MANITOBA

CANADA-MANITOBA

NREP

NON-RENEWABLE RESOURCE EVALUATION PROGRAM

2nd ANNUAL REPORT

1976-1977

Canada Department of Energy, Mines and Resources

Manitoba Department of Mines, Resources and Environmental Management

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(NREP)

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PART A TECHNICAL REPORTS

Canada Department of Energy, Mines and Resources

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INTRODUCTION

This report presents the results of the second year's work under the four-year (1975-1979) Canada-Manitoba Non-Renewable Resource Evaluation Program (NREP), which began April 1, 1975. A review of the first year's program is contained in Manitoba Mineral Resources Division Open File Report 77/1.

The objectives of NREP are the collection, synthesis and dissemination of metallogenic data on known mineral deposits in Manitoba and an evaluation of the undiscovered resources. In 1976/77 emphasis continued to be placed on:

a) the development of a comprehensive mineral inventory for the Precambrian Shield of Manitoba;

b) the development of computer files for mineral deposit and assessment file data;

c) the evaluation of the past exploration work conducted in the Shield areas of the Province, especially the Lynn Lake and Flin Flon belts and parts of Superior Province;

d) the geological examination and evaluation of known and potential host environments for nickel, disseminated copper, and copper-zinc massive sulphide deposits in the Thompson, Bird River, Flin Flon and Lynn Lake areas;

e) mineralogical investigations of Manitoba ores, with emphasis on nickel ores of the Thompson and Lynn Lake (Farley Mine) areas; and

f) the development of a computer model for determining the optimum rate of return, size and production life of a mining project.

1976/77 was the first year in which full field programs were conducted in the major mineral deposit evaluation projects and this is reflected in the presentation of project data in this report.

The main products of NREP will be qualitative but, where possible, quantitative estimates of Cu, Zn and Ni in Precambrian environments of Manitoba will be attempted. Interim products such as this report are intended to provide summaries and results to date of work-in-progress.

In the coming year (1977/78) the massive sulphide project will shift its emphasis to examination of greenstone belts of the Superior Province of eastern and southeastern Manitoba in order to obtain a fairly uniform coverage of the Province. Field work for the Ni-project will take place in the Lynn Lake area and in selected locations throughout the Province.

SUMMARY OF MANITOBA-NREP PROJECTS AND COSTS

The program comprises 11 main projects funded at a total cost of about $1.6 million over the 1975-1979 period. Costs are shared equally between the Manitoba Department of Mines, Resources and Environmental Management and the Federal Department of Energy, Mines and Resources.

In 1977/78 the Mineral Economics project (NM 7511) has been transferred to the Canada-Manitoba Subsidiary Agreement on Mineral Exploration and Development, a four year (1975-1979) $8.5 million program funded equally by Manitoba and the Federal Government (Departments of Energy, Mines and Resources and Regional Economic Expansion). Funds released through this transfer will be allocated to other existing NREP projects.

Projects are carried out by permanent and contract personnel of the Mineral Evaluation and Administration Branch of the Manitoba Department. Each NREP project leader (Manitoba) has a federal counterpart (mainly personnel of the Economic Geology Subdivision, Geological Survey of Canada), whose function is to provide consultation and, where feasible, active participation in the program.

Table 1 summarizes NREP projects, objectives and approximate four-year costs. Additional details are given in the individual project progress reports that follow. Table 2 provides a list of NREP personnel.

TABLE 1
SUMMARY OF MANITOBA-NREP PROJECTS AND COSTS [1]

Project No.	Title	Purpose	Estimated Costs 1975-1979 (thousands of 1975 dollars)
NM 7501	NREP Management	Direction and administration of the program.	184.9
NM 7502	Mineral Inventory	To prepare and publish a comprehensive mineral inventory file of all known mineral deposits and occurrences in Manitoba	174.5
NM 7503	Computerization and Data Management	To develop and implement a computerized mineral occurrence and mineral deposit file using input from Project NM 7502. To develop a parallel file for the storage and retrieval of provincial assessment records.	169.7
NM 7504	Evaluation of Nickel Environments	To investigate known and potential nickel deposits and environments in Manitoba including those of the Thompson and Lynn Lake belts; to develop deposit models to understand the genesis of known deposits.	234.1
NM 7505	Evaluation of Massive Sulphide Environments	Investigation and evaluation of massive sulphide deposits and environments. Initial emphasis to be on the Flin Flon-Snow Lake and Lynn Lake belts; later in the program to include Superior Province greenstone belts.	301.9
NM 7506	Investigation of Disseminated Base Metal Environments	Investigation and evaluation of the base metal (mainly copper) potential of possible "bedded" environments such as the Sickle-Wasekwan contact zone, and porphyry-type copper environments.	141.9
NM 7509	Exploration Review and Evaluation	Evaluation of recorded geophysical, geological and geochemical exploration data to determine past exploration coverage as an input to resource appraisal and as a measure of residual exploration potential of such environments.	258.2

(cont.)

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[1] *Revised, April, 1977.*

TABLE 1 (concluded)

Project No.	Title	Purpose	Estimated Costs 1975-1979 (thousands of 1975 dollars)
NM 7510	Ore Mineralogy	Investigation of ore mineralogy of known Manitoba deposits to determine further beneficiation possibilities and to provide a mineralogical basis for classification and correlation. Initial emphasis on deposits in the Thompson Belt and Flin Flon-Snow Lake belt. Laboratory work is being done at CANMET[1], Ottawa.	82.0
NM 7511[2]	Mineral Economics	Three sub-projects: -1) Capital Expenditure analysis — investigation of capital expenditures required to bring a given mineral deposit into production in a particular region of the Province -2) Mineral Production analysis — development of a "life-index" model to investigate viability of mining communities and required infrastructure -3) Economic Exploitability of Mineral Resources — development of a computer model to assess economic parameters of mineral exploitation	28.0
		Sub	1,575.2
		Contingencies	24.8
		Total	1,600.0

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[1] *Canada Centre for Mineral and Energy Technology (Department of Energy, Mines and Resources).*

[2] *Transferred to Canada-Manitoba Subsidiary Agreement on Mineral Exploration and Development, April 1, 1977.*

TABLE 2

LIST OF NREP PERSONNEL

	Manitoba	Canada
Project NM 7501 — Program Management	F.J. Elbers	D.C. Findlay (G.S.C.) 7)
NM 7502 — Mineral Inventory	J.D. Bamburak S.M. Haskins G.R. Josse	J.P. Goddard (M.D.S.) 8)
NM 7503 — Data Management and Computerization	H.A. Ambach C.G. Nahnybida 1) A.O. Waywanko 2)	D.D. Picklyk (G.S.C.)
NM 7504 — Evaluation of Ni Environments	P. Theyer R.H. Pinsent	O.R. Eckstrand (G.S.C.)
NM 7505 — Evaluation of Massive Sulphide Environments	G.H. Gale J. Koo	D.F. Sangster (G.S.C.)
NM 7506 — Evaluation of Disseminated Base Metal Environments	D.A. Baldwin	R.V. Kirkham (G.S.C.)
NM 7509 — Exploration History Review	I.T. Hosain 3) G.G. Southard 4) L. Solkoski G.M. Ostry 5)	J.M. Franklin (G.S.C.)
NM 7510 — Ore Mineralogy	J.D. Scott 6)	D.C. Harris (CANMET) 9)
NM 7511 — Mineral Economic Studies	R.G. Bagnall	J. Zwartendyk (M.D.S.)

1) commenced............September 20, 1976
2) commenced............January 31, 1977
terminated..............May 27, 1977
3) commenced............February 1, 1977
4) transferred ....March 26, 1977
5) commenced............October 18, 1976
6) commenced............July 5, 1976
7) Geological Survey of Canada
8) Mineral Development Sector, Department of Energy, Mines and Resources
9) Canada Centre for Mineral and Energy Technology

SUMMARY OF 1976-1977 WORK

During the second year of the Non-Renewable Resource Evaluation Program all projects were underway with nearly complete staffing. A complete field program was carried out in the massive sulphide, nickel and disseminated base metal projects in order to collect data for the development of deposit models and to characterize mineral deposit environments.

The Mineral Inventory for the Precambrian Shield of Manitoba is 95% complete. The information on the cards is being coded for inclusion in the MIND computer file.

The computerization project successfully developed a CLaims ASSessment (CLASS) and MINeral Deposit (MIND) computer file. All open file assessment reports and 500 Mineral Inventory cards have been indexed and entered into the files.

The evaluation of nickel environments has focused on the Lynn Lake and Bird River areas and models for the mineralization are proposed in this report.

The evaluation of massive sulphide environments continued in the Flin Flon – Snow Lake and Lynn Lake volcanic belts. Stratigraphic control of mineralization has been demonstrated in the Snow Lake and Lynn Lake areas and recommendations are made for further exploration.

Porphyry-type mineralization in the Flin Flon – Snow Lake greenstone belt was investigated under the disseminated base metals project. Low grade, sub-economic disseminated Cu-Mo mineralization was examined in a few plutons and a final report is in preparation.

Analysis, interpretation and compilation of ground geophysical data were started on February 1, 1977 in support of the mineral evaluation studies. Recommendations for further exploration in the Athapapuskow Lake area are made in this report.

The ore mineralogy project concentrated on the Thompson and Farley Mines, with minor work on the Centennial and Ruttan Lake Mines.

A computer model for mining project evaluation was developed as part of the mineral economic studies. The model determines the optimum size and life of a potential mining project.

PROJECT REPORTS

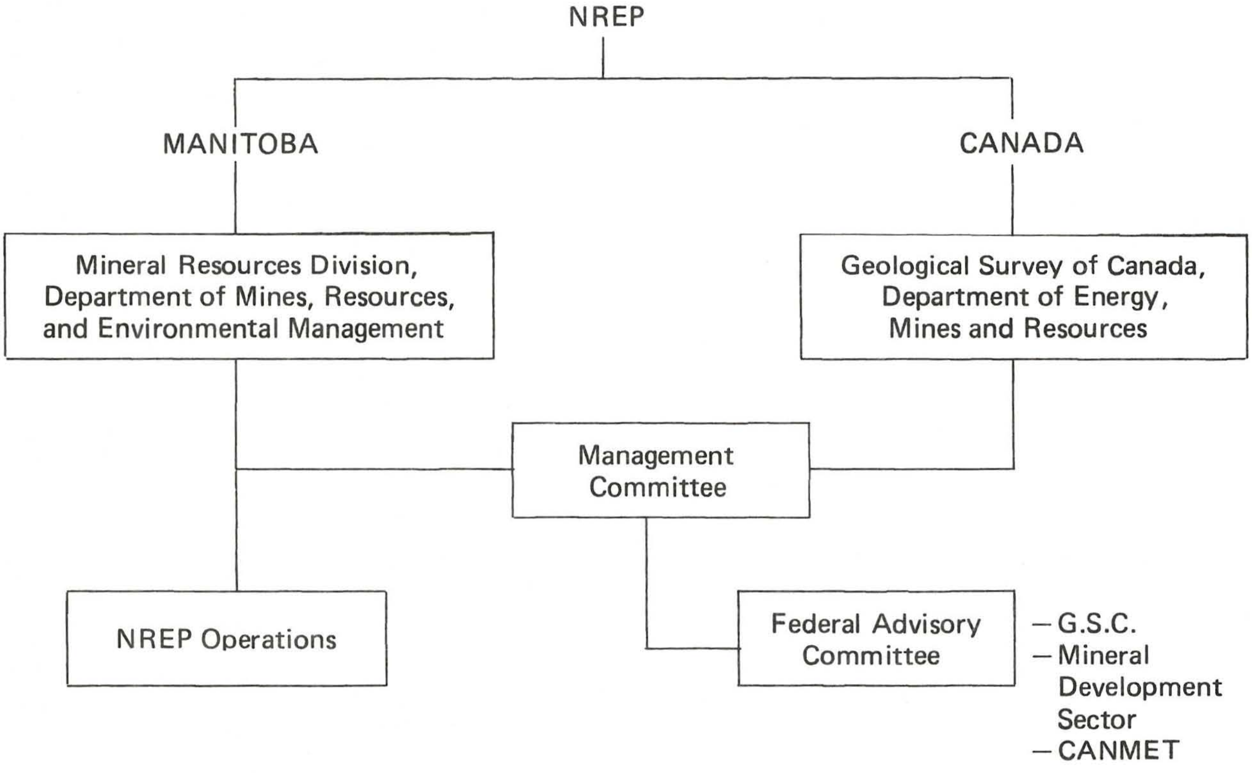
NM 7501 PROGRAM MANAGEMENT — *by F.J. Elbers and D.C. Findlay*

Overall NREP Management is provided by a two-man committee composed of a provincial representative (F.J. Elbers, Mineral Evaluation and Administration Branch, Department of Mines, Resources and Environmental Management) and a federal representative (D.C. Findlay, Geological Survey of Canada, Department of Energy, Mines and Resources). In addition, a federal advisory committee composed of representatives from the Geological Survey of Canada, Mineral Development Sector and CANMET (Canada Centre for Mineral and Energy Technology) provides technical advice. Figure 1 illustrates the NREP management structure.

All projects, except geophysical evaluation under Exploration History Review (NM 7509), were fully staffed during most of 1976/77. A vacancy for a geophysicist existed from April 1, 1976 until February 1, 1977 and delayed the compilation and analysis of geophysical data in support of the mineral evaluation projects. J. Grice, who undertook the ore mineralogy project during 1975/76 terminated on March 31, 1976 and was replaced by J.D. Scott on July 5, 1976.

Because of start-up delays and a limited field program, costs for the first year of the program, 1975/76, were only $210,000.00, well below the four year average of $400,000.00. Second year costs are approximately $375,000.00, reflecting nearly complete staffing and a full field program during the year.

Because of limited funding available under NREP, the mineral economic studies will be continued, commencing April 1, 1977, under the Canada/Manitoba Subsidiary Agreement on Mineral Exploration and Development.



NM 7501 Figure 1 NREP Management Structure

NM 7502 MINERAL INVENTORY – *by J.D. Bamburak*

Summary

- A total of 799 cards, representing 95% coverage of the Precambrian Shield in Manitoba has been prepared by the Mineral Inventory group.
- Coding of the MIND Mineral Deposit computer input documents is complete for all available Mineral Inventory cards.
- A print-out from a temporary computer file, IMP, containing the most Important Mineral Properties in Manitoba, was released as Open File Report 77/2.
- The Mineral Inventory group received 99 requests for information during 1976/77.
- Completion of the remaining 5% of the Mineral Inventory cards is expected by October 1, 1977 and it is anticipated that all cards will be updated by April 1, 1978.
- Publication of Mineral Inventory cards will begin after October 1, 1977.

Introduction

The objective of the Manitoba Mineral Inventory Project is to provide a readily accessible file, in index form, summarizing all available information on known mineral deposits in the Province. The details of this card file were described by Bamburak (1976).

Results of Work

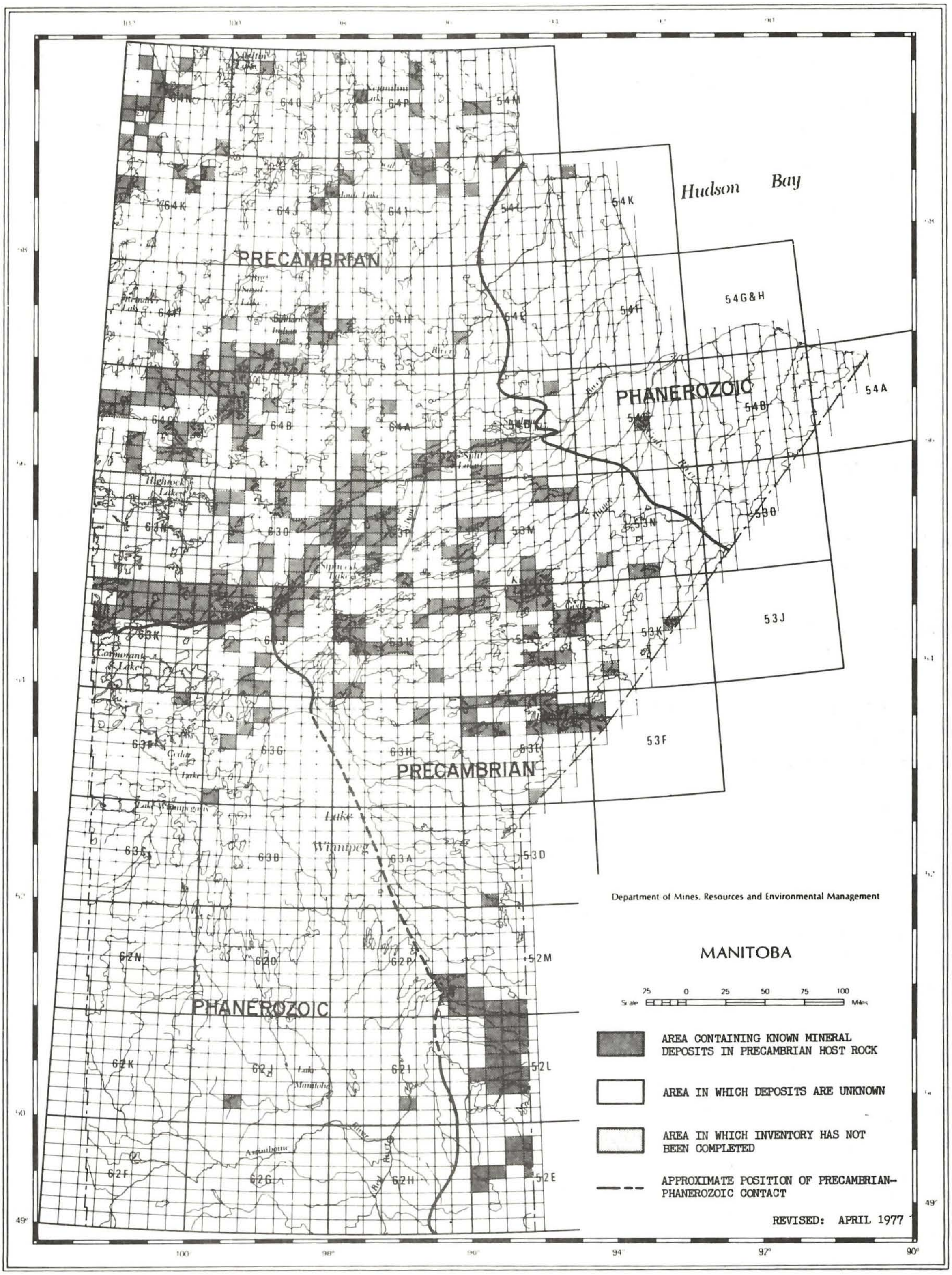
The addition of 170 cards compiled between April 1, 1976 and March 31, 1977 increased the total number of Mineral Inventory cards to 799. Figure 1 shows the N.T.S. areas containing the mineral deposits described on the cards. Some of the deposits are in Precambrian host rock underneath Phanerozoic sediments.

The former estimate of 1000 Mineral Inventory cards (Bamburak, 1976) was revised downward to 850 on the basis of the 1976/77 progress. The 799 completed cards represent a 95% completion of the first detailed inventory of mineral deposits in the Precambrian Shield of the Province.

Coding of the MIND computer input documents (Ambach, 1976) is complete for all available Mineral Inventory cards. The status of the MIND computer file is discussed by Ambach in this report (see Project NM 7503, following).

A temporary computer file containing the most important mineral properties in Manitoba was developed during the year; it will be used until the MIND computer file becomes fully operational. This temporary file was named IMP which stands for Important Mineral Properties. The first print-out from the file was obtained in September, 1976 and a revised print-out made in February, 1977 has been released as Open File Report 77/2 (Bamburak, 1977).

During 1976/77, the number of requests for information increased by 16% over the preceding year to 99. Of this total, 39 originated from within the Mineral Resources Division; 31 were from outside the Division, but within the Provincial Government; 16 came from industry; and 13 were from other sources.



NM 7502 Figure 1 Progress Map — Manitoba Mineral Inventory

Changes in Proposed Work

The inventory of known Phanerozoic mineral deposits (industrial minerals, excluding sand and gravel) is outside the scope of NREP, but can possibly be undertaken under the Federal/Provincial Mineral Exploration and Development Agreement.

Work Planned, 1977/78

Completion of cards describing known mineral deposits in Precambrian host rocks is expected by October 1, 1977. Because of frequent changes in disposition status the cards have to be regularly updated. It is expected that by April 1, 1978 the updating will have progressed to the point where no cards are more than one year out of date.

Selected References

Ambach, H., 1976: NM 7503 Data Management and Computerization; *in* Non-Renewable Resource Evaluation Program, First Annual Report 1975/76; *Man. Min. Res. Div.;* Open File Rept. 77/1.

Bamburak, J.D., 1976: NM 7502 Mineral Inventory; *in* Non-Renewable Resource Evaluation Program, First Annual Report 1975/76; *Man. Min. Res. Div.;* Open File Rept. 77/1.

Bamburak, J.D., 1977: Important Mineral Properties of Manitoba; *Man. Min. Res. Div.;* Open File Rept. 77/2.

NM 7503 DATA MANAGEMENT AND COMPUTERIZATION — *by H. Ambach*

Summary

- CLASS file is operational, with 1600 open-file assessment reports indexed.
- Over 1000 confidential assessment reports have been indexed and entered into the CLASS file.
- All of the 799 completed Mineral Inventory Cards have been indexed and 500 have been entered into the MIND file.
- Following evaluation of the results of a pilot study, development of the CORE file was suspended.

Introduction

The objective of this project is to develop computerized files for mineral resource inventory, mineral deposit description, and mineral exploration history. Originally, three files were designed (Ambach, 1976), each containing a different level of information appropriate to its ultimate use:

1. **CLASS File (Claims Assessment File)**

A broad-based historical information file to serve as an index to technical reports of exploration activities submitted to the Department for assessment purposes.

2. **MIND File (Mineral Deposit File)**

A file containing greater geological detail on mineral occurrences; to be used as an index to more complete deposit descriptions (see Mineral Inventory, NM 7502, this report) and as a summary of reserves and production figures.

3. **CORE File**

A detailed geological file containing information from diamond drill logs; additionally, an index to associated exploration information is provided.

Following pilot studies for each of these files, data collection began for the CLASS and MIND files. Further development of the CORE file was postponed pending a survey of utilization and applications.

Results

CLASS File

The nucleus of the Manitoba mineral inventory data base is the CLASS file. Contained within this file are indexes to approximately 2,600 claim assessment reports. These indexes are formed by summarizing the contents of the assessment reports into pre-defined categories (see Ambach, 1976) and entering this information into the computer-based file. The nature and definition of the information allows for accessing any report within the assessment file by means of individual or grouped data items.

A computer-produced index to assessment reports will be available in the near future. This index will replace the current manual index, and will be updated on a regular basis. It is intended that through this vehicle the public will be made aware of newly released reports sooner than is currently possible. In addition to the standard index, individually tailored searches will be carried out upon request.

MIND File

Five hundred of the 799 completed Mineral Inventory cards have been entered into the file. Data validation, entry programs, and report generating programs have been written. Additional retrieval programs can be written at public request.

CORE File

As pilot project for this file, one assistant summarized 200 diamond drill logs onto the computer input documents. This information was entered into a computer file. The quality of information, collection procedures, file architecture and information retrieval were evaluated. Although this prototype file was judged to be of some value, further development was suspended, pending a review of utilization and applications.

Projected Activity for 1977/78

All previously submitted exploration activity reports will have been summarized and entered into the CLASS file in the near future. The emphasis will then shift to utilizing this file. Towards this end, computer-generated indexes are planned to facilitate public access to the exploration activity reports. The file can also be used for researching previous exploration activity.

File entry of Mineral Inventory cards will continue, with a December, 1977 target date set for a fully operational MIND file, which will be accessible to the public.

References

Ambach, H., 1976: NM 7503 Data Management and Computerization; *in* Non-Renewable Resource Evaluation Program, First Annual Report 1975/76; *Man. Min. Res. Div.;* Open File Rept. 77/1: pp.22-32.

NM 7504 EVALUATION OF NICKEL ENVIRONMENTS IN MANITOBA — *by P. Theyer*

Summary

- Sulphide mineralization with economic potential in the vicinity of the Bird River Sill, S.E. Manitoba, comprises Fe-Ni-Cu-Zn sulphide assemblages in Rice Lake Series volcanic-sedimentary rocks (e.g. Dumbarton Mine), and Fe-Ni-Cu sulphides accumulated at the base of the mafic to ultramafic Bird River intrusion (e.g. Maskwa West Pit).
- A new genetic model for the Dumbarton Mine deposit is presented, in which concepts of previous authors are modified in the light of new evidence from the Maskwa West Pit and adjacent areas.
- On the basis of deposit type models, target areas for further Ni-Cu exploration in the Bird River Sill have been delineated.
- A sulphur isotope study is being carried out on material from the Dumbarton Mine and Maskwa West Pit with a view to obtaining information on the origin of the sulphides.
- A program of radiometric age determination has been initiated on samples of rock units associated with nickel mineralization in the Thompson Nickel Belt to help clarify the effects of geological events on the mineralization.

ACTIVITIES IN 1976-1977

Field Work

During the 1976 field season ultramafic-hosted Ni-Cu occurrences were examined in the Bird River and Rice Lake – Beresford Lake areas of S.E. Manitoba. Several nickel mines in the Thompson Belt and the Farley Mine at Lynn Lake were visited. In addition, ultramafic rocks in the Flin Flon area were examined.

Studies of the Bird River Region

Genetic interpretations of the main nickel deposits, and a preliminary assessment of the nickel potential of the Bird River Sill region were carried out and are presented in the following section. Ore samples from the Dumbarton Mine and the Maskwa West Pit were collected for sulphur isotope studies, which are currently in progress.

Thompson Belt Mines Tour

Several mines of the Thompson Nickel Belt were visited to obtain familiarity with their mineralization patterns. The underground visits were followed by studies of mine plans and sections, and discussions with mine geologists. Included in this program were the Manibridge, Pipe II, Birchtree and Thompson (T1) deposits.

Thompson Belt Radiometric Dating Program

A radiometric dating program on rocks from the Thompson Nickel Belt is presently under way. Samples and geological information will be provided by INCO Ltd. The laboratory work and interpretation of data will be carried out at the University of Montreal, Quebec. It is anticipated that ages obtained will help define (i) the age of formation, (ii) the age(s) of deformation, and (iii) the age of nickel mineralization.

Special emphasis is being placed on the exact derivation and description of the analyzed samples so as to permit future re-interpretation of the data in the light of new geological evidence.

Evaluation of Nickel Environments in the Lynn Lake Belt

The imminent closure of the Farley Mine in Lynn Lake made it imperative to collect and collate all data relevant to this deposit. A separate sub-project was created to study this mineralization, and eventually to extend the research to other gabbroic plugs of the Lynn Lake Belt. The geologist in charge of this work, R.H. Pinsent, has reported separately on his findings (NM 7504-B, this report).

Present emphasis is on developing an understanding of a few selected occurrences of Ni-Cu mineralization associated with ultramafic rocks in the Thompson Belt and in the Superior and Churchill Provinces. The resulting data on geology, mineralization and chemistry will then be incorporated into mineralization models which will be used in an assessment of the nickel potential of individual greenstone belts in Manitoba.

PRELIMINARY EVALUATION OF THE NICKEL POTENTIAL OF THE BIRD RIVER REGION, SOUTHEAST MANITOBA

General Geology

The Bird River Sill is a composite mafic – ultramafic intrusion with an average thickness of 1000 m. It crops out along both of the near-vertical limbs of an eastward plunging anticline developed in an east-trending belt of volcanic and sedimentary strata of the Rice Lake Group (Precambrian). On the northern limb (Euclid Lake – Cat Lake Belt) the Sill can be followed for 11 km and on the southern limb (Bird River Belt) for approximately 30 km. Block faulting and younger intrusions divide the Sill into many individual sectors.

A type section through the Sill, in the Bird River Belt, is described by Osborne (1949) and Trueman (1971). Trueman distinguishes 45 discrete layers: 19 of serpentinized peridotite; 18 of chromitite and serpentinized peridotite, interbanded; 1 of pyroxenite; and 7 of gabbro, anorthositic gabbro and anorthosite, undivided.

Figure 1, compiled from various publications, and data on open file in the Manitoba Mineral Resources Division, shows the location of sulphide deposits in the Bird River region. These deposits are classified exclusively on their mineralogy and host rock at this stage.

Three different types of sulphide mineralization, defined on the basis of the host rock and the amount and type of sulphide minerals present, are recognized within the region (Fig. 1). Of these, the first two types are of economic interest, by reason of their Ni and/or Cu content.

Type A represents Fe-Ni-Cu-Zn sulphides assemblages hosted by volcanic-sedimentary rocks of the Rice Lake Group. The most important is the Dumbarton Mine (Fig. 1, location 1). Other examples, each accompanied by its location number on Figure 1 are: Cup Anderson (3), Beaver (4), Wento (5), Ore Fault (6) – also shows association with Type B, see below; and Pay Ore (8).

Type B consists of Fe-Ni-Cu sulphides located in mafic to ultramafic rocks. The best known example of this type is the Maskwa West Pit (Fig. 1, location 2). Other Type B occurrences are: Ore Fault (6) – also included in Type A, see above; Coppermine Bay (7), Mayville (19) and New Manitoba (20).

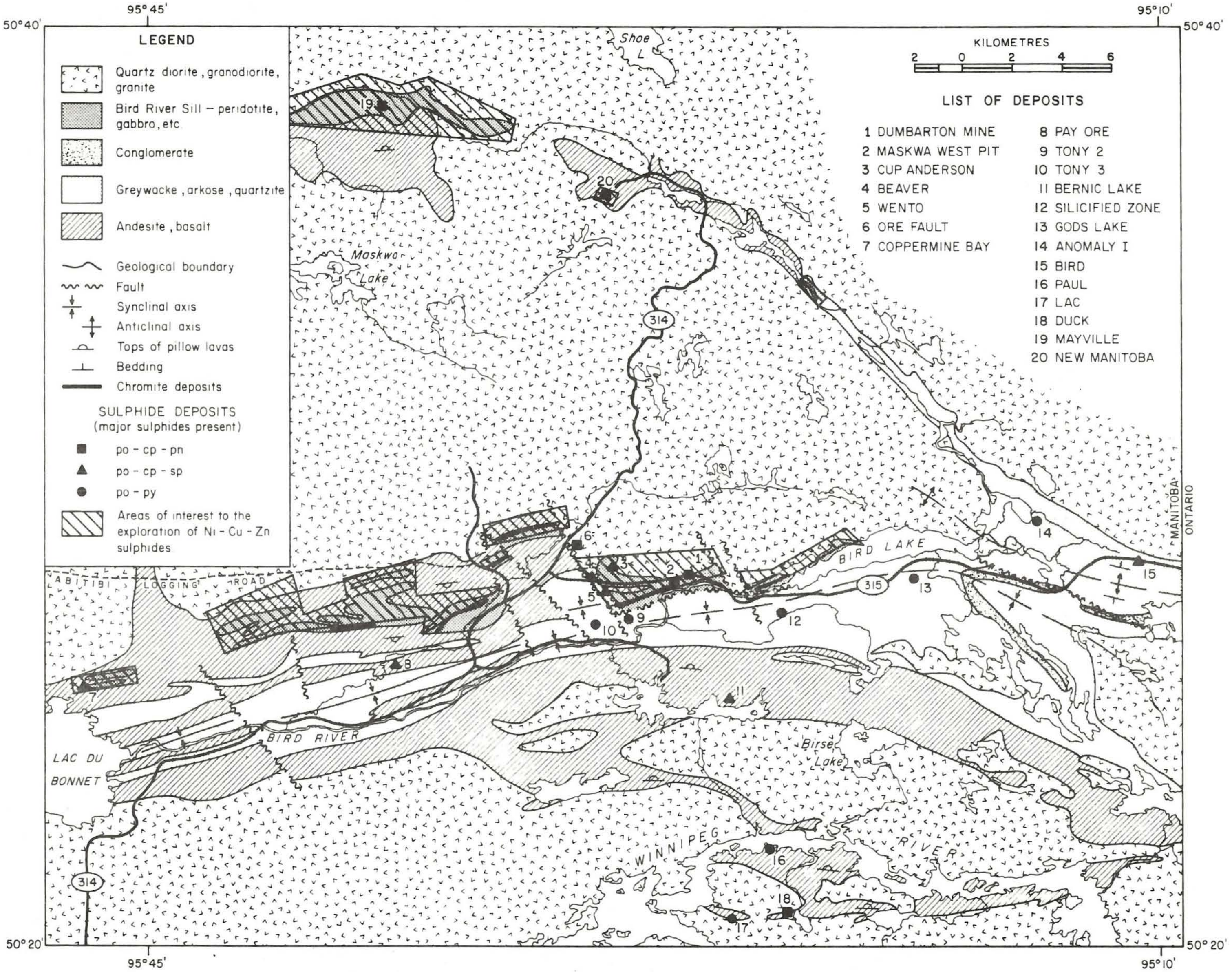
Type C consists of concentration of iron sulphides in Algoma type sulphidic iron formation which is intimately associated with volcanic and sedimentary rocks (Gross, 1964). One of the many examples of this type is the "silicified zone" showing described by Davies (1955, 1956) (see Fig. 1, location 12). Other Type C occurrences are: Tony 2 (9), Tony 3 (10), Bernic Lake (11), Gods Lake (13), Anomaly I (14), Paul (16), Lac (17), Duck (18).

Mineralization at the Dumbarton Mine and Maskwa West Pit

Karup-Møller and Brummer (1971) and Juhas (1973) documented certain characteristics of the mineralization of the Dumbarton Mine that seem to set it apart from "normal" Ni-Cu mineralization:

(a) The Cu-Ni ratio fluctuates over a wide range, showing distinct peaks near 0.2, 0.55 and 0.95 (Karup-Møller and Brummer, 1971). Juhas (1973) demonstrated similar fluctuations based on 734 diamond drill core assays.

(b) Juhas *(op. cit.)* found discrete zones within the mineralization, featuring enrichment of Cu relative to Ni and vice versa. He also noticed vertical enrichment in Ni relative to Cu, not related to the stratigraphy.



NM 7504 Figure 1 Sulphide deposits of the Bird River Sill area (geology adapted from Davies et al (1962))

On this evidence and on other petrographical and mineralogical observations, these authors conclude independently that mineralization in the Dumbarton Mine proceeded in two steps. They agree that the Cu-Zn sulphides were emplaced early, in a volcanic-exhalative stage, in combination with iron formation, and that Ni was added during a later stage.

However, the two papers disagree over the extent to which Cu and Zn were precipitated in iron formation, and on the crucial issue of the origin of the Ni mineralization. As a working model, Karup-Møller and Brummer *(op. cit.)* envisaged sulphur being mobilized out of the iron formation by intrusion of the Great Falls pluton, migrating into mafic and ultramafic rocks of the Bird River Sill, depleting the sill of Ni, and finally being deposited as sulphides at the interface between the Cat Lake granodiorite and the volcanic-sedimentary strata.

A model proposed by Juhas (1973) calls for release of Ni, by serpentinization, from silicate minerals in the Bird River Sill. Following metamorphism of these serpentinites, and triggered by intrusion of the Cat Lake pluton, this Ni would have migrated in the ionic state into nearby iron formation, partially replacing the iron in pyrrhotite.

The latter model is supported by analytical and statistical data. Highlights of the supporting evidence include the high grade of metamorphism and dehydration and Ni-depletion of serpentine in the Bird River Sill immediately south of the Dumbarton Mine. Some questions as to the quality of Juhas' data base arise from the fact that the dehydrated and Ni-depleted zone which he postulates to exist south of the Dumbarton Mine is based on the chemical data of four amphibole-rich samples; these might never have contained much olivine and Ni (Eckstrand, pers. comm. 1976). Evidence supporting a volcanic-sedimentary origin for the sulphur in the Dumbarton ore is provided by sulphur isotope data which indicate that the sulphur is of marine rather than magmatic provenance. This particular aspect of Juhas' evidence is followed up within the present program in greater detail. Further information is given separately (see Sulphur Isotope Study, this report).

Davies (1956) proposed that ultramafic and mafic rocks were assimilated by the intruding Cat Lake granodiorite. Ni and Cu contained in silicate minerals were freed, driven ahead of the intrusive front and eventually deposited at the contact with the Rice Lake volcano-sedimentary series.

Karup-Møller and Brummer (1971) rejected this model because no signs of assimilated ultramafic material have been found in the granite nor has any evidence of granitic material invading ultramafic rocks ever been found in this area.

A hydrothermal origin for the mineralization was proposed by Childerhouse (1928), Wright (1932) and Taylor (1950). These authors postulated that hydrothermal mineralizing fluids originated in the Cat Lake intrusion, either: (a) as residues of basic assimilation (Childerhouse, 1928); (b) as exudates of the Bird River Sill (Wright, 1932); or (c) as differentiates of the granitic magma (Taylor, 1950).

Springer (1950) postulated that sulphides which had accumulated at the base of the Bird River Sill were injected into their present location following mobilization by the Cat Lake intrusion; details of his model are somewhat unclear. H.D.B. Wilson (pers. comm. to Juhas, 1973) suggested that the sulphides might have accumulated at the base of the Bird River Sill and then have been injected along a shear plane into the andesite-granite contact.

None of the above-mentioned authors had the benefit of acquaintance with the Maskwa West Pit, opened in 1975, and located some 1200 m WNW of the Dumbarton Mine. Evidence seen by the writer during a visit to this pit, and in core from the same location, indicates that sulphides accumulated within the magma in a zone at the base of the Bird River Sill. Sulphides show progressive downward concentration within the Sill, from weakly disseminated in the higher parts to almost massive at the basal contact with the Rice Lake Group. Sulphide impregnations are noticeable in the underlying andesite for a distance of 1-2 m. This is a classical model for the origin of Ni concentrations and is of widespread occurrence (Naldrett, 1973).

Based on the conclusions of most of the cited authors, and on the evidence of many other similar occurrences (see Fig. 1), it is proposed that most of the sulphur of the Dumbarton Mine is of exhalative origin and only part of it is of magmatic origin. The mineralization commonly contains Cu and Zn values and is located within or near sulphide iron formations of the Rice Lake Group (Fig. 1).

Ni sulphides which had accumulated near the bottom of the Bird River Sill were mobilized by deformation and heating attributable to the Cat Lake intrusion; subsequently they were injected into the pre-existing Fe-Cu-Zn sulphide zone located along the contact between the Cat Lake intrusion and the Rice Lake Group.

This model explains the existence of Ni sulphides in the assemblage, the fluctuating Cu-Ni ratio of the Dumbarton Mine, the presence of Zn and the essentially marine sulphur isotope ratios.

Other Sulphide Occurrences in the Bird River Area

For locations, see Figure 1. Particulars in Table 1.

Conclusions and Recommendations

Most of the sulphide occurrences of the Bird River Sill area are of Type C: that is, essentially consisting of barren iron sulphides with some traces of Cu and Zn and generally associated with iron formation. These occurrences do not appear to hold much economic potential.

Deposits of Types A and B, on the other hand, are liable to be of economic interest. Both types are represented in the area by ore bodies which have supported mining operations (the Dumbarton Mine and the Maskwa West Pit).

To define target areas for Type B deposits, i.e. sulphide accumulations at the base of a layered mafic to ultramafic body, it is first essential to establish the exact outline of the ultramafic sill by geological mapping and geophysical methods.

Depressions of the lower contact of the sill would be prime targets for Type B deposits, as sulphides should be preferentially concentrated at such locations.

The Ni sulphide portion of the complex polymetallic deposits of Type A (Dumbarton Mine) is attributed to the injection of accumulated sulphides of Type B origin into adjacent rocks — a phenomenon commonly observed in sulphide deposits of the Thompson mining camp. Target areas for this type of deposit are located in strata adjacent to the Ni source — the stratigraphic bottom of the Sill. Figure 1 shows the target exploration areas.

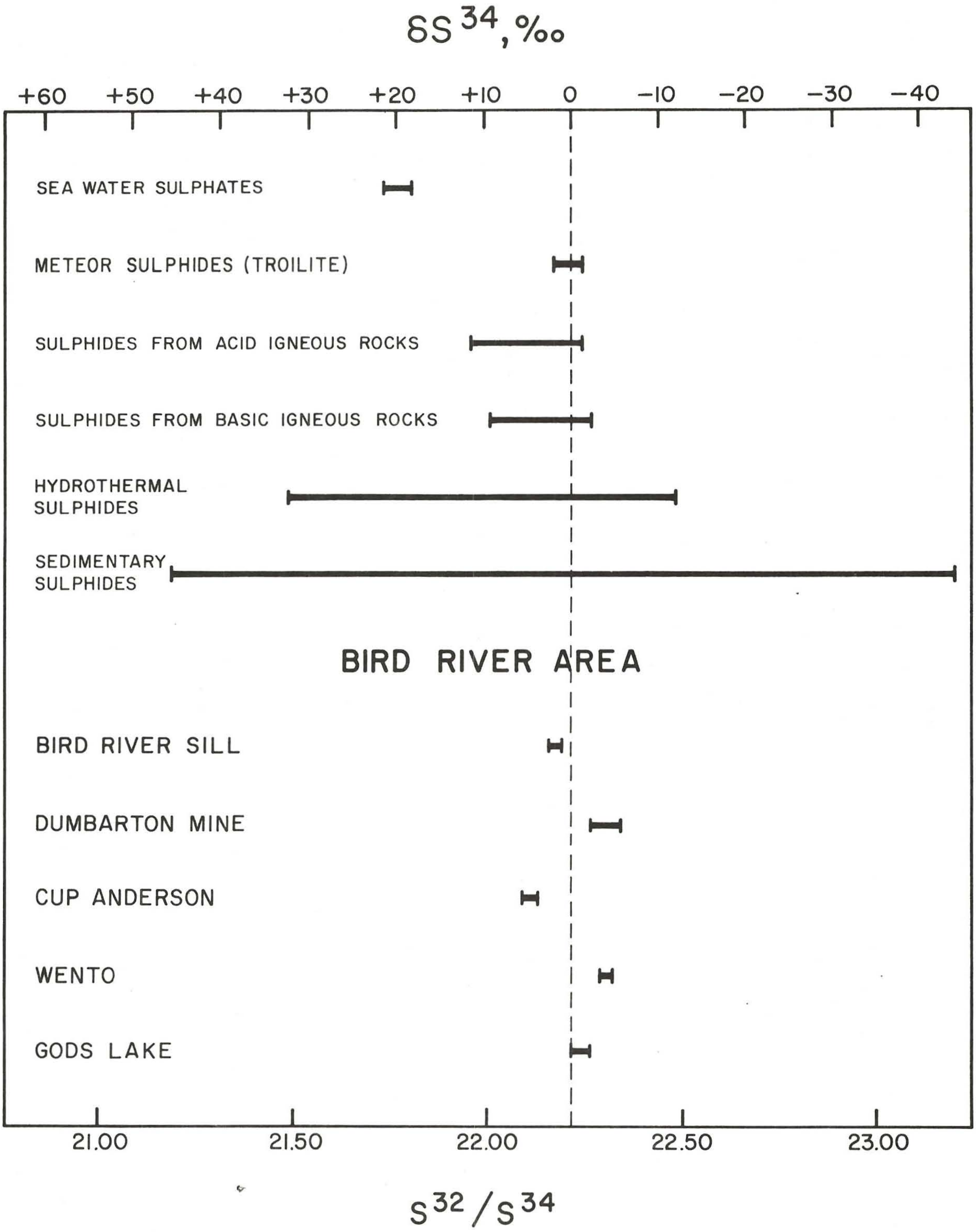
On the basis of a study of submitted exploration records and other relevant literature, it is the writer's opinion that the Bird River Sill area has not been explored as thoroughly as it deserves in light of the potential it offers for these types of Ni-Cu deposits.

NM 7504 TABLE 1 SULPHIDE DEPOSITS IN THE BIRD RIVER SILL AREA. (Only (1) and (2) were mined)

Name of Deposit	Deposit Type	Sulphides						Oxides				Tonnage, Grade and Width	Main Rock Types	Surface Openings	Drilling	References
		po	cp	sp	pn	py	cbn	mag	il	cr	hem					
Dumbarton Mine (1)	A	x	x	x	x	x	x	x	x			1 500 000 tons 1.16% Ni, 0.33% Cu	Andesite, iron formation, tuff, basalt	Decline	x	Various, cited in text
Maskwa West (2)	B	x			x	x				x	x	400 000 tons 1.11% Ni, 0.23% Cu	Peridotite	Open Pit	x	Northern Miner, July 15, 1976
Cup Anderson (3)	A	x	x	x		x		x			x	Cu 4.1%, 30 m Cu 3.8%, 10 m	Crystall tuff, iron formation, quartzite layers	Trenching	x	Wright (1932)
Beaver (4)	A	x	x	x		x		x				Cu 2% (estimate)	Tuff, pyroxenite, iron formation, amphibolite	Trenching	x	Wright (1932)
Wento (5)	A	x	x	x			x						Amphibolite, iron formation	Shaft	x	Wright (1932)
Ore Fault (6)	A & B	x	x	x	x	x		x				1640 000 tons 0.48% Ni	Amphibolite, tremolite-calcite rocks, tuff		x	Prospectus Bird River Mines Co. Ltd. (1972) Ritchie (1972); Juhas (1973)
Coppermine Bay (7)	B		x	?	x							0.46% Ni, 0.27% Cu 1 m	Basic volcanics, gabbro		x	Dept. of Mines, open file
Pay Ore (8)	A	x	x		x	x							Andesite, quartzite, basalt		x	Dept. of Mines, open file
Tony 2 (9)	C	x				x		x					Chert, greywacke, tuff, iron formation, quartzite			Juhas (1973)
Tony 3 (10)	C	x						x					Iron formation			Juhas (1973)
Bernic Lake (11)	C	x	x	x				x					Andesite, iron formation		x	Dept. of Mines, open file
Silicified Zone (12)	C	x	x			x		x					Iron formation			Juhas (1973)
Gods Lake (13)	C	x	x			x		x					Garnet-mica-kyanite schist			Juhas (1973)
Anomaly I (14)	C					x							Iron formation		x	Dept. of Mines, open file
Bird (15)	B		x			x							Ultramafic to mafic rocks		x	Dept. of Mines, open file
Paul (16)	C	x	x			x							Gabbro, quartzite, greenstone, metasediments		x	Dept. of Mines, open file
Lac (17)	C	x	x			x							Gabbro, mineralized, quartzite, gneiss		x	Dept. of Mines, open file
Duck (18)	C	x	x		x	x							Gabbro, iron formation, andesite		x	Dept. of Mines, open file
Mayville (19)	B	x	x		x							Small tonnages of Cu and Ni	Gabbro, mafic volcanics	Trenching	x	Davies et al. (1962)
New Manitoba (20)	B	x	x		x							646 000 tons 0.24% Ni, 0.54% Cu	Gabbro			Canadian Mines Handbooks – 1976/77; Davies et al. (1962)

Deposit Types

Type A	Fe-Ni-Cu-Zn sulphide assemblages in volcanic-sedimentary rocks
Type B	Fe-Ni-Cu sulphides in mafic to ultramafic intrusions
Type C	Generally barren Fe-sulphide associated with sulphide iron formation



NM 7504 **Figure 2** **Sulphur isotopic variations in nature and in deposits of the Bird River area. Diagram and upper part of data from Geochron Laboratories (with permission). Data on Bird River area from Juhas (1973).**

Sulphur Isotope Study

Measurements of the relative abundance of sulphur isotopes in a sulphide can provide information pertaining to the origin of the sulphur and the genesis of the host mineral. Isotope abundances are measured, and expressed in terms of relative depletion or enrichment of S^{34} compared to a standard (troilite sulphur) arbitrarily designated as having zero S^{34} depletion or enrichment.

Each of the isotopes of an element shows a slightly different behaviour pattern when entering into a chemical reaction, because of slight inherent differences in isotopic mass and concurrent vibrational frequency. Heavier, less energetic isotopes are more likely to remain bonded than are lighter, more energetic isotopes.

The upper section of Figure 2 shows data pertaining to sulphur isotope distribution in various types of natural occurrences (Geochron Laboratories, Technical Bulletin No. 4) and the lower section shows data from the Bird River Sill area (Juhas, 1973).

Samples of ore from the Dumbarton Mine and the Maskwa West Pit have been submitted for sulphur isotope studies. Pentlandite will be separated from the sulphide concentrates by selective flotation, and the sulphur isotopes of both sulphide fractions will then be investigated at McMaster University, Hamilton, Ontario.

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NM 7504-B THE LYNN LAKE NI-CU DEPOSITS – *by R.H. Pinsent*

Summary

- The Lynn Lake Ni-Cu project was set up to document and develop a genetic model for the Ni-Cu deposits at Lynn Lake.
- The project has involved (a) an examination of stopes in the "O" and "N" orebodies in the Farley Mine at Lynn Lake; (b) a study of Mine plans and sections supplied by Sherritt Gordon Mines Limited, and (c) petrographic work on the different varieties of ore and the silicate rock-types in the "gabbroic" plugs associated with Ni-Cu deposits. Future work will broaden the study to include data from other, non-mineralized "gabbroic" plugs in the Lynn Lake greenstone belt.
- The results indicate that the mineralized plugs were formed by several phases of magmatic intrusion. Brief descriptions of the "A" and "EL" plugs, and of the "O" orebody in the "A" plug are given.
- The Ni-Cu mineralization in the "A" plug consists largely of five varieties of ore which commonly occur in pipes of amphibolite. The amphibolite is thought to be derived from "norite" and "pyroxenite". The ore types are (a) disseminated ores, (b) plutonic breccia ores, (c) sulphide breccia ores, (d) massive sulphide ores and (e) siliceous "felsite" ores.
- The ores show features characteristic of both magmatic and hydrothermal deposits, and the study so far indicates that although the ores are essentially magmatic in origin, they were modified on emplacement by near-contemporaneous hydrothermal activity.

Introduction

The Lynn Lake Ni-Cu project, a subproject of the NREP Ni project (NM 7504), was started in July 1976 by the present author. The project was set up to collect and interpret data on the 13 near-vertical pipe-like orebodies in two of the "gabbro" plutons at Lynn Lake before permanent closure of the Farley Mines would make underground observations impossible.

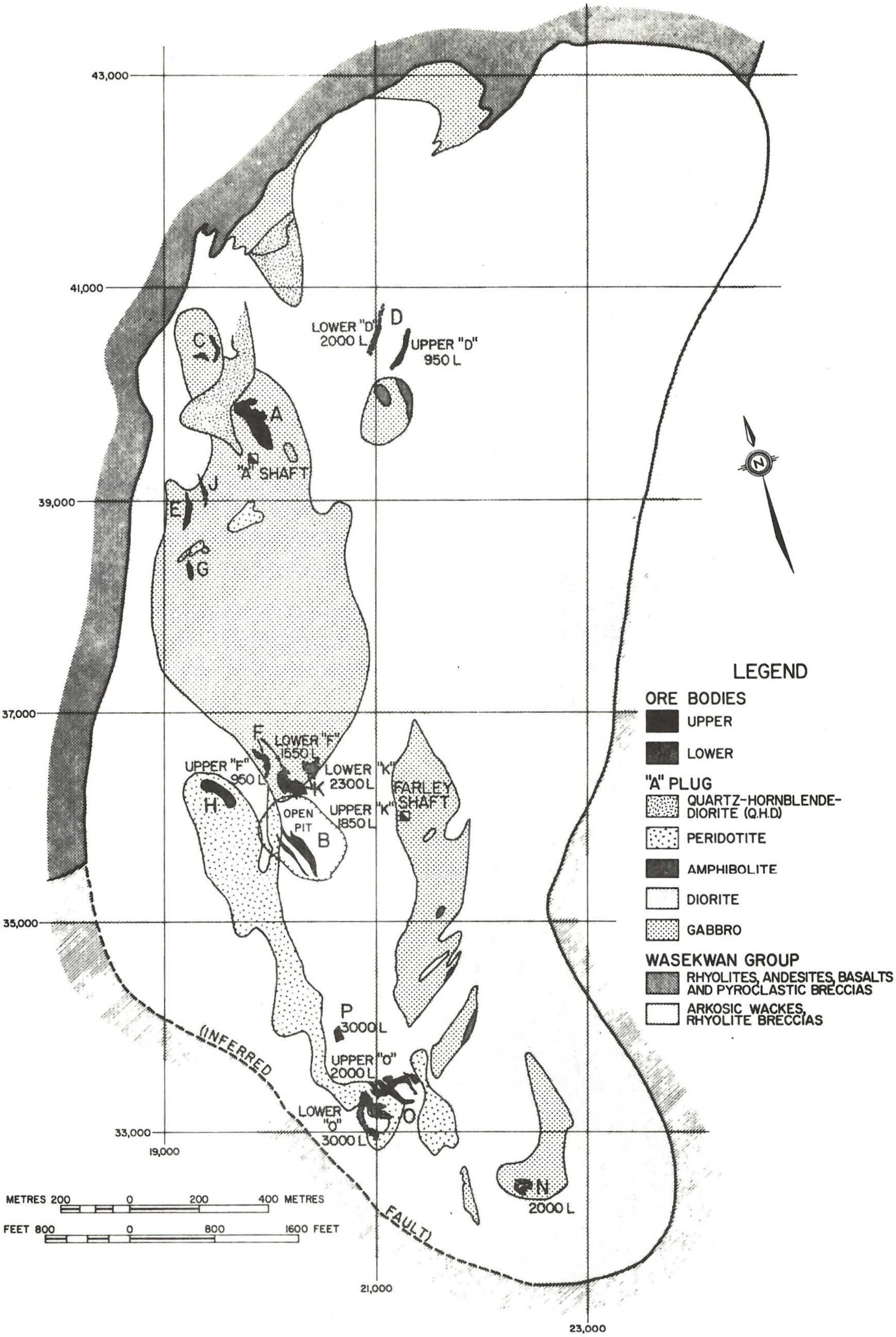
The deposits have been examined and described by several workers since their discovery in 1941. These include Allan (1950), Hunter (1950), Dornian (1950), Ruttan (1955), Milligan (1960), Emslie and Moore (1961), Macauley (1962) and Vellet (1963). The published and unpublished descriptions show general agreement on the main features of the deposits but there is no consensus on the genesis of the Ni-Cu orebodies.

The deposits display characteristics that can be used to support either a magmatic or a hydrothermal origin for the ores, and programs designed to produce the criteria required to enable a choice between the conflicting genetic models are being developed.

The project has also been set up to evaluate the Ni-Cu potential of other "gabbro" plugs in the Lynn Lake greenstone belt in the light of genetic models established for the two mineralized intrusives.

Background and Methodology

Sherritt Gordon Mines Ltd. ceased operation at the Farley Mine on 1st. July, 1976, bringing to an end 23 years of Ni-Cu production from the deposits at Lynn Lake. The Company produced in total 22.2 million tons of ore with an average grade of 1.02% Ni and 0.42% Cu. The Company



NM 7504-B Figure 1 Surface projections of orebodies in the "A" Plug, Lynn Lake; geology simplified from Sherritt Gordon Mines Limited data.

permitted access to the Farley Mine from July 1976 to April 1977, when the mine was finally closed after the completion of the Company's underground salvage operation. Access was restricted to drifts and stopes in the most recently mined "O" and "N" orebodies at the south end of the "A" plug (Fig. 1). These were sampled and examined for internal structure.

The petrography of the "A" plug was studied using material from the vicinity of the "B" pit (Fig. 1), the "O" and "N" orebodies, and from a systematic drilling program carried out on the 2000' level. The rock unit nomenclature used in the following descriptions of the "A" and "EL" plugs, and the "O" orebody, is that used by Sherritt Gordon Mines Ltd. The intermediate to mafic rock-types have been completely uralitized and the anhydrous rock names in quotation marks (e.g. "norite") are, in many cases, inferred.

Detailed whole rock geochemical and petrographic studies at present underway are designed to determine the nature and origin of the rock units defined as "peridotite", "hybrid" and "felsite". Mineralogical investigations are also being conducted by J.D. Scott (NM 7510). His studies are designed to evaluate the effect of metamorphic and hydrothermal processes on the sulphides and silicates.

The Company kindly provided access to all the relevant level plans and sections for the Ni-Cu orebodies and also provided the diamond drill logs and core. This material, the results of the geochemical studies, and previous literature, will be used to develop an understanding of the geology and structure of the two mineralized plugs and the orebodies they contain. Permission of Sherritt Gordon Mines Ltd. to use the material for this study is gratefully acknowledged.

Part of the 1977 summer field season will be spent studying the structure and geological setting of other, apparently non-mineralized, "gabbro" plugs in the Lynn Lake greenstone belt for comparison with the mineralized "A" and "EL" intrusions.

Geology and Structure of the 'A' Plug

Twelve of the 13 orebodies ("A", "B", "C", "D", "E", "G", "H", "J", "K", "N", "O", "P" and "EL") mined by Sherritt Gordon are located in the "A" plug (Fig. 1), a composite pluton of elliptical section (3.0 x 1.5 km) oriented NE-SW, parallel to the regional structural trend of the greenstone belt at Lynn Lake. The "A" plug consists of a "gabbro" body intruded by pipes of mineralized amphibolite. The plug is a near-concordant vertical intrusion located at the interface between two stratigraphic units of the Precambrian Wasekwan Group. To the north and west, the strata are a succession of rhyolites, andesites, basalts, pyroclastic breccias and tuffs; to the south and east, the country rocks consist of arkosic wackes, porphyritic rhyolite breccias and quartz-feldspar porphyries. The NW suite belongs to Unit 3, and the SE suite belongs to Unit 4, as defined by Gilbert (1976) and Syme (1976).

Contacts with the country rock are not well exposed but, where visible, the marginal "gabbros" are strongly sheared for 3-5 m into the plug. Some of the "gabbro" inside the plug displays weak compositional banding (mafic rich to mafic poor). The bands appear to be concordant with the western contact and the country rock foliation. The "gabbros" display a weakly cataclastic igneous fabric, but do not show the pronounced foliation found in the country rock. Small country rock inclusions found in some lengths of "gabbro" core are, however, strongly foliated.

The "A" plug is bounded on the south by a major fault (the Lynn Lake fault, which strikes in a northwesterly direction) and Emslie and Moore (1961) suggested that the "EL" plug, located

1000 m southeast of the "A" plug, is a faulted extension of the larger pluton. This was discounted by Vellet (1963). The "O" orebody has been truncated by a related fault (the "O" fault) below the 3550′ level. The footwall extension of this orebody has not been located.

Detailed sections through the orebodies by Ruttan (1955), Macauley (1962), Vellet (1963), and other Company geologists have shown that the orebodies have undergone considerable local, but irregular, block faulting. The faulting does not, as a rule, disrupt the overall vertical continuity of the orebodies within the plug.

Minor intrusions: The "gabbros" in the "A" plug are intruded by dykes and less regular bodies of "norite", "pyroxenite", "diorite", "diabase", "quartz-feldspar porphyry" and, possibly, "peridotite".

Most of the orebodies (including the "O" and "N") consist of sulphide concentrations in near-vertical pipes of amphibolite and feldspathic amphibolite. Relict pyroxenes found in the amphibolites (Hunter, 1950) indicate that the rocks were originally pyroxenites and norites. The amphibolites are clearly intrusive into the "gabbros", as xenoliths of the latter are abundant in the amphibolites around the pipe contacts.

Several phases of "diorite" have been identified in the "gabbros" close to the orebodies. Although most of them probably pre-date the emplacement of the mineralized amphibolites ("norites"), the variety known as "hybrid" is found in disrupted dykes which cut the mineralized amphibolites in the lower part of the "O" orebody.

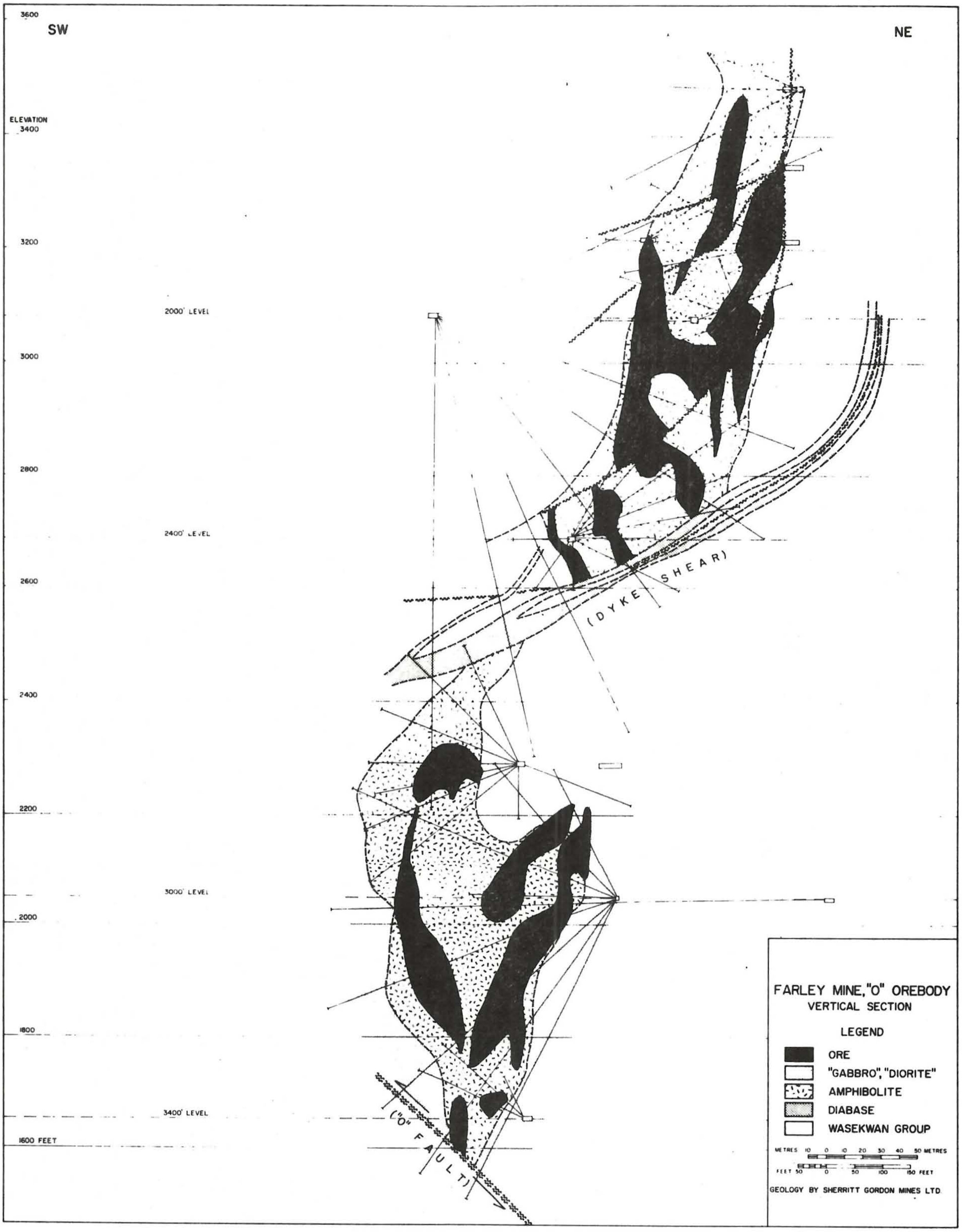
The "A" plug is cut by at least two varieties of aphanitic mafic dyke material. Dykes and irregular bodies of quartz-hornblende-diorite occur throughout the plug. Some quartz-hornblende-diorite bodies clearly pre-date mineralization, and one partially hosts the "K" orebody (Fig. 1).

Similar, but less deformed and altered, dykes of uralitic diabase post-date mineralization. Off-shoots from a dyke which intruded along a major fault that cuts the "O" orebody (the "dyke-shear"; Fig. 2) have also intruded the orebody. Locally, quartz-feldspar porphyry dykes intruded along faults, such as the "porphyry-shear" which cuts the "B" orebody on the 2000′ level.

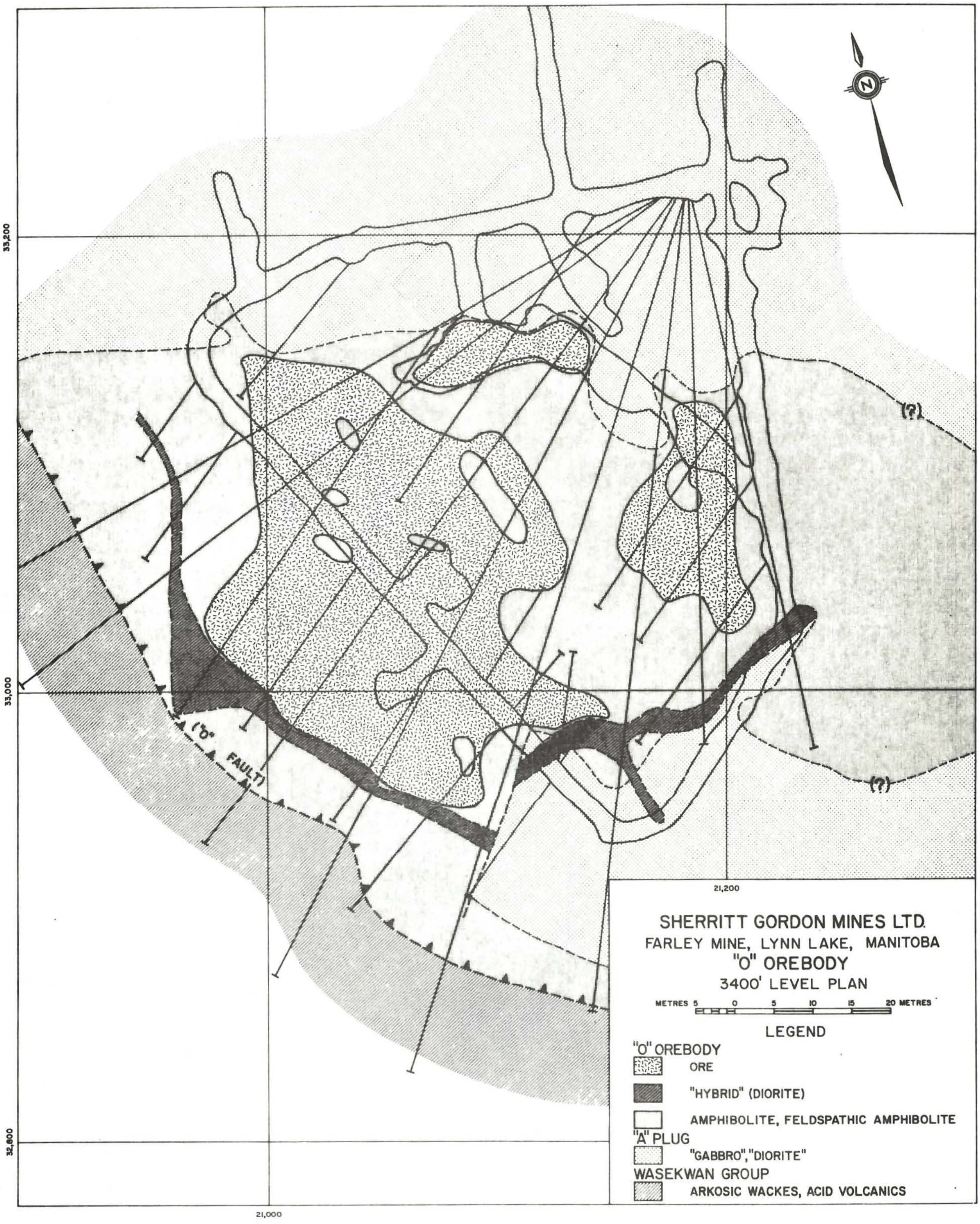
The plugs and dyke-like bodies of "peridotite" which occur in a belt along the western margin of the "A" plug may also be intrusive into the "gabbro", although Emslie and Moore (1961) considered that they were part of a cumulate sequence at the base of a layered gabbro intrusion. There appears to be an angular discordance between a peridotite body in the vicinity of the "N" orebody and the layering in the adjacent "gabbro", (A. DeCarle, personal communcation).

Geology and Structure of the "O" orebody: The "O" orebody consists of discrete ore lenses in a near-vertical mafic pipe located near the southwest corner of the "A" plug (Figs. 1 and 2). The pipe, which is approximately 100 m in diameter, consists largely of barren and mineralized amphibolites and feldspathic amphibolites. It extends more or less continuously from the "O" fault below the 3550′ level to the surface. The pipe has been block faulted, and the upper "O" orebody (above the 2400′ level) has been offset to the northeast with respect to the lower "O" (below the 2600′ level) by movement along a reverse fault (the "dyke-shear" which strikes NW-SE (Fig. 2)).

Mine level plans for the 3400′ and 2000′ levels (Figs. 3 and 4) show that the structure of the "O" orebody is essentially the same above and below the "dyke-shear" (Fig. 2). The ore, which is restricted to the amphibolite pipe, occurs in lenticular sulphide concentrations around the pipe contact and in cross-fractures. Although traces of mineralization occur throughout the pipe, ore grade concentrations have not been found above the 1600′ level.



NM 7504-B Figure 2 A SW-NE cross-section through the "O" orebody of the Farley Mine, Lynn Lake; geology after Sherritt Gordon Mines Limited.



NM 7504-B Figure 3 A geological plan of the 3400′ level in the "O" orebody of the Farley Mine, Lynn Lake; geology after Sherritt Gordon Mines Limited.

NM 7504-B Figure 4 A geological plan of the 2000' level in the "O" orebody of the Farley Mine, Lynn Lake; geology after Sherritt Gordon Mines Limited.

Geology and Structure of the "EL" Plug and Orebody

The thirteenth orebody was located in the core of the "EL" plug, which outcrops 3.8 km south of the "A" shaft at Lynn Lake. The plug is a vertical cylindrical pluton, intruded into quartz-feldspar porphyry and porphyritic rhyolite breccias belonging to Unit 4 (Gilbert, 1976 and Syme, 1976). On surface, the diameter of the plug is 0.4 km, tapering to 0.2 km below the 2000' level. The intrusion consists of a marginal unit of "diorite" or "gabbro" and a composite core formed of mineralized amphibolites and "peridotites". At depth (below the 900' level) the sulphides are weakly disseminated in the core amphibolite; nearer the surface, the sulphides become more concentrated, forming lenses and veins containing abundant host rock xenoliths. Near the surface the plug has been cut by a number of low angle faults and, as in the "A" plug, some of these have been exploited by mafic dykes.

Types of Mineralization

The mineralization consists of five transitional varieties which occur in varying proportions in the various sulphide lenses in the Ni-Cu orebodies. These varieties are:

(1) Disseminated ore
(2) Plutonic breccia ore (mineralized "norite" matrix)
(3) Sulphide breccia ore (sulphide matrix)
(4) Massive sulphide ore
(5) Siliceous "felsite" ore

Disseminated Ore: This ore-type consists of fine grained interstitial sulphide or coarse (0.5 – 1.0 cm) blebby sulphide uniformly distributed in structureless feldspathic amphibolite or "norite". Characteristically, the rock retains its igneous texture. Disseminated sulphides appear to be particularly abundant in the "N" orebody.

Plutonic Breccia Ore: This ore-type occurs at the interface of a mineralized amphibolite ("norite") pipe and the enclosing host rock "gabbro". Abundant subangular to subrounded (0.1 – 10.0 m) xenoliths of allochthonous, barren, "diorite", "gabbro" and "peridotite", and less common inclusions of disseminated ore (type 1, above) and siliceous "felsite" ore (type 5, above) are found in a sulphide-bearing matrix. The matrix ranges in composition from mineralized feldspathic amphibolite (type 1, above) to a completely re-crystallized sulphide-silicate assemblage which contains amphibole, but no feldspar. This variety of ore is particularly common in the "O" orebody.

Sulphide Breccia Ore: This ore-type consists of rounded, pebble to cobble sized inclusions of allochthonous host rock material, in a silicate (largely amphibole) contaminated sulphide matrix. This variety of ore may grade into type 2, which has a more silicate rich matrix. Sulphide breccia ores are well developed in the "EL" and "B" orebodies.

Massive Sulphide Ores: Veins of massive sulphide which cut ore-types 1 and 2 (and 3?) are controlled by three late, high angle fracture sets (NW-SE, north-south and NE-SW) which are found throughout the "A" plug. The veins have sharp contacts, appear to be local in extent, and contain angular blocks of locally derived amphibolite. The veins occur in the more highly deformed portions of all the orebodies. On the 3550' level in the "O" orebody they are oriented parallel to the "O" fault which truncates the orebody.

Siliceous "felsite" Ore: Siliceous "felsite" ore, which consists of an aphanitic assemblage of quartz, plagioclase and a variable amount of finely disseminated pyrrhotite, has been observed as rare veins which cut ore-types 1 and 2. Identical material is found as subangular blocks in the plutonic breccia ores (type 2). Somewhat similar material locally forms the sulphide-rich cement in sulphide breccia ores (type 3). The sulphide cement in type 3 ore may have become contaminated with quartz and plagioclase, as well as amphibole, near contacts with predominantly silicate rock-types. Small amounts of siliceous "felsite" ore have been found in all the orebodies. This ore-type appears to be particularly abundant in the "B" orebody.

Discussion

Evidence to date indicates that the "A" and "EL" plugs intruded the Wasekwan Group after at least one period of country rock deformation. The "gabbro" plugs were then intruded by minor igneous phases. In the case of the "EL" plug, the feeder pipe appears to have been the same during both events. The emplacement of mineralized norite appears to have been accompanied by hydrothermal activity which continued until after the injection of late mafic dykes.

The following sequence of events is inferred:

(1) Intrusion of "gabbro" plugs

(2) Faulting (?)

(3) Intrusion of minor phases ("peridotite", "quartz-hornblende-diorite", "diorite")

(4) Intrusion of mineralized "norite" (ore-type 1) with formation of contact breccias (ore-types 2 and 3)

(5) Initiation of hydrothermal activity, involving:

    (a) amphibolitization

    (b) dissolution of feldspar

    (c) deposition of siliceous "felsite" veins (ore-type 5)

(6) Deformation, involving:

    (a) disruption of siliceous "felsite" veins in plutonic breccia

    (b) further concentration of sulphides in plutonic breccias (ore-type 2)

    (c) concentration of sulphides in fracture sets (ore-type 4)

(7) Post mineral faulting

(8) Injection of late dykes

(9) Completion of hydrothermal activity

The origins of the Ni-Cu deposits at Lynn Lake appear to have involved both magmatic and hydrothermal processes. The geological setting of the deposits in "norite" pipes intruded into plugs of "gabbro" is clearly magmatic; however, in detail the distribution of the sulphide appears to show a strong case for superimposed hydrothermal activity.

Although the disseminated ores (type 1) and the sulphide breccia ores (type 3) may be formed by magmatic processes (as comparable material occurs in less altered deposits, such as at the Giant Mascot Mine, British Columbia; Aho, 1956), the remainder may be at least in part hydrothermal in origin. The absence of feldspar in the sulphide-silicate matrix of the plutonic breccia ores (type 2) and the presence of veins and inclusions of siliceous "felsite" ore (type 5) in the same rock, suggest that hydrothermal processes may have redistributed much of the feldspar in the rocks around the amphibolite pipe contacts. The strong fracture control showed by the massive sulphide veins (type 4) also points to a hydrothermal origin for this ore type.

Although the above petrogenetic model is subject to modification in light of evidence obtained during the remainder of the program, the indications are that hydrothermal and tectonic processes brought about redistribution of magmatic sulphides which were originally present in suspended form in partially consolidated "pyroxenites" and "norites".

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NM 7505 EVALUATION OF MASSIVE SULPHIDE ENVIRONMENTS — *by G.H. Gale and J. Koo*

Summary

- Investigations were conducted in the Flin Flon and Lynn Lake greenstone belts to determine the geological setting, deposit type and stratigraphic position of massive sulphide deposits and related mineral occurrences.

- Compilations of data on diamond drilling and mineralization, contained in the assessment files of the Department of Mines, Resources and Environmental Management, have been completed for most of the Province. Data for that part of the Superior Province covered by the Greenstones Project will be made available as an open file release in late 1977; other parts of the cancelled assessment data will be available upon request.

- The Zn-rich ore deposits of the Chisel Lake area occur within silicic volcanogenic sediments near the contact with an overlying mafic sedimentary and volcaniclastic sequence (Unit 2 of Harrison, 1949). This is considered an upper mineralized horizon and its position can be projected for a strike-length of more than 20 km.

- The Cu-rich deposits of the Anderson Lake area occur on a lower mineralized horizon within silicic volcaniclastic rocks.

- A major anticlinal structure has been proposed for the area east of Anderson Lake. Both the lower and upper mineralized horizons are considered to be present on the south limb of this structure.

- The stratigraphic position of mineralization in the Reed Lake area is uncertain but the stratigraphic section does exhibit some lithologic similarity to that of the Dickstone and Snow Lake areas.

- Existing geological maps for the Elbow Lake and Iskwasum Lake area are of insufficient detail to permit identification of centres of volcanism and individual sequences. Exhalative activity is suggested by the presence of chert and sulphide iron formation.

- A reconstructed stratigraphic section for the Flin Flon region indicates that the polymetallic massive sulphide mineralization occurs at approximately the same stratigraphic position throughout the region.

- Polymetallic massive sulphide deposits in the Lynn Lake area are closely associated with the centres of silicic volcanic rocks and form clusters within four segments of the Lynn Lake greenstone belt. Massive Fe-sulphide deposits occur both within the silicic centres and well outside the areas underlain by silicic volcanic rocks.

- In both the Flin Flon and Lynn Lake greenstone belts, most of the polymetallic massive sulphide mineralization was deposited prior to the latest known period of volcanic activity. The mineralization is commonly associated with silicic rocks near the top of the second-to-last sequence of volcanic rocks.

Introduction

The overall objectives of this project are (a) to provide an appraisal of the potential for massive sulphide deposits; and (b) to provide a picture of the metallogenesis of massive sulphide deposits in Manitoba in terms of deposit-type models. A comprehensive and integrated picture of massive sulphide type mineralization in Manitoba will serve as a basis for sophisticated resource potential evaluation, and assist exploration activities.

The main objectives for the year to April 1, 1977 were:

(a) to determine the geological setting and stratigraphic position of selected mineral occurrences in the major Cu-Zn producing mining camps at Flin Flon, Snow Lake, Fox Lake and Ruttan Lake.

(b) familiarization with the geology of presently non-producing volcanic segments of the Flin Flon and Lynn Lake greenstone belts.

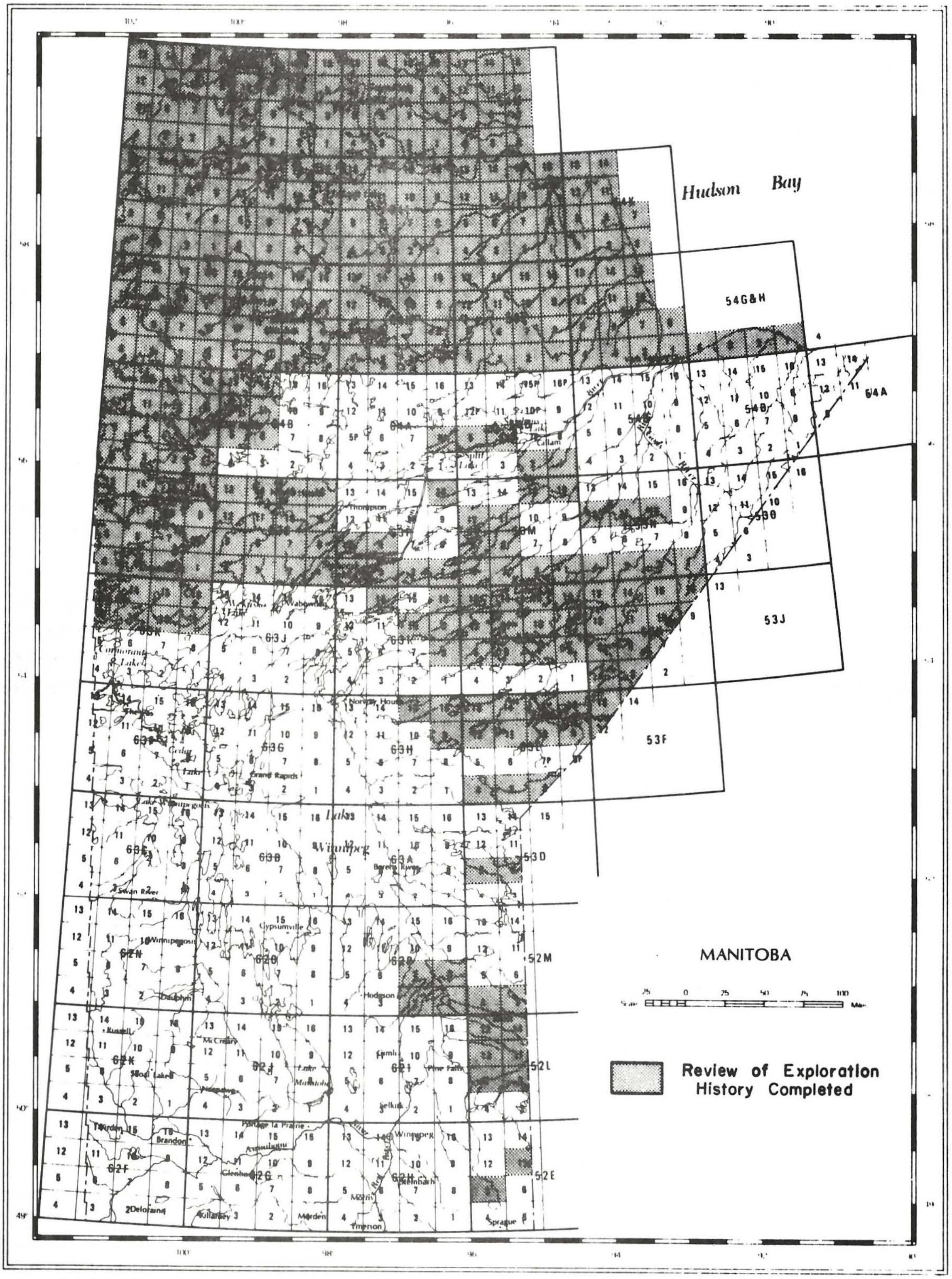
(c) compile information on mineralization and drilling, contained in cancelled assessment files.

Two economic geologists were engaged in the massive sulphide project during the year. Two full-time and one part-time junior geologists provided assistance during the field season, reviewed and synthesized information contained in the cancelled assessment files of the Mineral Resources Division, and compiled information for use in mineral deposit maps. A total of 4.3 man years were expended on the project in the year under review; this includes 1 man year of field work.

Field studies were restricted to the Flin Flon and Lynn Lake greenstone belts. Massive sulphide deposits and mineral occurrences of related type were studied in detail in selected areas to obtain information about geological setting, deposit-type, stratigraphic position and possible stratigraphic controls. Reconnaissance of volcanic terrains with few or no known massive sulphide deposits was made to obtain background information that can be used to compare and contrast producing and non-producing volcanic areas.

Compilations of diamond drilling and mineralization data from assessment files have been completed for Manitoba, with the exception of the Thompson nickel belt (see Fig. 1). At the time of writing, compilation of assessment data and mineral deposit information for the area of the "Greenstones Project" (Campbell, Elbers and Gilbert, 1971) is undergoing final editing, prior to publication (anticipated for the second half of 1977). In addition, mineral occurrence and deposit type compilations are in preparation and will form a basis for mineral resource potential maps.

The Flin Flon and Lynn Lake greenstone belts are treated separately in this report. This reflects the different emphasis placed on certain aspects of field investigations as a result of the different levels of data base established during the previous year of the project.



NM 7505 Figure 1 Progress of Exploration History Review

INVESTIGATIONS IN THE FLIN FLON – SNOW LAKE GREENSTONE BELT

Snow Lake Region

Detailed studies were carried out in the vicinity of the Chisel Lake and Ghost Lake Mines to determine the geological setting of these deposits. Reconnaissance of the geological setting of sulphide deposits in the Anderson Lake – Stall Lake area was conducted to provide a basis for comparison with the Chisel Lake setting. In addition, reconnaissance traverses were made to investigate the overall stratigraphic position of mineral deposits in the Snow Lake region.

Chisel Lake Area

The area of the Chisel Lake, Ghost Lake and Lost Lake Zn-deposits was mapped by Harrison (1949) at a scale of one inch to one mile. The immediate area of the deposits was remapped at a scale of 1:12 000 by Williams (1966).

The base of the succession in the Chisel Lake area has not been defined (it probably lies south of the area of Williams' map). Unit numbers used below refer to Figure 2 unless otherwise specified.

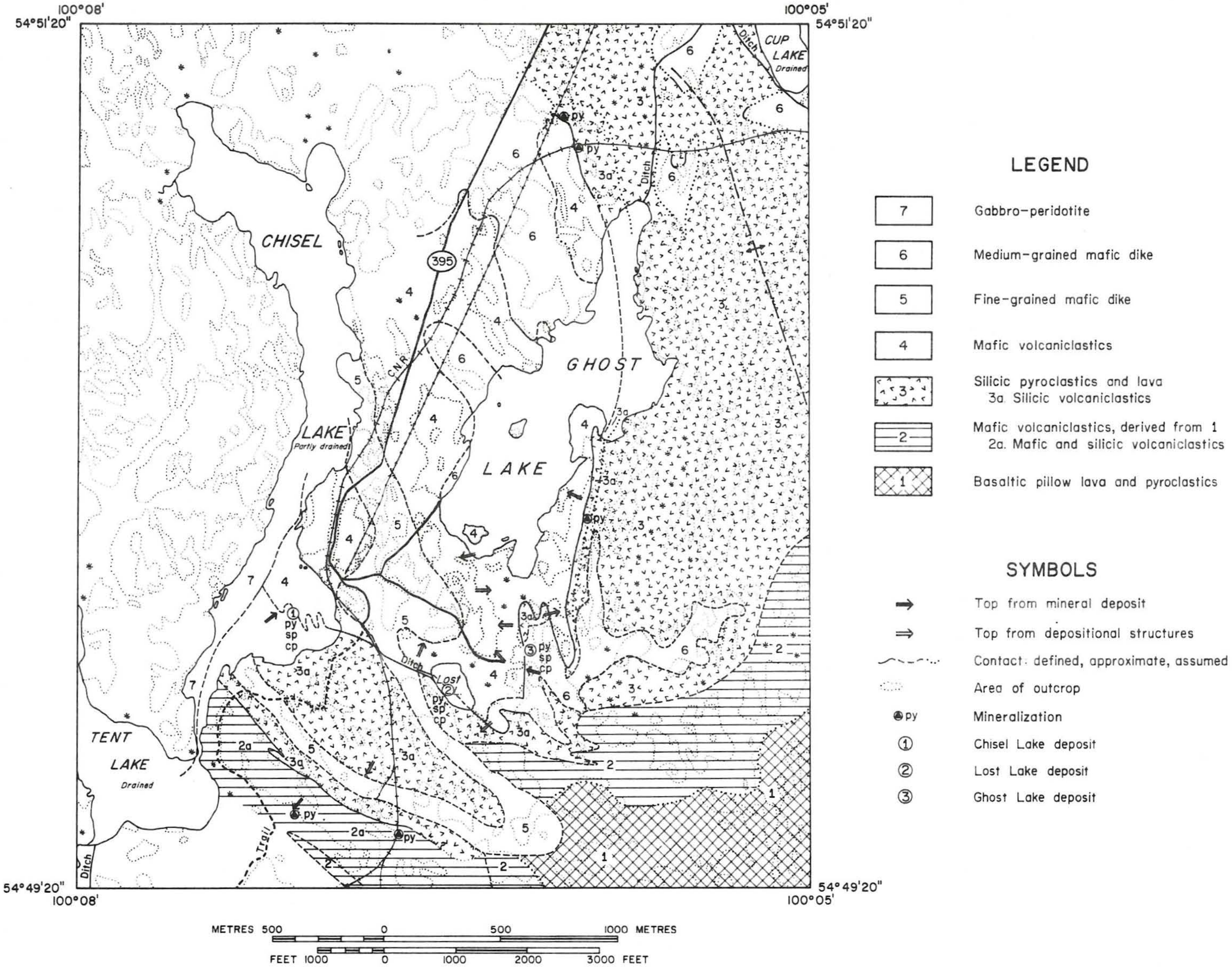
The oldest unit recognized (unit 1) consists of pillowed basalt and associated pyroclastics and is overlain by waterlaid volcaniclastics of mafic composition (unit 2). Unit 2a, a layered volcaniclastic with clasts of both mafic and silicic composition, may be either the stratigraphic equivalent of unit 2 or a clastic wedge within unit 3.

Unit 3 comprises silicic rocks, fragmental rocks, lavas and clastic sediments. Clastic sediments (unit 3b) in the vicinity of the Chisel Lake deposit change to pyroclastics and flows (unit 3a) along strike, to the east and northeast of the Ghost Lake deposit. Where examined, the top of unit 3 is a fine grained clastic sediment varying in thickness from several tens of metres north of the Ghost Lake deposit to several hundred metres south of the Chisel Lake deposit.

Mafic volcaniclastics (unit 4) stratigraphically overlie the silicic rocks with apparent conformity; the base of this unit has only been observed underground. In the Chisel Lake area, the lower 300–400 m of this unit consists of layered mafic volcanogenic sediment (<1 cm) with abundant minor sedimentary structures (cross bedding, flame structures, slump structures, graded bedding and scour channels). Rocks of undisputed primary effusive origin were not observed; however, the present study has been confined to the basal parts of the unit. Mafic lavas which crop out south of Snow Lake (Moore and Froese, 1972) may belong to unit 4.

Mafic sediments similar to those of unit 4 are present in the Threehouse Lake area (Fig. 3). Good exposures along the railway line display abundant minor structures indicating tops to the northeast, thus a major anticline is present between Threehouse Lake and the north end of Ghost Lake where the mafic sediments young westwards. The exact position of the anticlinal axis is not certain (Fig. 2). The core of the anticline consists predominantly of pyroclastic rocks which are coarsest toward the centre of the structure, but become finer grained and of a more sedimentary aspect outwards.

The massive sulphide deposits of Chisel Lake, Lost Lake and Ghost Lake occur in fine grained silicic sediments of unit 3 within a few metres of the contact with the mafic sediments of unit 4. Fe-sulphide mineralization occurs near this contact at a point on the railway north of Ghost Lake (Fig. 2). Elsewhere the contact is not exposed but is commonly marked by a depression. In the Threehouse Lake area (Fig. 3) the eastern contact between the silicic rocks and mafic sediments is



NM 7505 Figure 2 Geology of the Chisel Lake Area (modified after Williams, 1966) considered to be the equivalent of the unit 3 – unit 4 contact in the Chisel Lake – Ghost Lake area. On the basis of lithological comparisons, the sulphide horizon is projected to occur in unit 2 near the base of unit 3a (Fig. 3).

The Bomber deposit on Cook Lake may be situated at the same stratigraphic horizon. The mafic rocks overlying the Chisel Lake – Ghost Lake mineralization were included by Harrison (1949) within his unit 2 ("Basic volcanic breccia, agglomerate and tuff; minor flows; undifferentiated diorite; minor argillite"), thus the same mineralized horizon might well occur at other localities where Harrison identified his unit 2. All three Zn-rich massive sulphide deposits have been found in a thick sequence of reworked silicic volcaniclastic rocks surrounding a silicic volcanic edifice (dome ?). Extensive alteration has been observed in a position stratigraphically below both the Chisel Lake and Ghost Lake ore deposits; this indicates that the deposits are proximal to exhalative vents. Thus, the areas with the highest potential for additional massive sulphide deposits would seem to be those sectors of the unit 2 – unit 3 contact (Fig. 3) underlain by reworked volcaniclastic rocks and/or showing evidence of hydrothermal alteration.

Anderson Lake – Stall Lake Area

The general geology of the area, based on Moore and Froese (1972) and Harrison (1949), is shown in Figure 3.

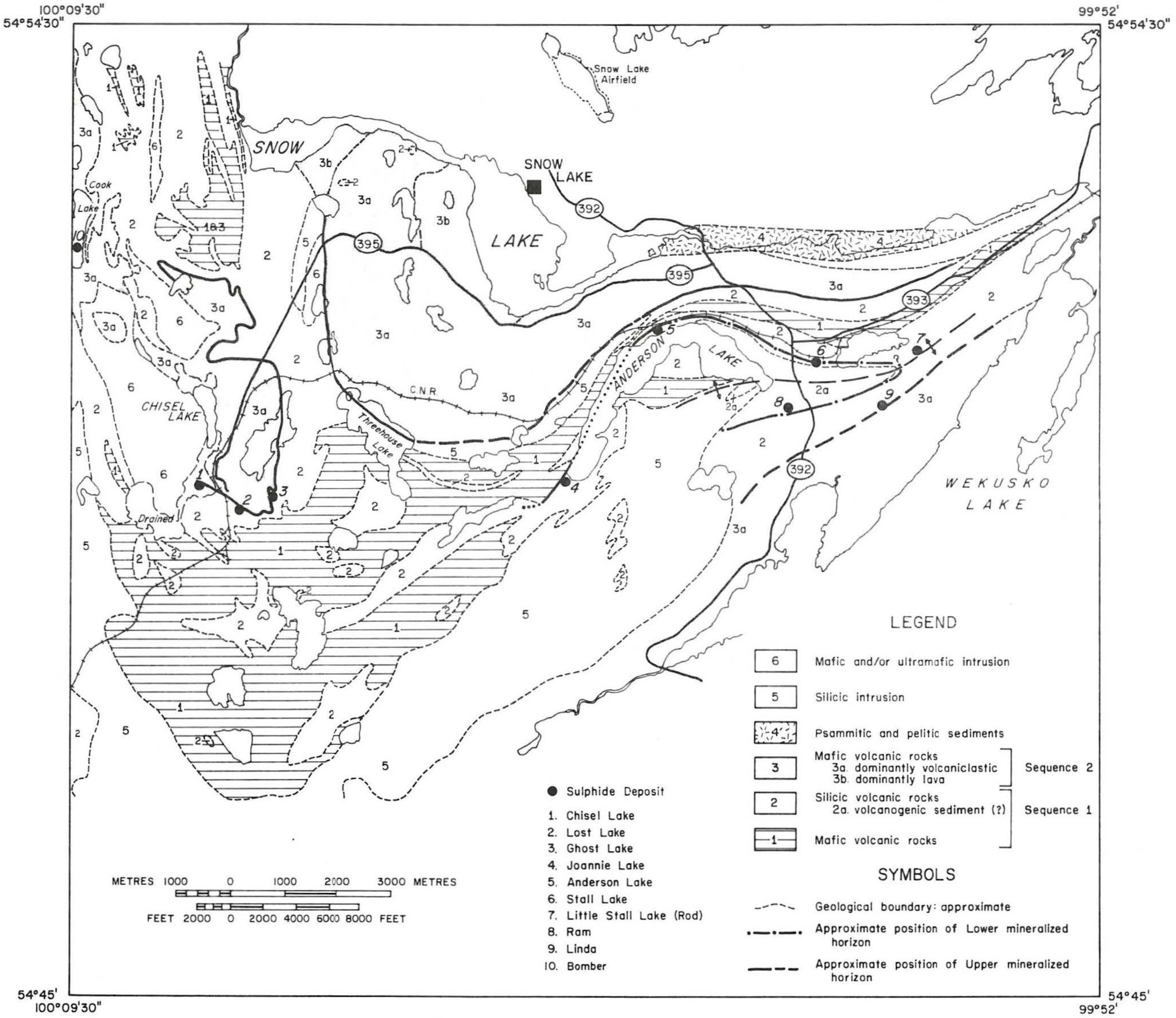
The area between the west end of Anderson Lake and the east end of Stall Lake is underlain predominantly by volcaniclastic and volcanogenic sediments of mafic to silicic composition; minor mafic pillow lavas are also present. Silicic lavas and pyroclastic rocks have not been positively identified in this area; some of the silicic fragmental rocks could be of pyroclastic origin, but most distinguishing features have been erased by deformation and metamorphism.

The oldest rocks in the area are thought to be the largely silicic rocks which occupy the core of an early fold structure at the east end of Anderson Lake. These rocks are massive to layered, fine to medium grained volcanogenic sediments and coarser (<30 cm) volcaniclastics. Alteration zones are characterized by garnet-chlorite (± kyanite) schists associated with several massive sulphide deposits, notably Anderson Lake Mine, and form several major outcrops elsewhere within unit 2a (Fig. 3). Pyrite is common in the rocks of unit 2a as disseminations and veinlets, and pre-dates deformation.

Silicic rocks, stratigraphically overlying unit 2a (Fig. 3), consist mainly of coarse fragmental rocks (>10 cm) and fine grained volcanogenic sediments. The origin of these silicic rocks is still problematical although Moore and Froese (1972) considered them to be of pyroclastic origin. There are no associated lavas, and clear pyroclastic structures have not been seen. The presence of layering suggests that most of unit 2, in the area east of Anderson Lake, is mainly reworked silicic volcanic material.

The mafic unit overlying the Stall Lake and Anderson Lake deposits probably represents a localized mafic volcanic centre; the lower part, formed of layered fine grained mafic sediments/tuffs, is overlain by basaltic pillow lavas which in turn are overlain by layered mafic sediments/tuffs.

From way-up criteria provided by minor structures and mineral deposit studies, it has been possible to establish the presence of a major fold structure at the eastern end of Anderson Lake (Fig. 3). The core of this fold is defined by unit 2a. Pillow structures at Stall Lake Mine and graded bedding in mafic sediments along a power line north of the Anderson Mine indicate younging to the north.



NM 7505 Figure 3 General Geology of the Snow Lake Region (modified after Harrison, 1949, and Moore & Froese, 1972)

With recognition of the anticlinal structure, the unit of 'psammitic rocks' mapped by Moore and Froese (1972) at the eastern end of Anderson Lake is not only the oldest rock unit in that area, but can no longer be correlated with the younger psammitic and pelitic rocks at Snow Lake. The rocks of unit 2a (Fig. 3) at the eastern end of Anderson Lake lie stratigraphically below the projected positions of the Anderson and Stall Lake Mines. These rocks are considered to have been volcanogenic sediments and volcaniclastics prior to undergoing widespread "soaking" in hydrothermal fluids at the time of the mineralizing activity producing the massive sulphide deposits at its upper contact.

Garnet-chlorite (± kyanite) schists similar to rocks in the footwall alteration zone of the Anderson orebody, and the presence of abundant sulphide stringers and disseminations throughout unit 2a, suggest that hydrothermal activity with associated mineralization affected this unit in many places. However, it should be noted that not all of this unit has undergone intense alteration. The Joannie and Ram deposits (Fig. 3) are considered to occur on or close to the stratigraphic horizon on which the Anderson Lake and Stall Lake Mines are located. Thus mineralizing activity was taking place at approximately the same time over a distance of at least 9 km.

The present interpretation of stratigraphic relationships in the Anderson Lake — Stall Lake area shows the mafic unit overlying the Anderson Lake and Stall Lake Cu-sulphide deposits to be older than the mafic rocks that stratigraphically overlie the Ghost Lake and Chisel Lake massive Zn-sulphide deposits. The environment of deposition in the Anderson Lake — Stall Lake area would appear to be somewhat similar to that of the Chisel Lake area in that the rocks stratigraphically underlying the mineral deposits are mainly silicic volcanogenic sediments and volcaniclastics. The Chisel Lake deposits appear to have been deposited closer to a volcanic centre(s) in that stratigraphically underlying mafic and silicic lavas and pyroclastic rocks are present in close proximity to the ore zones. Although no effusive flow rocks have been definitely identified in the unit stratigraphically underlying mineralization in the Anderson Lake — Stall Lake area, lavas and pyroclastics may be present below unit 2a (Fig. 3) in the Anderson Lake anticline.

Known massive sulphide mineralization in the Snow Lake area appears to be confined to two specific stratigraphic levels. In the Anderson Lake area, the Joannie, Anderson Lake, Stall Lake, Ram, and Rod deposits occur at or close to the same stratigraphic horizon. The position of the Linda deposit is considered by the writer to be stratigraphically above this horizon at a position analogous to that of the Chisel Lake and Ghost Lake deposits. The projected positions of the two "favourable horizons" are outlined on Figure 3. The zones with the highest potential for Cu-deposits appear to correspond to the areas mapped as unit A by Harrison (1949), whereas the zones with highest potential for Zn-deposits lie immediately below the lower contact of Harrison's unit 2.

Reed Lake Region

On the basis of compilations of assessment work, and previous geological mapping (Rousell, 1966), an examination was made of Fourmile Island and surrounding areas to determine whether tonalite and fragmental rocks recorded in the area constitute part of a volcanic centre. Tonalitic rocks are exposed along the south shore of the island; however, the northern part of the unit shown as tonalite by Rousell (1966) is considered to be quartz-eye chlorite schist derived from mafic volcanogenic sediments. The central part of the 'tonalite' consists of layered volcanogenic sediments (D. Baldwin pers. comm.).

Rocks on islands south and west of Fourmile Island include pillow basalt, pillow breccia, mafic and silicic volcaniclastic rocks, volcanogenic sediments, chert, argillite and greywacke. Commonly the rocks are layered, poorly sorted and appear to have been deposited as reworked pyroclastics, and volcanic epiclastic rocks.

In the vicinity of the H.B.M. & S. Reed Lake deposit, and to the north of it, many of the islands consist of a fine to medium grained gabbro. These outcrops are considered by the writer to be the erosional remnants of an extensive dike-like body that has been rotated into its present relatively flat-lying position.

Approximately 1.5 km north of Fourmile Island, 500 m of a northward facing sequence is exposed on an island (6056600 399300 – UTM co-ordinates). This sequence consists of a lower unit of basaltic pillow lava, a middle unit of mafic fragmental rocks containing blocks of quartz porphyry with a 50x40 cm oval cross section, and an upper unit of quartz porphyry lava. This bimodal fragmental resembles "mill rock" (Sangster, 1972). The volcanic sequence has an easterly strike and is overlain to the north by a mafic volcanogenic sediment, followed by a thick sequence of greywacke, calcareous argillite and argillite which resembles the sedimentary rocks in unit 3 of Harrison (1949). The volcanic rocks probably occupy a stratigraphic position similar to that of unit 3 in the Snow Lake area (Fig. 3).

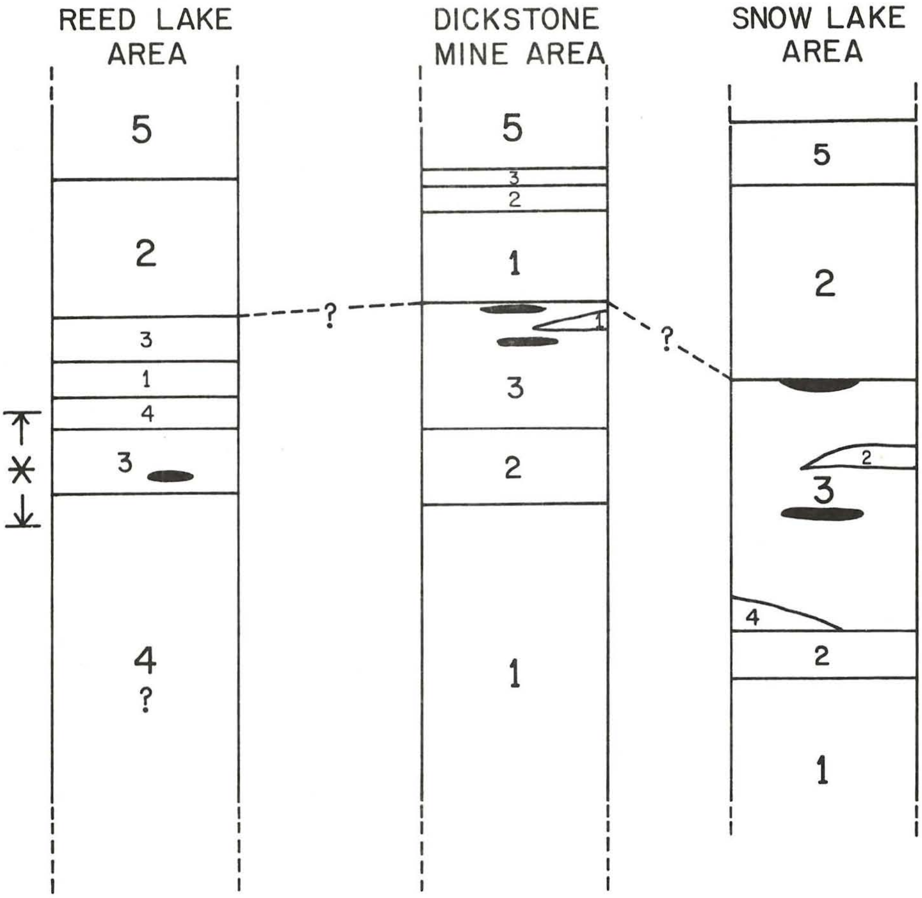
The Fourmile Island area does not appear to represent a volcanic centre. On the other hand the sequence at (6056600 399300), with its silicic lava, "mill rock" and pillow basalt may well represent a local (?) volcanic centre; this centre post-dates the dominantly volcaniclastic rocks which are found west of, and presumed to host, the Reed Lake Cu-deposit. A tentative stratigraphic section is shown in Figure 4.

The Dickstone Mine area, north of Reed Lake, has been studied in detail by A. Bailes, who constructed a stratigraphic column for the area (Fig. 4). From Figure 4 it can be seen that there is a close similarity in the lithologic succession hosting massive sulphide deposits in both the Snow Lake and Reed Lake regions. Detailed remapping of the Reed Lake region should be undertaken to provide a better definition of rock units and to establish local stratigraphy.

Elbow Lake and Iskwasum Lake Region

Brief reconnaissance visits to Elbow Lake and Iskwasum Lake areas were made to study the geological environments and mineral occurrences present. Submarine mafic to silicic lavas and fragmental rocks and derived volcanogenic sediments are present in both areas. Volcaniclastic rocks and volcanogenic sediments are more abundant than lavas. The level of present geological mapping (Hunt, 1970; McGlynn, 1959) is not sufficiently detailed to permit identification of volcanic centres or individual volcanic sequences. Chert and sulphide iron formation may be related to period(s) of exhalative volcanic activity. Minor Cu-Zn occurrences at both Elbow Lake and Iskwasum Lake are known from the open file assessment records. General geology and the major sulphide deposits in the Elbow Lake, Iskwasum Lake and Reed Lake regions are illustrated in Figure 5.

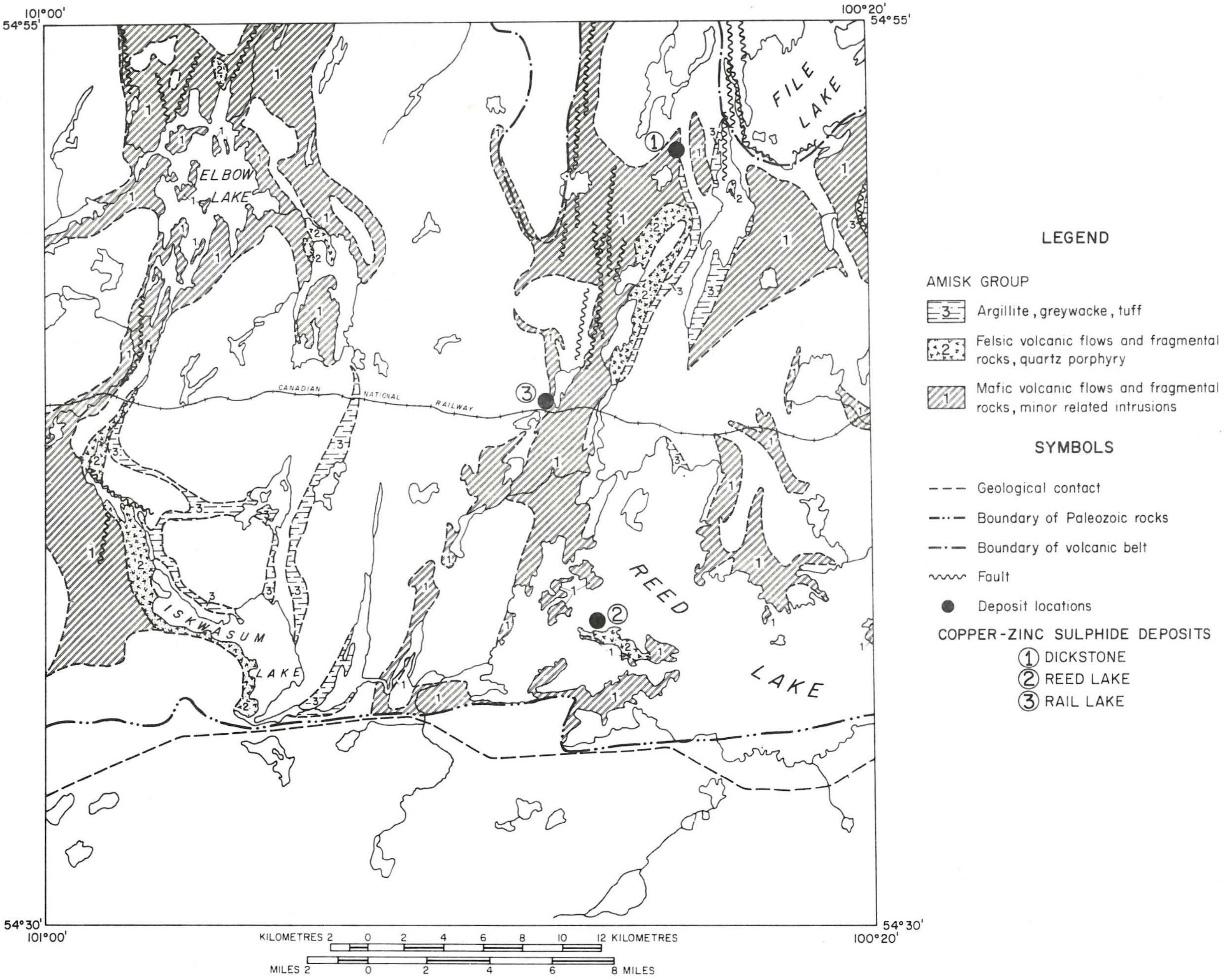
Reconnaissance work has led to the distinct impression that volcanic environments in this region are closely analogous to those prevailing in the Flin Flon and Snow Lake regions. This suggests that the Elbow Lake – Iskwasum Lake region would be a favourable area for massive sulphide exploration. An attempt should be made to establish the volcanic stratigraphy in the area and to determine whether the silicic rocks north of Elbow Lake (McGlynn, 1959) are contemperaneous with silicic rocks in the Flin Flon and Snow Lake regions.



N.B. ✳ PROJECTED EASTWARDS (THIS PART OF SECTION NOT EXPOSED)

5. GREYWACKE AND ARGILLITE
4. MAFIC AND SILICIC VOLCANICLASTICS ± MINOR LAVA
3. SILICIC VOLCANICLASTICS ± LAVA
2. MAFIC VOLCANICLASTICS ± LAVA
1. MAFIC LAVA ± MINOR VOLCANICLASTICS

NM 7505 Figure 4 Schematic cross sections for the Reed Lake and Snow Lake Regions



NM 7505 Figure 5 Major mineral deposits of the Elbow Lake – Iskwasum Lake and Reed Lake Regions

Flin Flon Region

Thompson Lake Area

In the Thompson Lake area and the north end of Athapapuskow Lake, there are seven known Cu-Zn deposits in an area predominantly underlain by silicic volcanic rocks (Bateman and Harrison, 1945). The silicic rocks consist mainly of pyroclastic rocks, volcaniclastic rocks and volcanogenic sediments. Silicic lavas were found to stratigraphically overlie two of the Cu-Zn deposits. Fragmental silicic rocks, which appear to have been derived by autobrecciation of silicic lavas, are present in the vicinity of the Baker-Patton and North Star deposits.

The largest area of exposed silicic rocks in the Flin Flon region occurs at Thompson Lake and it probably represents a major centre of silicic volcanism. All top determinations, from pillow lavas and mineral deposit data, made between the east shore of Thompson Lake and the Centennial Mine indicate a westward younging succession.

White Lake Area

Massive sulphide deposits occur in eastward younging volcanogenic sediments above a thick mafic volcaniclastic sequence. These are overlain by a greywacke-argillite succession with layers of silica-carbonate that are tentatively correlated with similar layers that stratigraphically overlie the Centennial ore deposit.

Schist Lake Area

A unit of silica-carbonate rock with unusual characteristics appears to overlie the Schist Lake — Mandy Mine massive sulphide horizon. Stockwell (1959) interpreted the unit to be sericite-carbonate schist, derived from quartz porphyry. The rock varies from a dense massive carbonate-rich silicic rock with widely spaced carbonate veins to a "breccia" with angular blocks of carbonate-rich silicic material pervaded by a network of iron-carbonate veinlets 1 mm to >2 cm in width. Individual layers with more carbonate than silica have been identified. The unit stratigraphically overlies waterlain mafic volcaniclastic rocks and has a gradational upper contact with greywacke. The carbonate-silica rock may be a sediment, possibly of exhalative origin.

Heywood (1965) found close similarities in the lithologies present in the northwest and west arms of Schist Lake. Geophysical data (I.T. Hosain pers. comm.) and top determinations (Heywood, 1965) indicate that an anticlinal fold hinge may be present at the junction between these arms. This interpretation would place the West Arm, Schist Lake and Mandy Mines at approximately the same stratigraphic position.

Correlation of the predominantly mafic fragmental rock units which stratigraphically underlie the Flin Flon Mine, with those under the Schist Lake Mine, is complicated by the presence of faulting along both sides of the northwest arm of Schist Lake. Further detailed studies of stratigraphy in the area are necessary before this correlation can be verified.

Big Island Lake Area

Big Island Lake and the terrain to the east are underlain mainly by mafic to silicic volcaniclastics and volcanogenic sediments; minor amounts of both mafic and silicic lavas are present. Mafic pillow lavas and breccias predominate west of the lake. Top determinations from pillows and sediments indicate a consistently westward-younging sequence; similar observations were made by D. Baldwin (pers. comm. 1976) in the vicinity of the Cliff Lake porphyry.

Sulphide mineralization is common in the Big Island Lake area and layers of pyrite and graphite occur at several different stratigraphic levels. Zones of hydrothermal alteration are present at several localities along the west shore and the northwest corner of Big Island Lake.

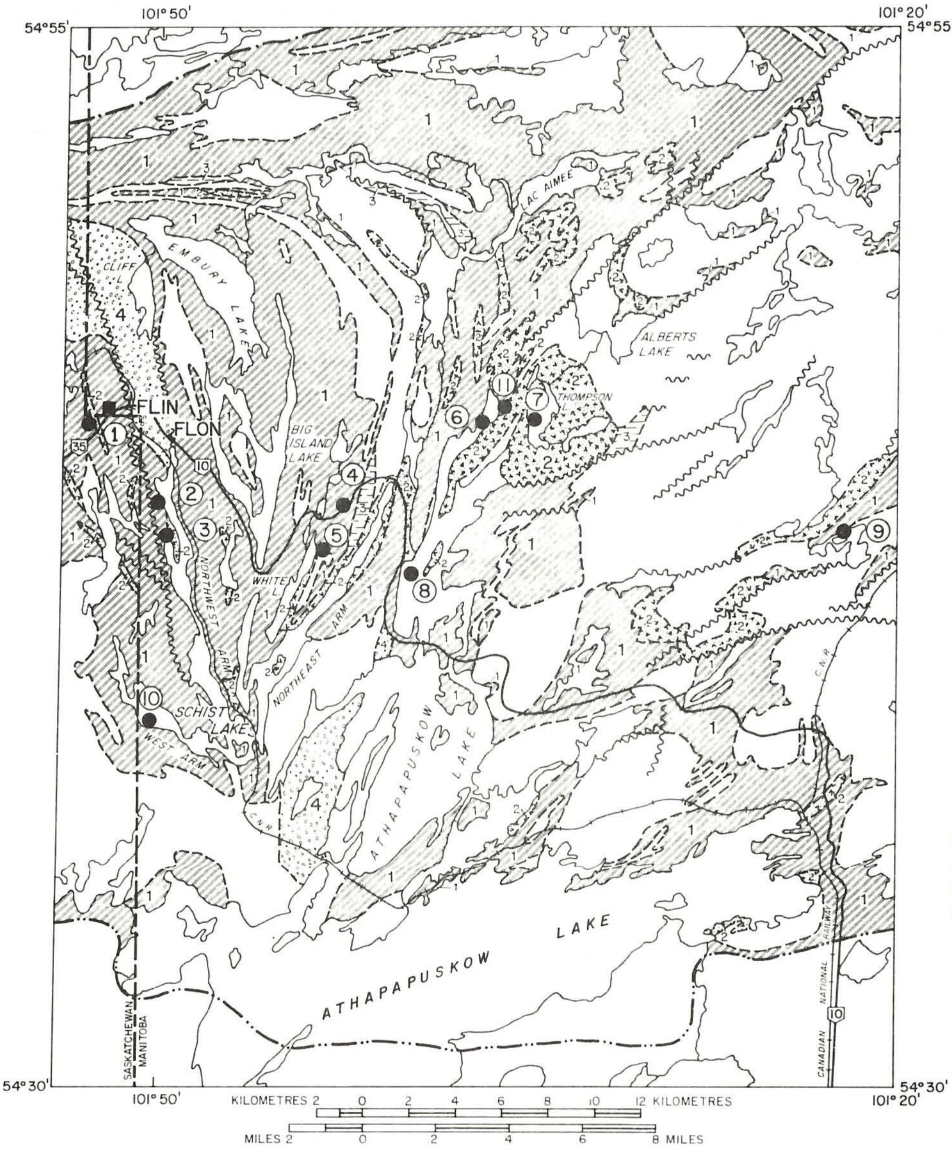
Mafic lavas west of Big Island Lake and east of the southward projection of the Cliff Lake fault zone may be equivalent to those of the Hidden Lake area, immediately northeast of the Flin Flon Mine. Both areas have thick piles of dominantly basaltic pillow lava and pyroclastic rocks. This correlation is tentative as there are no known marker horizons in the two successions.

If correlation of the mafic volcanics of Hidden Lake area with those west of Big Island Lake is valid, the sulphide occurrences of the Big Island Lake area would be at approximately the same stratigraphic position as the Flin Flon deposit. Mapping in the area should be directed towards establishing stratigraphic sections in detail, and the correlation of volcanic units.

Relationship Between Sulphide Deposits and Stratigraphy

Polymetallic massive sulphide deposits in the Flin Flon area (Fig. 6) occur mainly within volcaniclastic rocks and volcanogenic sedimentary sequences. It has not yet been possible to establish a direct relationship between centres of volcanism and centres of polymetallic mineralization. Thin units of silicic fragmentals and/or lavas do occur in close proximity to a number of the deposits; however, the sulphide deposits in these can occur above, below or within the silicic volcanic rocks.

On the basis of field studies and compilations to date, polymetallic mineralization has been identified in several major "zones" that are probably stratigraphic equivalents. The probable stratigraphic relationships between these "zones" are shown in Figure 7. Further studies in the Flin Flon area will test this interpretation.



LEGEND

MISSI GROUP

4 Arkose, greywacke, quartzite, basal conglomerate

AMISK GROUP

3 Argillite, greywacke, tuff

2 Felsic volcanic flows and fragmental rocks, quartz porphyry

1 Mafic volcanic flows and fragmental rocks, minor related intrusions

SYMBOLS

--- Geological contact

-··- Boundary of Paleozoic rocks

-·- Boundary of volcanic belt

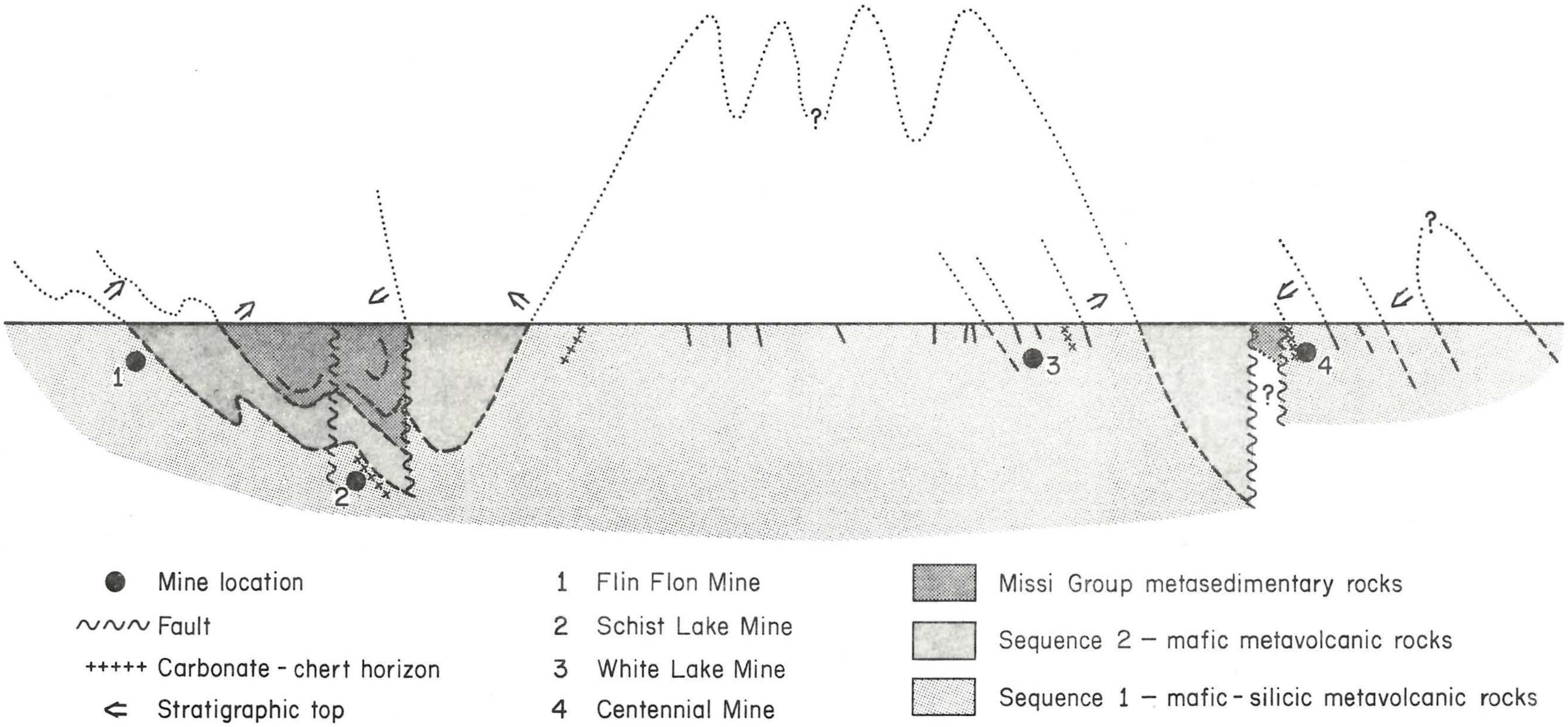
〰 Fault

● Deposit locations

COPPER-ZINC SULPHIDE DEPOSITS

① FLIN FLON
② MANDY
③ SCHIST LAKE
④ CUPRUS
⑤ WHITE LAKE
⑥ PINE BAY
⑦ NORTH STAR
⑧ CENTENNIAL
⑨ LUCILLE LAKE
⑩ WEST ARM
⑪ BAKER PATTON

NM 7505 Figure 6 Major mineral deposits of the Flin Flon Region



NM 7505 Figure 7 Schematic geological cross section of the Flin Flon Region

INVESTIGATIONS IN THE LYNN LAKE GREENSTONE BELT

The Lynn Lake greenstone belt extends from west of the Fox Mine area through Lynn Lake and Barrington Lake to the Ruttan Lake area (Fig. 8).

The volcanic and sedimentary rocks belong to the older Wasekwan Group and the younger Sickle Group respectively (Roy and Haugh, 1971). The Wasekwan Group consists of three main units: (1) a lower "Epiclastic Unit" consisting of greywacke, volcaniclastic rocks and impure quartzite; (2) a middle "Volcanic Unit" consisting of basaltic to rhyolitic lavas and breccias; and (3) an uppermost "Volcaniclastic Unit" which consists of tuffs, breccias, volcanic conglomerates, siltstones, quartzites and greywackes, with subordinate lavas.

The overlying Sickle Group is made up of conglomerates, arkoses, amphibolites and quartzites. The stratigraphic relationships between the Wasekwan and Sickle Groups still remain a subject of debate (McRitchie, 1974). Post-Wasekwan intrusions comprise ultramafic rocks, gabbros, diorites and granites.

Stratigraphy of the Massive Sulphide Deposits

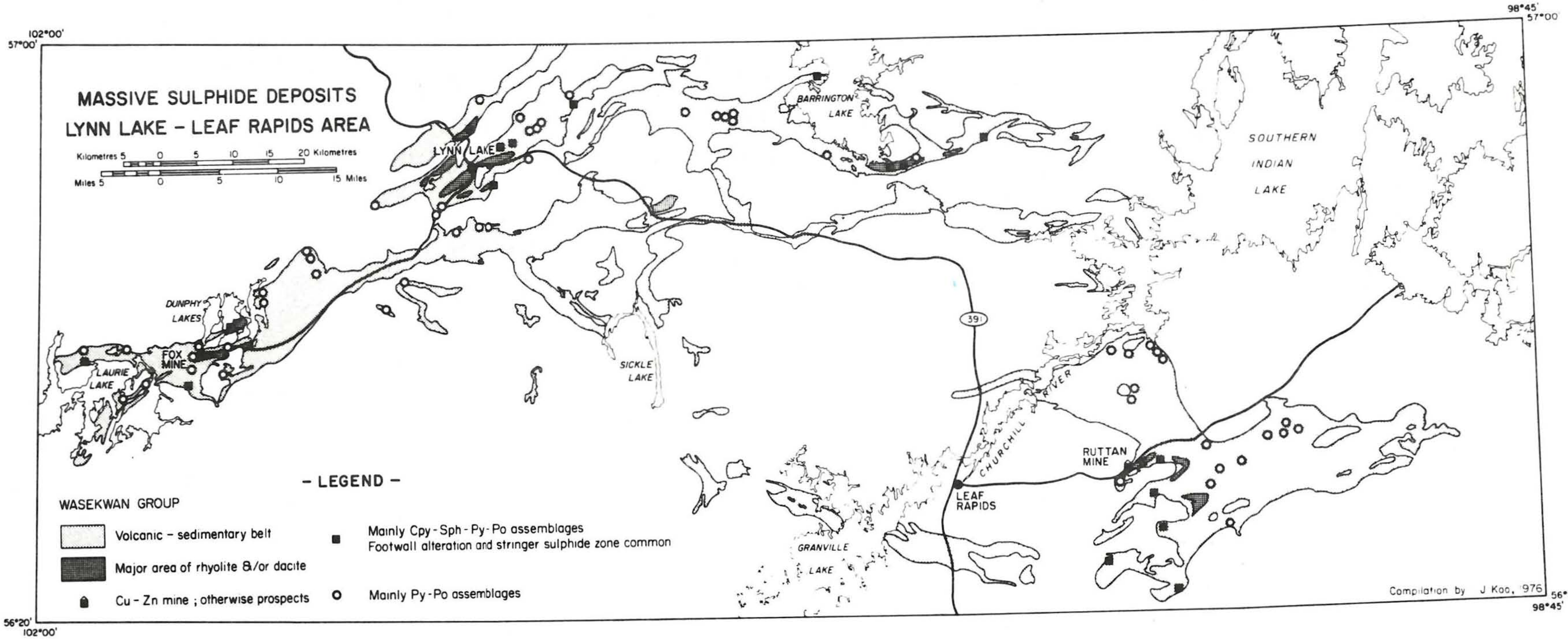
Since geological work in the region began in the 1930's, some 70 massive sulphide occurrences have been found within Wasekwan volcanic and sedimentary rocks. Only two Cu-Zn massive sulphide deposits, the Fox and Ruttan Mines, have been brought into production to date.

The massive sulphide lenses are in most cases confined to tuffs, siliceous sediments, and pelitic rocks, within a narrow stratigraphic interval. Polymetallic massive sulphide layers, including the Cu-Zn sulphide ore lenses at the Ruttan and Fox Mines, tend to occur preferentially within silicic tuffaceous layers. The polymetallic massive sulphide deposits consist mainly of pyrite, pyrrhotite, chalcopyrite and sphalerite. Typically, mineralogical zoning is shown in which a chalcopyrite-rich basal zone is stratigraphically overlain by a sphalerite-rich zone. These massive sulphide bodies commonly assay at $Cu \geqslant 0.5\%$ and/or $Zn \geqslant 1\%$.

Massive Fe-sulphide lenses, consisting mainly of pyrite and pyrrhotite, occur not only in tuffaceous units but also in siliceous and pelitic units. These massive sulphide bodies commonly assay at $Cu < 0.5\%$ and $Zn < 1\%$. The majority of the massive Fe-sulphide deposits contain graphite, in contrast to the polymetallic massive sulphide deposits which are virtually devoid of graphite.

The polymetallic massive sulphide layers and associated tuffaceous units are stratigraphically underlain by up to 1500 m of coarse-grained, polymictic volcaniclastic rocks, together with volcanic flows of mafic to intermediate composition. Volcaniclastic sequences are generally thin or virtually absent in the sequence stratigraphically below the massive Fe-sulphide deposits. Clasts in the volcaniclastic rocks are conspicuously larger (up to 3 m across) and more abundant in the proximity of the polymetallic massive sulphide deposits than in the proximity of the massive Fe-sulphide deposits.

Felsic subvolcanic intrusions with quartz and/or feldspar phenocrysts commonly occur stratigraphically below the polymetallic massive sulphide deposits (e.g. Ruttan and Fox). Felsic flows and breccias occur in the upper parts of the "Volcanic Unit", both stratigraphically above and below the polymetallic massive sulphide deposits. In contrast, felsic subvolcanic and effusive rocks are rarely found in association with the massive Fe-sulphide deposits.



NM 7505 Figure 8 Massive Sulphide Deposits of the Lynn Lake — Leaf Rapids Area

Wall Rock Alteration

The polymetallic massive sulphide deposits, including the Ruttan and Fox Mines, show chloritization, sericitization, silicification, carbonatization and sulphidization in the stratigraphically underlying rocks. Chloritic alteration increases in intensity towards the massive sulphide lenses and is closely associated with semi-massive and/or stringer mineralization comprised mainly of chalcopyrite and pyrrhotite. Sericitic and silicic alteration occurs around the chloritized zone.

The zone of alteration and stringer sulphide mineralization crosscuts the layering in the volcaniclastic rocks underlying the polymetallic massive sulphide bodies. The stratigraphic relationship of the massive sulphide body, stringer sulphide mineralization and alteration zone becomes complicated in some instances, due to post-ore deformation and metamorphism. At the Ruttan and Fox Mines massive sulphide bodies and the associated stringer sulphide and alteration zone, together with the enclosing wall rocks, are tightly folded. These structural disturbances have resulted in modification of the original morphologies of the deposits to such an extent that polymetallic massive sulphide lenses are now enclosed by zones of alteration and stringer sulphide zones, giving the appearance of an 'epigenetic' or replacement origin. However, it can easily be established that, prior to folding, the alteration and stringer mineralization occurred stratigraphically below the massive sulphide body.

Massive Sulphide Deposits and Regional Stratigraphy

In the Fox Mine area, polymetallic massive sulphide deposits are associated with a volcanic sequence up to 1000 m thick consisting of tuffs, fine-grained siliceous and pelitic rocks, coarse-grained volcaniclastic rocks, and mafic to intermediate flows. Mafic to felsic sills or dykes occur within the sequence. This relatively thick volcanic sequence can be traced into a thin (100 m) succession of volcanogenic sediments and amphibolites at Laurie Lake, southwest of the Fox Mine (Zwanzig, 1976). Within this thin unit, only massive Fe-sulphide deposits have been found to date.

Two major volcanic sequences are recognized within the 3000-4000 m volcanic-sedimentary pile mapped by Gilbert (1976) in the Lynn Lake area. Each of these sequences consists mainly of mafic to intermediate flows and breccias, felsic tuffs, and quartz-feldspar porphyry. Polymetallic massive sulphide deposits are associated with tuffaceous sediments in the upper part of each sequence.

Southeast of Lynn Lake, Symes (1976) has established a composite stratigraphic section (7600 m thick) for the Wasekwan Group, in which a 5400 m sequence of mainly mafic to intermediate flows, breccias and tuffs is stratigraphically overlain by felsic flows, breccias and tuffs. So far, only massive Fe-sulphide deposits associated with mafic to intermediate tuffs have been discovered in this volcanic succession.

Two major volcanic sequences have been distinguished at Barrington Lake (Zwanzig, 1974). The lower sequence (2000 m) consists mainly of mafic to felsic tuffs, breccias and flows; polymetallic massive sulphide deposits are associated with felsic rocks in the upper part of this sequence. Five miles west of Barrington Lake, the felsic rocks pass laterally into tuff, argillite and/or chert. The tuffaceous rocks contain massive Fe-sulphide lenses, whereas the argillite and chert contain magnetite and hematite lenses. The upper volcanic sequence (1300 m) at Barrington Lake consists mainly of mafic to intermediate flows and pyroclastic rocks; the top of this sequence is cut out by a granite pluton. No massive sulphides have been found in the upper sequence.

Gilbert (1974) has established stratigraphic columns for the Wasekwan Group in the Ruttan Lake area. The lower part (1590 m) of the lower Wasekwan consists mainly of amphibolite, arkose, conglomerate, greywacke, siltstone, and quartzite. The upper part (8000 m) of the Lower

Wasekwan consists of basalt, pyroclastic breccias and acid volcanic rocks, with subordinate conglomerate, arkose and greywacke. Polymetallic massive sulphide deposits, including the Ruttan Mine are closely associated with acid volcanic rocks in the upper part of the Lower Wasekwan. The Upper Wasekwan Group (5700 m), which crops out northeast of the Mine, is composed mainly of greywacke, siltstone and volcanogenic conglomerate. Massive Fe-sulphide deposits are associated only with the felsic component of felsic to mafic volcanic layers near the base of the Upper Wasekwan.

Massive Sulphide Environments

Hydrothermal alteration and stringer sulphide mineralization are present in the rocks which directly underlie the massive sulphide deposits, including the Ruttan and Fox Mines. These rocks include polymictic volcaniclastics, felsic volcanic flows and felsic intrusions. It is conceivable that anomalous heat flow associated with local felsic volcanism could have caused a circulation of interstitial water, which leached metals (Fe, Cu, Zn, Au, Ag) from the mafic components of volcaniclastic sequences underlying the palaeo sea floor.

The polymetallic massive sulphide bodies appear to have resulted from precipitation of metalliferous fumarolic exhalations associated with felsic magmas which were extruded in the waning phase of the volcanic activity corresponding to the Wasekwan "Volcanic Unit". Deposits of this type form clusters in four different segments of the Lynn Lake greenstone belt. These segments are located close to the Fox Mine, Lynn Lake, Barrington Lake and the Ruttan Mine. The polymetallic massive sulphide deposits are associated with the main areas of felsic volcanic rocks. An additional felsic volcanic centre in the area southeast of Lynn Lake (Syme, 1976) is considered to have a high potential for polymetallic massive sulphide deposits.

Polymetallic massive sulphide deposits fall into two sub-groups: (1) Cu-Zn deposits with Cu $\geqslant$ 0.5% and Zn $\geqslant$ 1.0%, and (2) Zn deposits with Zn $\geqslant$ 1.0%. In many cases, the Cu-Zn deposits occur within felsic volcanic areas and the Zn deposits occur on the fringes. Further away from the felsic volcanic areas, polymetallic massive sulphide deposits are rare or absent, and massive Fe-sulphide deposits are dominant. Massive Fe-sulphide deposits also occur within or near areas of felsic volcanic rocks where they are stratigraphically underlain by or laterally transitional into polymetallic massive sulphide deposits. Locally the polymetallic and Fe-sulphide deposits are mutually transitional within a single narrow stratigraphic zone, and are considered to have formed penecontemporaneously. In some places, massive Fe-sulphide deposits are connected along a stratigraphic zone by layers containing disseminated Fe-sulphide, thereby constituting Fe-sulphide formations which extend for several kilometres from the felsic volcanic areas.

It is suggested that the polymetallic massive sulphide deposits have formed close to the exhalative vent, whereas the massive Fe-sulphide deposits were formed by precipitation over a much wider area.

Objectives for Forthcoming Year

During the 1977 field season, activities will be concentrated in the Superior Province where mineral deposits will be investigated and their geological environments and stratigraphic positions established. During the latter part of the field season additional studies will be carried out in the Flin Flon and Lynn Lake volcanic belts to establish, in greater detail, the geological environments hosting selected massive sulphide deposits and to re-examine critical stratigraphic sections. Compilation of mineral deposit maps and a classification of massive sulphide deposit environments will be the main objectives of office work for the remainder of the 1977/78 fiscal year.

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NM 7506 EVALUATION OF DISSEMINATED BASE METAL ENVIRONMENTS — *by D.A. Baldwin*

The objective of this project is to evaluate the potential for the occurrence of disseminated (sedimentary- and porphyry-type) base metal deposits in the shield area of Manitoba.

Stratabound-Sedimentary Environment

In 1975, a field program was initiated to investigate geological environments favourable for sedimentary-type base metal deposits in contact zones between (i) the Sickle Group and the Wasekwan Group, and (ii) the Sickle Group and the Burntwood River Supergroup. As part of this study, Baldwin (1976) described a copper occurrence at Kadeniuk Lake. A compilation of data from various sources has been completed and will be made available to the public in the near future. It includes (a) a mineral occurrence map (1:250 000) for the Granville Lake (NTS 64C) and Uhlman Lake (NTS 64B) areas, and (b) a review, based on non-confidential assessment file data, of exploration work that has been carried out in this region, plus a brief description of the geology and the mineralization encountered. A final project report on geology, mineralization, environments of base metal deposition, and economic potential, is in preparation.

Igneous Environment

Eight intrusions that are interpreted to be synvolcanic were investigated in the Flin Flon — Snow Lake area in 1976 to determine whether they are host to porphyry-type mineralization. One of these intrusions contains porphyry-type Cu-Mo mineralization (Baldwin, 1977). Felsic effusive rocks occur in close proximity to the intrusives, suggesting a genetic affinity. Thin section studies of alteration have been carried out, and whole-rock chemical analyses will be available shortly. A final report on porphyry-type mineralization in the Flin Flon — Snow Lake area is in preparation.

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NM 7509 EXPLORATION HISTORY REVIEW – GEOPHYSICAL EVALUATION – *by I.T. Hosain*

Summary

- Due to staff turnover, progress on this project was interrupted from April 1, 1976 to June 31, 1977.
- Analysis, interpretation and compilation of ground geophysical data from open and confidential assessment files were started on February 1, 1977.
- Geophysical anomalies from the open assessment files will be plotted on 1: 50 000 NTS sheets.
- Tabulated comments on geology and geophysics will accompany each map.
- A summary of the highlights of each map sheet will indicate the mineral potential.
- The above compilations will be made available to the public after completion.
- Due to the time restrictions of NREP, it will not be possible to cover the whole of the Province.

Introduction

The analysis, interpretation and compilation of geophysical data from open and confidential assessment files is being carried out to assist in evaluating the mineral potential of various areas of Manitoba. The areas are selected and priorities established in consultation with the geologists involved in NREP. The results of the project will be presented as maps showing the geophysical anomalies, with accompanying comments on the geophysics and geology in tabular form, and a list of areas with geophysical anomalies which have not yet been adequately tested. These compilations will help evaluate the resource potential of the areas and will also indicate zones where more exploration work is warranted. Compilations incorporating open file assessment data will be released to the public.

Previous Work

The results of previous work within this program have been summarized by Burton (1976), whose report contains a comparison of airborne electromagnetic (hereafter A.E.M.) surveys over selected orebodies in the Flin Flon – Snow Lake mineral belt. A.E.M. systems and a brief assessment of their qualities were outlined (Data Recovery, Record Quality, Data Presentation and Rating). Due to staff turnover, no work has taken place under this project from March 31, 1976 until commencement of the present author's employment on February 1, 1977. A new approach to the evaluation of geophysical data has been adopted. More emphasis is now placed on the results of ground geophysical surveys; airborne geophysical surveys are essentially a reconnaissance method, whereas ground geophysical surveys provide a more accurate assessment of the mineral potential.

Methodology

Only a limited area of the Province of Manitoba can be covered, due to the late start (two years after the beginning of the NREP program) made in analyzing, interpreting and compiling the ground geophysical data. The amount of geophysical data is large. For example, in the Flin Flon – Snow Lake belt approximately 500 ground geophysical surveys (open and confidential assessment files) have been reported.

Because of the time element the surveys can only be dealt with in a qualitative manner. Qualitative analysis of an anomaly involves determination of the strike length, strength, direction of dip, and width; quantitative analysis will, in addition to the above, attempt to determine the angle of dip, depth, conductivity-thickness product, and would use master curves, tables, nomograms, computer programs, etc. In some of the surveys quantitative analysis cannot be undertaken on account of the incomplete data provided by the companies; the more recent surveys submitted have a better data base.

The method of handling the data involves direct interpretation on the maps, which are mostly on a scale of 1 inch to 200 or 400 feet. The interpreted data are next transferred to maps on a 1: 50 000 scale. These latter maps, showing all the relevant geophysical information and the areas covered by the surveys, will be accompanied by a table giving the assessment file number, area location, name of the company registering the claim block, year the survey was carried out, geophysical method or methods employed, quality of the surveys, anomalies and their characteristics, whether tested by drilling, cause of the anomaly, whether more geophysical work of a particular kind is warranted, and a comparison of the geology and geophysics. An example of part of a 1: 50 000 map with the corresponding table is given in Figure 1 and Table 1. Geophysical work done in interesting areas will be synthesized, regardless of claim boundaries, and a summary of the mineral potential of each area provided. This will assist in determining where further exploration work is required.

Most of the ground geophysical data analyzed so far have been obtained from magnetic surveys or from some form of electromagnetic survey. An attempt is being made to standardize the results of the different geophysical surveys in a manner which will allow comparison of the anomaly intensity produced by systems measuring the same physical parameters.

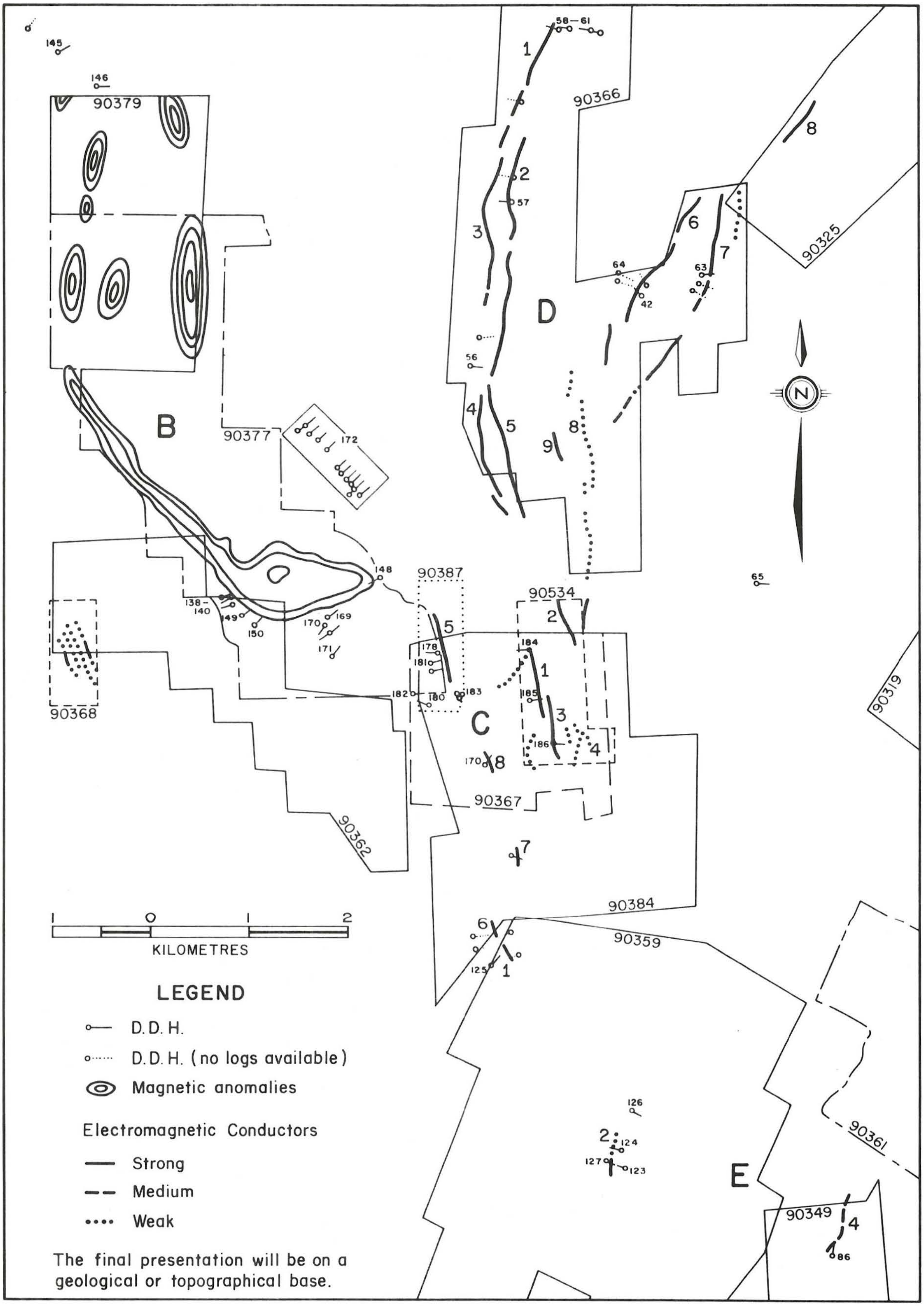
Difficulties may be expected in the field of electromagnetic surveys, where the results from horizontal and vertical loop instruments, and even from different instruments employing the same configuration, are not directly comparable. For example, in a horizontal loop electromagnetic survey, the frequencies of the various instruments employed and their coil separation are taken into consideration; in a detailed vertical loop survey, the frequencies, the transmitter-receiver separation and the transmitter location are taken into consideration. In addition, attention will be paid to the effect of geological and topographical environment. For example, the horizontal loop would be more susceptible to the masking effects of conducting overburden, which would limit the depth of penetration. Therefore, in surveying over lakes where the lake bottom may be composed of conducting material, the vertical loop would be a better method to penetrate the conducting layer. Also, the frequency of the instrument employed should be low enough to penetrate the conducting material. On the other hand, the ratio of the in-phase to the quadrature component (obtainable with the horizontal loop) would give a better handle in interpreting the strength of the conductor.

All, or most of these factors will have to be taken into consideration before assigning an anomaly to one of several arbitrarily chosen levels of intensity, namely; strong, medium or weak.

The airborne data will be used to determine whether the airborne anomalies have been followed up by ground geophysical surveys, and to pick out any airborne anomalies that may have been overlooked during subsequent surface exploration.

Work Accomplished

A review has been completed of ground geophysical work carried out in a part of the Flin Flon — Snow Lake mineral belt corresponding to NTS sheet 63K-12 and part of 63K-13. In addition, part of the Bird River area (52L-5 and 52L-6) has been covered. Eighty-five geophysical



The final presentation will be on a geological or topographical base.

NM 7509 Figure 1 Geophysical anomalies on part of N.T.S. Area 63K—12

NM 7509 TABLE 1 ATHAPAPUSKOW LAKE AREA – OPEN FILE

63K–12

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Ass. File Number	Area	Company	Year	VLEM	HLEM	MAG	Other Geophy.	Drilling	Comments on Drilling	Minerals Encountered	Comments Geophysics	Comments Geology and Geophysics
90367	South end of Schist Lake	Parres & Associates	1953	Area covered previously (no record in files)	(1949)	Sharp Askania type-Sen. 26 γ / Sc. div. One weak anomaly – 200 γ		The weak mag. anomaly drilled. – diorite	Drilled in correct direction		No work warranted	Previous trenching (no record in files)
90384	South of Schist Lake. Overlaps 90367	Cypress Expl.	1955		Loop-Frame 4 strong condrs. and 1 medium strength condr. Nos. 5, 6, 7, 8, and 1			All the conductors have been drilled	Drilled in correct direction	Graph., Py in cond. no. 1, 3, 4, 5, and 8. Log not available for no. 6 and 7.	No work warranted	Drilled continuation of conductor no. 6 – file number 90359 – graph., Py and Po
90534	South end of Schist Lake. Overlaps 90367 and 90384	Rio Tinto	1962	1000 HZ Parallel line and detailed. 3 strong condrs. no. 1, 2 and 3, 1 med. strength condr. no. 4		Sharp A2. No mag anomalies		Drilled 3 holes to test condrs. 1, 3 and 4	Drilled in correct direction	Graphite Shear Zone	Work warranted on condr. no. 2	
90387	South end of Schist Lake	Parres & Associates	1970	SE-300.1600 HZ Transceiver 1 strong condr. no. 5		MF-1. Sen. 20 γ/ Sc. div. 1 weak mag. anomaly. N-S trends		Previously drilled		Graphite Py	No. mag. ass. with condr. No work warranted	

surveys recorded in open file were analyzed, interpreted and compiled. These include 50 surveys in sheet 63K-12, 28 surveys in sheet 63K-13 and 7 surveys in sheets 52L-5 and 52L-6. In addition, 55 surveys contained in confidential files have been treated in a similar manner, but the results cannot be released to the public. As an example, a summarized review of the ground geophysical survey activities in an area follows:

NTS Sheet 63K-12

(Athapapuskow Lake and Schist Lake region)

Most surveys of this region employed the horizontal loop EM method, with frequencies of 2400 or 876 HZ, and coil separations of 200 or 300 feet. In a limited number of surveys, 1000 HZ vertical loop EM equipment was used and some magnetometer surveys were carried out.

The quality and completeness of the data submitted from the various surveys vary considerably from one company to another. In general, the older surveys are less complete.

Findings of particular interest are listed below:

(i) In an area between Schist Lake and the Manitoba-Saskatchewan border (Area 1, Fig. 2) magnetic anomalies were recorded, but no EM work appears to have been done. This omission should be rectified.

(ii) The area immediately east of Manistikwan Lake (Area 2, Fig. 2) requires more work. A survey outlined a few Self-Potential anomalies which were not tested further.

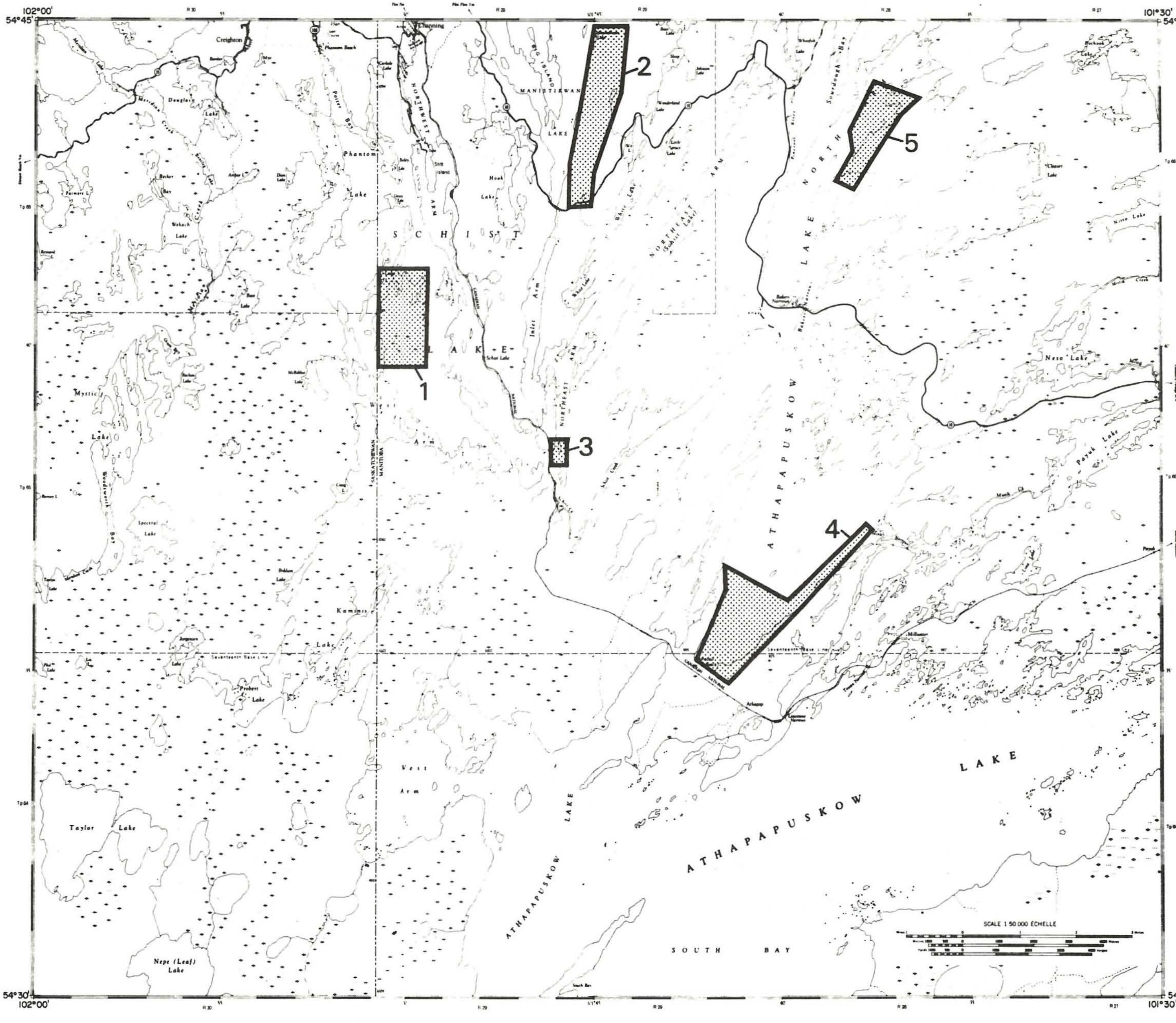
(iii) In the southern part of the Northeast Arm and Inlet Arm of Schist Lake (Area 3, Fig. 2) a vertical loop EM survey outlined several conductors which warrant further investigation to explain the anomalies.

(iv) North of Athapap Beach on Lake Athapapuskow (Area 4, Fig. 2) conductors revealed by vertical loop EM require follow up by Induced Polarization (I.P.) for improved penetration and discrimination.

(v) Approximately 3 km north-northeast of the Centennial Mines (Area 5, Fig. 2) a Crone JEM survey outlined several conductors which warrant further investigation to explain the anomalies.

Plans for the Remaining NREP Period

The above outlined methodology of analyzing the geophysical data will continue for the remaining NREP period. The results — comprising maps, tables and summary — will be made available to the public upon completion. A similar set of maps showing the airborne anomalies complemented by tables and a summary will be prepared after completion of the compilation of ground geophysical data.



NM 7509 Figure 2 Areas recommended for further exploration — N.T.S. 63K–12

NM 7510 ORE MINERALOGY – *by J.D. Scott*

Summary

- **Thompson Mine**

  Studies of ores from the Thompson Mine (Inco Limited) indicate that:

  - there is demonstrable compositional equilibrium over distances up to 400 m;
  - linear relationships of (Ni+Co) pentlandite vs Ni pyrrhotite and Co pentlandite vs Co pyrite (secondary after pentlandite) can be demonstrated;
  - the bulk chemistry and sulphide texture are not correlatable with local structure based on present information;
  - Zn is mainly in an Al, Zn-chromite. Sphalerite is rare;
  - Pd is in gersdorffite and was not detected in other sulphides;
  - a computer program was developed to calculate the normative components of ores.

- **Centennial Mine**

  In the Centennial Mine (Hudson Bay Mining and Development Co.):

  - zincian tennantite-tetrahedrite is locally common;
  - fine-grained cobaltite is present.

- **Farley Mine**

  Work on ores from the Farley Mine (Sherritt Gordon Mines Ltd.) indicated:

  - that the paragenesis of the "B" pit zone is mainly hydrothermal in nature, with extensive violaritization, whereas violarite is not present in the underground workings;
  - that oriented laths of native Te exsolving from pentlandite are present in one "norite" specimen studied.

- **Ruttan Lake Mine**

  In the Ruttan Lake Mine (Sherritt Gordon Mines Ltd.):

  - cubanite and valleriite occur in the massive pyrite-sphalerite ore of the open pit. This is the second known Canadian occurrence of valleriite and the only one not associated with nickel sulphides.

- **Earthy Pyrite Deposits**

  In the "Earthy Pyrite" deposits such as the Big Island occurrence:

  - a thin graphite sheath around pyrite grains apparently inhibits metamorphic recrystallization; thus a potential geothermometer based on the degree of agglomeration of pyrite grains is possible.

Introduction

Mineralogical investigations in the period July 1976 through March 1977 can be classified into four general projects: I — structure vs chemistry project initiated by Inco Limited on material from two fold structures in the T3 zone of the main Mine at Thompson (completed); II — detailed metalogical studies of ore suites from the Centennial Mine, Flin Flon (ongoing); III — detailed mineralogical study of the Ni sulphide mineralogy of the Farley Mine, Lynn Lake (ongoing); IV — miscellaneous minor examinations, frequently confidential in nature, for both project and company geologists. In addition, comprehensive mineralogical investigations were made of aspects of the projects which are of particular scientific interest and suitable for journal publication.

I. Structure vs Chemistry Project, Thompson Mine

Localized specimens 373534 through 373559, from the 319 stope, 2000 level (Fig. 1a) and 373560 through 373571, from the 328 stope, 2800 level (Fig. 1b) of the Thompson Mine (T3 zone) were made available for study by Inco Limited, together with the results of bulk-chemical (A.A.) analyses made on these samples. The two sets of samples come from two separate fold structures of different geometry.

All specimens were subjected to detailed mineralographic examination, with electron microprobe analyses of all Ni-bearing phases in each sample. The project objectives were:

a) to investigate the feasibility of using bulk analytical data to predict accurately the location of a sample within the known structural geometry of the stopes,

b) to extend and refine the concept of the pyrrhotite-to-nickel ratio (po/Ni) currently used by Inco, as calculated from the bulk analyses, and

c) to make any other observations which might assist in determining the position of a sample (e.g. core from exploration drilling) within a specific structure.

A computer program, ANALP[1], was developed to process the bulk analyses. The program is of general application and is fully described; it should therefore prove easily adaptable to other types of deposits. The current version accepts raw analytical data for total Fe and sulphide-contained Ni, Co, Cu and S, and uses an iterative matrix-algebra approach to produce a normative estimate of the whole-rock composition, expressed in terms of sulphide and gangue components. A sample page of this output is reproduced as Table 1. Percentages of pentlandite present, obtained by Quantimet image analysis of the polished sections, were in excellent agreement with computer-calculated values for the bulk samples. As a rough estimate, the percentage of pentlandite present in a sample may be calculated by the equation:

$$\%pn = 2.59(Ni + Co) - 0.61$$

where Ni and Co are the values returned from bulk analysis.

Regression analysis of potentially useful variables (ore zone width, sample location within a fold structure, various factors related to the grain size of the pentlandite, raw percentage of pentlandite in the ore, po/Ni ratio, bulk analytical values) for the full data set of 38 samples failed, in that no correlation coefficient exceeded 0.6. It can thus be stated that in the two fold structures

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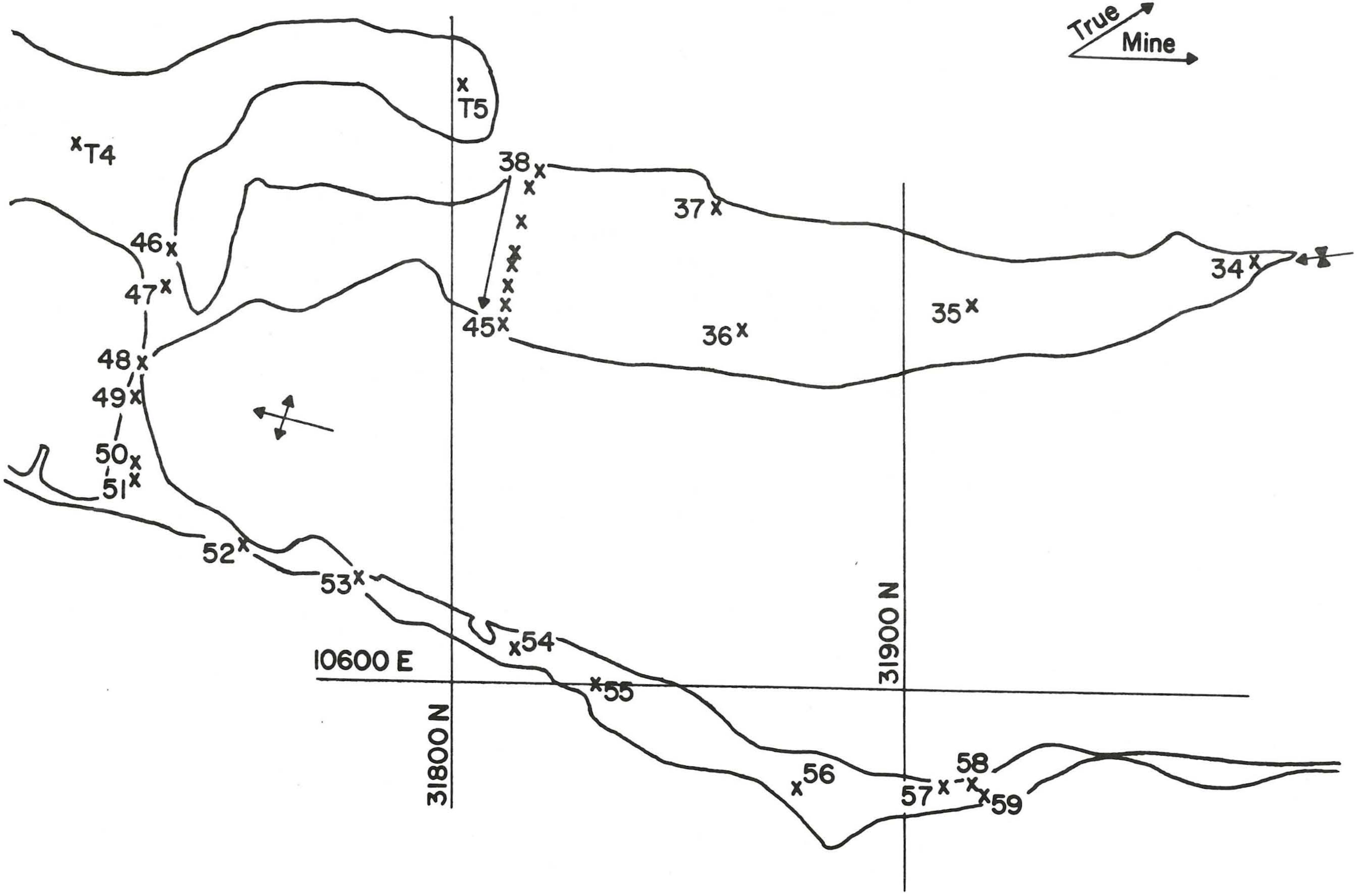
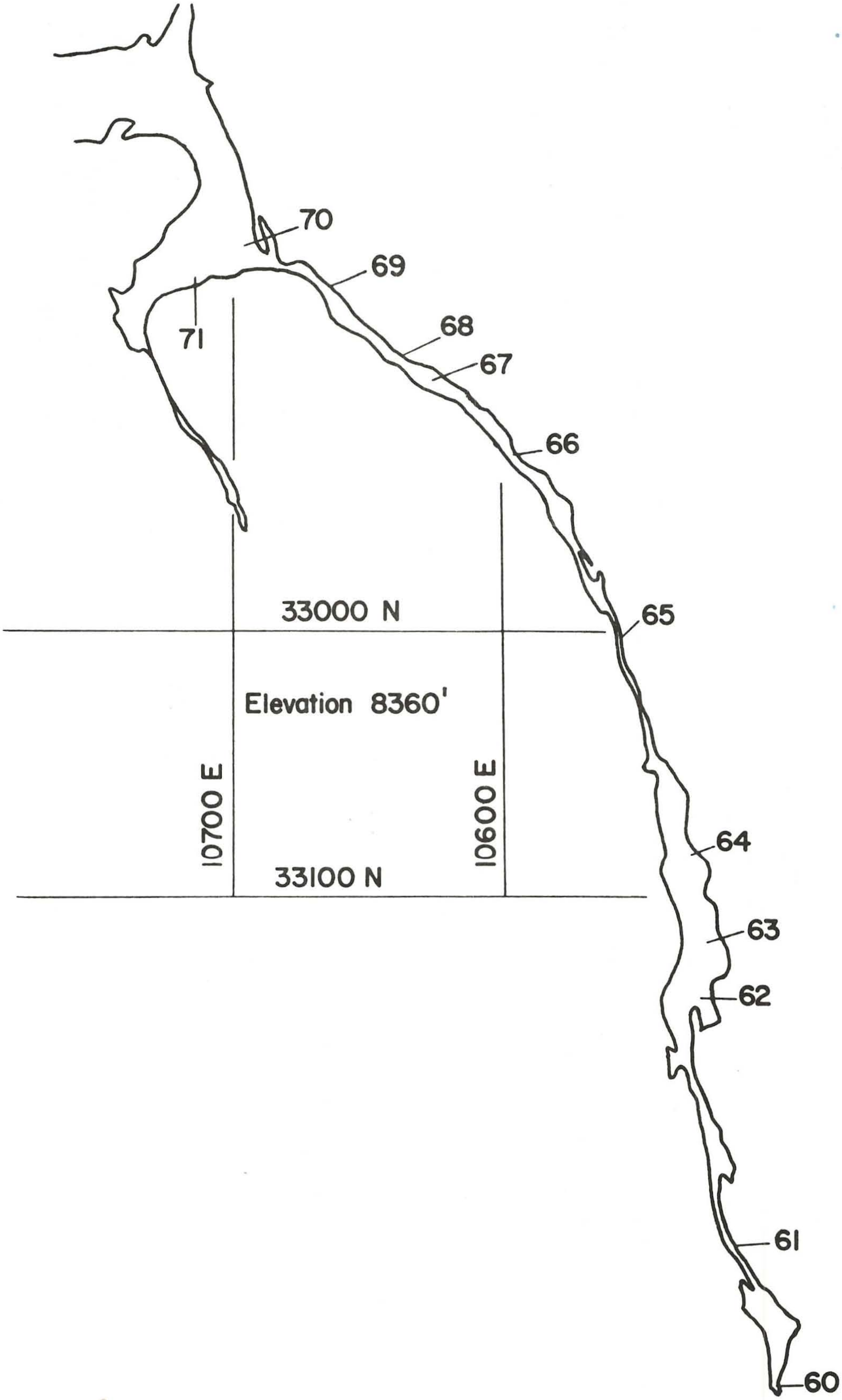
[1] ANALP — Analysis of Pentlandite. This program is available on application to the Mineral Resources Division.



NM 7510 Figure 1a Thompson Mine 2000 level, 319 stope



NM 7510 Figure 1b Thompson Mine sample locations, 328 stope (ore zone outlined)

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THIN LIMB, 319 STOPE, 2000 LEVEL, THOMPSON MINE.                                    TABLE 1

SAMPLE      PO       PN      CPY     PY    BI+MT   GANGUE        PO/NI    %PN     %S      DS

373553   58.40   12.50     .40   0.00     9.51   28.69          11.43   17.63   27.30     .50     53     VISUAL PYRITE = 0.0%
373553   59.70   12.47     .40   0.00     6.12   27.43          11.68   17.28   27.80    0.00     53
373553   60.99   12.44     .40   0.00     2.72   26.16          11.94   16.94   28.30    -.50     53
373553   60.12   12.46     .40   0.00     5.00   27.01          11.77   17.17   27.96    -.16     53     STANDARD ESTIMATE

373554   68.99   14.43     .66   0.00    -8.17   15.92    **    11.67   17.29   32.20     .50     54     VISUAL PYRITE = 0.0%
373554   70.28   14.40     .66   0.00   -11.57   14.66    **    11.89   17.00   32.70    0.00     54     GROSS ERROR IN S ANALYSIS
373554   71.58   14.37     .66   0.00   -14.97   13.39    **    12.11   16.72   33.20    -.50     54
373554   63.97   14.54     .66   0.00     5.00   20.82          10.82   18.52   30.26    2.44     54     STANDARD ESTIMATE

373555   53.86   12.93     .26   0.00    13.21   32.95          10.30   19.36   25.60     .50     55     VISUAL PYRITE = 0.0%
373555   55.15   12.90     .26   0.00     9.82   31.69          10.55   18.95   26.10    0.00     55     CHECK SAMPLE FOR UP TO  2% MT
373555   56.45   12.87     .26   0.00     6.42   30.42          10.79   18.57   26.60    -.50     55
373555   56.99   12.86     .26   0.00     5.00   29.90          10.90   18.41   26.81    -.71     55     STANDARD ESTIMATE

373556   65.13   16.24     .14   0.00    11.03   18.48           9.94   19.96   31.10     .50     56     VISUAL PYRITE = 0.0%
373556   66.43   16.21     .14   0.00     7.63   17.22          10.14   19.62   31.60    0.00     56
373556   67.72   16.18     .14   0.00     4.24   15.95          10.34   19.29   32.10    -.50     56
373556   67.43   16.19     .14   0.00     5.00   16.24          10.29   19.36   31.99    -.39     56     STANDARD ESTIMATE

373557   45.69   10.33     .49   0.00    10.94   43.49          10.88   18.43   21.60     .50     57     VISUAL PYRITE = 0.0%
373557   46.99   10.30     .49   0.00     7.54   42.23          11.19   17.98   22.10    0.00     57
373557   48.28   10.27     .49   0.00     4.14   40.96          11.49   17.54   22.60    -.50     57
373557   47.95   10.28     .49   0.00     5.00   41.28          11.42   17.65   22.47    -.37     57     STANDARD ESTIMATE

373558    9.33    1.66    4.21   0.00     7.75   84.79          13.53   15.06    5.70     .50     58     VISUAL PYRITE = 0.0%
373558   10.63    1.63    4.21   0.00     4.36   83.53          15.40   13.27    6.20    0.00     58
373558   11.92    1.60    4.21   0.00      .96   82.27          17.28   11.82    6.70    -.50     58
373558   10.38    1.63    4.21   0.00     5.00   83.77          15.05   13.58    6.11     .09     58     STANDARD ESTIMATE

373559   73.98   16.77    1.21    .50    -2.26    7.54    **    10.83   18.48   35.40     .50     59     VISUAL PYRITE = .5%
373559   75.27   16.74    1.21    .50    -5.66    6.28    **    11.02   18.20   35.90    0.00     59
373559   76.56   16.71    1.21    .50    -9.05    5.01    **    11.21   17.92   36.40    -.50     59
373559   71.21   16.83    1.21    .50     5.00   10.24          10.43   19.12   34.33    1.57     59     STANDARD ESTIMATE


ANALYSES FLAGGED  **  ARE CHEMICALLY IMPOSSIBLE.

GANGUE REFERS TO 100-(PO+PN+CPY+PY) AND SHOULD BE COMPARED WITH BI+MT

PERCENTAGES OF PY, BI AND MT IN THE SAMPLE MUST BE ESTIMATED FOR PROPER INTERPRETATION OF THE CALCULATIONS.

THE MESSAGE  CHECK SAMPLE FOR UP TO X% MT  GIVES THE AMOUNT OF MT (+5% BI) FOR AN IDEAL S ANALYSIS.

PO/NI AND %PN REFER TO PO+PN=100%   (NI+CO IN PN= 37.0%)

MEAN SIGMA FOR PO/NI=0.17, FOR %PN=1.25%

THE STANDARD ESTIMATE CONTAINS  1.13% FE IN (BI+MT)
```

studied there is no reliable method of predicting sample location from either bulk chemistry or visually estimated grain size variation in the pentlandite. (Experience in the stopes indicates that if the diameter of the largest visible pentlandite eye is greater than 2 mm, then the ore zone is probably more than 3 m wide).

As can be seen from Figures 2a and 2b, a somewhat better indication of sample location can be obtained from exact measurement of the entire range of pentlandite grain size by Quantimet image analysis. In Figure 2a samples from the nose and thin limb of the 319 stope fold (group A) are clearly demarcated from those of the refolded thick limb (group B). Examination of Figure 2b, however, shows that this demarcation is a relative one and is not exactly reproduced in the 328 stope fold. Given the effective compositional equilibrium attained by the sulphides (see Tables 2, 3, 4), it is probable that the controlling variable is not the width of the present ore zone but, rather, the degree of tectonic mobilization undergone by the ore horizon.

Electron microprobe analyses of coexisting pentlandite, pyrrhotite and pyrite are given in Tables 2, 3 and 4. These provide sufficient reliable data to test properly the theory of conjoint variation in composition between coexisting sulphides. For the pair pentlandite-pyrite (in the presence of monoclinic pyrrhotite),

$$\text{at.\% Co in pn} = 0.338\ \text{at.\% Co in py}$$

with a correlation coefficient of 0.957. This relationship breaks down when Ni in pyrite exceeds about 0.2 atomic percent, or when the assemblage contains pyrite in excess of pentlandite (sample 373534). For the pair pentlandite-monoclinic pyrrhotite, the relationship is more complex than was previously thought:

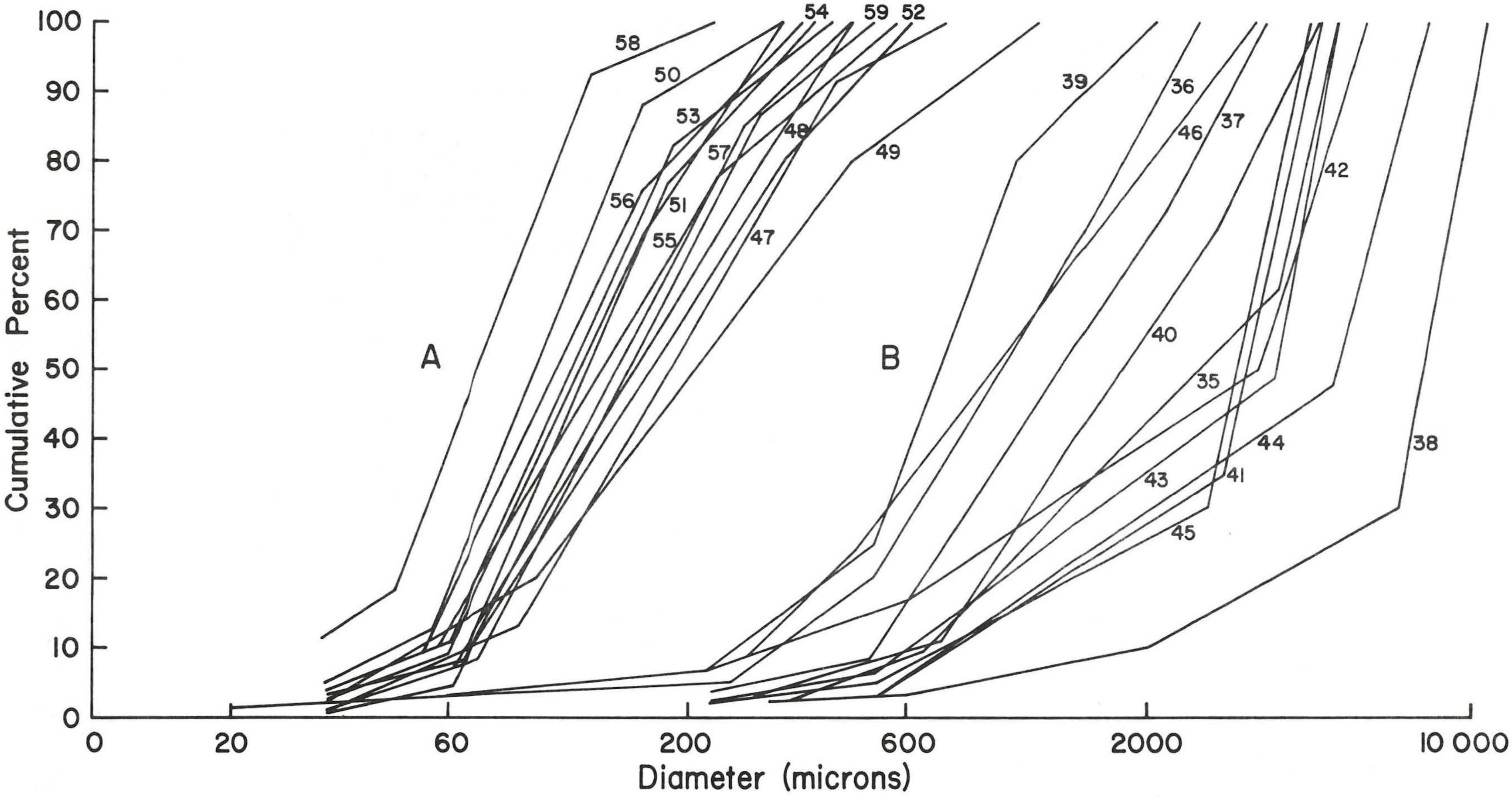
$$\text{at.\% Ni in po} = 0.281\ \text{at.\% (Ni + Co) in pn} - 7.45$$

with a correlation coefficient of 0.922. The correlation matrix for a multiple regression is, however, as follows:

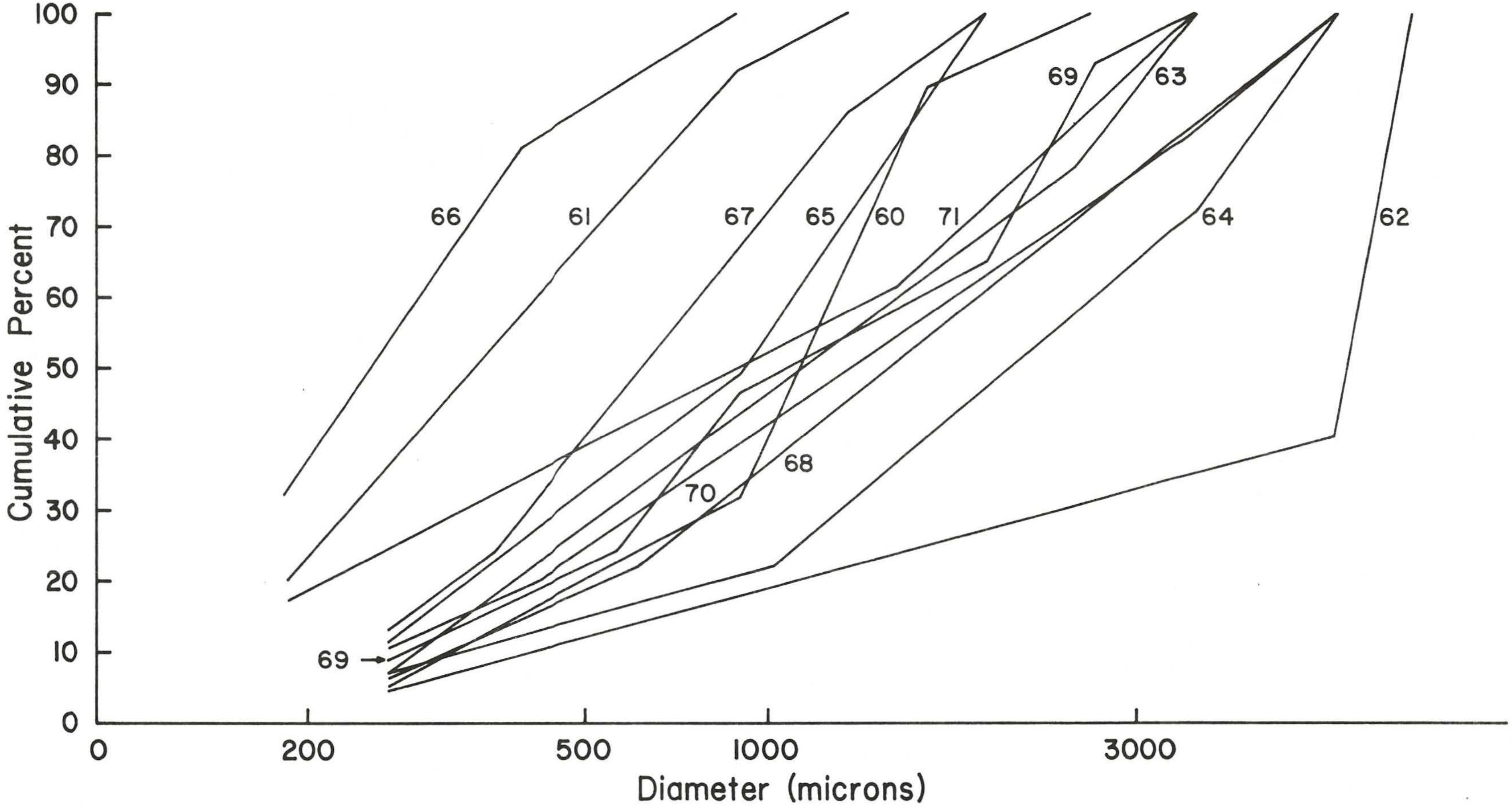
	pn Fe	pn Ni	pn Co
pn Ni	–0.88		
pn Co	–0.10	–0.23	
po Ni	–0.85	0.83	0.21

These results are surprising in that they indicate both that there is long-range compositional equilibrium in the fold structures (over 200 m within them and over 430 m between them, down plunge) and that the role of cobalt in the pentlandite structure is not as simple as has been thought. A paper by the present author on the partitioning of nickel among coexisting Ni sulphides, containing a fuller discussion of these observations, appears in "The Canadian Mineralogist", vol. 15, part 4, 1977, under the title: Coexisting nickel sulphides. I. The pentlandite-monoclinic pyrrhotite-(pyrite) assemblage.

The ore specimens examined are not mineralogically complex, consisting of pentlandite in monoclinic pyrrhotite with some or all of: minor chalcopyrite, pyrite, gersdorffite, chromite, magnetite and graphite. The texture of the pentlandite appears to be a function of its grain size; a correlation of grain size range (as determined by Quantimet image analysis – cf. Figs. 2a and 2b) with observed texture is given in Table 5. Chalcopyrite is present as a minor-to-trace constituent in all samples, usually restricted to veinlets or dots along pyrrhotite grain boundaries. It may invade pentlandite eyes along fractures, or partly rim the eyes, but is rarely seen as true inclusions within them. Pyrite occurs in two distinct and probably unrelated forms. In the nose of a fold it may occur, in quantities equivalent to the local pentlandite content, as brecciated subhedral primary



NM 7510 Figure 2a Quantimet size analysis of pentlandite, 319 stope, Thompson Mine



NM 7510 Figure 2b Quantimet size analysis of pentlandite, 328 stope, Thompson Mine

NM 7510 Table 2 Microprobe Analyses: 319 and 328 stopes, Thompson Mine

MICROPROBE ANALYSES: 319 AND 328 STOPES, THOMPSON MINE TABLE 2

PENTLANDITE

	WEIGHT PERCENT				ATOMIC PERCENT				METAL/SULFUR-ATOMS	RAW SUM
SAMPLE	FE	NI	CO	S	FE	NI	CO	S		
34	31.31	35.48	.04	33.18	25.48	27.47	.03	47.03	9.006/ 7.994	99.95
35	29.56	36.54	.84	33.06	24.09	28.33	.65	46.93	9.023/ 7.977	100.16
36	29.67	36.40	.79	33.14	24.17	28.21	.61	47.01	9.008/ 7.992	100.40
37	30.76	35.39	.75	33.11	25.05	27.41	.58	46.96	9.017/ 7.983	99.98
38	30.01	36.01	.95	33.03	24.46	27.92	.73	46.89	9.029/ 7.971	100.33
38V	29.59	36.37	.88	33.16	24.10	28.18	.68	47.04	9.002/ 7.998	100.17
39	29.91	36.20	.72	33.18	24.35	28.04	.55	47.05	9.001/ 7.999	100.25
40	30.02	35.96	.83	33.19	24.44	27.85	.64	47.07	8.998/ 8.002	100.56
41	30.13	35.91	.90	33.06	24.55	27.84	.69	46.92	9.024/ 7.976	100.16
42	29.84	36.06	.86	33.23	24.29	27.93	.67	47.11	8.990/ 8.010	100.60
43	29.68	36.30	.81	33.21	24.17	28.11	.62	47.10	8.993/ 8.007	100.56
44	30.00	36.07	.80	33.14	24.43	27.94	.62	47.01	9.008/ 7.992	100.18
45	30.08	35.91	.82	33.19	24.49	27.81	.63	47.06	9.000/ 8.000	100.19
T4	30.79	35.23	.90	33.08	25.08	27.30	.69	46.93	9.022/ 7.978	101.15
T5	30.04	36.35	.25	33.36	24.43	28.12	.19	47.25	8.967/ 8.033	100.06
46	31.53	34.45	.76	33.26	25.64	26.65	.58	47.12	8.990/ 8.010	100.29
47	31.13	34.95	.64	33.29	25.32	27.04	.49	47.15	8.984/ 8.016	100.46
48	31.33	34.76	.57	33.34	25.47	26.89	.44	47.20	8.975/ 8.025	100.16
49	31.29	34.85	.56	33.30	25.45	26.96	.43	47.17	8.981/ 8.019	100.41
50	30.30	35.92	.58	33.20	24.67	27.81	.45	47.08	8.997/ 8.003	100.29
51	29.44	36.59	.63	33.35	23.95	28.31	.48	47.25	8.967/ 8.033	100.34
52	30.52	35.73	.46	33.29	24.83	27.65	.35	47.17	8.981/ 8.019	100.29
53	30.77	35.71	.30	33.23	25.04	27.64	.23	47.09	8.994/ 8.006	100.43
54	30.07	35.97	.52	33.44	24.44	27.81	.40	47.34	8.952/ 8.048	100.36
55	30.29	35.85	.46	33.40	24.63	27.72	.35	47.30	8.959/ 8.041	100.32
56	30.70	35.66	.33	33.31	24.97	27.59	.25	47.19	8.978/ 8.022	100.53
57	31.54	34.98	.36	33.12	25.68	27.09	.28	46.96	9.017/ 7.983	100.21
58	31.20	35.18	.44	33.18	25.39	27.24	.34	47.03	9.005/ 7.995	100.16
59	30.77	35.51	.34	33.38	25.02	27.46	.26	47.26	8.966/ 8.034	100.16
60	30.38	35.26	.91	33.45	24.69	27.26	.70	47.35	8.950/ 8.050	101.40
61	31.41	34.61	.66	33.31	25.54	26.77	.51	47.18	8.980/ 8.020	101.10
62	29.64	36.06	.97	33.33	24.12	27.91	.75	47.23	8.971/ 8.029	101.17
63	30.08	35.64	.99	33.29	24.48	27.58	.77	47.17	8.980/ 8.020	101.78
64	29.39	36.46	.97	33.17	23.94	28.25	.75	47.06	9.000/ 8.000	100.98
65	31.21	35.12	.40	33.27	25.39	27.17	.30	47.13	8.987/ 8.013	101.11
66	29.83	36.18	.73	33.26	24.28	28.01	.57	47.15	8.985/ 8.015	100.81
67	30.87	34.97	.92	33.24	25.12	27.07	.71	47.11	8.992/ 8.008	101.20
68	30.29	35.57	.86	33.29	24.64	27.53	.66	47.17	8.981/ 8.019	101.39
69	31.58	34.75	.58	33.08	25.71	26.92	.45	46.92	9.024/ 7.976	101.08
70	31.23	34.87	.67	33.23	25.41	26.99	.51	47.09	8.995/ 8.005	100.63
71	31.22	34.69	.54	33.56	25.35	26.79	.41	47.45	8.934/ 8.066	100.73
MEAN	30.47	35.62	.66	33.24	24.80	27.57	.51	47.11	8.991/ 8.009	100.55
SIGMA	.66	.60	.23	.11	.53	.47	.18	.13	.022/ .022	.44

MICROPROBE ANALYSES: 319 AND 328 STOPES, THOMPSON MINE TABLE 3

MONOCLINIC PYRRHOTITE

	WEIGHT PERCENT				ATOMIC PERCENT				METAL/SULFUR	RAW
SAMPLE	FE	NI	CO	S	FE	NI	CO	S	ATOMS	SUM
34	60.23	.31	0.00	39.46	46.60	.23	0.00	53.18	7.024/ 7.976	100.50
35	59.28	1.10	0.00	39.62	45.84	.81	0.00	53.36	6.997/ 8.003	100.20
36	59.41	.97	0.00	39.63	45.93	.71	0.00	53.36	6.996/ 8.004	100.51
37	59.98	.56	0.00	39.47	46.40	.41	0.00	53.18	7.022/ 7.978	100.39
38	60.09	.68	0.00	39.24	46.55	.50	0.00	52.95	7.058/ 7.942	100.42
38V	59.75	.82	0.00	39.44	46.24	.60	0.00	53.16	7.026/ 7.974	100.44
39	59.72	.70	0.00	39.58	46.18	.51	0.00	53.30	7.005/ 7.995	100.21
40	60.04	.60	0.00	39.36	46.49	.44	0.00	53.08	7.039/ 7.961	100.76
41	59.42	.93	0.00	39.66	45.93	.68	0.00	53.39	6.991/ 8.009	100.46
42	59.58	.98	0.00	39.44	46.11	.72	0.00	53.17	7.024/ 7.976	100.42
43	59.69	.91	0.00	39.40	46.20	.67	0.00	53.12	7.032/ 7.968	100.71
44	59.65	.95	0.00	39.41	46.18	.70	0.00	53.13	7.031/ 7.969	100.52
45	60.08	.66	0.00	39.27	46.54	.48	0.00	52.98	7.053/ 7.947	100.29
T4	60.09	.55	0.00	39.36	46.52	.40	0.00	53.08	7.038/ 7.962	100.42
T5	59.90	.64	0.00	39.46	46.35	.47	0.00	53.18	7.023/ 7.977	100.55
46	59.96	.35	0.00	39.69	46.33	.26	0.00	53.41	6.988/ 8.012	100.08
47	60.14	.41	0.00	39.46	46.53	.30	0.00	53.17	7.024/ 7.976	100.44
48	59.98	.42	0.00	39.60	46.37	.31	0.00	53.32	7.001/ 7.999	100.27
49	60.02	.37	0.00	39.61	46.40	.27	0.00	53.33	7.000/ 8.000	100.55
50	59.95	.65	0.00	39.40	46.40	.48	0.00	53.12	7.032/ 7.968	100.55
51	59.52	.87	0.00	39.61	46.02	.64	0.00	53.34	6.999/ 8.001	100.23
52	59.97	.51	0.00	39.53	46.38	.37	0.00	53.25	7.013/ 7.987	100.34
53	59.91	.50	0.00	39.59	46.32	.37	0.00	53.31	7.003/ 7.997	100.23
54	59.79	.60	0.00	39.61	46.22	.44	0.00	53.34	6.999/ 8.001	100.24
55	59.80	.59	0.00	39.61	46.23	.43	0.00	53.34	6.999/ 8.001	100.50
56	59.96	.45	0.00	39.59	46.36	.33	0.00	53.31	7.003/ 7.997	100.38
57	60.13	.46	0.00	39.41	46.54	.34	0.00	53.13	7.031/ 7.969	100.68
58	60.11	.32	0.00	39.58	46.47	.23	0.00	53.29	7.006/ 7.994	100.24
59	59.79	.51	0.00	39.70	46.20	.37	0.00	53.43	6.985/ 8.015	100.27
60	59.82	.74	0.00	39.44	46.29	.55	0.00	53.16	7.026/ 7.974	100.86
61	60.10	.35	0.00	39.55	46.48	.26	0.00	53.27	7.010/ 7.990	100.66
62	59.59	.96	0.00	39.45	46.12	.70	0.00	53.18	7.023/ 7.977	100.47
63	59.69	.82	0.00	39.49	46.18	.61	0.00	53.21	7.018/ 7.982	100.92
64	59.44	1.14	0.00	39.43	46.01	.84	0.00	53.16	7.027/ 7.973	101.20
65	60.14	.40	0.00	39.46	46.53	.29	0.00	53.18	7.024/ 7.976	100.86
66	60.03	.59	0.00	39.37	46.48	.44	0.00	53.09	7.037/ 7.963	100.91
67	60.25	.39	0.00	39.36	46.64	.28	0.00	53.07	7.039/ 7.961	101.16
68	60.05	.54	0.00	39.40	46.48	.40	0.00	53.12	7.032/ 7.968	101.08
69	60.27	.27	0.00	39.47	46.63	.20	0.00	53.18	7.023/ 7.977	101.43
70	60.19	.42	0.00	39.39	46.58	.31	0.00	53.11	7.034/ 7.966	100.37
71	60.25	.18	0.00	39.57	46.58	.13	0.00	53.28	7.007/ 7.993	99.90
MEAN	59.90	.61	0.00	39.49	46.34	.45	0.00	53.21	7.018/ 7.982	100.53
SIGMA	.26	.24	0.00	.11	.21	.18	0.00	.12	.017/ .017	.32

NM 7510 Table 4 Microprobe Analyses: 319 and 328 stopes, Thompson Mine

MICROPROBE ANALYSES: 319 AND 328 STOPES, THOMPSON MINE TABLE 4

HEXAGONAL PYRRHOTITE

	WEIGHT PERCENT				ATOMIC PERCENT				METAL/SULFUR	RAW
SAMPLE	FE	NI	CO	S	FE	NI	CO	S	ATOMS	SUM
46H	60.50	.55	0.00	38.95	46.95	.40	0.00	52.65	8.997/10.003	100.48
71H	60.55	.43	0.00	39.02	46.96	.32	0.00	52.72	8.984/10.016	99.97
MEAN	60.52	.49	0.00	38.99	46.96	.36	0.00	52.68	8.990/10.010	100.23
SIGMA	.02	.06	0.00	.03	.01	.04	0.00	.03	.007/ .007	.26

PYRITE

	WEIGHT PERCENT				ATOMIC PERCENT				METAL/SULFUR	RAW
SAMPLE	FE	NI	CO	S	FE	NI	CO	S	ATOMS	SUM
34	44.82	.04	1.81	53.33	32.14	.03	1.23	66.61	1.002/ 1.998	100.24
35	44.72	1.61	.14	53.54	32.03	1.10	.09	66.78	.996/ 2.004	100.10
39	44.35	.06	2.42	53.17	31.83	.04	1.64	66.48	1.006/ 1.994	100.50
40	44.27	.07	2.74	52.92	31.82	.05	1.86	66.26	1.012/ 1.988	100.88
T5	45.29	.02	.98	53.71	32.40	.01	.67	66.92	.992/ 2.008	100.75
46	44.67	.02	2.06	53.25	32.05	.01	1.40	66.54	1.004/ 1.996	100.16
48	44.76	.04	2.04	53.17	32.12	.03	1.38	66.47	1.006/ 1.994	100.21
49	44.32	.19	2.27	53.23	31.80	.13	1.54	66.53	1.004/ 1.996	100.57
51	44.35	.05	2.02	53.58	31.76	.03	1.37	66.83	.995/ 2.005	100.32
59	45.02	.05	1.42	53.51	32.25	.03	.96	66.76	.997/ 2.003	99.57
69	44.61	.11	1.94	53.34	31.99	.07	1.32	66.61	1.002/ 1.998	100.42
71	45.05	.06	1.62	53.27	32.31	.04	1.10	66.55	1.003/ 1.997	100.63
MEAN	44.68	.19	1.79	53.34	32.04	.13	1.21	66.61	1.002/ 1.998	100.36
SIGMA	.31	.43	.66	.21	.20	.29	.45	.18	.005/ .005	.33

NM 7510 Table 5 Relation of Texture to Grain Size of Pentlandite from 319 and 328 stopes, Thompson Mine

Size Range (μ)		Observed Form of Pentlandite
0 – 70	–	flames and/or triangular blebs at triple-point junctions in pyrrhotite.
70 – 500	–	discontinuous veinlets and flame-veinlets along and in part around pyrrhotite grain boundaries.
	–	small irregular eyes, in general at pyrrhotite grain boundaries.
	–	pseudo-veins composed of partly coalesced eyes.
500 – 2000	–	large subcircular to ellipsoidal eyes emplaced without regard to pyrrhotite grain boundaries.
	–	veins, without definite eye formations, along fractures in the pyrrhotite (or crosscutting).
2000+	–	large irregular eyes, in part coalescing into areas of massive pentlandite or irregular vein-like formations.

crystals which have been massively invaded/replaced by chalcopyrite. In fold limbs, on the other hand, sparse Co-rich pyrite (Table 4) is invariably found replacing pentlandite flames and veinlets. Hexagonal pyrrhotite was observed in only two samples, both from fold noses and both with major pyrite content (373546 and 373571). In these it was the dominant phase, with only occasional lathlike crystals of monoclinic pyrrhotite. Gersdorffite is widely disseminated in both the pyrrhotite and the pentlandite as subhedral-to-rounded grains averaging about 40 microns in diameter. In the 319 stope the refolded thick-limb zone samples contain an average of 9 grains per polished section while the nose and thin-limb zone samples contain an average of 2 grains. Microprobe analyses show individual crystals to be homogeneous in major elements, but slightly zoned in Pd, being Pd-rich toward the outer margin. The overall range in Pd content is 0.18 to 0.65 weight percent. No Pd (or other member of the Pd/Pt groups) could be detected in either the pentlandite or the pyrrhotite. Representative normalized analyses of gersdorffite from the three stopes sampled are given below; in all cases Sb was searched for but not detected.

Gersdorffite Analyses

	319 stope	328 stope	890 stope
Fe	5.99	5.85	5.74
Ni	20.34	21.06	21.98
Co	7.61	7.11	6.71
Pd	0.29	0.25	0.27
As	47.49	47.55	47.95
S	18.28	18.18	17.35
	100.00	100.00	100.00
	(98.94)	(99.94)	(99.56)

The dominant spinel-group mineral, present as large subhedral crystals in both pyrrhotite and pentlandite of samples from the 319 and 328 stopes, is an unusual Al, Zn chromite (a = 8.279Å, D_{meas} = 4.75(5) g/cc), with no detectable Mg. In the 328 stope these crystals are commonly associated with (or contained within) large wine-red almandite garnet crystals (a = 11.491Å). A representative microprobe analysis, recalculated to oxides to yield a formula of the type $M^{+2}M_2^{+3}O_4$, is given below (sample 373562):

Chromite

FeO	30.04
ZnO	3.94
MnO	0.49
Cr_2O_3	42.44
Al_2O_3	15.52
Fe_2O_3	6.41
TiO_2	0.31
	99.15

Sphalerite was observed only in the atypical sample 373558. This specimen has pyrrhotite and/or chalcopyrite veinlets along fractures and in an open net-texture through a quartz-orthoclase rock fragment. There is less than 2% pentlandite present in the pyrrhotite veinlets, and sphalerite occurs sparingly in the chalcopyrite veinlets. It is therefore concluded that the low level of Zn reported in some bulk analyses (P.J. Rush, pers. comm.) results from the presence of substantial chromite in the sample, unless the Cu value is anomalously high, in which case sphalerite might be suspected.

A single sharply defined 50-micron lath of gold was observed in a chalcopyrite inclusion within a large chromite crystal in sample 373563. Qualitative microprobe analysis showed Au 95%, Ag 5%, trace Cu.

II. Centennial Mine, Flin Flon

A suite of specimens from the 390 level at the extreme north end of the orebody (bottom of plunge) was supplied by N. Provins, mine geologist. Similar material had returned some unusual assay results, with Sb and Co reported as well as the expected Cu and Zn. This zone is of limited extent, occurs only at the stratigraphic base, and is separated from the main massive pyrite-chalcopyrite-sphalerite ore zone by a zone of sheared chloritic schist containing disseminated chalcopyrite and pyrite with minor arsenopyrite.

In hand specimen, the material contains numerous discontinuous crenulate black bands (some with chalcopyrite cores), together with bands of disseminated chalcopyrite and/or pyrite with a thin black rind, in a matrix of grey-white cherty carbonate. Microprobe analysis of the finely disseminated black material showed it to be a zincian tennantite-tetrahedrite $(Cu_{19.92}Zn_{2.35}Fe_{1.76})$ $(As_{4.08}Sb_{4.01})$ S_{26}, with cell edge $a = 10.310(5)$Å. Sphalerite is extremely rare in these specimens. Arsenopyrite is concentrated as small euhedral crystals in the tennantite-rich zones and especially at the tennantite-chalcopyrite interfaces. The chalcopyrite bands are essentially monomineralic with the chalcopyrite strongly invading/replacing carbonate grains in a three-dimensional net texture. Pyrite-rich bands with abundant infilling chalcopyrite are common, often with the pyrite occurring as large ragged structureless blotches resembling a brecciated and compacted pyrite-mat. Cobaltite is pervasive in the chert-carbonate matrix as widely disseminated 5-micron euhedral crystals; these tend to concentrate and form larger crystals near the outer edges of tennantite bands. The carbonate matrix is very fine grained and complexly intergrown with quartz, comprising some 50% of the rock; microprobe analyses show a compositional range from ferroan dolomite to ferroan magnesite.

A comprehensive suite of localized specimens is currently under study in order to define the mineralogical zoning of the orebody.

III. Farley Mine, Lynn Lake

The sulphide mineralogy of the Farley Mine is the subject of an ongoing project in support of the detailed study of the deposits by R.H. Pinsent (see project NM 7504-B, this report). To date, 28 unlocated samples from the "B" zone open pit and 7 located samples from underground ("O" and "N" orebodies) have been examined. Comprehensive polished- and thin-section descriptions, as well as tables of microprobe analyses, can be made available upon request.

A tentative synthesis can be made from the available mineralogical data. There is a lack of any pronounced metamorphic fabric in the samples and it would appear that the orebodies were emplaced, faulted, cut by dykes and then metamorphosed in situ. The pyrrhotite, with exsolved flame and rim pentlandite, is clearly of very early origin (although the chalcopyrite and possibly the pyrite may be of a later generation). This sulphide mass cooled and was then severely fractured. The fractures are now commonly filled by "intrusive" pentlandite (probably remobilized), which can be observed to truncate and "replace" the earlier flames; no significant difference in composition between the two generations of pentlandite could be detected by the microprobe. The main stage of chalcopyrite remobilization or injection appears to postdate the "injected" pentlandite veins and certainly postdates the euhedral and recurrently fractured and crack-filled pyrite crystals. Subsequent to the chalcopyrite stage there was a (final?) period of local(?) hydrothermal circulation, possibly accompanied by minor tectonic movement, in the "B" pit zone. Belonging to this stage are the Ni-free-marcasite cockade structures in open faults, the pyrite altered to nickeliferous marcasite, the local alteration of some pyrrhotite to nickeliferous pyrite with the formation of goethite in a few fractures, and the formation of some or all of the violarite. All the underground samples contain unaltered pentlandite. The great majority of the open pit samples contain pentlandite violaritized in varying degree, occasionally with violarite partly replacing pyrrhotite as well. This suggests that the bulk of violarite alteration is of "recent" origin and related at least in part to circulating-groundwater weathering (similar to that found in Western Australia). An examination of drill core (which has been stored for a long period in the open) from areas adjacent to the unaltered underground samples will be made to test this theory.

In order to determine whether the olivine crystals and the hornblendic amphibole of the peridotite mass are of primary or secondary origin, it is planned to carry out a series of microprobe analyses. These should assist in resolving the local metamorphic sequence and grade(s). This, together with the evidence from the ore-mineral assemblage, should permit the construction of a deposit model.

Native tellurium. A unique assemblage was noted during the investigation. In sample 57-76-133 from the 2200 level of the "O" orebody, several tiny (7x15 microns, maximum) oriented laths of exsolved native tellurium were observed in a pentlandite vein which crosscuts a large isolated blotch of monoclinic pyrrhotite. Microprobe analysis showed pure Te (Fe and Ni less than 0.1%). The apparent orientation is [0001] Te parallel to [111] pentlandite. No tellurides have been reported from this Mine. Careful microprobe checks on all local phases showed them to be Te-free. The associated rock is a feldspathic amphibolite (mine term: "norite") in which isolated subspherical blebs of pyrrhotite (to 1 cm) occur in a fine grained matrix composed of abundant zoned plagioclase, primary amphibole, and quartz crystals. It is postulated that this rock is of early origin, was intruded as a crystal mush, and solidified in the pipe, suffering only very minor subsequent remobilization of the pentlandite.

IV. Miscellaneous Investigations

A) Ruttan Lake Mine

The sulphide mineralogy of this deposit has been characterized as major pyrite with subordinate chalcopyrite and sphalerite, and minor amounts of pyrrhotite, galena and arsenopyrite (Grice, 1976). A specimen of massive banded pyrite-sphalerite ore collected from the south-east end of the open pit on the #8 bench was found, however, to have an unusual mineral assemblage. The sphalerite (containing 6.77 wt. % Fe, no Cd) bands contain, in addition to numerous splashes of galena (to 2 mm), both cubanite and valleriite. The cubanite occurs as wormy irregular blebs in the sphalerite, usually selectively rimming/replacing carbonate and phlogopite grains. The larger cubanite blebs frequently have a chalcopyrite core. Valleriite was also found replacing carbonate; microprobe analyses gave Cu 19.12%, Fe 24.86%, Mg 10.94%, Al 2.70%, S 23.63%, OH (calculated) 18.95%, yielding the formula $(Cu_{0.81}Fe_{1.19}S_2)\cdot 1.512(Mg_{0.80}Al_{0.18}Fe_{0.02}(OH_2))$, which is very close to the theoretical formula. A short note on this assemblage by the present author appears in "The Canadian Mineralogist", vol. 15, part 4, 1977 under the title: Valleriite from the Ruttan Mine, Manitoba.

B) **Earthy Pyrite Project**

Specimens of drill core from three graphitic earthy-pyrite deposits in the Flin Flon belt were provided by G.H. Gale in connection with the evaluation of massive sulphide environments (Project NM 7505). These cover the spectrum of deposit types from very fine-grained pyrite (average 2 microns, Big Island, 01/03/76) through banded fine-grained and partly recrystallized pyrite (Pine Bay Mine, Pby 123-329') to fine-grained pyrite cut by pyrite veinlets (Eppa 9-579'). All specimens have a quartz matrix and are cut by graphite and quartz chlorite veinlets. Transmission electron microscope and SEM studies are under way to determine whether a graphite monolayer around the pyrite grains has inhibited metamorphic recrystallization.

Study of the Big Island material indicates that internal (pyrite-pyrite) crystal boundaries within the grains are sharp and clean in all cases but that a thin ($<0.1 \mu$) graphite layer is present around the pyrite grains. Inside this graphite sheath, a continuous layer (some 60Å thick) of 1C-pyrrhotite single-crystal platelets has developed on the surface of the pyrite. The Pine Bay Mine material examined to date shows a number of different textures. The occasional very fine grained portions of the sample closely resemble the Big Island material. More common, however, is what appears to be a "transition zone", in which the graphite sheath around individual pyrite grains thins and becomes discontinuous, permitting 2-8 pyrite grains to join together into composite aggregates. The pyrrhotite skin is absent where pyrite grains adjoin, but remains present around the outside of the pyrite aggregates. Pyrite crystals in the coarse-grained ($>200 \mu$) areas of the specimen have sharp clean boundaries both with the surrounding quartz matrix and with each other; there appears to be neither a pyrrhotite nor a graphite sheath around these grains.

If these preliminary results are substantiated by additional work, they may provide an explanation for the failure of the pyrite in these deposits to recrystallize during metamorphism. The results also suggest that it might prove possible to predict regional metamorphic temperature (i.e. grade) within such a deposit by relating the degree of agglomeration of the pyrite (amount of breakdown of the graphite sheath) to increasing temperature.

C **Pipe Mine**

A specimen of very fine-grained, very weakly magnetic, bronze-pink massive sulphide from the crosscut on the the 2460 level of the Pipe #2 underground workings was examined. The specimen consists largely of hexagonal pyrrhotite (5C structure from x-ray patterns) in a complex mass of equant interlocking 5-15 micron crystals. Monoclinic pyrrhotite laths are extremely rare and are always associated with calcite veinlets. Pentlandite occurs as lacy elongate blebs and highly deformed eyes to 1 mm in size. The pentlandite from this type of ore is said to be considerably different in composition from that of the open pit (W.V. Peredery, pers. comm.). Chalcopyrite, cobaltite and magnetite are present as rare blebs or small subhedral crystals, in the pyrrhotite. The specimen is cut by several thin calcite veinlets and contains numerous tiny euhedral quartz and augite crystals. Microprobe analysis of the suphides gave the following results:

	pentlandite	hex-pyrrhotite	mono-pyrrhotite
Fe	31.25	60.50	60.30
Ni	33.94	0.56	0.38
Co	1.58	n.d.	n.d.
S	33.36	39.03	39.52
	100.13	100.09	100.20

This specimen is atypical in that virtually all of the ore in this mine contains monoclinic, not hexagonal, pyrrhotite, and also in that both the Ni and Co contents of the pentlandite are lower than average.

References

Grice, J., 1976: NM 7510 Ore Mineralogy; *in* Non-Renewable Resource Evaluation Program, First Annual Report 1975/1976, *Man. Min. Res. Div.,* Open File 77/1.

NM 7511 MINERAL ECONOMIC STUDIES

NM 7511-3 COMPUTER MODEL FOR MINING PROJECT EVALUATION – *by R. Bagnall*

Summary

- The model determines the optimum size and life of a potential mining project either by maximizing the internal rate of return of the mining operation, or by increasing investment so long as the marginal rate of return exceeds a pre-determined minimum.
- Sufficient data must be assembled to allow computation of two grade-size functions relating to mineral reserves, and seven cost-size functions relating to capital investment and operating costs.
- By an iterative process using the above functions the computer is able to arrive at the optimum size and life for the project.
- The computer model allows an evaluator to undertake sensitivity and probabilistic analyses on the optimum project.
- The model can be used to undertake other kinds of economic analysis such as comparison of different royalty and income tax policies, or determination of the resource potential needed to support the development of new town sites.

Introduction

This study commenced in March 1976 and was completed in March 1977. A final report describing the model and detailing procedures for its use is in preparation.

A brief description of the model and its use follows. It is a summary of Chapter 1 of the final report.

Purpose of the Model

The model is basically designed to calculate the internal rate of return from a potential mining operation under evaluation. That is, it calculates the annual cash flow for the project and determines the discount rate which will equate cash out-flows and in-flows over the life of the project, as of the beginning of year one. However, the model does not simply calculate the rate of return anticipated for an operation. The size and productive life of the project are adjusted until either (i) the maximum rate of return is achieved, or (ii) the marginal rate of return equals or exceeds a pre-determined minimum rate.

The model in its present form would optimize a project from the point of view of a private investor. Money costs and values would be used throughout. This may be acceptable in a smoothly operating market economy where social and private values roughly coincide; it may also be acceptable where the Government wishes to measure possible private returns to a project; it is not as acceptable where the project may call for Government investment in addition to the private investment considered. In the latter instance, provision should be made for the inclusion of all costs and benefits from a project.

A model of this kind also has potential for use by a Government in the analysis of a number of economic problems relating to the mining industry. For example, it could be used to evaluate the effects of different tax and royalty systems on calculated ore reserves, the rate of extraction, and overall project profitability. Further, it could be used to estimate the level of mining activity needed to support the development of new town sites. These and other possible applications will be discussed in more detail in the final report.

Operation of the Model

Two types of data are required by the program in evaluating a mining project. The first consists of geological data relating to the mineral deposit being evaluated. Sufficient information must be provided to enable the program to calculate two grade-tonnage functions: one function will express the relationship of tonnage to average grade; the other will express the relationship of tonnage to cut-off grade.

The second kind of information which must be provided is of a financial nature. For purposes of calculating income tax and royalty liabilities, five categories of capital costs are used. These are: (i) pre-production exploration costs; (ii) pre-production development costs; (iii) mining investment; (iv) processing investment; and (v) social capital investment. For purposes of calculating annual profits, information is needed on mining costs, processing costs and value per unit of production. As with the geological data, sufficient information must be provided to enable the program to calculate functions of cost against annual capacity. There are five capital costs functions and two operating cost functions.

Once the program has been provided with the above data, the following sequence of operations occurs. Initially, the program calculates the cost-size and mineral grade-size functions; each function will be either linear, log-linear or hyperbolic. In each case the curve that best fits the data is chosen. This is done once for each mineral deposit being evaluated. Then initial values for the size and production life of the project are assigned.

Following this, the program begins an iterative process designed to calculate the optimum size and life of a mining operation for the mineral deposit. The steps in this process are as follows: (1) assign the project a pre-production period (based on the size of the project being evaluated) and a total life (this being the sum of the pre-production period and the productive life being tested); (2) calculate the annual revenue the assumed project could expect from the mineral deposit; (3) calculate working capital, distribute the capital investment over the pre-production period, and calculate the annual gross profit; (4) calculate the total royalty the proposed project could anticipate; (5) calculate the capital taxes and income taxes the project could anticipate; (6) calculate four cash flows, each assuming different tax liabilities; (7) calculate the internal rate of return for each of the cash flows; and (8) compare the internal rate of return for the assumed project to the internal rate of return that would be obtained if either the size or the productive life of the project were different.

Depending on the results of the comparison, the life or size of the project will be increased or decreased by small steps until the maximum IRR is determined. Subsequently, a test can be made to see if an additional increment of investment is able to earn the minimum acceptable return. This test would be repeated so long as each increment of investment would earn the minimum return.

Once the optimum-sized project is determined, a sensitivity analysis and probabilistic analysis can be carried out. Sensitivity analysis involves varying (by 5-20%) up to 11 variables that affect profitability, to note the effect on the anticipated rate of return. Probabilistic analysis involves using Monte Carlo techniques to generate a rate of return distribution. The evaluator will provide estimates of upper and lower values of each of the above 11 variables at the 90% confidence level (assuming normal or split-normal distribution). Samples are taken for each variable and the rate of return calculated. This is done many times (say 1000) to generate the rate of return distribution.