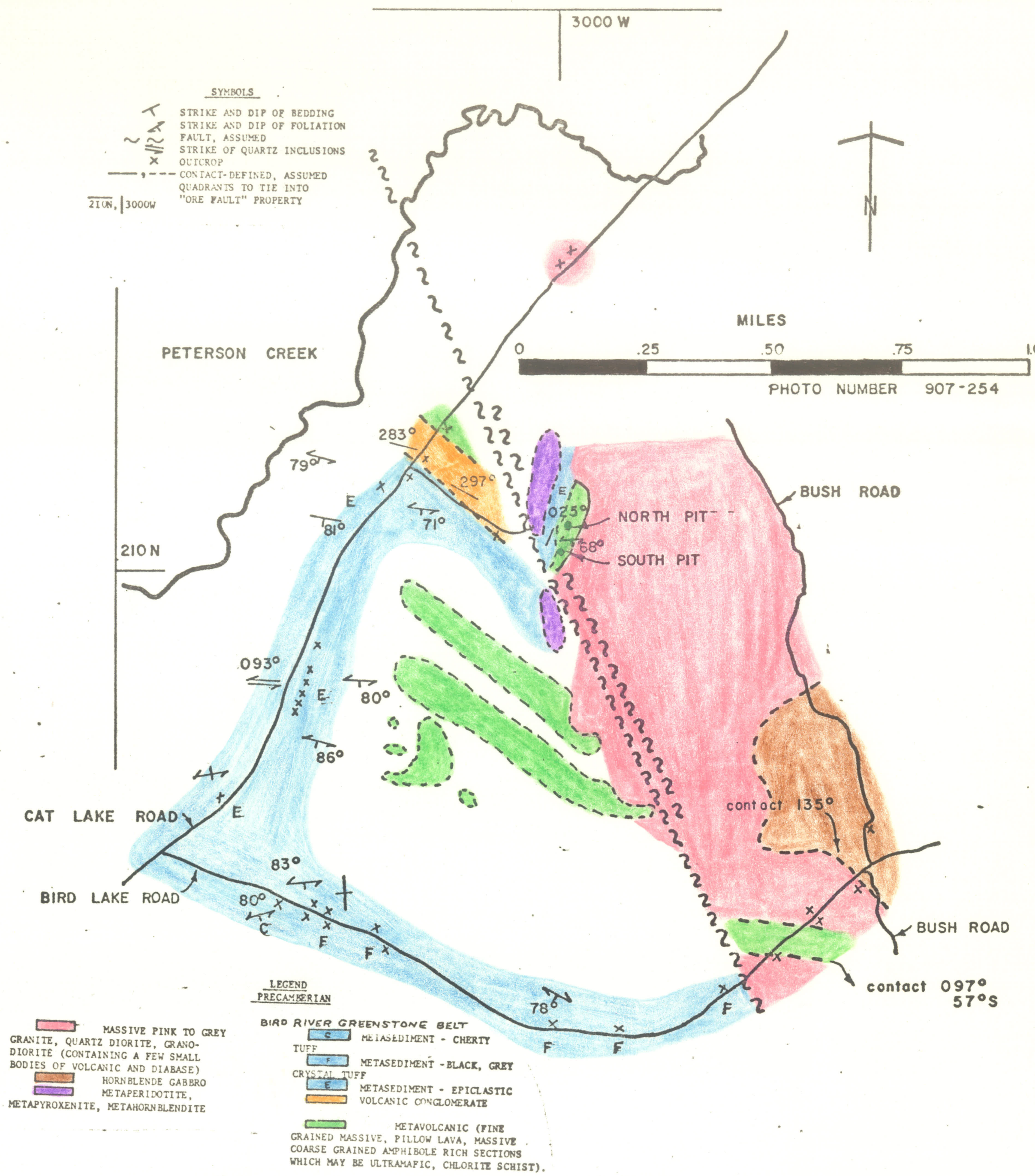


FIGURE 2: Regional Geology in the immediate area of the Ore Fault Deposit (after H.D.B. Wilson, 1952). The ultramafic body is outlined on the basis of data from drill cores, magnetic maps and surface mapping.

3.1.1 Bird River Greenstone Belt

3.1.1.a Metavolcanic Rocks

Metavolcanic Rocks are observed in many varieties: fine grained massive, pillow lava, chlorite schist, and massive coarse grained amphibole rich sections which may be ultramafic rocks. In addition, a fine grained massive variety occurs along the Cat Lake Road northwest of the deposit area (Figure 2).

All four varieties of metavolcanic rocks occur also in the surface exposures of the "Ore Fault" deposit. The north pit contains two varieties: a fine grained massive slightly mineralized variety which is located in a small area in the northern portion of the pit and a medium grained highly mineralized amphibole rich rock which is observed in the rest of the north pit. Thin section analysis indicates that this latter rock is composed of 99% blue green actinolitic amphibole which exhibits a non-oriented texture. This rock is either a highly altered metavolcanic rock or possibly an ultramafic rock (an actinolitic hornblendite - chemical analysis 804) which has intruded the pre-existing volcanic and sedimentary rocks. This amphibole rich rock in the north pit becomes less mineralized and less coarse grained toward the east. A granite intrusion is observed in contact with this amphibole rich rock a few hundred feet east of the north pit (Figure 2).

The south pit contains all four varieties of metavolcanic rocks. The chlorite schist appears to be an extension of the mineralized shears into the nonmineralized metavolcanic rock. The pillow basalts are located in the northern part of the pit (Plate A & chemical analysis 500). The small area of amphibole rich rock in the south central portion of the pit is similar to the amphibole rich rock in the north pit. This fine to medium grained amphibole rich rock could either be an extremely altered volcanic rock, as it is shown on the map, or an actinolitic hornblendite ultramafic rock which has intruded the pre-existing volcanic rock (chemical analysis 506). Plate B shows the amphibole rich rock, left, in sheared contact with a metasedimentary rock, right. Fine grained massive

PLATE A: Pillow basalt in northern part of south pit.

PLATE B: Sheared contact between amphibole rich rock (left) and metasediment (right) in the south pit.

metavolcanic rock which is similar to the fine grained rock in the north pit is observed in areas of the south pit.

Small outcrops of fine grained massive metavolcanic rock occur between the north and south pits. A small mineralized shear was observed in one of these outcrops (large map in back folder).

3.1.1.b Volcanic Conglomerate

Volcanic conglomerate occurs along the Cat Lake Road approximately 50 feet north of the road leading into the "Ore Fault" property. This unit strikes in a westerly direction (283^{o}). The conglomerate is observed in contact with a fine grained epiclastic metasediment at the junction of the Cat Lake Road and the road into the "Ore Fault" property. This metasediment also strikes in a westerly direction (278^{o}). Another outcrop of this conglomerate is observed southeast of the above occurrence close to the deposit area.

The fragments of the conglomerate consist of fine grained basic to intermediate volcanic rocks and fine grained quartzo-feldspathic rocks. The fragments are poorly rounded and range in size from half an inch to six inches. The matrix is argillaceous and ineguigranular.

3.1.1.c Metasediments

Pelitic metasedimentary rocks occur commonly in the deposit area and the surrounding area. These metasediments appear to be partly conglomeratic metagreywackes.

Metasedimentary rocks containing garnet, clear quartz and/or cordierite are observed in the southwest portion of the south pit. Plate C shows a rounded elongated fragment in a metasediment; note the presence of garnets, quartz eyes and/or cordierite crystals.

A small outcrop of mineralized metasediment is located between the two pits. Thin section analysis shows a fine grained rock containing mostly biotite and quartz with some chlorite but no feldspar. This rock type appears to be related to the metasediment

PLATE C: Elongated fragment in metasediment

in the south pit and the metasediment located northwest of the north pit.

3.1.2 Intrusive Rocks

3.1.2.a Ultramafic and Gabbroic Rocks

Two narrow bands of ultramafic rock occur in the vicinity of the "Ore Fault" deposit. These ultramafic bodies strike northeasterly, perpendicular to the strike of the Bird River sill. There is no evidence suggesting that these ultramafic bodies are related to the Bird River sill.

An ultrabasic rock type is observed on surface approximately 150 feet north and 200 feet west of the north pit. A thin section of this rock shows radiating crystals of amphibole and chlorite. This rock type is a metapyroxenite (chemical analysis 103). Another ultramafic rock (a medium grained grey talc-actinolite schist) is found in drill core close to the surface approximately 200 feet west and 100 feet north of the latter surface ultramafic rock. This rock type is a metaperidotite (chemical analysis 24-262). The proximity of these ultramafic bodies suggests that the "Ore Fault" copper-nickel sulphide body may be related to an ultramafic source rock. The mineralized amphibole rich "metavolcanic" rock in the north and south pits is a possible ultramafic rock.

A polished section taken from drill core located approximately 380 feet west of the north pit and at a depth of approximatly 10 feet contains chromite crystals indicating that the talc schist host rock is an ultramafic rock (Plate H, Polished Sections chapter).

A hornblende gabbro body occurs southeast of the "Ore Fault" deposit along the Bird Lake road (chemical analysis 323). Davies (1955), states that this gabbro is part of the Bird River sill.

3.1.2.b Granitic Intrusive Rocks

The deposit area is intruded by granitic rock (chemical analysis PR9, Figure 2). The volcanic rock and metasedimentary rock are in sheared contact with the granite in the southeast portion of the south pit (Plate D). The granite also intrudes the metavolcanic

PLATE D: Sheared contact between volcanic (top) and metasediment (bottom) on the left with granite on the right; looking northeast.

rock in the northwest portion of the south pit. This contact is very irregular (Plate E).

The granite also intrudes the metavolcanic rock in a small outcrop located between the north and south pits.

3.1.3 Structural Geology

The strike of the rock units in the deposit area is different from the regional strike of the Bird River area. This anomalous trend suggests that the small area containing the "Ore Fault" deposit is a fault block that is wedged between two shears.

The fault block is bounded on the southeast by a granite intrusion (Figure 2). The sheared contact between the fault block and the granite is observed on surface (Plate D). The granite also bounds the fault block to the east and north. The western part of the fault block is bounded by a major northwest trending fault (the 'ore fault') which has been described by Davies (1955).

The 'ore fault' which also displaces the Bird River sill does not appear on surface. The reason why it has been called a fault is because of the apparent displacement of the rock types on either side.

3.1.4 Sulphide Mineralization

The deposit area contains three surface showings: the north and south pits and the original prospect trenches located northeast of the north pit. Plate F shows a view of the south pit and Plate G a view of the north pit. The sulphide mineralization is contained in a series of shears in the north and south pits. The north pit also contains an area of massive mineralization located west of the main north-south trending shear.

A small outcrop of mineralized metasediment is located between the two pits. South of the latter metasediment a small mineralized shear is observed in a small outcrop of metavolcanic rock.

PLATE E: Irregular contact between granite (left, light grey) and metavolcanic (right, brownish); looking east.

PLATE F: South Pit looking southeast.

PLATE G: North Pit looking northeast.

CHAPTER 4

METAL RATIOS

4.0 INTRODUCTION

Metal ratio graphs were utilized to determine whether or not the "Ore Fault" deposit originated as a copper-nickel-zinc ore body or as the result of the mixing of two separate ore bodies. Drill core assays from the "Ore Fault" deposit were used to calculate the metal ratios. Assays were also plotted on two triangular co-ordinate graphs to determine the relationships between the copper, nickel, zinc, and silver mineralization in the deposit.

A relationship between copper and nickel generally exists in typical Canadian Archean ore bodies associated with mafic and ultramafic rocks (Wilson and Anderson, 1959). The author has chosen the ratio Cu/Cu+Ni plotted against frequency to express this relationship. The distribution obtained from the "Ore Fault" deposit is compared to the distribution from a typical copper-nickel ore body. A cumulative frequency curve has been plotted (Logarithmic Ratio Cu/Cu + Ni against Cumulative Frequency), for the "Ore Fault" deposit to compare the median copper-nickel ratio to other deposits.

The distribution of copper and zinc in copper-zinc ore bodies differs from that of copper and nickel in copper-nickel ore bodies (Wilson and Anderson, 1959). Copper-zinc samples do not have a well defined median like copper-nickel ores but they do have a definite pattern of distribution. The author has chosen the ratio Cu/Cu+Zn plotted against frequency to express this relationship. The distribution obtained from the "Ore Fault" deposit is compared to the distribution from a typical copper-zinc ore body.

A triangular co-ordinate graph with copper, nickel and zinc at each of the three co-ordinates is plotted to determine if any relationship exists between the three metals (Figure 3). The individual assays are expressed as a percent of the total weight per cent of the three assays (i.e. Cu+Ni+Zn = 100%). The individual assays are then calculated as a per cent of the total (203 assays from drill core) for equal areas and then contoured.

Silver assays from the deposit have been superimposed on the above triangular co-ordinate graph to indicate a possible relationship between silver and either copper, nickel, or zinc. The silver assays have also been contoured according to their per cent frequency.

The drill core assays were done by the Department of Earth Sciences chemistry laboratory at the University of Manitoba and the Mineral Processing Division, Geological Survey of Canada, Ottawa.

4.1 DISCUSSION OF RESULTS

4.1.1 Copper-Nickel Ratios

The Cu/Cu+Ni graph plotted for the "Ore Fault" deposit (Figure 4) resembles other typical ore bodies (Figure 5) in many ways but differs in some important features. The large peak to the left of the graph is a typical distribution curve suggestive of a copper-nickel deposit associated with a magmatic environment. The unusual smaller peak to the right of the graph in the copper rich zone is perhaps indicative of a separate mineralization; i.e., a copper-zinc mineralization. This small peak could also be indicative of a copper rich zone within the copper-nickel deposit. Present studies, however, with polished sections and hand specimens have not indicated that a copper rich zone exists. Polished sections studies also indicate that copper and zinc sulphides occur together and are intimately associated (Plate M). The small peaks in the Cu/Cu + Ni = 0.00-0.07 range and 0.95-1.00 range may be related to the inaccuracy of trace assays.

The Cu/Cu+Ni median value for the "Ore Fault" deposit is 0.26 (Figure 7). This value is similar to values obtained for

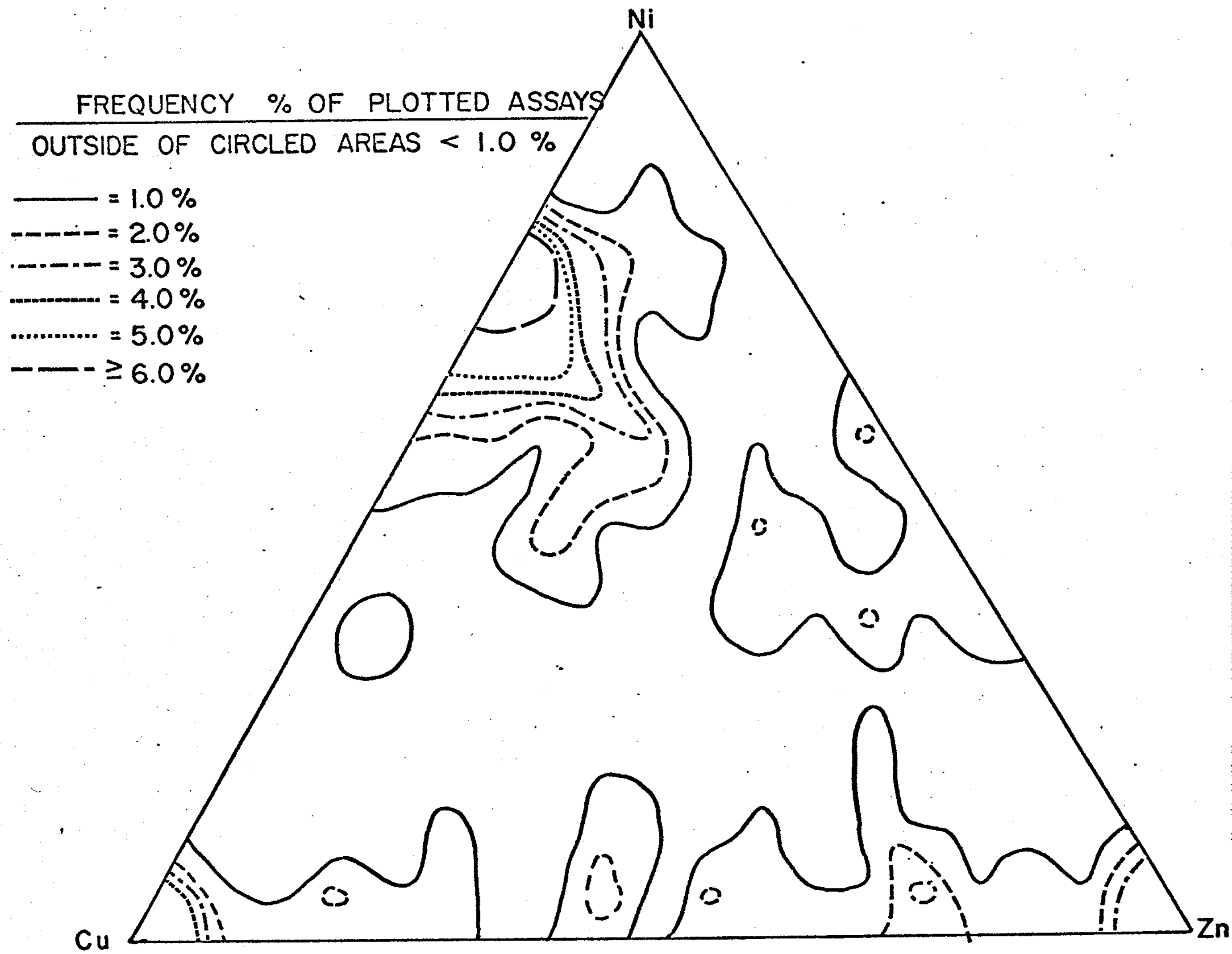


FIGURE 3: Plots of copper, nickel and zinc in the "Ore Fault" deposit (203 assays).

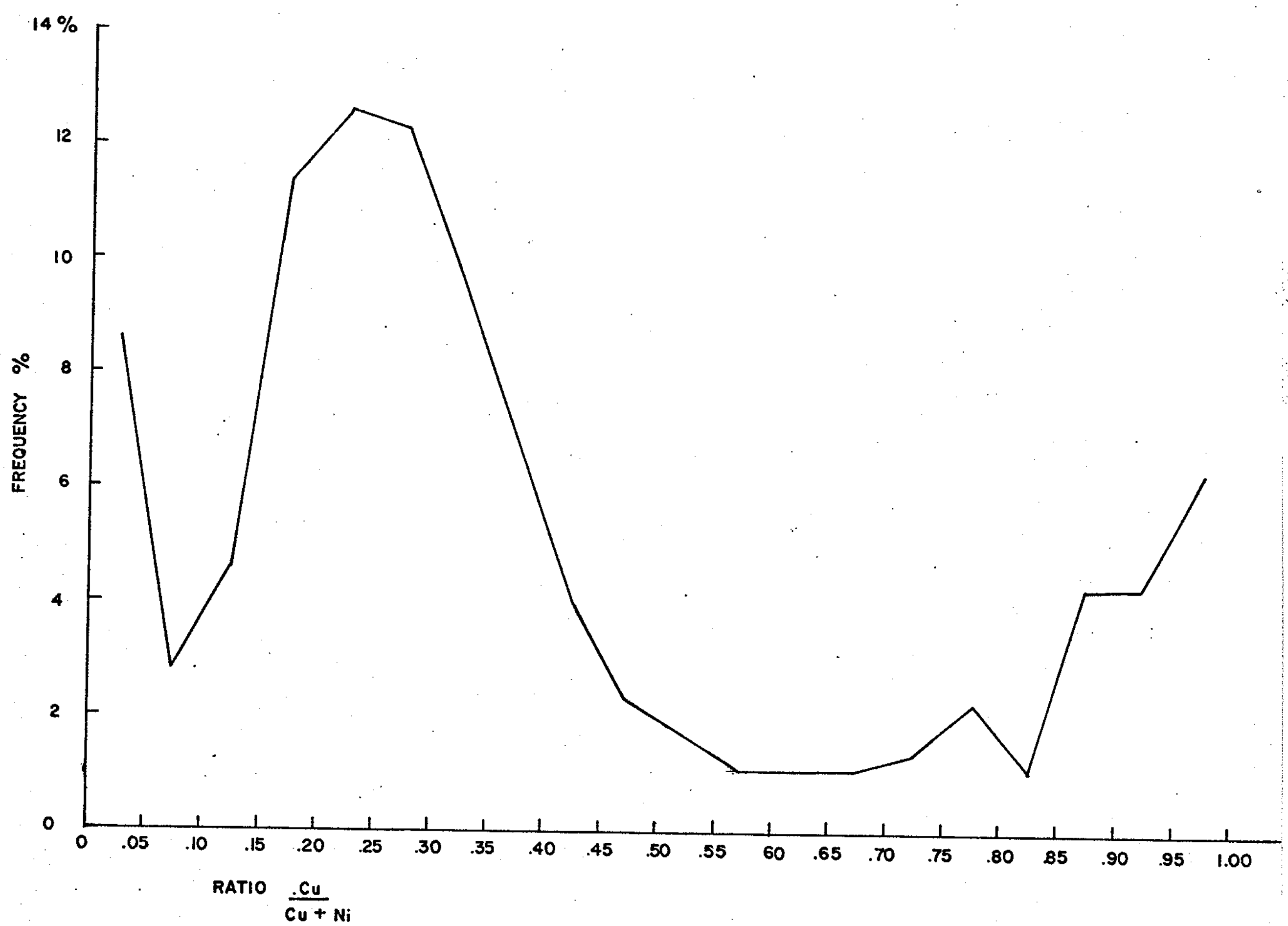


FIGURE 4: The frequency distribution of copper-nickel ratios for the "Ore Fault" deposit (350 assays from drill holes 1, 4 - 28 and surface samples).

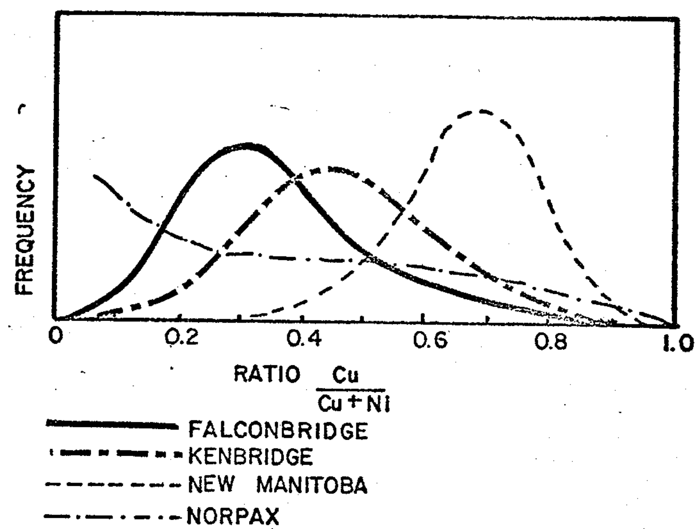


FIGURE 5: Frequency distribution of copper:nickel ratios in copper-nickel sulphide ores (after Wilson and Anderson, 1959).

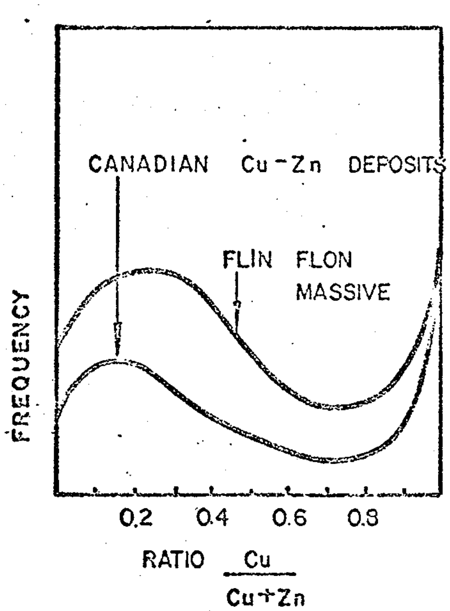


FIGURE 6: Comparison of the frequency distribution of copper-zinc ratios in samples of Flin Flon massive ore with frequency of compositions of Canadian copper and zinc ore deposits (after Wilson and Anderson, 1959).

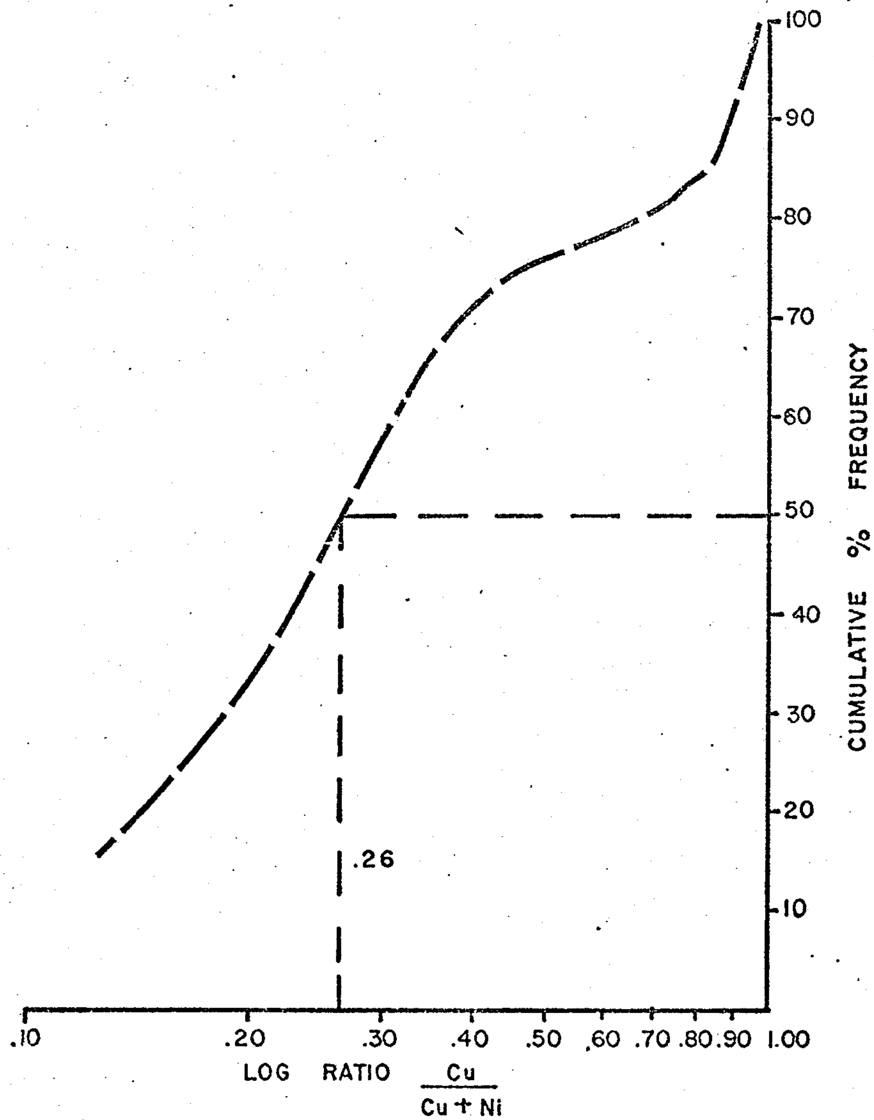


FIGURE 7: A cumulative frequency curve for the "Ore Fault" deposit. The median value obtained is Cu/Cu+Ni=0.26.

other typical copper-nickel ore bodies related to ultrabasic rocks. The values for the nearby Dumbarton deposit are 0.50(0-0.75% Ni), 0.21(0.75-1.5% Ni), and 0.13(1.5+% Ni) (Wilson and Anderson, 1959).

4.1.2 Copper-Zinc Ratios

The Cu/Cu+Zn plotted against frequency for the "Ore Fault" deposit does not exhibit a definite pattern of distribution (Figure 9). This random pattern suggests that the "Ore Fault" deposit is not a typical copper-zinc deposit (Figure 6-Page 28). This random pattern may be the result of the mixture of two different mineralizations.

4.1.3 Copper-Nickel-Zinc Relationships

A triangular co-ordinate graph with copper, nickel, and zinc at each of the co-ordinates clearly shows two types of mineralization: a copper-nickel mineralization with nickel equal to approximately three times the copper; a copper-zinc mineralization spread over a wide range.

4.1.4 Silver

The silver appears to be related to the copper-zinc mineralization (Figure 10). This is especially true for the zinc rich mineralization. The silver is not related to the maximum zone of copper-nickel mineralization. The few silver values located in the nickel-zinc region can be explained by the presence of argentian pentlandite (Dr. D.T. Anderson, personal communication). There are, therefore, two types of pentlandite: one carrying silver with little associated copper and one without silver and associated with copper.

4.2 CONCLUSIONS

The distribution curve for the Cu/Cu+Ni graph and the favourable median copper-nickel ratio suggest that the "Ore Fault" deposit is primarily composed of a copper-nickel magmatic ore body. The triangular co-ordinate graph provides further proof of the presence of a strong copper-nickel association suggestive of a copper-nickel ore body derived from a mafic to ultramafic magma.

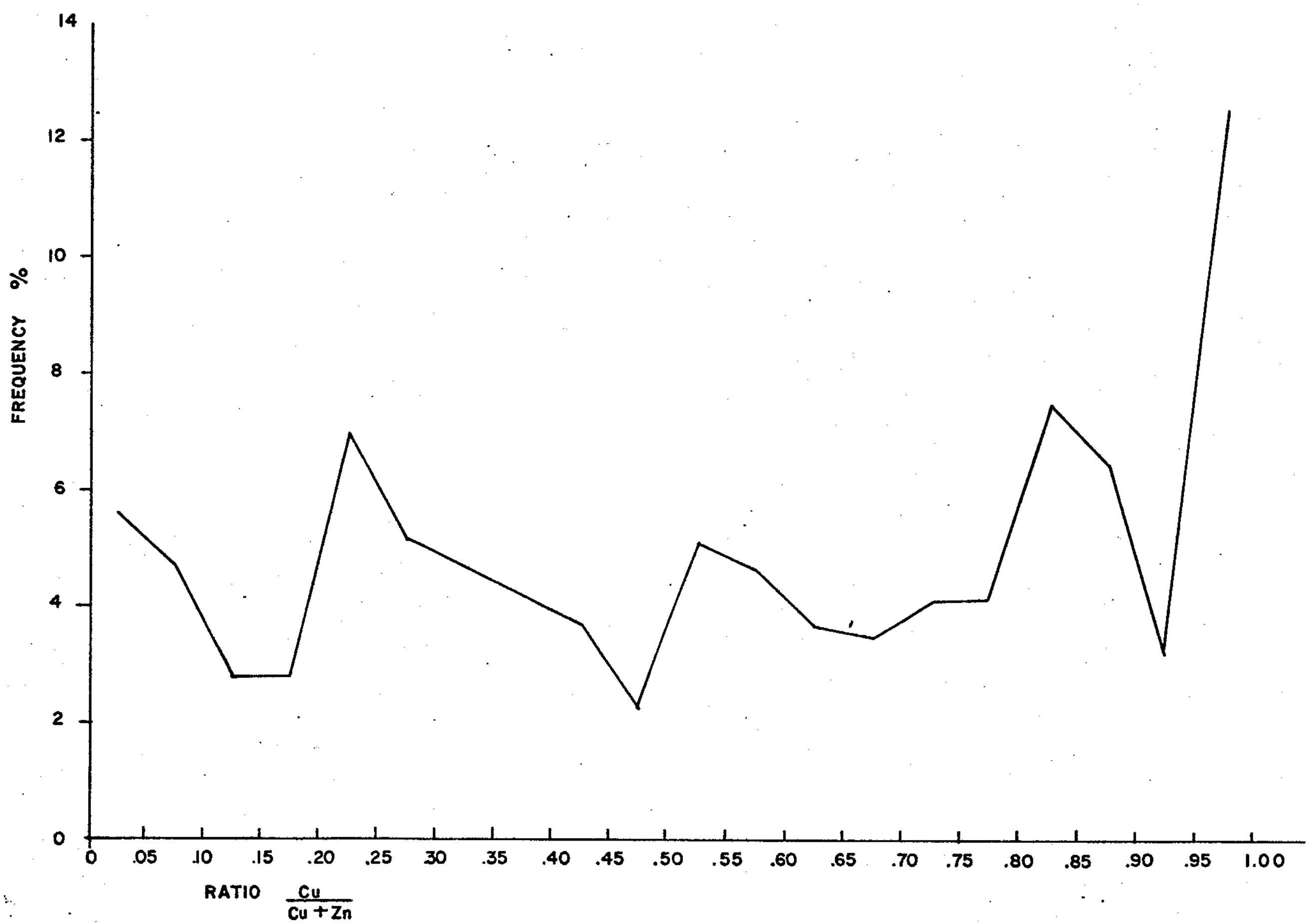


FIGURE 9: The frequency distribution of copper-zinc ratios for the "Ore Fault" deposit (214 assays from drill holes 1, 4 - 28 and surface samples).

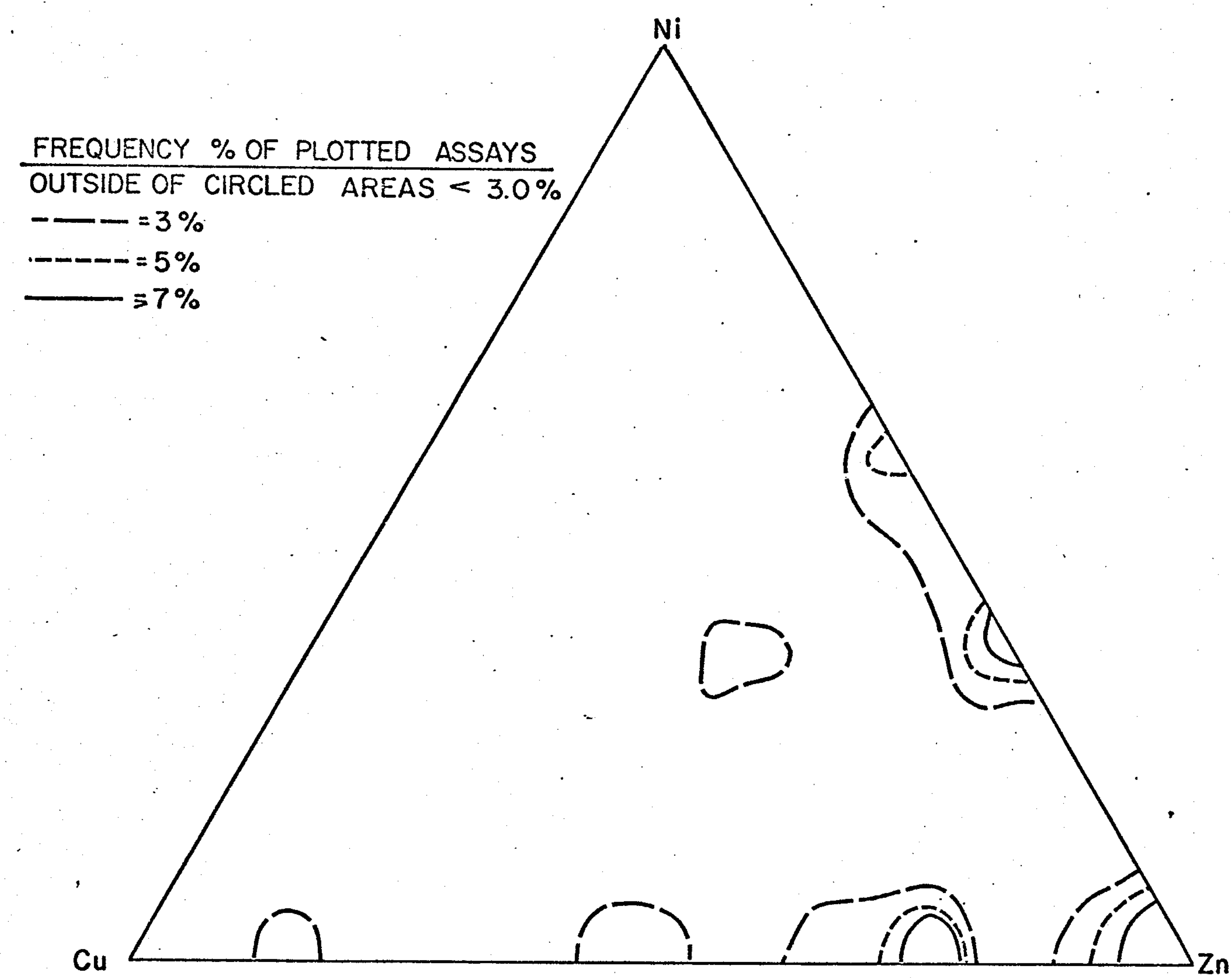


FIGURE 10: Silver values of "Ore Fault" deposit, superimposed on Figure 3 (57 assays ≥ 0.50 oz./ton silver).

The bi-modal distribution for the Cu/Cu+ Ni graph suggests that the "Ore Fault" deposit is composed of two periods of mineralization or possibly remobilization. These two periods of mineralization are a copper-nickel mineralization and a zinc or copper-zinc mineralization. Polished section studies and the copper-zinc concentration in the triangular co-ordinate graph suggest that zinc occurs predominantly with copper mineralization.

The random pattern displayed in the Cu/Cu+ Zn graph suggests that the "Ore Fault" deposit is partially composed of a non-typical copper-zinc ore body. The triangular co-ordinate graph provides further proof of the presence of an irregular copper-zinc mineralization.

The random pattern may be the result of two overlapping periods of mineralization; i.e., the copper related to the copper-nickel mineralization may overlap the copper related to the copper-zinc mineralization.

This atypical copper-zinc occurrence appears to be associated with the volcanic host rock. The copper-nickel-zinc ore body appears to have been caused by the deposition of a copper-nickel mineralization related to an ultramafic intrusion near an earlier copper-zinc mineralization. Later faulting and intrusions have helped to mix the two sulphide occurrences together to form the "Ore Fault" deposit. It is unlikely that the granite was a possible source for the copper-zinc mineralization, because the granite is not mineralized.

CHAPTER 5

POLISHED SECTION EXAMINATION

The opaque minerals present in the "Ore Fault" deposit and nearby host rocks are pyrite, pyrrhotite, pentlandite, sphalerite, chalcopyrite, ilmenite, chromite, magnetite, and violarite. Smythite (approximate formula is $Fe_3 S_4$), which can contain up to 15% nickel, and argentian pentlandite have been identified by X-ray analysis (Personal communication: E.H. Nickel and S. Scott to Dr. D.T. Anderson).

The opaque minerals observed in the south pit listed in their order of abundance are pyrite 72%, sphalerite 16%, chalcopyrite 8%, pyrrhotite 4%, and a trace of ilmenite. 'Sooty' violarite is present but it is not observed in polished sections due to its unpolishable nature. The opaque minerals observed in the north pit listed in their order of abundance are pyrrhotite 60%, chalcopyrite 30%, sphalerite 7%, and ilmenite 3%. 'Sooty' violarite is also present but it is not observed in polished sections. The opaque minerals observed in Hole 21 (Figure 11) listed in their order of abundance are pyrrhotite 42%, sphalerite 28%, chalcopyrite 20%, pentlandite 9%, and ilmenite 1%. The opaque minerals observed in Hole 28 (Figure 11) listed in their order of abundance are pyrrhotite 85%, sphalerite 5%, ilmenite 5%, and chalcopyrite 5%.

5.0 PYRITE

Pyrite mineralization is observed only in the south pit. Euhedral pyrite crystals are commonly observed (Plate J). Pyrite does not have the brecciated appearance that is common in the other opaque minerals. This is especially true of the south pit which exhibits more shearing than the north pit.

FIGURE 11 : POLISHED SECTION LOCATIONS "ORE FAULT" DEPOSIT; 1 inch = 100 feet.

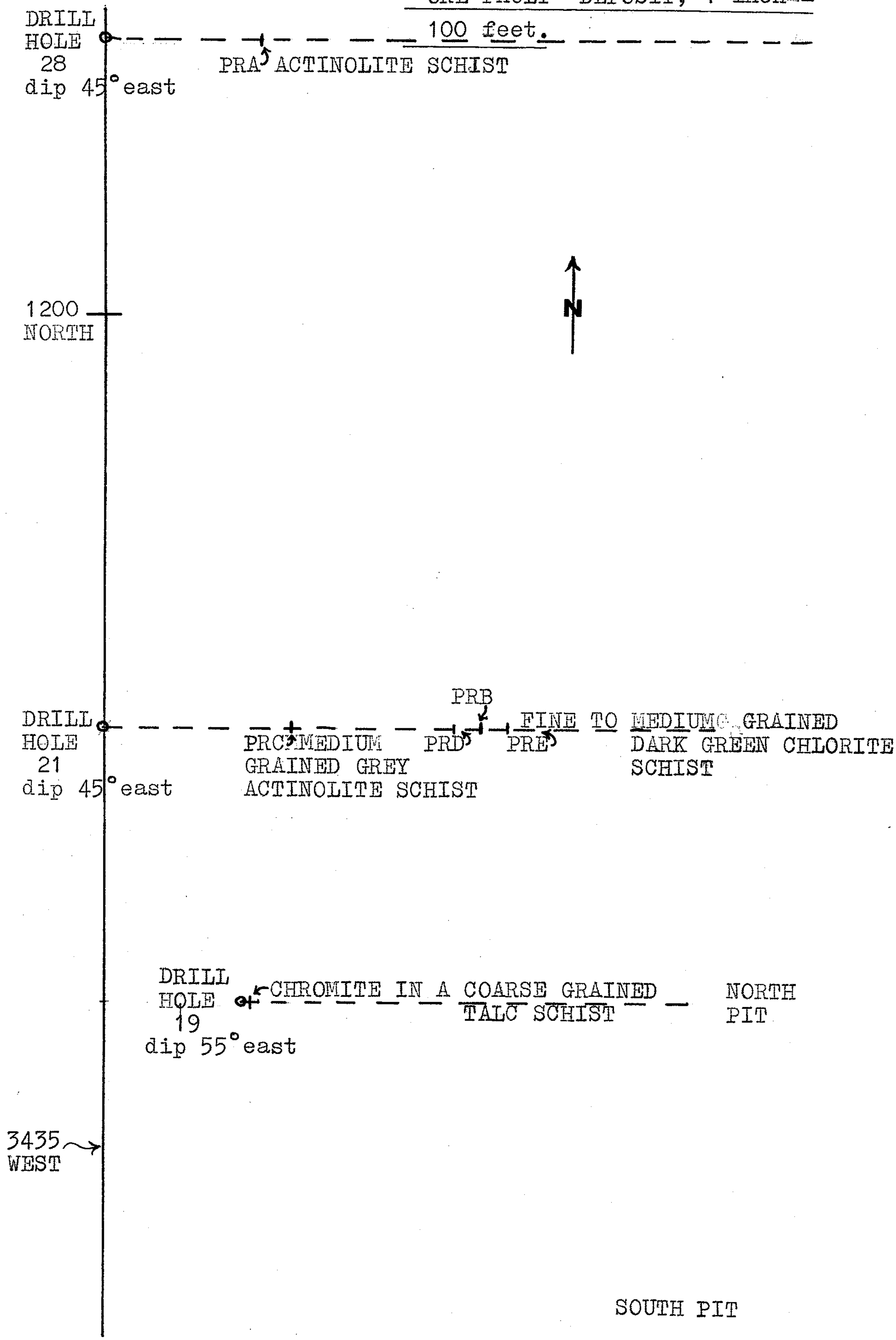
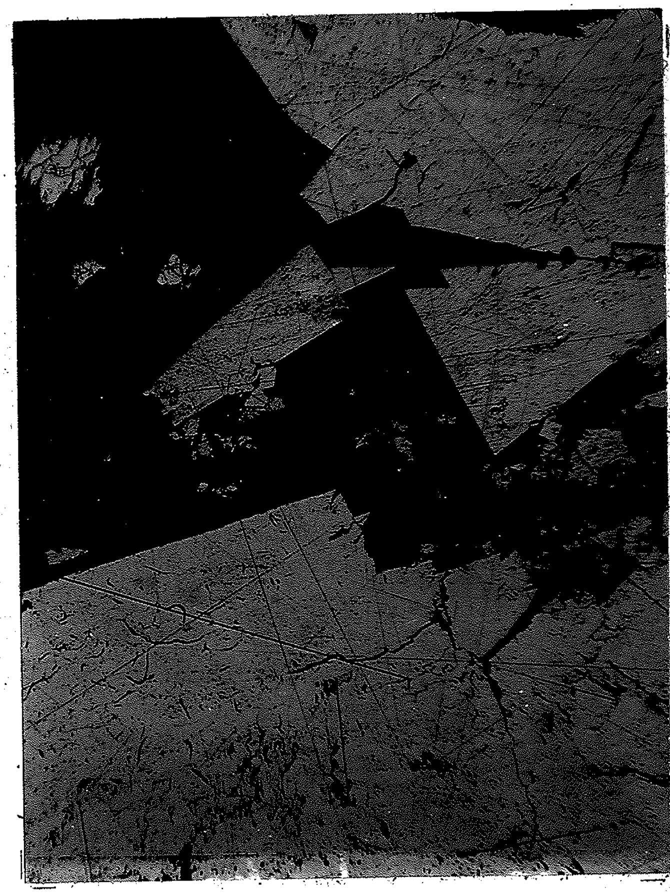


PLATE J : Pyrite crystals. X 44.



Pyrite is almost certainly the last mineral to crystallize because of the presence of euhedral crystals. It appears probable that most of the pyrite was formed from the oxidation of pyrrhotite as this is part of the normal oxidation process of nickel sulphide ores (Michener and Yates, 1944). Sample 3-1 (Plate K) shows the oxidation of pyrrhotite to pyrite. The absence of pyrite from drill core also suggests that the pyrite in the south pit is a secondary mineral.

The assays from the south pit indicate that nickel is present. Pyrrhotite and pentlandite mineralization do not seem to be plentiful enough to warrant this amount of nickel. This discrepancy is explained by the oxidation of pentlandite to nickel-rich violarite. This process is also part of the normal oxidation process of nickel sulphide ores. 'Sooty' violarite is present in the "Ore Fault" deposit. It is, however, not observed in polished sections because it cannot be polished.

5.1 SMYTHITE

Smythite is one of the rare minerals which occurs in the "Ore Fault" deposit (Personal communication, Dr. D.T. Anderson). This mineral is similar in appearance to pyrite and may be present in solid solution with violarite and pentlandite. Smythite may be another source for the nickel in the south pit.

5.2 CHROMITE

Chromite is observed in drill core (Figure 11) contained in a coarse grained talc schist. The chromite represents 20% of the polished section and exhibits a solid (85% of the chromite) and a cored (15% of the chromite) nodular texture. Small grains of pyrrhotite representing approximately 3% of the section are also present. The pyrrhotite does not show any relationship with the chromite (Plate H).

PLATE K: Po = pyrrhotite, Py = pyrite, Zn = sphalerite. Crossed nicols, X 44.

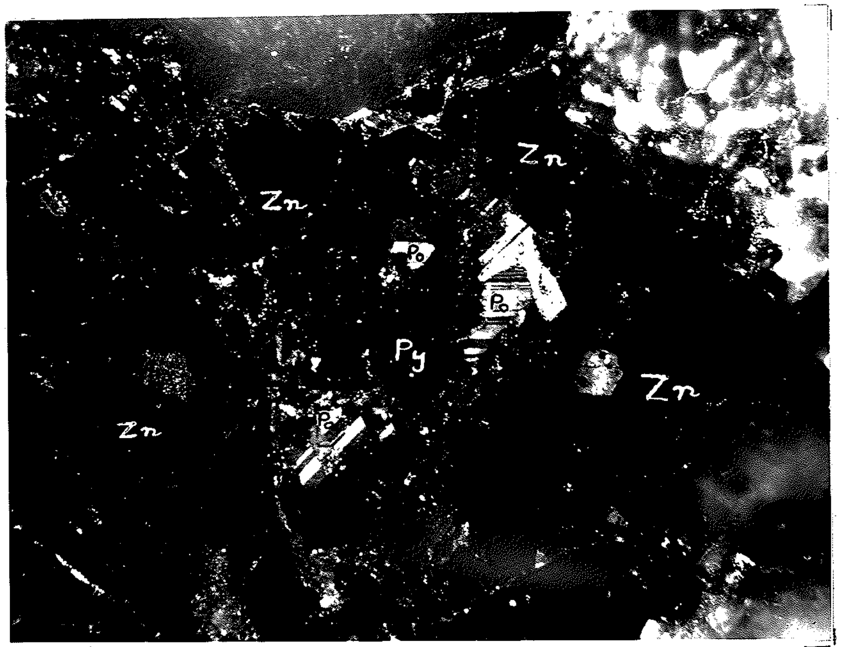


PLATE L: Zn = sphalerite, Cu = chalcopyrite, Po = pyrrhotite. X 100.8

PLATE H: Po = pyrrhotite, Cr = chromite, X 44

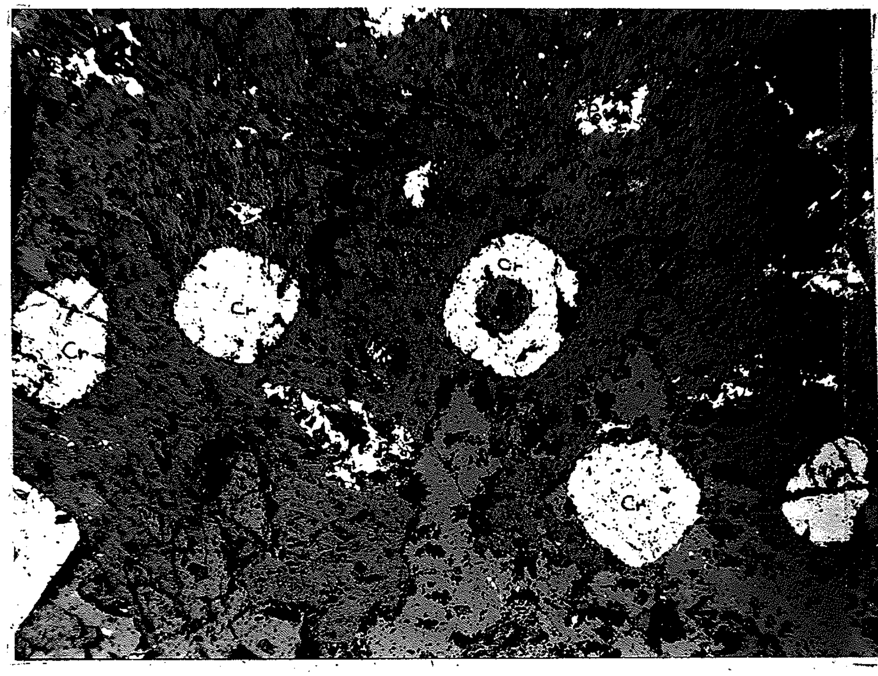
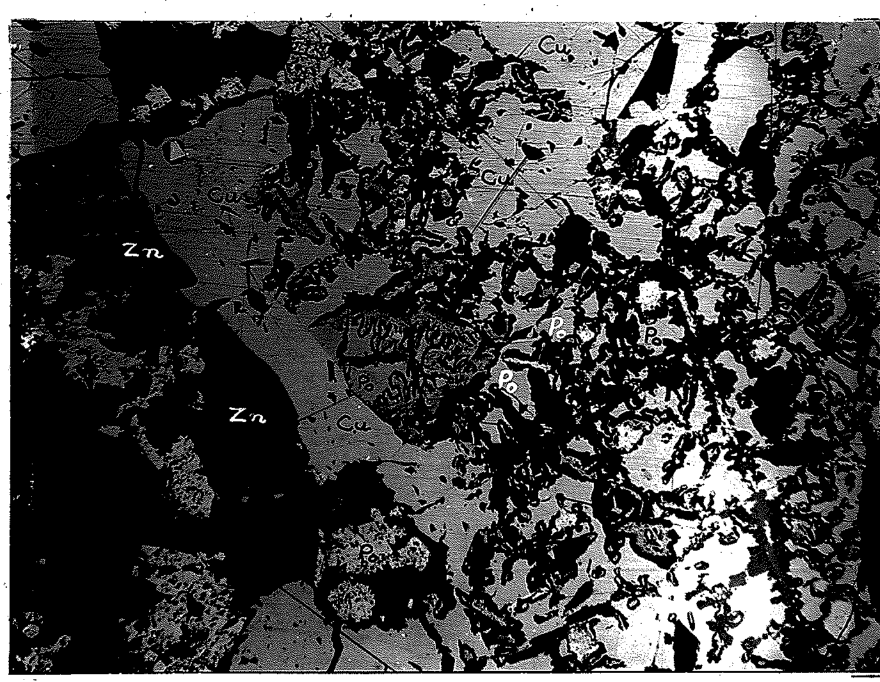


PLATE I: Po = pyrrhotite, Cu = chalcopyrite, Zn = sphalerite. X 44.



5.3 Ilmenite

Ilmenite is found in small quantities in the south pit (sample 3 - 7), north pit (in a fine grained metavolcanic rock), drill hole 21 (sample PRA) and drill hole 28 (sample PRC and PRE). The amount of ilmenite present ranges from 5% of opaques in hole 28 to a trace amount in the south pit. The ilmenite occurs as small grains disseminated in the gangue. Ilmenite occurs with pyrrhotite, chalcopyrite, pyrite and sphalerite. The ilmenite does not appear to be associated with the sulphide minerals.

5.4 Pentlandite

Pentlandite is observed in polished sections PRB, PRC, and PRD; drill hole 21. The nickel content in these sections is 1.09, 0.44, and 0.43 weight per cent respectively. Pentlandite and pyrrhotite occur together in the three polished sections mentioned above. Chalcopyrite is generally present where pyrrhotite and pentlandite occur (Plate Q).

Most of the pentlandite and pyrrhotite originally contained in the present surface exposures has been oxidized to violarite and pyrite respectively.

5.5 Pyrrhotite

Pyrrhotite occurs in the north pit, south pit, drill hole 28 and drill hole 21. Pyrrhotite has a 'broken' and 'ragged' appearance as compared to the relatively undisturbed chalcopyrite and sphalerite mineralization (Plate I). Pyrrhotite shares common mineral boundaries with chalcopyrite and sphalerite in the north pit. The pyrrhotite represents only a small proportion of the opaque minerals in the south pit. In the south pit pyrrhotite and chalcopyrite occur as small grains disseminated in the gangue. Pyrrhotite and chalcopyrite also occur together as massive sulphides in the south pit. Sample 3 - 2 located close to the small body of amphibole-rich metavolcanic rock is an example of this massive mineralization (Plate N).

PLATE Q: Cu = chalcopyrite, Po = pyrrhotite,
Pn = pentlandite, Zn = sphalerite. X 88

PLATE M: Zn = sphalerite, Cu = chalcopyrite. X 44.

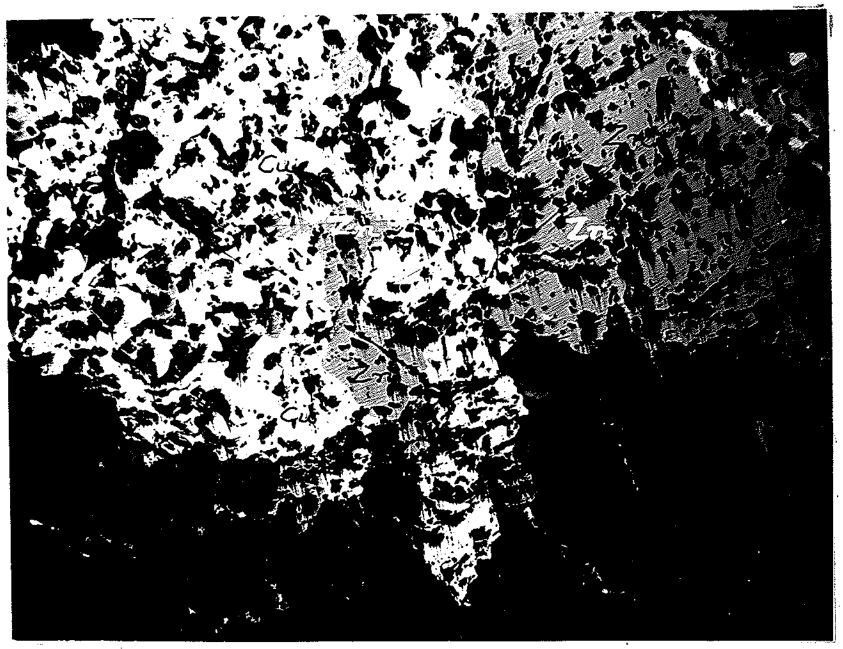


PLATE N: Po = pyrrhotite, Cu = chalcopyrite. X 44

The pyrrhotite which occurs in drill hole 28 has a 'broken' and 'pitted' appearance and occurs as small grains with chalcopyrite and sphalerite disseminated in the gangue. The pyrrhotite in drill hole 21 occurs most commonly with pentlandite. Pyrrhotite also occurs with sphalerite and chalcopyrite in a few zones.

Pyrrhotite appears to be the first sulphide mineral to be deposited in the north pit due to its brecciated appearance as compared to the relatively undisturbed appearance of the other sulphides.

5.6 CHALCOPYRITE

Massive and disseminated chalcopyrite occur in the north pit, south pit, drill hole 28, and drill hole 21. Chalcopyrite occurs with all of the sulphides in the "Ore Fault" deposit. The most common association is chalcopyrite and sphalerite. Plate M from the south pit is a typical example of this close association. Polished section PRE from drill hole 21 is another example of chalcopyrite and sphalerite occurring together. The assays for PRE are: Zn = 6.03 and Cu = 2.18 weight per cent. The second most common association is chalcopyrite and pyrrhotite.

5.7 SPHALERITE

Sphalerite occurs in the north pit, south pit, drill hole 28, and drill hole 21. The south pit contains considerably more zinc mineralization in the form of sphalerite than the north pit. Sphalerite occurs both as a massive and a disseminated mineralization. Sphalerite has a 'broken' and 'pitted' appearance in parts of the deposit.

Sphalerite occurs with all of the sulphides in the "Ore Fault" deposit. The most common association is chalcopyrite and sphalerite (Plate M). Plate L from the south pit shows sphalerite in close association with chalcopyrite and pyrrhotite. The sphalerite and chalcopyrite appear to have a closer relationship than the sphalerite and pyrrhotite along their respective common mineral borders in this plate.

An example of copper, nickel, and zinc minerals occurring together is observed in Plates O and P (identical photo with different magnifications). Pyrrhotite, pentlandite and chalcopyrite are contained within relatively undisturbed sphalerite suggesting that the sphalerite was the last to crystallize.

5.8 PARAGENESIS

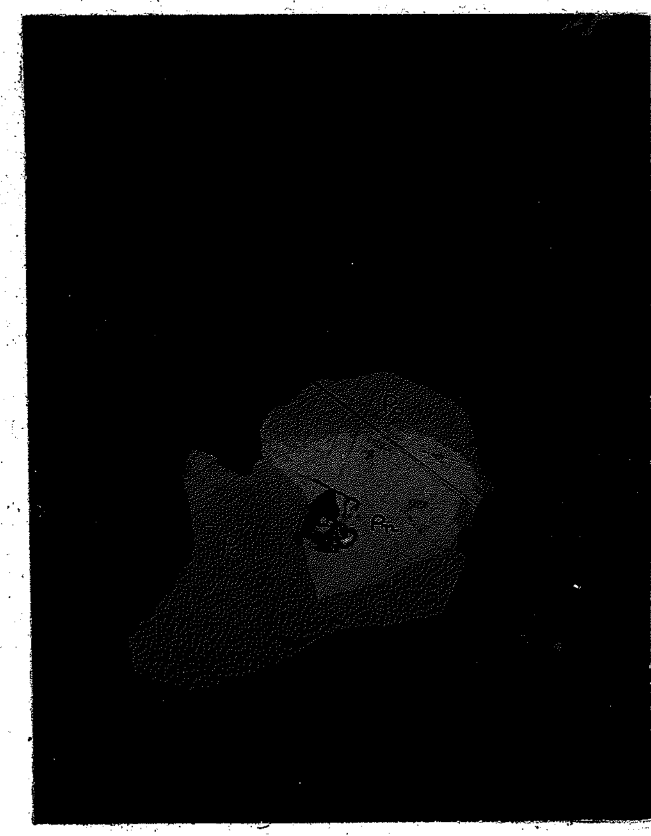
The original order of crystallization of the sulphides based on textural relationships observed in polished sections appears to be: (1) sphalerite and chalcopyrite; (2) pentlandite, pyrrhotite, chalcopyrite, and smythite; and (3) pyrite and violarite. This original paragenesis is not observed in every case, however, because remobilization and recrystallization appears to have taken place.

5.9 CONCLUSION

Polished sections show that copper, nickel and zinc minerals occur together in the "Ore Fault" deposit. Sphalerite which represents the zinc mineralization is found throughout the deposit. The higher grade zinc mineralization is localized in rocks bordering the granite contact. Nickel occurs in pyrrhotite, pentlandite, smythite, and violarite. These nickel sulphides occur throughout the "Ore Fault" deposit. The higher grade nickel mineralization is localized in the north pit. Copper mineralization which occurs in chalcopyrite is found in equal proportions throughout the deposit.

Most of the pentlandite and pyrrhotite originally contained in the present surface exposures in the "Ore Fault" deposit have been oxidized to violarite and pyrite respectively. The most prevalent mineral associations in the "Ore Fault" deposit are: (1) chalcopyrite and sphalerite; (2) pyrrhotite and chalcopyrite; and (3) pyrrhotite, pentlandite and chalcopyrite. The original order of crystallization of the sulphides appears to be: (1) sphalerite and chalcopyrite; (2) pentlandite, pyrrhotite, chalcopyrite, and smythite; and (3) pyrite and violarite.

PLATE P : Po = pyrrhotite, Pn = pentlandite, Cu = chalcopyrite, Zn = sphalerite. X 200.



CHAPTER 6

SULPHUR ISOTOPES

Sulphur isotope techniques were used to help ascertain a possible origin for the sulphur contained in the zinc and nickel sulphide mineralization in the "Ore Fault" deposit. The sulphur in the sphalerite could possibly have one of the following origins based on field studies: a sedimentary origin, a magmatic origin associated with the copper-nickel in an ultramafic environment, or a hydrothermal origin.

In recent years the measurement of sulphur isotopic abundances in minerals has added new information pertaining to the origins of these minerals and the processes involved in their formation (Jenson, 1967).

The background theory appears in appendix 1.

The experimental procedure for obtaining sulphur isotope ratios is outlined in appendix 2. The experimental error for the sulphur isotope measurements is reported in appendix 2.

6.0 Presentation of Isotope Values:

A total of 15 samples were prepared for sulphur isotope measurements (6 pyrrhotite, 8 sphalerite and one pyrite). These samples are from various parts of the deposit - most are surface samples, 4 samples are taken from drill core. The sulphur isotope ratios have been plotted on a geological map of the deposit. (Figure 12). The drill core samples are located on the plan view by vertical projection to the surface elevation.

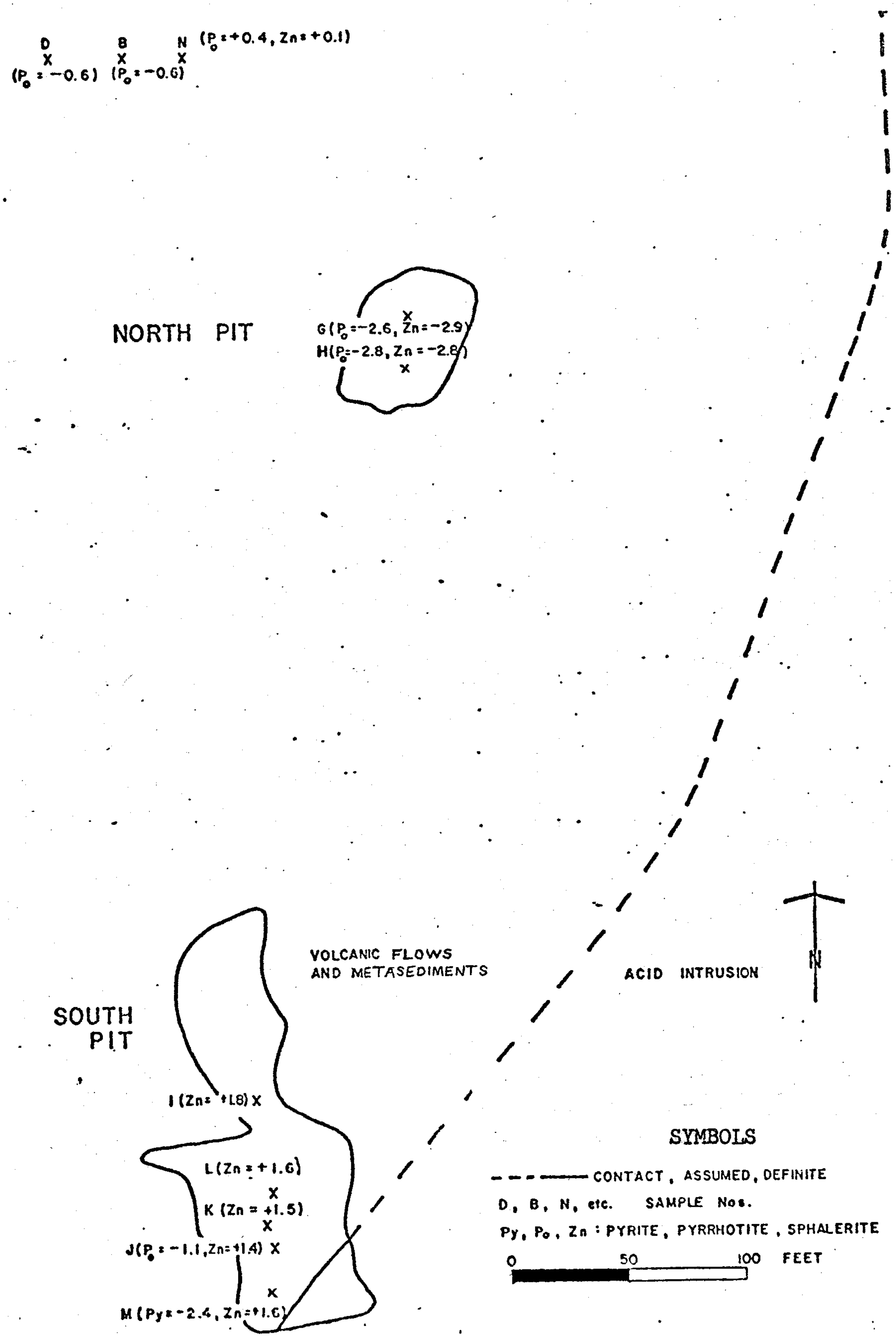


FIGURE 12 : Sulphur Isotope Ratios (δS^{34} $^{o}/oo$), "Ore Fault" deposit.

6.1 <u>RESULTS</u>:

The sulphur isotope ratios for pyrrhotite (which represent the nickel mineralization) present a small range (δS^{34} + 0.4 to -2.8). The sulphur isotope ratios for the pyrrhotite do not seem to have any spatial relationship to the geology of the deposit.

The sulphur isotope ratios for sphalerite have a slightly greater range of values (δS^{34} + 1.8 to -2.9).

There is a slight zonal difference in the sulphur isotope ratios for the sphalerite with respect to the geology of the deposit. In the south pit (the surface showing closest to the acid intrusive contact and also the zinc rich zone), all ratios are positive or enriched in S^{34} and range from +1.4 to +1.8. In the north pit (the surface showing containing the nickel rich zone and further away from the acid intrusive contact) the ratios are negative or depleted and range from -2.8 to -2.9. The sphalerite sample taken from drill core (Hole No. 21 - 586 feet) has a sulphur isotope ratio of +0.1. This ratio is less enriched in S^{34} than the south pit ratios for sphalerite. The amount of zinc in this sample is an anomalously high 6.03%. Isotopic ratios are not available for the acid intrusion in the "Ore Fault" deposit because the acid intrusion is not mineralized. The δS^{34} values for sphalerite are therefore greater closer to the acid intrusion (i.e. the south pit) than they are further away from the acid intrusion (i.e. the north pit and possibly Hole No. 21).

The pyrite sample which is located in the south pit has a sulphur isotope value (-2.4) similar to the pyrrhotite sample located in the south pit (-1.1).

Sulphur isotope ratios were determined on four samples of coexisting sulphides (i.e. pyrrhotite and sphalerite). The two samples in the nickel rich north pit have similar δS^{34} values for both minerals. The sample from Hole 21 also has a similar δS^{34} value for both minerals. The sample in the south pit, however, has slightly divergent ratios: pyrrhotite -1.1, sphalerite +1.4.

6.2 CONCLUSIONS

The small range of values for pyrrhotite suggests that the "Ore Fault" deposit is a magmatic deposit.

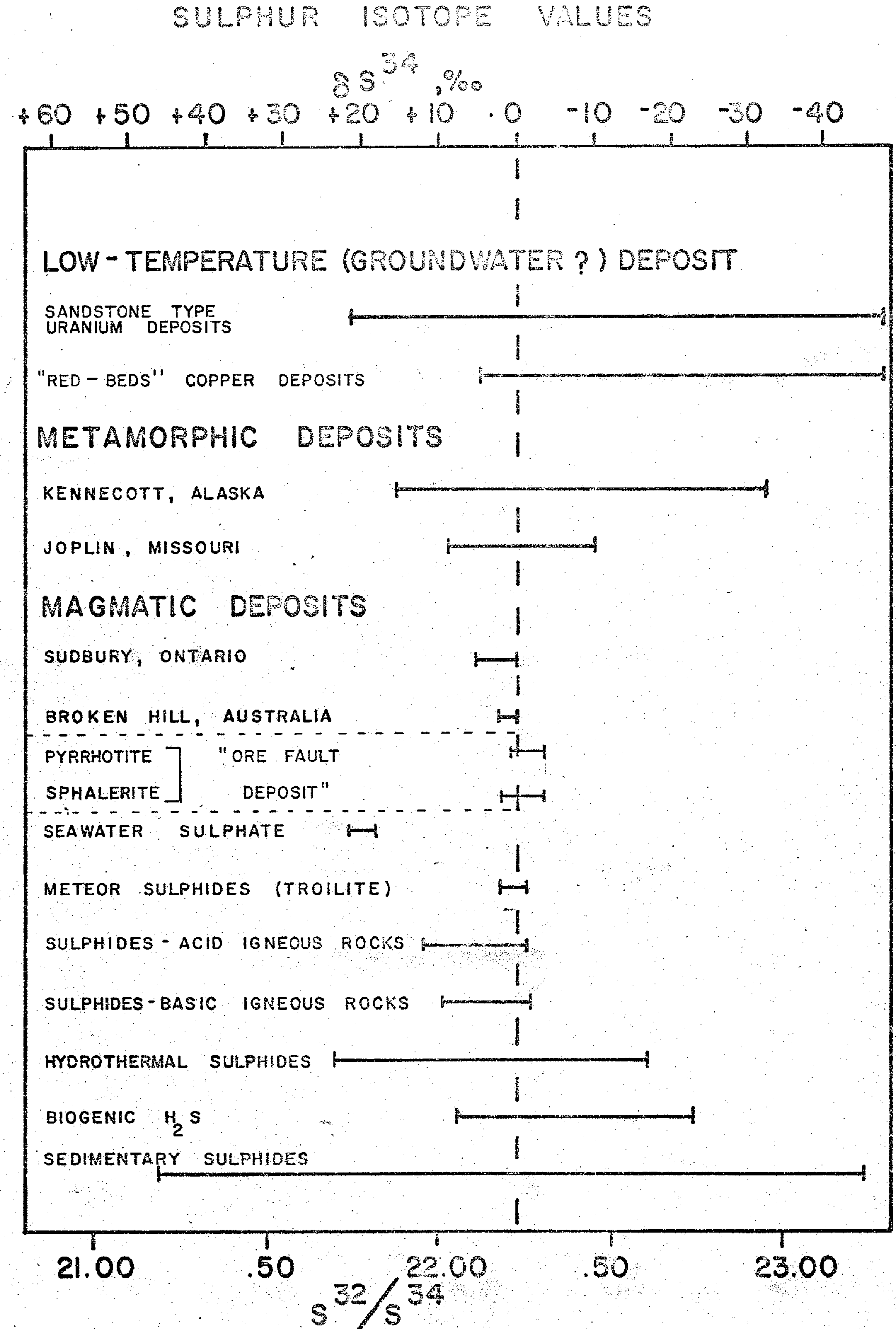
The slightly greater range of values for the zinc is not significantly different from the sulphur isotope measurements for the nickel. The zinc mineralization could have originated with the mafic volcanic or the granite and still exhibit this relatively narrow range of sulphur isotope ratios about the meteoritic value (Figure 13). This narrow range suggests that the sulphur in the sphalerite is not of sedimentary origin.

The δS^{34} values for sphalerite are greater closer to the acid intrusion than they are further away from the acid intrusion. Other studies have shown a direct correlation between the isotopic ratio and the distance from an acid intrusion - greenstone contact; sulphides in the acid intrusion are the most enriched in S^{34} whereas sulphides in the adjoining metamorphic rocks contain progressively less S^{34} outward from the acid intrusion contact (Wanless, Boyle, and Lowden, 1960). The acid intrusion in the deposit area is probably responsible for the mobilization of the sulphur contained in the sphalerite, through diffusion or a type of fractionation process. The zinc now contained in the sphalerite could also have been mobilized providing it was present when this diffusion of the sulphur was taking place. This metamorphic diffusion process diffuses the lighter, more energetic S^{32} isotope further away from the energy source (the intrusion of the granite) than the heavier S^{34} isotope.

The zinc mineralization originated either from the volcanic rocks or possibly from the acid intrusion. Mobilization possibly could have moved the sphalerite from the above possible sources into the magmatic environment of the copper-nickel mineralization in the north pit.

The similarity of sulphur isotope values for pyrrhotite and pyrite suggest that they have a similar origin. The pyrite is a secondary mineral which has been oxidized from the pyrrhotite. Polished sections of pyrite from the south pit show that the pyrite is euhedral and not broken or sheared as are the rest of the ore

FIGURE 13: Examples of Sulphur Isotope Values. (after Jensen, 1967).



minerals. Therefore, the pyrite is probably the last to crystallize. This oxidation of the pyrrhotite to pyrite can take place at depths of 100 feet or more (Michener and Yates, 1944). The similarity of the sulphur isotope ratios for pyrite and pyrrhotite suggests that oxidation of this type does not have a very great affect on isotope ratios. Pyrrhotite has been almost completely oxidized to pyrite in the south pit.

Sphalerite and pyrrhotite have similar δS^{34} values if they are co-existing sulphides (D.J. Bachinski, 1969). The sample in the south pit suggests that the two minerals are not co-existent. This seems reasonable because the south pit is a zinc rich zone with only a small amount of nickel, suggesting that the sphalerite represents the original mineralization and the pyrrhotite represents a mineralization introduced at a later time. The nickel and zinc perhaps represent two periods of mineralization with only a slight amount of mixing of the minerals (with subsequent exchange of sulphur isotopes and homogenizing of the sulphur isotopes).

The ratios from the north pit and Hole 21, however, suggest a mixing and homogenizing of the sulphur isotope values because the values for the two minerals are similar. Previous evidence indicates that the sphalerite and pyrrhotite are not co-existent sulphides (see metal ratios). There is more of a chance for mixing of the sulphur isotopes in the north pit than in the south pit. The reason for this is that the nickel-rich north pit contains small high grade pockets of zinc mineralization. High grade pockets of nickel do not occur in the predominantly zinc-rich south pit.

It is suggested that the products of two different periods of mineralization were mixed by a later event. This later event could have been one of or a combination of the following events: the intrusion of the Bird River sill, the intrusion of the granite body and/or faulting.

The narrow range of sulphur isotope values obtained may be explained by the following hypothesis. This hypothesis states that the metamorphism which caused the mixing of the two periods of mineralization could have resulted in localized isotopic homogenization.

CHAPTER 7

CONCLUSIONS

The "Ore Fault" copper-nickel deposit contains an anomalous high amount of zinc mineralization. The sulphide mineralization is contained in a series of shears. The main sulphides are pentlandite, pyrrhotite, violarite, smythite, chalcopyrite, and sphalerite. The surface showings exhibit a nickel-rich zone (the north pit) and a zinc-rich zone (the south pit) with copper, nickel, and zinc minerals present in both pits. The massive nickel mineralization appears to be related to an amphibole-rich metavolcanic rock and/or lenses of ultramafic rocks which occur in the deposit area.

The small area containing the "Ore Fault" deposit is a faulted block containing metasedimentary and metavolcanic rocks of the Bird River Greenstone Belt and a sill-like body of ultramafic rock. The fault block is bounded on the east by a granite intrusion. The western part of the fault block is bounded by the 'ore fault' which also displaces the Bird River sill.

The copper-nickel plot for the "Ore Fault" deposit has a bimodal distribution. This distribution is suggestive of two types of mineralization or possibly remobilization. The two types of mineralization are: (1) an ultramafic copper-nickel mineralization and(2) a copper-zinc mineralization. The random pattern obtained in the copper-zinc plot suggests that the "Ore Fault" deposit is not a typical copper-zinc deposit. The copper-nickel-zinc triangular plot suggests that copper-nickel and copper-zinc mineralization are present in the "Ore Fault" deposit. The silver mineralization is associated predominantly with the zinc mineralization.

Sulphur isotope techniques were helpful in ascertaining a possible origin for the nickel and zinc mineralization. The sulphur isotope ratios for pyrrhotite suggest that the nickel has a magmatic origin. The narrow range of the isotope ratios about the troilite value for the sphalerite suggests that the sulphur in the sphalerite is not of sedimentary origin. The zinc mineralization could have originated with the mafic volcanic rock or the granite and still exhibit this relatively narrow range of sulphur isotope ratios about the meteoritic value. The isotope ratios for the sphalerite seem to have a spatial relationship to the geology of the deposit. This relationship suggests that the acid intrusion is probably responsible for the mobilization of the sulphur contained in the sphalerite from the zinc-rich south pit into the magmatic environment of the nickel-rich north pit. The narrow range of sulphur isotope values obtained for the "Ore Fault" deposit suggests that the subsequent metamorphism could have resulted in localized isotopic homogenization.

It is suggested that the products of two different periods of mineralization were mixed by a later event. This later event could have been one of or a combination of the following events: the intrusion of the Bird River sill, the intrusion of the granite body and/or faulting.

BIBLIOGRAPHY

Anderson, D.T. (1959): The Distribution of Copper and Nickel in Magmatic Sulphides; MSc Thesis, University of Manitoba.

Bachinski, D.J. (1969): Bond Strength and Sulfur Isotopic Fractionation in Coexisting Sulfides; Econ. Geol., Vol. 64, pp. 56-65.

Barnes, H.L. (1967): Geochemistry of Hydrothermal Ore Deposits; Ch. 5, Sulphur Isotopes and Mineral Genesis by M.L. Jensen.

Dana, E.S. (1944): Dana's System of Mineralogy; Seventh Edition, Vol. 1, New York, John Wiley and Sons, Inc.

Davies, J.F. (1952): Geology of The Oiseau (Bird) River Area; Manitoba Mines Branch Publication 51-3.

Davies, J.F. (1955): Geology and Mineral Deposits of the Bird Lake Area; Manitoba Mines Branch Publication 54-1.

Davies, Bannatyne, Barry and McCabe (1962): Geology and Mineral Resources of Manitoba; Manitoba Mines Branch Special Publication.

Dechow, E. and Jensen, M.L. (1965): Sulfur Isotopes of Some Central African Sulfide Deposits; Econ. Geol., Vol. 60, No. 5.

Edwards, A.B. (1947): Textures of the Ore Minerals and Their Significance; The Australasian Institute of Mining and Metallurgy.

Geochron Laboratories Inc.: Sulfur Isotope Analyses and Their Applications to Economic Geology; Technical Bulletin No. 4.

Jensen, M.L., (1967): Sulphur Isotopes and Mineral Genesis: Geochemistry of Hydrothermal Ore Deposits, ed. H.L. Barnes, Chapt. 5, Holt, Rinehart and Winston, Inc., pp.143-165.

Karup-Möller, S. and Brummer, J.J. (1971): Geology and Sulphide Deposits of the Bird River Claim Group, Southeastern Manitoba; Paper presented at the G.A.C. meeting August 1970, Winnipeg, Manitoba.

Michener, C.E. and Yates, A.B. (1944): Oxidation of Primary Nickel Sulphides; Economic Geology, Vol. 39, pp. 506-514.

Sherwood, H.G. (1964): The Significance of Cu, Pb, Zn, Au and Ag distributions in Canadian Base Metal Deposits; MSc Thesis, University of Manitoba.

Springer, G.D. (1950): Mineral Deposits of the Cat Lake - Winnipeg River Area; Manitoba Mines Branch Publication 49-7.

Wanless, Boyle and Lowden, Economic Geology, Vol. 55, Dec. 1960, No. 8.

Wilson, H.D.B. and Anderson, D.T. (1959): The Composition of Canadian Sulphide Ore Deposits; Symposium on The Genesis of Massive Sulphide Deposits CIMM, Vol. 62, pp. 10-22.

Wright, J.F. (1938): Geology and Mineral Deposits of a Part of Southeastern Manitoba; Canada Dept. of Mines and Resources, Memoir 169.

APPENDIX 1

Sulphur Isotope Theory:

The two most abundant stable isotopes of sulphur with their approximate natural abundances are $S^{32} = 95.1\%$ and $S^{34} = 4.2\%$. Simply stated, it may be said that the relative strengths with which the various isotopes of an element are bound into a given molecule depend upon the vibrational frequencies of the isotopes, and these frequencies are in turn a function of the isotopic masses. The heavier isotopes have lower vibrational frequencies, are less energetic, and are somewhat more likely to be held in a particular bond than are the lighter, more energetic isotopes.

For most of the elements of the Periodic Table the relative differences between the isotopic masses are too small to produce any significant natural variations in their isotopic compositions due to chemical reactions. These effects are noted only in the lighter elements, and sulphur is one of the heaviest elements in which such effects are found. This process, generally termed "isotopic fractionation", is further enhanced in the case of sulphur through oxidation-reduction reactions. In these reactions sulphur undergoes a valence change of -2 to + 6 and the bond strengths of the oxidation products are generally much stronger than those of the reduction products. Therefore, in redox reactions involving sulphur in which equilibrium is achieved, or at least closely approached, we would expect to find the heavier sulphur isotopes to be somewhat enriched in the oxidation products relative to the reduction products (Jensen, 1967).

The absolute abundance of an isotope cannot easily be measured. However, the relative isotopic abundances can easily be measured (ie the amount of one isotope compared with another). An accuracy of about ± 0.01% can be obtained with these ratio measurements. Sulphur isotope measurements are made in terms of S^{32}/S^{34}. The abundance figures given above yield a S^{32}/S^{34} ratio of about 22.6, but this is only an approximate value, and measurements of this ratio in diverse samples of natural materials have yield values ranging from 20.4 to 23.6, for a total variation of about 15%. The isotopic fractionation of sulphur isotopes in natural processes is affected by many factors, including temperature, rate of reaction, completeness of equilibration, etc. The amount of fractionation, therefore, is often quite variable and the measurements of S^{32}/S^{34} abundances generally yield a range of values for a particular process, rather than discrete values. The most nearly uniform S^{32}/S^{34} values found in nature are those of troilite sulphur in meteorites. The average of many different measurements of troilite sulphur has yielded a value of S^{32}/S^{34} = 22.220 with a variation of about ± 0.04%. The troilite S^{32}/S^{34} value is also believed to be similar to the primordial S^{32}/S^{34} composition of the earth.

Sulphur isotope measurements could be reported in terms of the S^{32}/S^{34} ratios. Since these values would vary only through the range of 20.4 to 23.6, as a maximum these values when tabulated would all look pretty much alike and small abundance differences would not be too obvious. In place of this system, it has become customary to report sulphur isotopic analyses in terms of the relative enrichment (or depletion) of S^{34} in the samples. This enrichment is given in terms of S^{34} in parts per thousand (per mil) and the notation for this is δS^{34} ‰.

Troilite sulphur is arbitrarily defined to have zero enrichment in S^{34}, and all other measured sulphur isotope values are reported as + or - variations about this value. The δS^{34} values are calculated as follows:

$$\delta S^{34}\ {}^{o}/oo = \left(\frac{S^{34}/S^{32}\ \text{sample} - S^{34}/S^{32}\ \text{standard}}{S^{34}/S^{32}\ \text{standard}} \right) \times 1000$$

where S^{34}/S^{32} standard $= \dfrac{1}{22.220} = 0.0450045.$

In terms of δS^{34} the natural sulphur isotopic variations of $S^{32}/S^{34} = 20.4$ to 23.6 become $\delta S^{34} = +\ 89.2\ {}^{o}/oo$ to $-\ 58.5\ {}^{o}/oo$, or a total variation of about 150 $^{o}/oo$.

The oxidation- reduction reactions which cause significant fractionation of the sulphur isotopes can occur in two ways - geochemically and biochemically - both of which are important with respect to the occurrence of mineral deposits. The geochemical reactions are almost any of the usual redox reactions that can occur in geologic processes. The biochemical reactions occur through the action of certain anaerobic bacteria which are ubiquitous to the surface of the earth and which act on sulphate in solution, reducing it to H_2S, The H_2S thus produced is somewhat depleted in S^{34} while the sulphate residue is enriched in S^{34}. Sulphur isotope studies have shown that these bacteria operating on a vast scale have been one of the prime factors, if not the major factor, in the production of certain large metallic sulphide deposits and of the Gulf Coast native sulphur deposits. Both the geochemical and biochemical mechanisms can cause primary fractionation of several percent and these effects can be cumulative. Other mechanisms such as diffusion, precipitation are not believed to cause significant isotopic fractionation.

Figure 13 is a compilation of many sulphur isotope measurements which have been made of a wide variety of geologic materials and mineral deposits (after Jensen, 1967).

At the bottom of the diagram is given the spread of values for sulphides of sedimentary origin. These values encompass nearly the entire range of isotopic values found for sulphur and reflect the fact that these sulphides can be derived from nearly any crustal material. Next are the hydrogen sulphides of biogenic origin, which are generally light (δS^{34} $^{o}/oo$ is negative) and have a fairly wide range of values. Such sulphides are produced through the reducing action of bacteria on sulphates, and during this process fractionation occurs producing sulphide that is somewhat depleted in the heavier isotope. The amount of fractionation is temperature dependent and can vary considerably as a result.

The sulphides of hydrothermal origin show a large spread of values. Hydrothermal sulphides are divided into 3 subgroups: magmatic hydrothermal, metamorphic hydrothermal and groundwater hydrothermal. (These subdivisions consider all hot-water mineralizing solutions to be hydrothermal regardless of their origins).

With magmatic hydrothermal deposits, it is often found that the sulphides of individual deposits show a spread of values of only a few per mil. This is explained by the fact that the late-stage (or residual) fluids of magmatic intrusion are probably quite homogeneous in composition. The transport and deposition of the sulphide material takes place at elevated temperatures, consquently little, if any, fractionation of sulphur isotopes is likely to occur during these processes. Metamorphic hydrothermal deposits yield relatively wide ranges of S^{34} $^{o}/oo$ values due to the fact that the source material from which the solutions were mobilized may have themselves contained sulphur of widely varying composition. In addition, the pathways through which these remobilized solutions passed may not have been long enough or open enough to permit the solutions to be homogenized to any appreciable extent.

Groundwater hydrothermal deposits also show wide isotopic variations, which are most probably due to the fact that a major influence in their formation was the reducing action of anaerobic bacteria on sulphates in solution. This process results in isotopic fractionation between the sulphate and sulphide, the amount of which is temperature dependent and thus can vary widely with time.

δS^{34} values can be no more significant than the extent of knowledge available on the paragenetic, mineralogic, and geologic setting of each specimen analyzed. It is therefore imperative that such information be obtained before isotope results are interpreted.

APPENDIX 2

Procedure for Obtaining Sulphur Isotope Ratios:

1. A suitable sulphide is chosen. A sulphide that is entirely composed of one type of mineral is preferable because little or no mineral separation is required.
2. The sample is crushed and sieved to a -80 +150 mesh range.
3. The sample is washed to remove any extra fine material.
4. The sample is treated with heavy liquids (eg. methylene iodide) to remove minerals with low specific gravities (eg. silicates). This procedure is not followed if the sample is predominantly pyrrhotite because pyrrhotite can be removed and purified with a hand magnet. The pyrrhotite would be ready for weighing after this procedure.
5. The sample is run on a magnetic separator (Frantz Isodynamic Separator) to further separate out unwanted minerals and to purify the sample.
6. The sample is weighed (approximately 100 mg. is needed), mixed thoroughly with copper oxide (rather than oxygen; 5 times the sample's weight is needed) and roasted in a furnace. The procedure for collecting and purifying the SO_2 which evolves from the furnace (H_2O, CO_2, N_2 and O_2 is removed) is described by E.Dechow and M.L. Jensen (Economic Geology, Vol. 60, No. 5, 1965).
7. The yield of SO_2 collected is measured and the sample is now ready for the mass spectrometer. This

instrument measures the S^{34} enrichment or depletion with respect to standard SO_2 produced from meteoritic troilite which has an assigned S^{34} value of 0 per mil.

Replicate analyses performed on a sulphide standard showed a standard deviation of $\pm$ 0.2 $^{o}/oo$ (P.K. Seccombe, personal communication). The type of instrument used in this investigation is a " 180° Dual Collector Varian MAT GD 150 Mass Spectrometer".

APPENDIX 3: CHEMICAL ANALYSES OF ROCK TYPES.

Sample No.	PR 9	24-262	103
Rock Type	Granite	Drill Core Ultramafic -Metaperidotite	Surface Ultramafic -Metapyroxenite
SiO_2	71.35	34.45	47.60
Al_2O_3	13.78	6.64	7.02
Fe_2O_3	1.05	2.61	2.11
FeO	2.24	10.28	10.12
MgO	1.10	23.70	16.80
CaO	2.74	8.57	10.59
Na_2O	3.46	0.04	0.35
K_2O	1.22	0.01	0.18
H_2O	1.35	5.50	3.54
CO_2	0.38	6.45	0.33
TiO_2	0.35	0.22	0.26
P_2O_5	0.04	0.06	0.06
MnO	0.02	0.19	0.47
S	-	1.48	-
Cu	0.023	0.087	0.007
Ni	0.000	0.37	0.39
Zn	0.003	0.055	0.175

APPENDIX 3: CHEMICAL ANALYSES OF ROCK TYPES

Sample No.	323	500	506
Rock Type	"Bush Road" Gabbro	Pillow Lava South Pit	Amphibole Rich Rock in South Pit -Possible Actinolitic Hornblendite
SiO_2	49.55	51.65	43.35
Al_2O_3	12.02	14.53	12.08
Fe_2O_3	0.89	3.24	1.90
FeO	11.48	8.94	13.36
MgO	10.90	7.30	13.50
CaO	10.98	7.82	9.51
Na_2O	1.24	3.22	0.46
K_2O	0.24	0.70	0.11
H_2O	1.98	1.58	4.13
CO_2	0.02	0.00	0.01
TiO_2	0.64	0.93	0.40
P_2O_5	0.11	0.10	0.18
MnO	0.17	0.19	0.65
S	-	-	-
Cu	0.010	0.003	0.114
Ni	0.019	0.015	0.13
Zn	0.010	0.018	0.092

APPENDIX 3: CHEMICAL ANALYSES OF ROCK TYPES

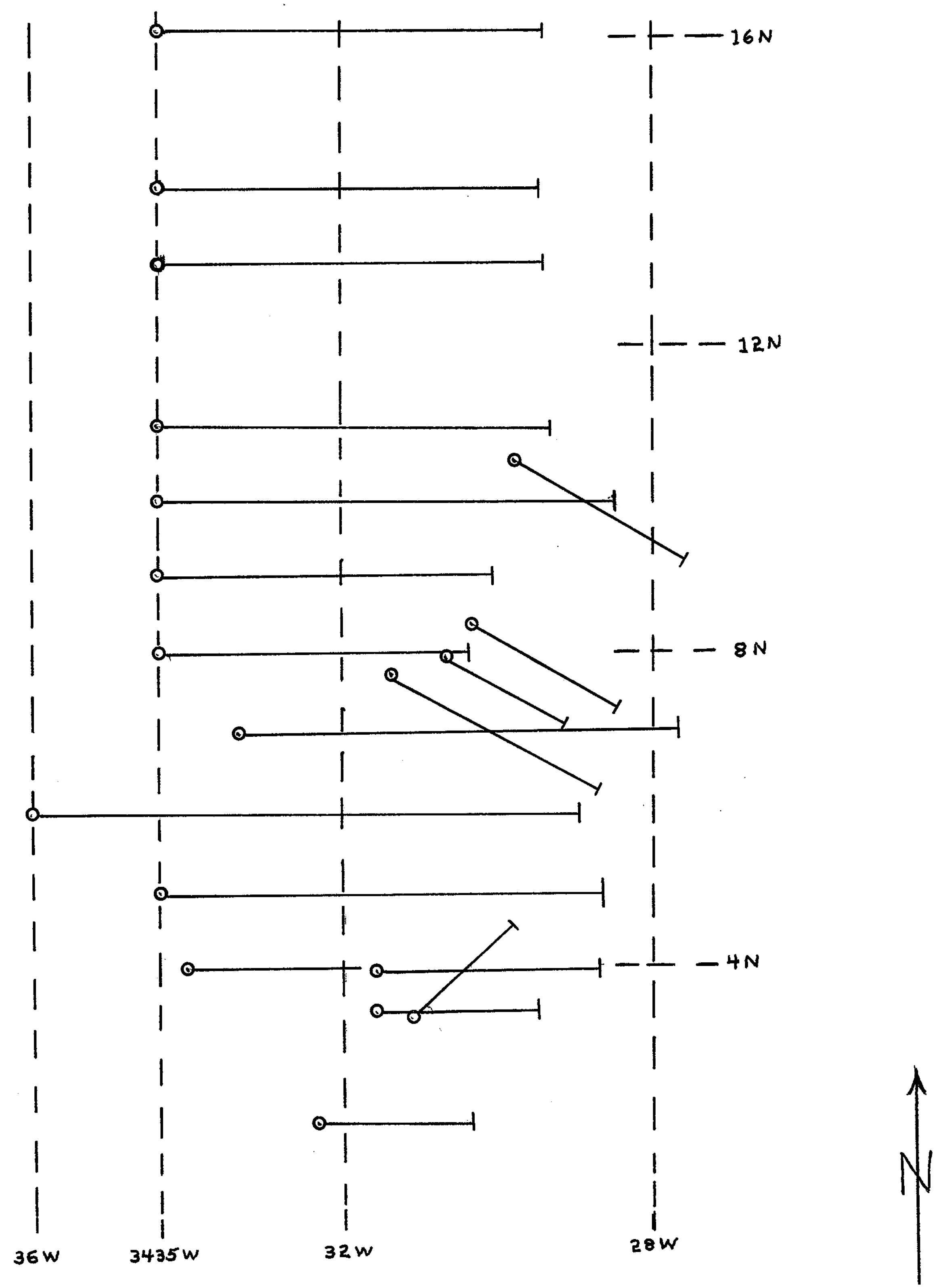
Sample No.	804 Amphibole Rich Rock In North Pit -Possible Actinolitic Hornblendite
SiO_2	40.15
Al_2O_3	12.26
Fe_2O_3	4.19
FeO	12.60
MgO	12.10
CaO	11.04
Na_2O	0.92
K_2O	0.18
H_2O	3.12
CO_2	0.13
TiO_2	0.38
P_2O_5	0.15
MnO	0.21
S	3.10
Cu	0.138
Ni	0.84
Zn	0.062

APPENDIX 4: SULPHUR-NICKEL RATIO FOR THE "ORE FAULT" DEPOSIT.

The sulphur-nickel ratio for the "Ore Fault" deposit is 6/1. This ratio is calculated from a bulk sample analysis of the North Pit sulphides: S/Ni = 30.69/5. 12 weight per cent = 6.0/1; the sulphur value used takes into account the sulphur needed for the other sulphide minerals present: Cu = 0.50%, Zn = 1.18%.

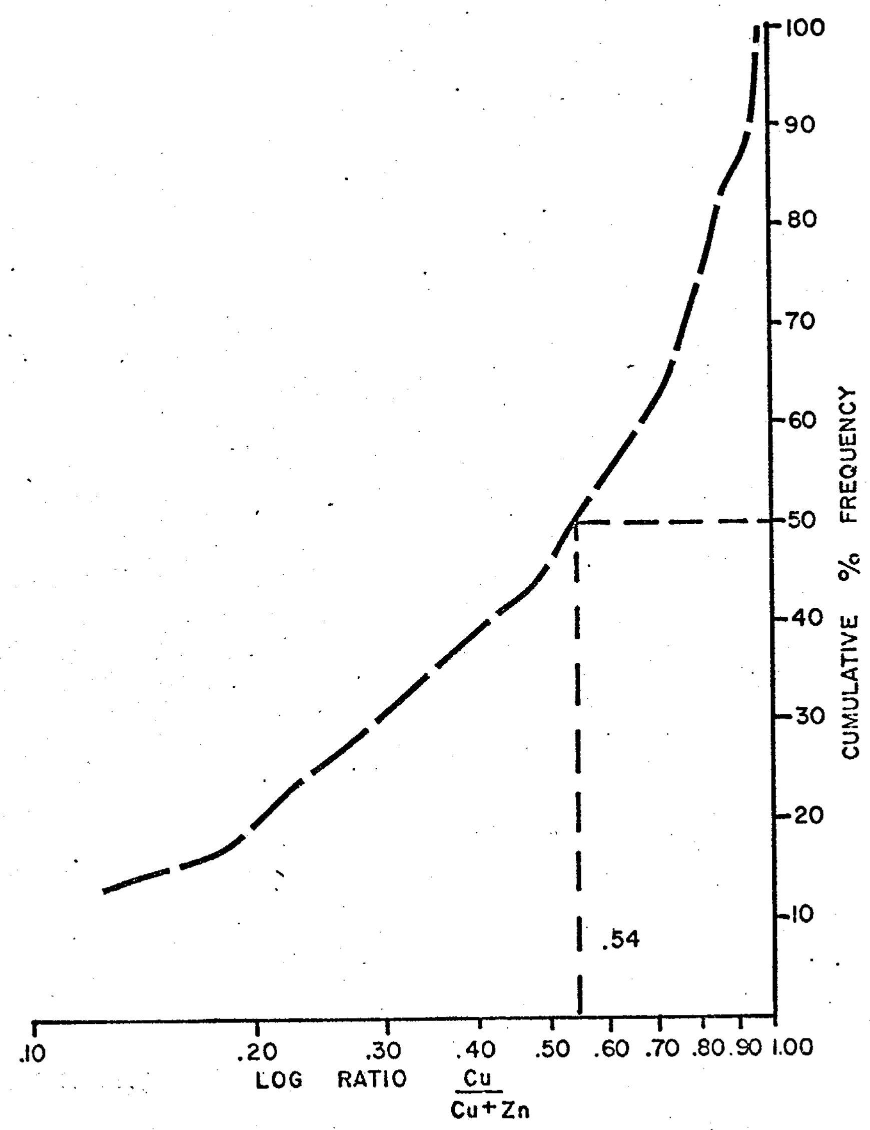
APPENDIX 5

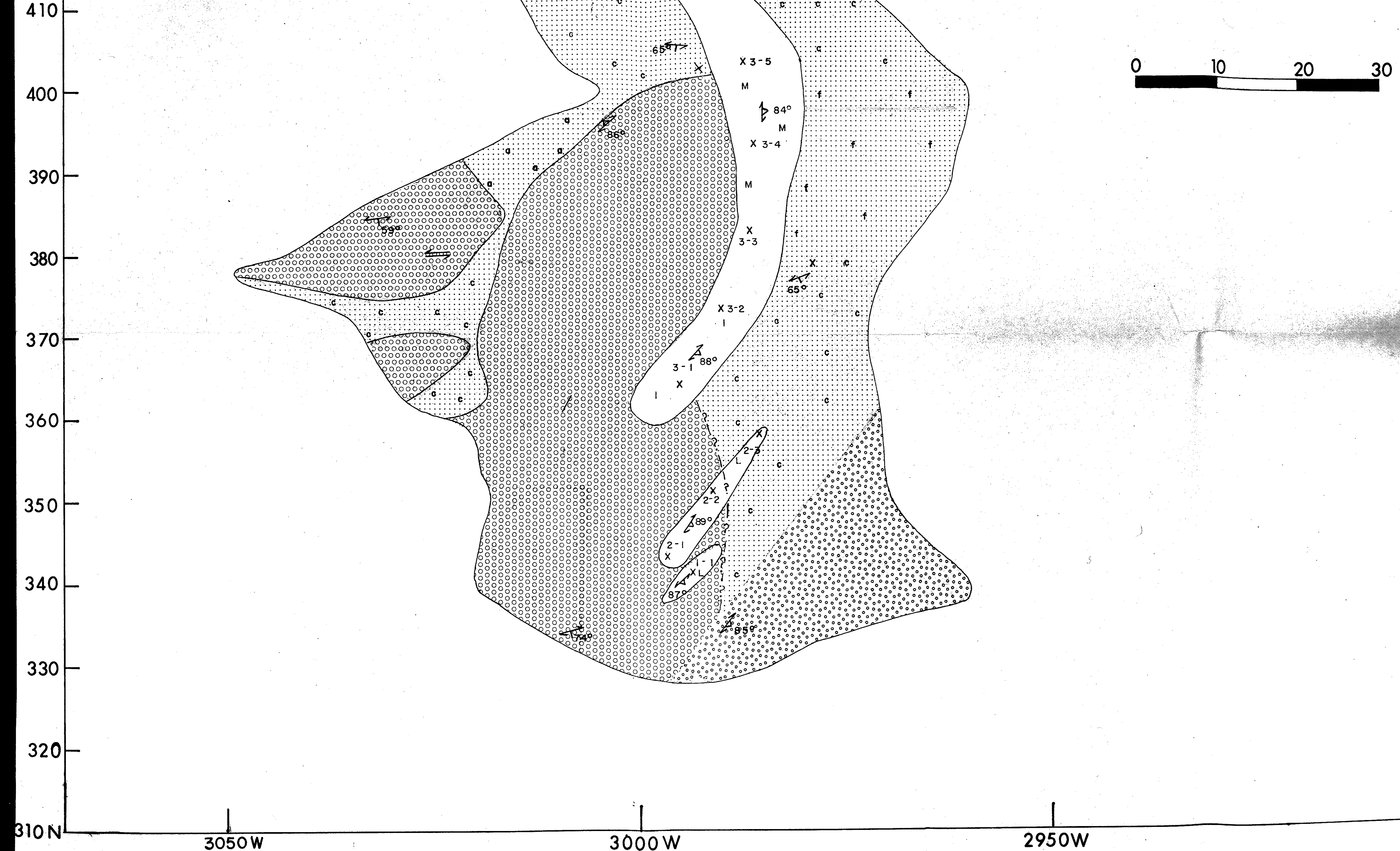
FIGURE 14: Diamond drill plan for the "Ore Fault" deposit. The dip of the diamond drill holes varies from 30° to 60° East.



APPENDIX 6

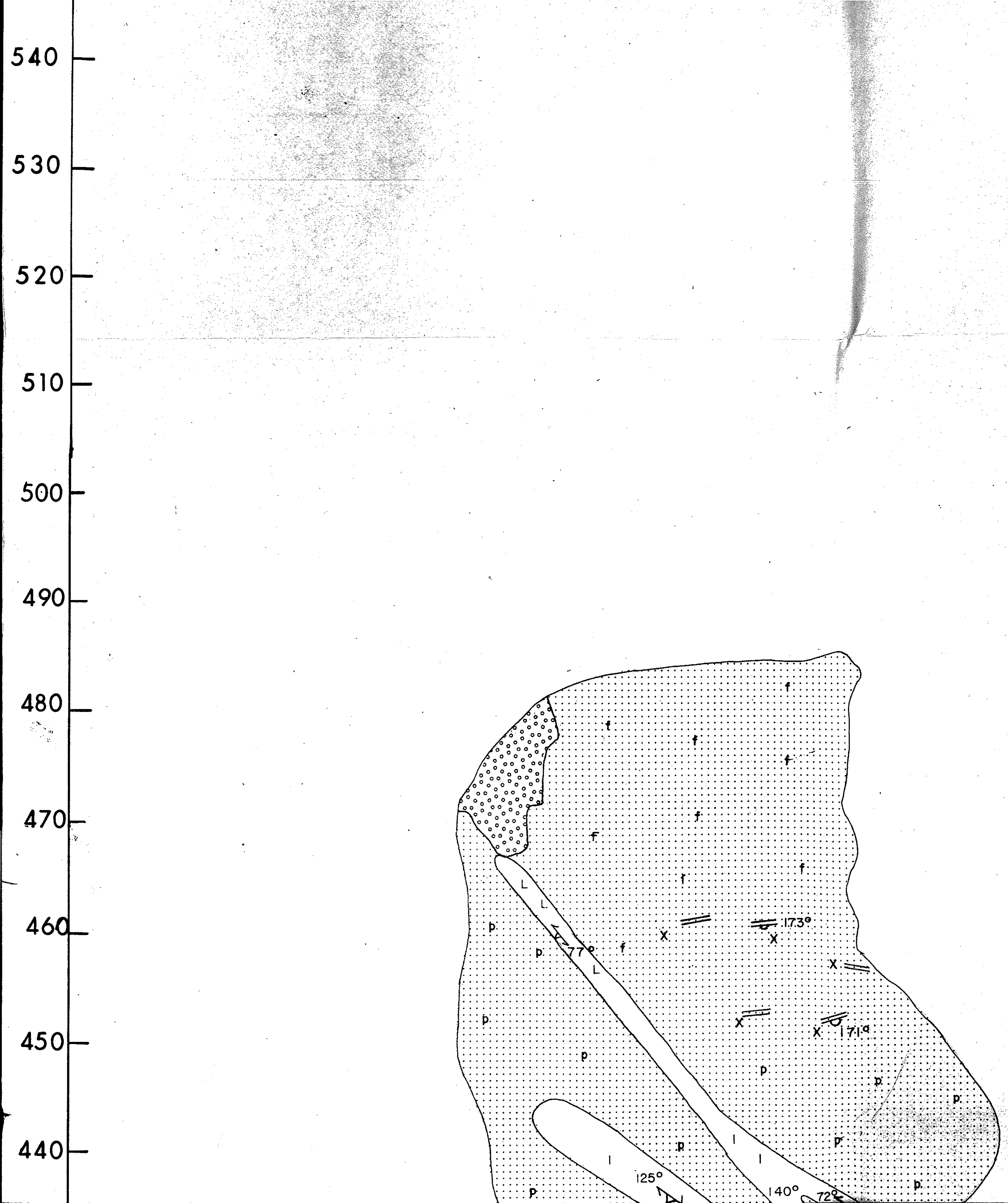
Fig. 8: A cumulative frequency curve for the "Ore Fault" deposit. The median value obtained is Cu/Cu + Zn = 0.54.





410
400
390
380
370
360
350
340
330
320
310 N
3050 W
3000 W
2950 W
0
10
20
30
X 3-5
X 3-4
X 3-3
X 3-2
3-1
2-3
2-2
2-1
1-1
84°
86°
65°
59°
88°
89°
87°
85°
74°

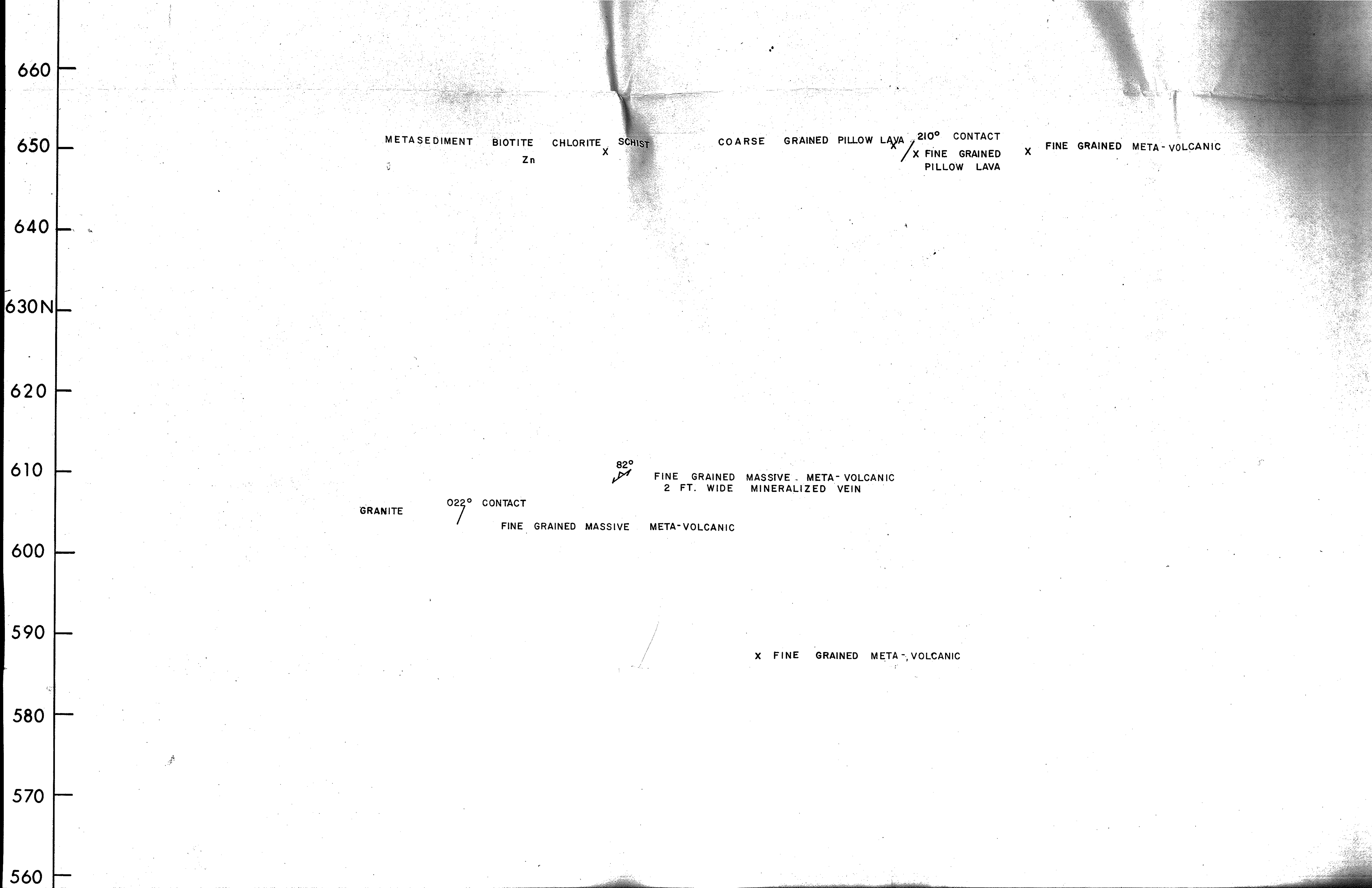
ORE FAULT PROPERTY



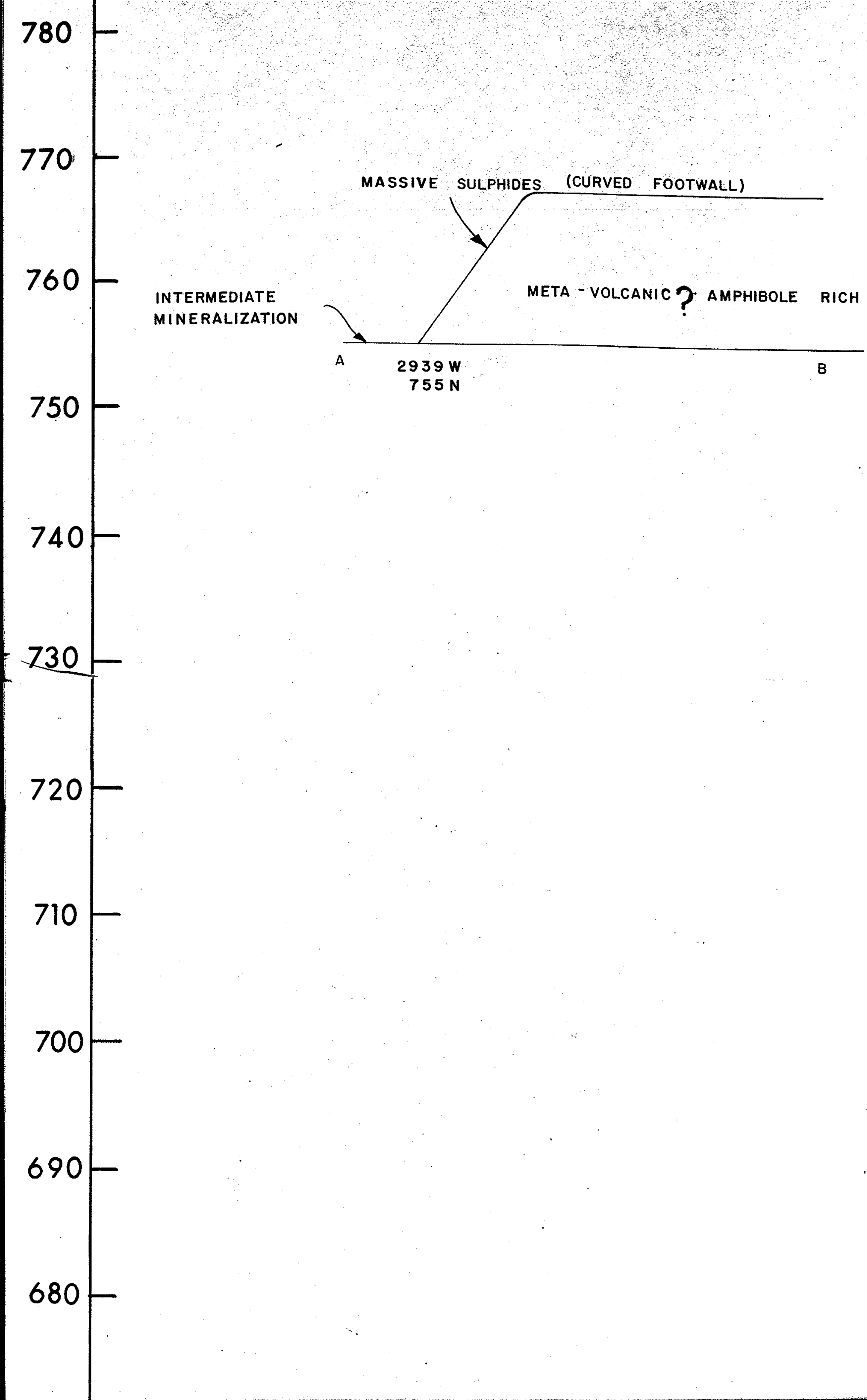
BIRD RIVER
GREENSTONE
BELT

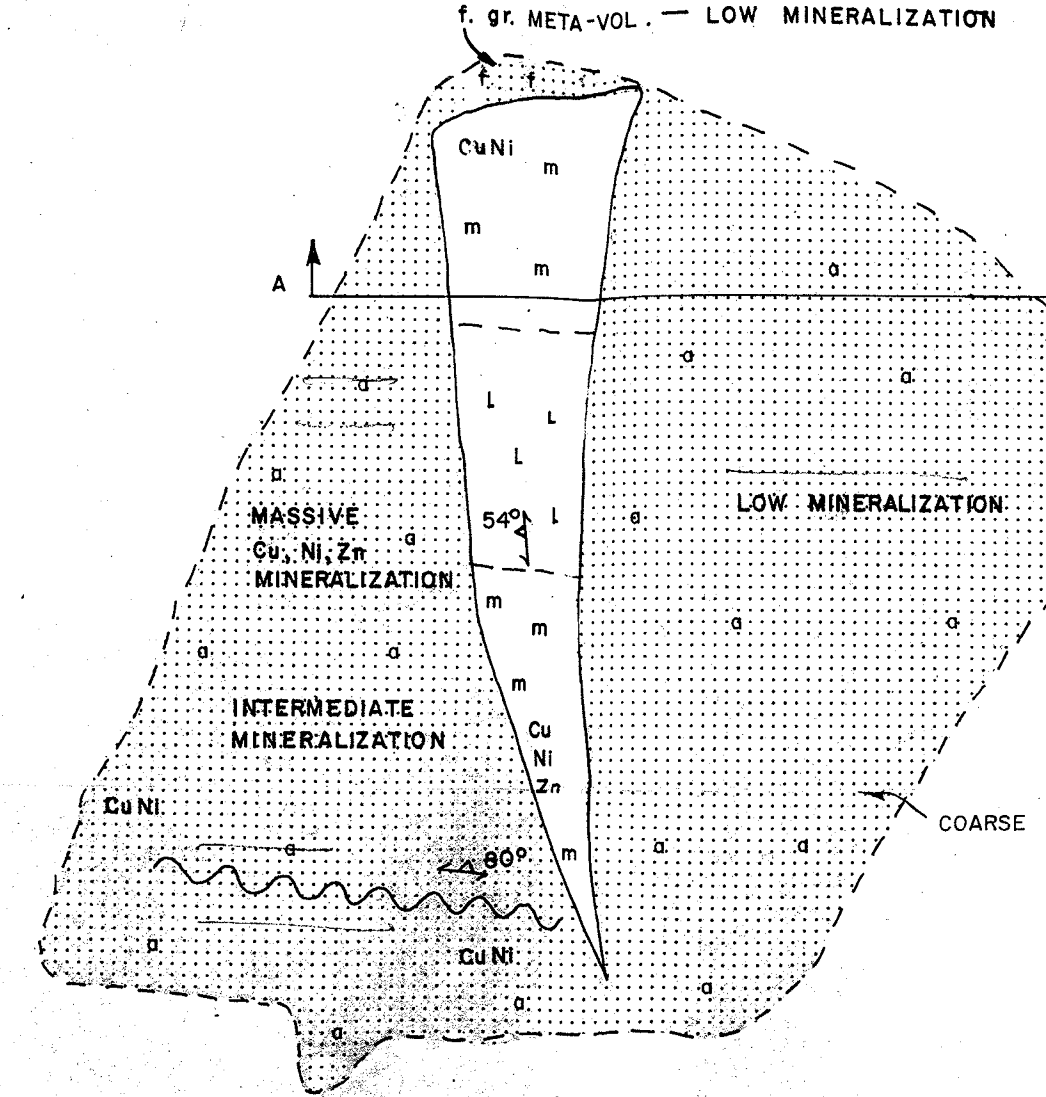
MINERALIZED SHEA
L LOW MINERA
I INTERMEDIAT
M MASSIVE MIN
MASSIVE PINK TO C
METASEDIMENT
p META-VOLCANIC –
c META-VOLCANIC -
a META-VOLCANIC –?
f META-VOLCANIC –

GEOLOGICAL BOUN
STRIKE AND DIP OF
STRIKE AND DIP O
STRIKE OF PEBBLE
STRIKE AND TOP
ILL-DEFINED SHEARED
META – VOLCANIC
SHEAR
STRIKE AND DIP O
Cu, Ni CHALCOPYRITE, PYR
Cu, Ni, ... CHALCOPYRITE, PYR



660
650
640
630N
620
610
600
590
580
570
560
METASEDIMENT BIOTITE CHLORITE SCHIST
Zn
COARSE GRAINED PILLOW LAVA
210° CONTACT
X FINE GRAINED PILLOW LAVA
X FINE GRAINED META-VOLCANIC
82°
FINE GRAINED MASSIVE META-VOLCANIC
2 FT. WIDE MINERALIZED VEIN
GRANITE
022° CONTACT
FINE GRAINED MASSIVE META-VOLCANIC
X FINE GRAINED META-VOLCANIC


780
770
760
750
740
730
720
710
700
690
680
MASSIVE SULPHIDES (CURVED FOOTWALL)
INTERMEDIATE MINERALIZATION
META - VOLCANIC ? AMPHIBOLE RICH
A
2939 W
755 N
B


f. gr. META-VOL. — LOW MINERALIZATION
CuNi
A
MASSIVE
Cu, Ni, Zn
MINERALIZATION
LOW MINERALIZATION
54°
INTERMEDIATE
MINERALIZATION
Cu
Ni
Zn
CuNi
COARSE
60°
CuNi

STRIKE OF PEBBLE ELONGATION (FOLIATION)

STRIKE AND TOP OF LAVA FLOW

ILL-DEFINED SHEARED CONTACT BETWEEN TUFF AND META-VOLCANIC

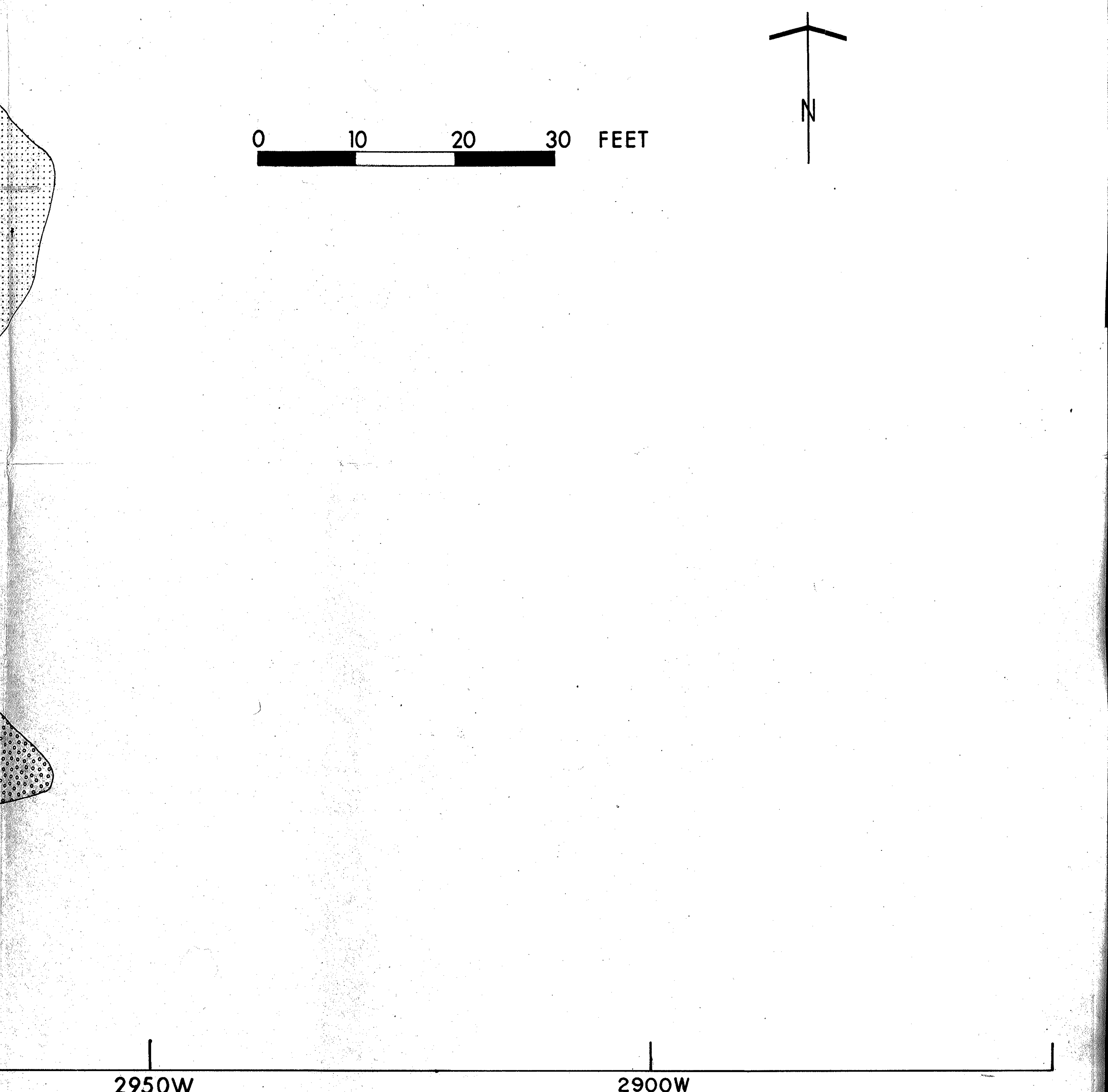
SHEAR

STRIKE AND DIP OF SHEAR

Cu, Ni CHALCOPYRITE, PYRRHOTITE-PENTLANDITE MINERALIZATION

Cu, Ni, Zn CHALCOPYRITE, PYRRHOTITE-PENTLANDITE, SPHALERITE MINERALIZATION

1-1, 3-7 SAMPLE NUMBERS



IC

ETA .VOLCANIC

ORE FAULT PROPERTY – BIRD RIVER MINES CO. LTD.

MINERALIZED SHEAR ZONES

- L — LOW MINERALIZATION
- I — INTERMEDIATE MINERALIZATION
- M — MASSIVE MINERALIZATION

MASSIVE PINK TO GREY GRANITE

BIRD RIVER GREENSTONE BELT

METASEDIMENT

P — META-VOLCANIC – PILLOW LAVA

C — META-VOLCANIC – CHLORITE SCHIST

A — META-VOLCANIC –? AMPHIBOLE RICH

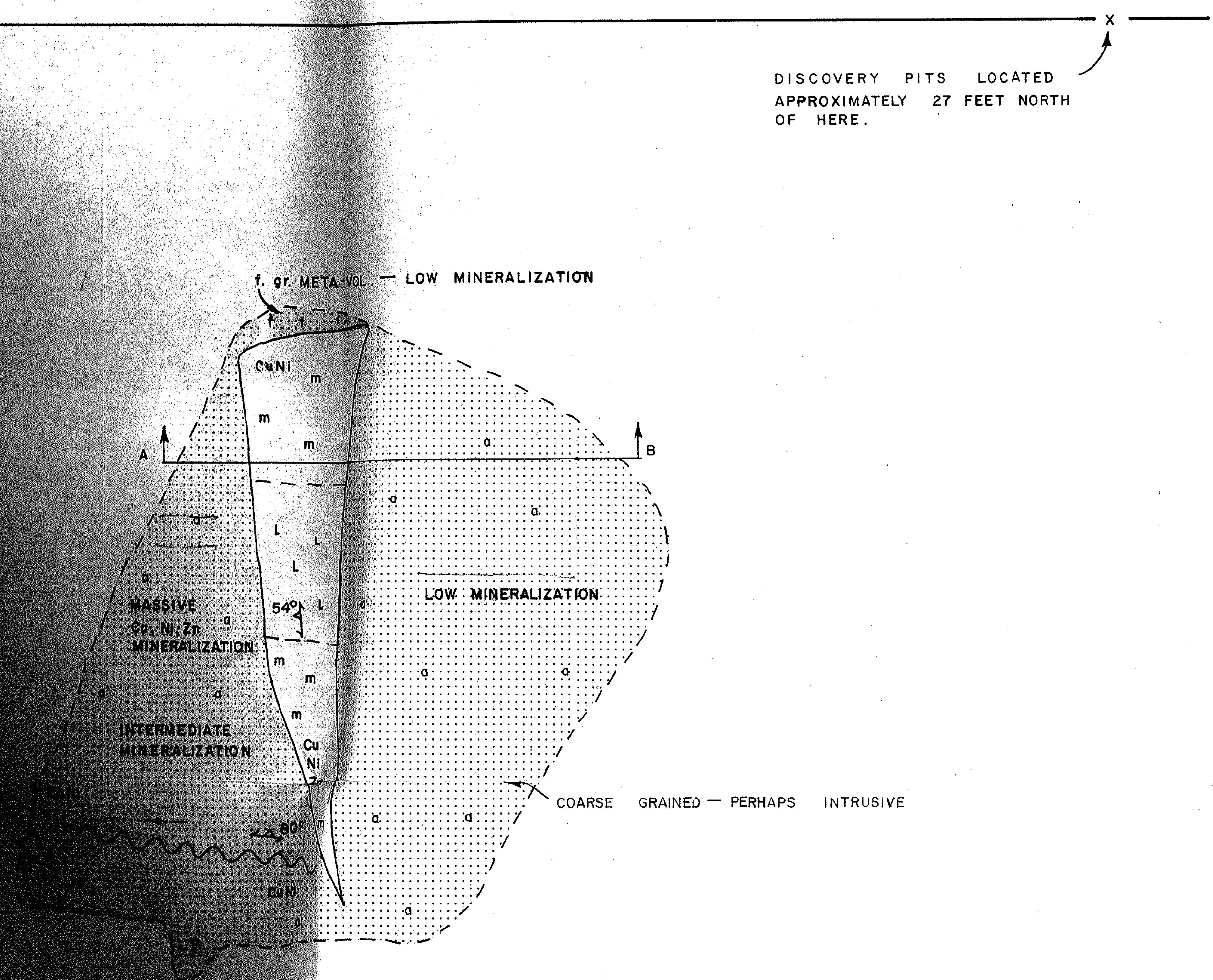
F — META-VOLCANIC – FINE GRAINED MASSIVE

GEOLOGICAL BOUNDARY – DEFINED, ASSUMED

STRIKE AND DIP OF BEDDING

STRIKE AND DIP OF FOLIATION

STRIKE OF PEBBLE ELONGATION (FOLIATION)



210° CONTACT
X FINE GRAINED PILLOW LAVA

X FINE GRAINED META - VOLCANIC