PRELIMINARY REPORT

Exploration Model

MEQB REGIONAL COPPER-NICKEL STUDY

A PRELIMINARY REPORT
OF EXPLORATION MODELS

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REGIONAL COPPER-NICKEL STUDY
MINNESOTA ENVIRONMENTAL QUALITY BOARD

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SUMMARY

INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are: 1) to characterize the region in its pre-copper-nickel development state; 2) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 3) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 4) to conceptualize alternative degrees of regional copper-nickel development; and 5) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering and analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

EXPLORATION MODEL INTRODUCTION

This report gives, in a brief outline form, the type of mineral exploration tools and techniques that are being used or have been used by companies exploring for copper and nickel in the Duluth Complex of northeastern Minnesota. Exploration programs are complex and the types of tools are numerous; therefore, an explanation of how exploration in the study area is conducted and organized is presented to define such a program. This will be done by describing the four stages of exploration and where and when key decisions are made in the program. The types of equipment and techniques used and their ratings as detection methods are also discussed. Surface areas that are disturbed, and the potential for water quality alteration are described. The costs involved in exploration and the variability in cost due to differing programs is also a topic of this report.

EXECUTIVE SUMMARY

This report deals with an idealized exploration program in the Copper-Nickel Study area. The exploration program is divided into four stages: Regional Appraisal, Reconnaissance, Surface Investigation, and Three-Dimensional Physical Sampling. The first stage is simply getting a feel for the area and determining the liklihood of finding a mineable area of mineralization. The second stage is a detailed survey of a large area to determine where mineralization would most likely occur. This investigation is carried out by various geologic exploration techniques such as photography, geologic compilations, geochemical

surveying and geophysical techniques. In the third stage most of the techniques used in stage two are employed again in a detailed investigation of indicated mineralized zones. The fourth and last stage is the most costly and most time consuming as drilling and bulk sampling comprise the majority of the report. The drilling and bulk sampling stages will impact the largest area and have the greatest potential for changes in water quality or any stage in the entire program. Surface disturbance will be spread over a two square mile area, but will total only 40 acres. This disturbed area will include roads, more than 200 drill sites, and bulk sampling.

Costs of exploration are broken down by stage and a range is given to cover differing conditions encountered in locating mineralized zones.

The first model costed out and detailed is a near surface mineralized zone, depicting an open pit mine potential. The second model is for a mineralized zone at depths greater than 1,000 feet, an underground mine application. Each model analysis results in cost, manpower, time, disturbed area, and the total area over which exploration takes place. The following table summarizes the facts from these two models.

EXPLORATION MODEL DATA EXAMPLES

Exploration Model	Exploration Stage	Cost, 1977 $s	Stage Duration, Years	Manpower Requirements No.	Area Disturbed, Acres
Open Pit Mine	1	21,000	1	5 part time	--
	2	100,000	1	10 part time	--
	3	66,000	1	15 part time	--
	4	3,700,000	2	20	40
	Total	3,887,000	5		40
Underground Mine	1	21,000	1	5 part time	--
	2	100,000	1	10 part time	--
	3	80,000	1	20 part time	--
	4	11,300,000	2	40	40
	Total	11,501,000	5		40

DEFINITION AND PURPOSE OF MINERAL EXPLORATION

Mineral exploration as it is applied to the mining industry includes all the activities and evaluations necessary to locate and define new mineral deposits that can become economic operations today, or in the foreseeable future.

The exploration program is designed to define the following parameters of a potentially mineable area:

1) Geographic location
2) Physical shape, attitude, and size
3) Estimated tons of ore
4) Depth to ore zone
5) Grade of ore body
6) Rock characteristics (type, competency, etc.)
7) Variations in grade within mineralized area
8) Mineralization type (stratiform, disseminated, replacement)
9) Ore minerals (oxide, sulfide, etc.)
10) Distribution of groundwater

After a deposit has been discovered, drilling is initiated to further determine the following parameters:

1) Geology of mineralized zone
2) Quantitative data on grade and tons
3) Mineralogical and metallurgical characteristics of the ore
4) Physical characteristics of the ore
5) Data on other factors that could affect mining operations such as ground conditions, groundwater, etc.

The end of exploration and the beginning of development can be defined according to the United States Internal Revenue Code (Secs. 1.615.1 and 1.616.1), as when "deposits of ore or other minerals are shown to exist in sufficient quantity to reasonably justify commercial exploitation by the taxpayers." This does not mean that exploration is stopped at that point, but that subsequent exploration costs are considered development costs.

Development is the transition period between exploration and production, the first half of development being closely related to exploration, and the last half to production and actual operation of a mine.

THE EXPLORATION PROGRAM

Exploration for minerals is set up as a four-stage program consisting of:

Stage 1 - Regional appraisal

Stage 2 - Detailed reconnaissance of favorable area

Stage 3 - Detailed surface appraisal of target area

Stage 4 - Detailed three-dimensional sampling and preliminary evaluation

DEFINITION AND PROCEDURE OF AN EXPLORATION PROGRAM

Stage #1

Regional appraisal - This first stage consists of collecting geologic maps of the area, aerial photos, structural maps, along with some field investigation. The field investigation consists of flying over the area and, if accessible by road, driving through. This is done to determine accessibility of the area, favorability of the geology, topography, and to provide an exploration geologist's first-hand appraisal of the area.

Stage #2

Detailed field reconnaissance of favorable area - If stage 1 indicates a favorable area, it is followed by stage 2 which consists of locating outcrops from photos and then (if any are found) sampling and mapping these outcrops by surface investigation. Planes are used in completing aerial surveys such as magnetics, gravity, and radiation. If anomalies are indicated by these air born investigations, geophysical and geochemical tests at ground level are used to better define the anomalous conditions.

The aerial surveys are flown on the standard half mile grid. A 1,000-foot grid is used to conduct the geochemical and geophysical tests. The aerial survey does not furnish positive proof that an anomaly is present, therefore, ground tests are needed to furnish additional indications that anomalies exist. At this time, there is no need for detailed examinations of the located anomalies. This will follow during the next stage.

Stage #3

The detailed surface appraisal of target area.- Stage 2 has been used to indicate anomalous conditions in an area. In stage 3, these conditions are investigated by detailed geochemical and geophysical testing. The goal of this testing is to outline the anomalies that have been found. In most cases, the same type of geochemical and geophysical tests used in stage 2 are used again with additional testing methods. One such method is induced polarization. The geochemical tests would be extended to look at minerals other than copper-nickel which may be as good or better indicators of mineralization. These tests will be carried out on closer grids than the 1,000-foot grid of stage 2. A spacing of 400-500 feet, the same as AMAX and INCO used, is based on the size of the anomaly and type of information desired from the testing. The data from all the tests would hopefully show that an anomaly exists, its extent, and, from some of the tests, if copper-nickel mineralization is the reason for the anomalies.

Stage #4

Detailed three-dimensional sampling and preliminary evaluation - The final and most expensive stage is not started unless there is every indication from preliminary stages that an economic ore body does exist. Drilling is used to prove out the existence of an ore body and also to give needed geologic information that will be used in planning a mining operation. These details include shape, size, grade, depth, mineralization, etc. of the prospective mineralized area.

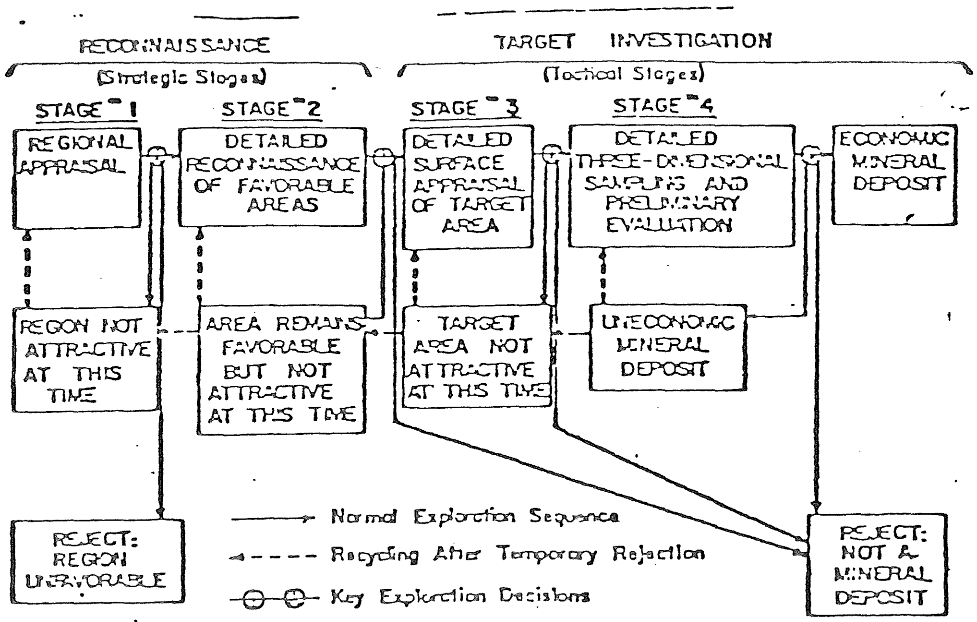
As each hole is drilled, more information is gathered, and at some point, a potentially economic ore body is said to exist (or not to exist). If an economic ore deposit does exist, a feasibility study is started and the exploration program is then required to gather information predicting the magnitude and economics of an operation, as well as factors controlling decisions in mining and processing.

Other considerations investigated are water, topography for site selection of roads, plants, tailing ponds, and water storage areas. Bulk samples are taken at this point and pilot plant testwork used to make preliminary processing evaluations.

THE EXPLORATION SEQUENCE

When evaluations are being made at key decision points (see Figure 1), profit-margin estimates are also made. During all stages, there is frequent re-evaluation of the profit-margin calculation as new geologic information becomes available.

Figure 1. Exploration Sequence



As the exploration proceeds from the first stage to the fourth, decisions to go on or to stop are made at the key points shown in Figure 1. The area that is being investigated is also being reduced in size and is increasing in favorability as progress is made. If at the end of the first stage the region is not attractive for reasons such as unfavorable geology, taxes, political or internal economics, there are two options the company can follow. First, if the geology is unfavorable, the area is completely rejected. Secondly, if taxes, politics, etc. are the reasons for rejection and the company feels the geology indicates the area has a possibility of having favorable mineralization, then the project would be put in a hold situation. The region would not be attractive at this time but changes in the economic or political situation could renew company interest.

After the second stage has been completed, the decision to go ahead, reject, or put a hold on the project is again made. Total rejection would occur if no indication of mineralization is found. The hold or favorable but not attractive at this time decision could be made if mineralization or anomalies are indicated, but not of the grade or size the company deems necessary to continue exploration. The go ahead decision leeds to stage three.

When stage three has been reached and completed, the three options are available again. The property would be rejected if, under closer scrutiny, the anomalis conditions indicated in stage 2 proved not to be due to economic minerals. The geophysical and geochemical tests may have indicated mineralization but not enough to go ahead to stage 4. Still, sufficient mineralization might be found to keep interest up and the option of saying the target area is not attractive at this time would be used.

At stage 4, land position plays a major role in whether or not a company will go ahead with more exploration. If a company cannot obtain control (via leases or direct ownership) of the area that they are exploring, they will not go into the three-dimensional exploration stage. If in the future the area becomes available, the project would go from unattractive to stage 4, and drilling would commence.

It should be pointed out that the decision to continue is also made at times other than those shown in Figure 1. This is particularly true in the drilling stage. A number of holes are drilled, and the resulting information used to determine how much more drilling will be needed. This continues until an economic mineral deposit is identified or, if drilling shows no mineralization, the area is rejected. If mineralization is found but determined uneconomical at the time, the area is put on hold. In some cases, this is because of grade, recovery, or other processing problems as determined by laboratory testworks. Also, the size of the deposit could be a problem, both too small or too large. If the deposit is too small for one company, a smaller company may be encouraged to take over the property. In the case of a deposit being too large, a larger company could take over or two companies could pool capital and technology to start up and operate a joint venture.

Increases in the value of minerals can make low grade deposits economical. Also, new technology in mining and processing can improve recovery and/or reduce costs, resulting in an economic mineral deposit.

In order to take a more detailed look at the exploration, this report will discuss, stage by stage, five ventures that have been investigated and reported in the SME Handbook (Figure 2). By looking at the different ventures, one can see what makes up an exploration stage as described above, and which parts of an exploration program are

Figure 2. Example of five exploration ventures.[a]

Exploration Stages	Venture #1	Venture #2	Venture #3	Venture #4	Venture #5
	Search for a New Porphyry Copper Ore Deposit in Southwest U.S.A.	Search for Blind Stratiform Lead-Zinc Deposit in Carbonate Formations	Search for Massive Sulfide Deposit with Base-Precious Metal Values in Canadian Precambrian Shield	Search for a New Iron Deposit in Precambrian Shield	Search for a New Placer Gold-Tin Depo in Alaska
Regional Appraisal (Stage #1)	O—Geologic Compilation* O—Photogeologic study (rock units and structure) O—Structural analysis* F—Field inspection of area selected from air and/or on ground*	O—Geologic Compilation* O—Paleogeologic and Paleogeographic reconstitutions	O—Geologic Compilation* O—Photogeologic study (rock units, contacts and structures)	O—Geologic Compilation*	O—Geologic Compilatior O—Photogeologic study (geomorphology)
Detailed Recon-naissance (Stage #2)	F—Reconnaissance geologic mapping of outcrops* F—Stream Sediment geochemical surveys F—Aeromagnetic survey F—Gravity survey in gravel-covered areas F—Reconnaissance Induced Polarization survey of covered areas	F—Reconnaissance drilling for stratigraphic and facies data* O—Photogeologic study F—Stream Sediment geochemical surveys F—Mercury Sniffer Surveys	F—Airborne Electromagnetic Survey* (with or without aeromagnetic) F—Stream-Sediment geochemical survey F—Field inspection of anomalous areas	F—Aeromagnetic Survey* F—Photogeology (formation, structure) F—Reconnaissance (formational mapping)*	F—Reconnaissance pann F—Reconnaissance drill and sampling (phy separation of heavy minerals)
Detailed Surface Investiga-tion of Target Area (Stage #3)	F—Detailed Geologic* structural-alteration mapping of outcrops L—Petrographic-mineralogy-trace element study of rock samples. F—Detailed Induced Polarization Survey of anomalous covered areas		F—Mapping of outcrops if any* F—Detailed helicopter-borne or ground electromagnetic (and magnetic) survey*; or detailed Induced Polarization Survey. F—Detailed stream sediment and/or soil geochemical survey	F—Detailed mapping* F—Detailed ground magnetic surveys*	F—Detailed magnetic su
Detailed Three-Dimensional Physical Sampling of Target Area (Stage #4)	F—Drilling*-Logging* L—Mineralogical, Chemical analyses and physical tests on samples, cores and cuttings* F—Down-hole geophysical surveys L—Amenability tests on ore-grade mineralization O—Reserves computations* O—Preliminary Valuation* F—Investigation of water problems and water availability for plants* F—Investigation of suitability of ground for plant, tailings, dump and town sites F—Shaft sinking or tunneling to obtain bulk samples L—Ore dressing bulk tests	Same as for Venture #1	Same as for Venture #1	Same as for Venture #1	Same as for Venture #1 excluding down-hole geophysics and tunneli

Legend: O = office study; F = Field investigation; L = Laboratory tests
* = activity or method which is indispensable

[a]After Bailly, Surface Mining, Pfleider, E.P., ed., AIME, New York, 1968.

indispensable. One can also see where each of these studies and investigations are conducted.

From the descriptions of these deposits (Figure 2), one can see that each is unique. However, there are a number of studies, tests, and investigations that are common to all. These will be explained in the following discussion of geologic exploration techniques.

GEOLOGIC EXPLORATION TECHNIQUES

The exploration geologist has at his disposal hundreds of exploration techniques none of which individually will give the geologist a complete picture of an area. Each technique gives a partial picture so, with enough tests, good interpretation,(and some luck), a geologist will be able to accurately interpret the geology of the mineralized zone.

Photography

There is a wide choice of aerial photographic techniques from planes and satellites with a variety of interpretive approaches available for the exploration geologist's use. The techniques include color, black and white and infrared photos used for detailed geologic mapping. These photos can be taken with foliage on and off. By using this approach, it is hoped geology that could not be detected by one method alone could be inferred from the type of vegetation or lack of vegetation. These geologic features, once mapped, would be looked at more closely in ground surveys.

Geologic Compilation

The Federal and State geological surveys collect information on all regions in the United States. In Minnesota this information is made available through the U.S. Geological Survey, U.S. Bureau of Mines, Minnesota Geological Survey, Minnesota Department of Natural Resources, and other state agencies. This information consists of structural trends (faulting, folding, and lineaments), local geologic column and lithologic descriptions of sedimentary units, and metamorphic basement rocks and igneous rocks including intrusives and volcanics. Geologic history is gathered for reference to periods of sedimentary deposition and structural origin.

All of this information is used in conjunction with other data to set up the initial geophysical and geochemical tests and testing frequency.

Geochemical Surveying

A geochemical survey consists of systematic collection and chemical analysis of samples. This type of sampling can be used to detect a wide variety of naturally occurring elements, but in most exploration work, it is used to detect traces of the ore metals. The tested samples can be of rock, soil, stream sediment, surface or groundwater, vegetation, and air.

Geochemical testing is a good method of exploration: 1) when outcrops are scarce because of forest cover or glacial overburden; 2) in looking for low-grade deposits where the ore minerals are not obvious and have not been recognized; 3) in detailed surveying of areas containing mineralized zones, for the purpose of finding additional high-grade deposits hidden by forest cover, vegetation, soil or glacial till; and 4) as a method of checking geophysical anomalies. Geochemical anomalies originating at depth are called primary anomalies while those originating on the surface are called secondary anomalies.

Geophysical Techniques

As applied to mineral exploration, the electrical, gravitational, magnetic, compositional, mechanical, and thermal properties of the earth are measured by geophysical techniques. The methods of collecting geophysical data such as electrical resistivity, induced polarization, magnetic susceptibility, gamma radiation, density, seismic velocity, and electrical conductivity are complex and highly-skilled people are required to properly interpret the data. The following are brief definitions of geophysical methods.

Magnetic Methods

These geophysical prospecting methods map variations in the magnetic field of the earth which are attributable to changes of structure or magnetic susceptibility in certain near-surface rocks. Sedimentary rocks generally have a very small susceptibility compared with igneous or metamorphic rocks and most magnetic surveys are designed to map structure on or within the basement rocks, or to detect magnetic minerals directly.

Gravitational Method

This geophysical prospecting method measures irregularities or anomalies in the gravitational attraction produced by differences in the densities of rock formations, and interprets the results in terms of lithology and structure. This method is unable to detect small changes in gravitational intensity, and therefore, is not used in the direct searching for ore deposits. The measurements of gravity are accomplished, generally, by one of three methods: dropped ball, pendulum, or spring gravimeter. The latter mathod, based on variations in the length of a weighted spring which are a function of the gravitational field at different locations, is the most widely used method today.

Electromagnetic Methods

This geophysical method employs electromagnetic waves, which penetrate the earth and impinge on a conducting formation or an ore body. The waves induce currents in the conductors which become the sources of new waves, which are detected by instruments at the surface. An alternating electromagnetic field of suitable frequency is created in the area to be explored. Transmitted by the aircraft, this field is received by the conducting body in the earth and re-radiated with some change in phase. The resultant field is picked up by a detector towed behind the aircraft and compared with the transmitted field. The phase shift is measured automatically and recorded as a profile during flight. This method can be employed in aerial geophysical prospecting for the direct detection of conducting ores, such as the sulfides of copper, zinc, nickel and lead.

Electrical Prospecting

This prospecting method makes use of three fundamental properties of rocks. One is the resistivity or inverse conductivity which governs the amount of current that passes through the rock when a specified potential difference is applied. This method is used to determine lateral or vertical variations in conductivity within the earth and is frequently used to measure depth to bedrock in connection with civil engineering projects, since there is normally a large contrast in conductivity between unconsolidated overburden material and the hard rock below. Another rock property is the electrochemical activity with respect to electrolytes in the ground which is the basis of the self-potential method. The third is the dielectric constant which indicates the capacity of a rock material to store electric charge, and is used indictive prospecting techniques. In this method an electric current is introduced into the ground by means of induction and the magnetic field that is associated with the current is measured. Electrical methods are more frequently used in searching for metals and minerals than in exploring for petroleum, mainly because most of them have proven effective only for shallow explorations.

DRILLING

Definition and Purpose

This is the operation of drilling deep holes for prospecting, exploration, or valuation. Two general methods of drilling are common: (1) percussion systems which consist of breaking up the ground by means of a sharp-point instrument of a particular form, which is made to strike the ground in a series of blows; and (2) rotary systems which aim at the extraction of a core or permit all the disintegrated material to be washed away.

Drilling is directed toward finding the grade, volume, and a three-dimensional outline of a mineralized zone that has been generally located by detailed surface investigations. Information provided by such a program consists of:

1) Geologic framework of the deposit
2) Variations in grade
3) Distribution and mineralogy of the economic minerals, also samples for laboratory metallurgical testwork
4) Shape of the ore zone
5) Physical properties of the ore and waste
6) Occurrence of mineralization and its dependence on structure, weathering cycles, rock types, alteration, etc.
7) Distribution of groundwater

Gathering this information can be divided into three drilling stages:

1) Information drilling
2) Outline drilling
3) Sampling drilling

1) Information drilling is done to verify the working hypothesis of an existing ore deposit that has been developed from indirect exploration methods. 2) Determining the size, location, dip, and other characteristics of the deposit is the main goal of the outline drilling. 3) Sample drilling more accurately determines the qualitative and quantitative parameters of the deposit so that reasonably reliable economic appraisals can be made.

Exploration information gathered before the drilling begins is used to determine which of the numerous drilling methods and techniques should be used to provide the best data on which to make the required decisions concerning the economics of an ore deposit. The cost involved in a drilling program and the accuracy of the information gathered, depends on the type of drilling and the geology.

Drilling Frequency and Grid

The grid, frequency, and diameter of holes drilled determine a drilling program's accuracy and whether the holes accurately represent the areas assigned them. The cost of the drilling program is also determined by the type of drilling and the frequency. In order to insure that maximum information is gained with the minimum number of holes drilled, computers with programs developed by exploration companies are used to set up the grids and determine the frequency of drilling. These programs take into account geophysical information and, as drilling is started, the program will include drilling information which will determine the additional number of holes needed to insure the sample recovered is representative of the geology. The use of the computer is another way the exploration geologist has of bringing together information and eliminating the guesswork. In the area under consideration as few as 150 holes might be drilled to define an ore body mineable by open pit methods, or there could be in excess of 300 holes drilled for an underground mine. Figure 3 shows a typical drilling grid on a property that would be mineable by open pit methods. The finished grid has a 350 to 400 foot spacing.

TYPICAL EXPLORATION DRILLING GRID

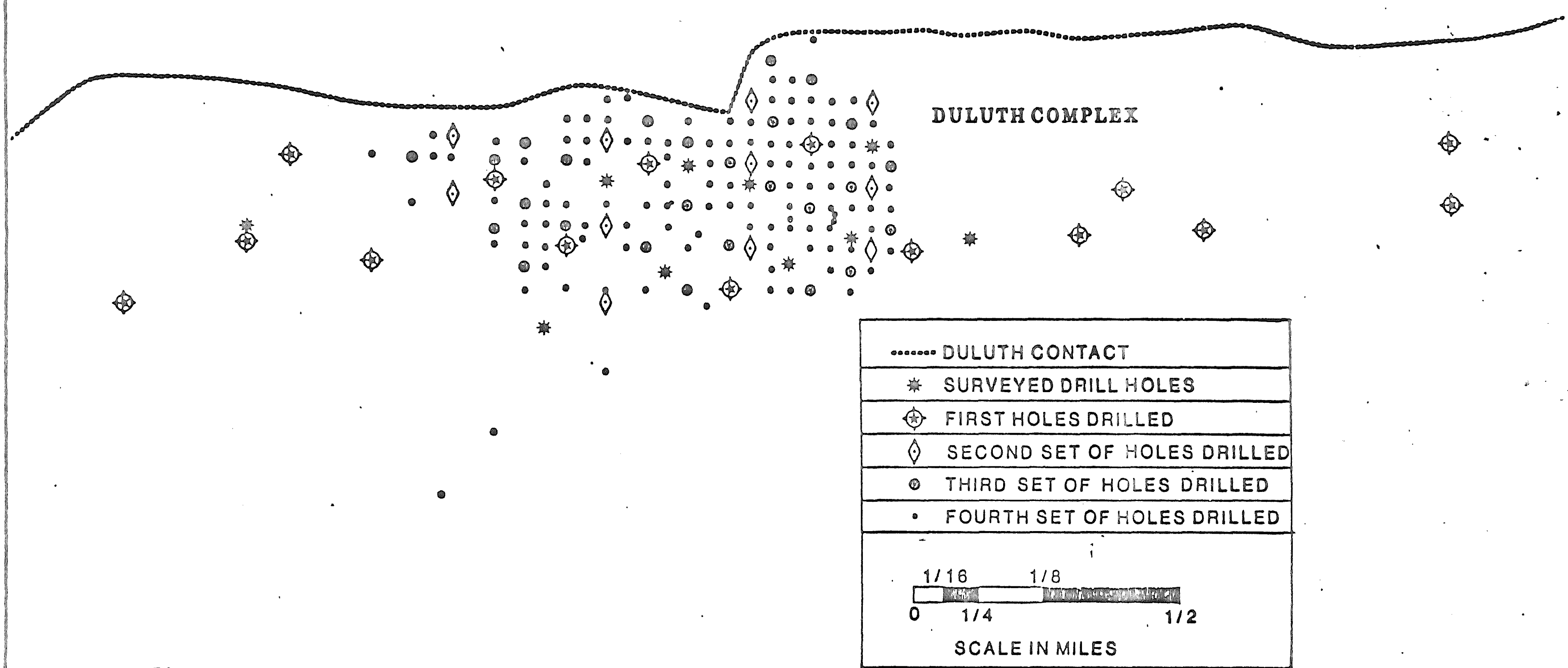


Figure 3

Drilling Types and Definitions

There are a number of drilling systems. A short definition plus the advantages and disadvantages of each major system is listed below.

Diamond Drilling

This method involves a rotary-type drilling machine using equipment and tools designed to recover rock samples in the form of cylindrical cores from rocks penetrated by boreholes. This is done by using a diamond-inset annular bit as the cutting tool. This tubular bit and attached core barrel are rotated under controlled pressure by means of hollow steel, flush-jointed rods, through which water is pumped to cool the bit and remove rock cuttings. With the advance of the bit, a cylindrical core of rock passes up into the core barrel, where it is held by a core lifter or other device for periodic removal.

This type of drilling has the distinct advantage of producing a core that can be brought to the surface for study. In competent rock, core recovery approaches 100 percent and will show thickness of rock units, rock fractures, competence, and mineralization. Additionally, the core results in a sample for metallurgical testwork to evaluate processing techniques. The cost of diamond drilling is high (approximately $~~20~~ 12/foot), and if a core is not required, other less expensive methods can be used to produce drill cuttings for sampling.

In poorly consolidated or highly fractured material, core recovery can be low and what is recovered can provide a poor indication of what type of material is being drilled.

The holes are not always drilled vertically, by design or due to deviations caused by variations in structure. Long drill holes must be surveyed to determine the exact vertical and horizontal coordinates and location of samples.

Percussion Drilling

This drilling procedure incorporates a reciprocating hammer striking a rotating bit or a long column of rotating drill steel that has a cutting bit on the lower end. When the reciprocating hammer is used at the bottom of the hole, the term "down the hole hammer drill" is used. This method produces chips of rock which are collected, sampled, and tested to give information over the interval that has been drilled. The main disadvantage of this method is that there is no core for geological study. Advantages are cost savings of ($1 to $2 per foot), and faster drilling rate. There is also little or no deviation from vertical of the drilled hole. This eliminates the need for surveying the hole.

Rotary Drilling

This drilling method consists of rotating a column of drill pipe, to the bottom of which is attached a drilling bit, and, during the operation, circulating down through the pipe a current of mud-laden fluid, under pressure, by means of special slush pumps. The drilling mud and cuttings from the bit are forced upward and outside the drill pipe to the surface. With both the rotary and percussion, care has to be taken to ensure that all the cuttings have been brought to the surface from each drilling interval so they do not contaminate the sample collected in the next drilling interval.

After a deposit has been explored and confirmed by three-dimensional drilling development drilling is conducted to determine in more detail:

1) Geology of the mineralized zone
2) Quantitative data on grade and tonnage at different cut-off grades
3) Physical size and shape of the ore zone
4) Mineralogical and metallurgical characteristics of the ore
5) Physical characteristics of the ore
6) Data on factors that could affect mining operations, such as groundwater, ground conditions, etc.

BULK SAMPLING

Definition and Purpose

Bulk sampling, as the name implies, is the collecting of a large sample for bench-scale testing or pilot plant study. Collection of this sample is done in a pit, trench, shaft, or tunnel depending on the location of the mineralization.

The high cost of underground work precludes shaft and tunnel methods of sampling if other procedures can be used. Pits and trenches produce satisfactory information in areas where there is little overburden and the ore zone is a near-surface feature.

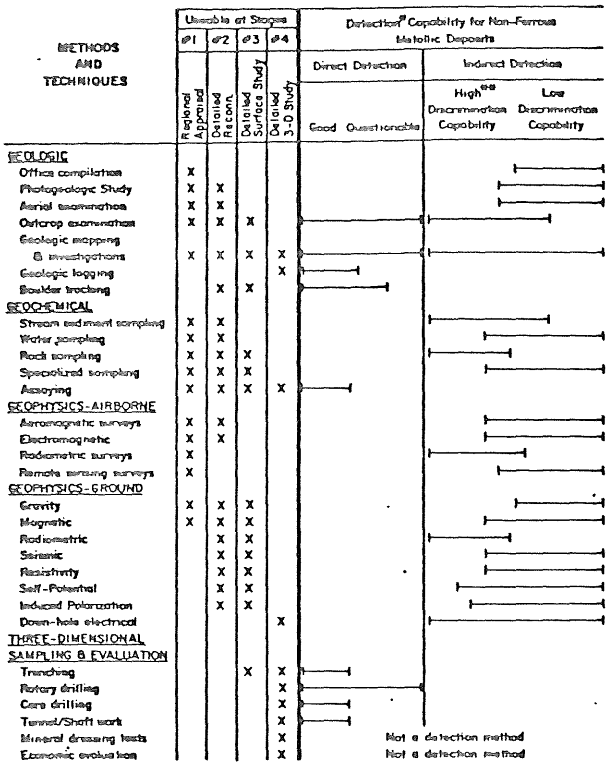
The bulk sample is taken to provide adequate material for metallurgical analysis and for verification of drill hole sample test work. This information will enable mill and smelter design to proceed in a reliable manner.

The size of the sample can vary from a few hundred pounds to thousands of tons, depending on the work that will be done on the sample. In the Copper-Nickel Study area, the companies have developed four sample sites; two at INCO, one at U.S. Steel's holdings and one at the AMAX site. To show how sample size can vary, at AMAX the company took 20,000 tons for concentration and smelting tests. The M.R.R.C. received 1,000 tons and the Bureau of Mines 300 tons. The U.S. Steel bulk sample was only 300 tons and INCO's samples were 10,000 tons from each of their two areas.

PILOT PLANT

Definition and Purpose

Laboratory bench-scale beneficiation testwork must be considered directional at best. To establish operating parameters and a reasonably accurate prediction of the concentration flowsheet, continuous pilot plant testwork is necessary. Properly conducted pilot plant testwork will result in reasonable estimates of operating parameters. Information is gathered using one of two forms of pilot plant tests; one being the fully integrated, and the other the non-integrated plant. The fully integrated pilot plant is a scaled-down model of a commercially sized beneficiation plant where water and intermediate products would be recycled and the process would be continuous. In the non-integrated plant, the tests are basically large batch tests and are not continuous. The advantages of a fully



* Detection refers to the ability to detect a deposit if it is there. Indirect detection refers to a geological, chemical or physical response showing a deposit may be the cause of the response; this is in opposition to direct evidence of the presence of a deposit.

** Discrimination with regard to indirect methods refers to the ability to determine if a certain response (anomaly) is due to a deposit or to another cause.

—Main exploration methods and techniques (scientific aids) (*after* B[illegible]. *Public Land Law Conf., Univ. of Idaho, 1966*).

Figure 4

integrated plant over the non-integrated plant can be summarized as follows:

1) Observe the behavior of various types of ore on a large scale (a few hundred tons) and on a continuous basis.

2) Establish the weight recovery and chemical and physical qualities of all products.

3) Determine the effect of local water and recirculated water on processing systems.

4) Develop more definite engineering criteria for equipment sizing in the commercial plant design.

5) Assess the possibility and desirability of developing instrumentation and automatic controls in continuous operations.

6) Evaluate waste-product disposal, including air emissions, stream discharges and waste storage.

7) Collect operating data such as power required for grinding, steel consumption in grinding mills, reagent requirements; and develop information on possible trouble spots associated with excessive wear of equipment in continuous operations.

With the last of the information obtained from the bulk sampling, plans will be finalized for mine, mill, and smelter. Even at this point, exploration is not over. During the life of the operation, there is continuous exploration to ensure that all of the ore is found and defined. This drilling also assists in grade control planning for mining operations, to assure consistent feed to the milling operation.

Exploration Program Summary

Figure 4 is presented to summarize the utility of the methods and techniques used in different stages of exploration. Included is the detection capability, indicating the relative value a method has as an exploration tool. For example, under geologic methods, outcrop examination is relied on in the regional appraisal, detailed reconnaissance and in the detailed surface study. This method has a good to questionable direct detection capability, depending on the number of outcroppings and the number that show mineralization. For indirect detection, again depending on the number and type of outcrops even if no mineralization is found, the method has the ability to determine if the area is capable of being mineralized. However, with fewer and fewer outcrops the detection capability is lowered.

WATER PROBLEMS

Exploration drilling, geophysical testing, and stream level measurements often result in good indications of groundwater levels (hydrologic studies by other Copper-Nickel staff will report on both levels and quality). Smelter, processing, and mining reports will indicate the quantity of water that will be required and the quality and quantity of water that will be discharged.

Drilling Water

Water is pumped down the center of the drill steel to flush cuttings and fines to the surface and also to cooling the drill bit. After the water flows out of the top of the drill hole with the suspended solids, it is trenched to two small pits. The first pit is used for settling out the solids. These solids can be composed of oil, grease, drill cuttings and/or drilling muds. The drilling pits and water quality associated with these will be addressed in the natural sciences section of the copper-nickel study reports.

The overflow from the first pit goes into the second, or holding pit, from which it is pumped back down the drill hole. With this system, there is typically no discharge to surface waters; however, losses do occur as seepage in the hole and in the ponds.

Conate Water

There is some indication that water would be encountered at depth. The origin of this water has not been determined at this time, but it will be referred to as conate water in this text.

At the AMAX site, conate water was encountered in one hole being drilled with a down the hole hammer drill, at a depth of about 1,400 feet. Normally when water is encountered with this drilling system, it is simply blown to the surface by the compressed air used to operate the hammer and clear the hole of drill cuttings. If the flow of conate water into the hole is great enough, the result is similar to a geyser. If the flow of water is in excess of the lifting capacity of the compressed air, the drill cannot function; then a different type of drill must be brought in. This not only poses problems to the driller, but the water encountered and discharged could be harmful to the environment depending on its quality. The water in the AMAX hole, for example, contained chlorides 1,000 times higher than normal groundwater. The hardness and conductivity were also high.

The total quantity of water brought to the surface from this hole was estimated to be 300,000 gallons.

The fact that one hole drilled into the Duluth Complex encountered water of the quality and quantity mentioned above may seem insignificant when considering the total number of dry holes drilled. However, the majority of these holes were drilled with diamond drills, and this type of drilling does not indicate the presence of water. In another situation a contractor did report water similar to that mentioned above while hammer drilling in the Gunflint Trail area of the Duluth Complex.

Conate water was also reported by Duval in an area southeast of the Dunka Pit. The drilling was also done with a down the hole hammer drill. The extent of conate water has not been fully evaluated at this time and no judgment has been made as to the extent of the problem. If conate water is encountered only once during the life of a mining operation, then the resulting problem would be far less than say 8 to 10 such encounters per year. There is a need to know this both from the environmental and economic viewpoint, because if water treatment is necessary prior to discharge, costs would be high.

There are several approaches that can be used to treat drill water. For example, the chlorides can be removed by reverse osmosis, but this is costly. An inexpensive approach is to dilute drill water ~~as an example~~, if dilution was used to treat the AMAX water mentioned previously, there would have had to be a mixing of one part drill water to 1,000 parts of clean water to achieve the chloride level measured for groundwater in the area. This means that for each 300,000 gallons of drill water there would have to be available a flow of 155 cubic feet per second for 3 days to obtain desired dilution.

Bulk Sample Sites

Bulk sample sites have the potential of contaminating water in a number of ways. Surface bulk sample sites result in pits that can fill with water. Depending on the surrounding rock types and water conditions, the resulting water may have high concentrations of dissolved metal. This contaminated water could be flushed out by inflowing surface water, or it could seep through the ground into the groundwater systems, or eventually appear as base flow into streams. One such pit at the U.S. Steel bulk sample site has filled with runoff and seepage water. This water was analyzed and Table 1 lists the results.

Table I

Parameters	Levels
pH	5.90
Alkalinity (mg/ℓ as $CaCO_3$)	~1
Specific conductance (μmhos/m)	349
Dissolved oxygen	8.0
Temperature (°C)	24
Silica	13.9
Chloride	1.23
Sulfate	240
Dissolved organic carbon	ND
Dissolved inorganic carbon	ND
Copper, total (mg/ℓ)	2.42
Copper, filtered (mg/ℓ)	2.45
Nickel, total (mg/ℓ)	6.70
Nickel, filtered (mg/ℓ)	6.70
Iron, total (mg/ℓ)	.038
Iron, filtered (mg/ℓ)	.011
Calcium (mg/ℓ)	17.0

The low alkalinity level indicates the lack of buffering capacity of this water which means the pH can change rapidly. If the pH was lowered, the toxicity due to the contained metals would, in most cases, increase.

If a shaft is used to obtain a bulk sample, water would be encountered and pumped to the surface and then discharged or held in a pond. If held in a pond, the water could filter out by building the pond with a permeable base. This filtration should help in removing metals, oils, greases, and chemical residues from explosives. However, chlorides would not be removed by this type of filtration. The only way of removing these ions is by desalinization, which is done by either evaporation or reverse osmosis. A third choice is dilution. With the quality (1000 mg/l of Cl) of the water that was produced at AMAX's test shaft, a dilution of 100 parts chloride-free water per one part shaft water would be needed to reduce the chloride level to the same as the stream water in the study area (about 10 mg/L). At this time, there is no chloride removal program for water that is being removed from the shaft. If the amount of water being removed is between 7 and 20 gallons per minute and the amount of clean water (less than 10 mg/L chlorides) necessary for dilution to 10 mg/L would be 1.5 ft^3/sec to 4.5 ft^3/sec, or, 700 gpm to 2,000 gpm.

Rock containing copper-nickel mineralization brought to the surface and left exposed to the elements will oxidize. If rain is allowed to fall on these piles, some leaching will occur resulting in elevated metal ion values. If this water is allowed to flow into the groundwater system or to streams and lakes, their quality could be changed.

Pilot Plants

In order for a pilot plant to be built at any site, a number of permits have to be obtained from agencies such as the MPCA, MDNR, EQB, and local or county agencies. The increased time and cost necessary to go through this procedure may make it more economical to ship the test ore to an existing pilot plant, either a contract facility or the company's own pilot plant. A company's potential desire for confidentiality of the information gained from the testing can also be met by either of these alternatives. With the above mentioned reasons in mind, no prediction of water demands or quality are made with the assumption that the probability of a pilot plant operation being located in the study area is low, unless there is extensive development.

SURFACE DISTURBANCES

Geochemical and Geophysical

The first stage in the exploration program that has an effect on the surface is the geochemical or surface geophysical work done to locate a target area. This is done on a large grid, the size of which is best explained by taking a statement about geochemical sampling from the SME Mining Engineering Handbook, 1973:

> Soil surveying commonly involves the collecting of samples usually not more than 100g-at depths rarely greater than a few inches. Samples normally are collected at fixed intervals either along straight traverse lines or along topographic or cultural features, such as ridge tops or roads. The spacing of samples should be only close enough to permit two samples to fall within the anomalous feature being sought.

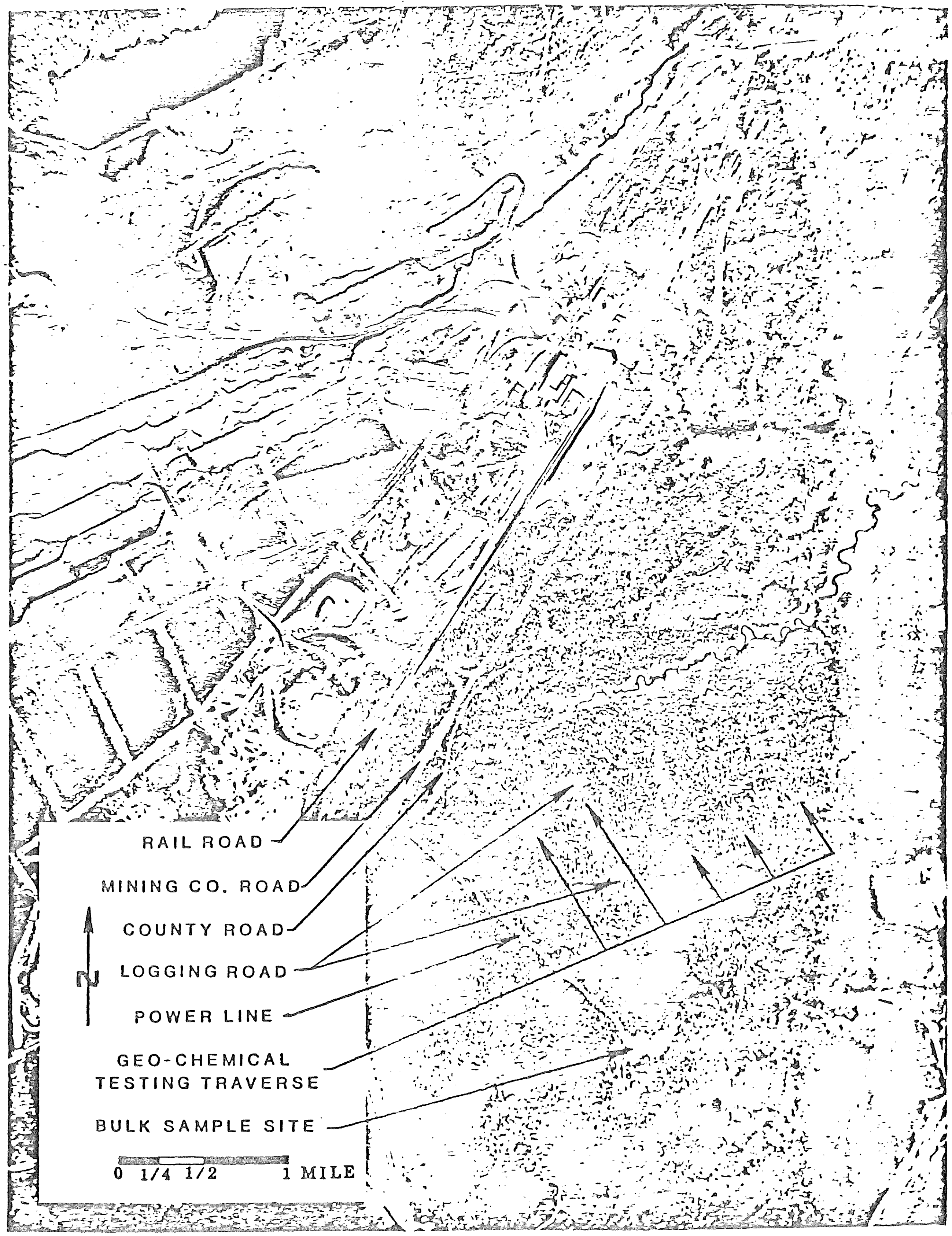
If the desired target is an ore body 6,000 feet long and 3,000 feet wide, the grid would only have to be 1,500 feet by 1,500 feet.

The basis for the 6,000 by 3,000 foot target comes from the geologic information obtained in the first stage of the exploration program; in this case the target area is a disseminated low grade (less than 1 percent) combined copper-nickel resource. With present technology, the quantity of ore that would supply a plant for 20 years at a rate of 10 million metric tons of ore per year would come from an open pit mine with a surface area of 6,000 by 3,000 feet. The 1,500 foot by 1,500 foot grid would be used to locate a target area where detailed geochemical exploration is performed. A common number of samples taken in detailed exploration would be 500 per square mile. This would mean (using a square grid) a spacing of 250 feet between samples.

The procedure for this testing is to clear a four-foot wide traverse on parallel lines in the east-west or north-south direction. Along these lines, sample sites will be located at 250 foot intervals. These grid lines can also be used to do geophysical testing and, in most cases, this grid would also be used for the drilling pattern. There would probably be no need to cut more lines. To put these lines in perspective, Figure 4 is an air photo of such a grid. Also noted is a railroad, mining company road, county road, logging road, power line, and bulk sample site.

Drilling

Drilling exploration holes would follow a successful geochemical and geophysical program. Because of the high cost of drilling, not all the holes shown in the typical drilling grid for a near surface deposit would be drilled at any one time (Figure 5). A number of holes are drilled and the data analyzed. Then more holes are drilled, and this additional data is analyzed. Again, another set of holes is drilled and each time data is gathered it it used to redefine the configuration of the mineralized zone, and also to determine if and where more drilling should be done.



RAIL ROAD
MINING CO. ROAD
COUNTY ROAD
LOGGING ROAD
POWER LINE
GEO-CHEMICAL TESTING TRAVERSE
BULK SAMPLE SITE
N
0 1/4 1/2 1 MILE

Figure 5

As the program progresses, the accuracy of all parameters increases until the company is satisfied that the ore body is sufficiently detailed.

When drilling is being done on a near surface target that could be mined by open pit methods, the average depth drilled would be between 750 and 1,000 feet. For deeper subsurface targets that could be mined by underground methods, an average drilling depth of 2,000 feet would be realistic.

In order to make a three-dimensional physical sampling of a target area, between 150 to 200 holes would have to be drilled over an area about one mile long and one-half mile wide.

The study area is cross-crossed with logging roads which would be used to get as close as possible to drill sites without clearing new roads. When road clearing is necessary, a dozer would be used to first push in a rough road 10 to 14 feet wide, and then to dig the pits and level the drill sites.

The area needed for each drill site would be about 50 feet by 50 feet. The two small pits that are dug for collecting and recycling water are filled with surface material when drilling is finished. The total land area needed for roads and drill sites would be 25 to 30 acres.

Bulk Sampling

Five bulk samples have been taken in the study area; three from open pits and two from underground shafts. One of the open pit samples was taken in 1972 by U.S. Steel south of Babbitt. The other samples were taken in 1966 and 1974 at INCO's Spruce Road site near Highway 1 along the Kawishiwi River. The underground bulk samples were taken by AMAX and INCO. The AMAX sample was taken in 1977 from a 1700 foot deep shaft south of Babbitt, and INCO's sample was in 1965 from the 1,100 foot Maturi shaft south of Highway 1 along the Kawishiwi River. The area of disturbance for each sampling was between 5 and 10 acres. This area would include, in the case of the underground sampling sites, the head frame and hoist house, holding ponds, rock piles, supply yard and offices. Surface bulk sample sites would have a pit, overburden stockpile (which would be reused and contoured after the sample is removed), an office, and supply yard.

In most instances, a road would have to be built to the bulk sample site. When a shaft is used to gain access to an underground bulk sample, a powerline would be necessary. Ponds are also built to hold water pumped from the shaft.

The hole left by pit or trench bulk sampling can be filled in and the area revegetated. When a shaft has been used, the ponds can be filled, the rock piles removed or covered, and the shaft capped. These methods would be used in the event that no mining occurs.

If an ore deposit is found and mining follows, the shaft would be used as a part of the mining operation, and the surface bulk sample site would become part of the open pit.

EXPLORATION COSTS

Due to the great variety of exploration programs, absolute cost figures applicable to every endeavor cannot be given. Each program has its own problems of access, type (and depth) of target being sought, and scale of expenditure. Costs will be given as a range for each stage. These costs (in 1977 dollars) apply to a model for exploration of a near surface mineralized zone and a mineralized zone at depth. As the exploration goes from one stage to the next, the expenditures mount rapidly.

Stage 1: In order to complete the regional appraisal, $14,000 to $35,000 would be spent. This would consist of hiring a consultant for 30 to 90 days at a cost of $350 per day. If available aerial photos are not up to date, new photos would be required at a cost of approximately $3,000.

Stage 2: Detailed reconnaissance would have a total cost of about $100,000. This work is field work as well as data analysis (each of which will account for about half the amount spent).

Reconnaissance geologic mapping would cost about $25,000. This would be for two men working in the field for three months, and would include data analysis.

Stream sediments would be tested at a cost of $33,000, two men would work for 30 days at a cost of $8,400. They would collect 800 samples and testing at $20 per sample would cost $16,000. The analysis of the data collected would cost $8,400.

An aeromagnetic study would be flown at a cost of $30,000. The entire study area would be flown over at a cost of $15,000 and another $15,000 would be spent for the data analysis.

A gravity survey would cost $17,000, two men would work for 30 days at a cost of $8,500 to collect data and $8,500 for the data analysis.

Stage 3: The detailed surface investigation of the target area would cost a total of $100,000. The detailed geologic structural-alteration mapping of outcrops would take two men three months at a cost of $25,000 for data collection and $25,000 to prepare this data in a useable form. Detailed induced polarization surveys would be conducted by two men for 10 days at a cost of about $3,200. The data analysis would be about $5,000 for a total of $8,200.

Detailed soil sampling along with detailed stream sampling would have to be performed. There will be about 800 samples collected at a cost of $8,500 plus $20 per sample for elemental analysis ($16,000)and $8,500 for data analysis totalling $33,000.

Surface magnetic surveys would be conducted with a 4-man crew for 10 days and would cost $6,400. The cost for the data analysis would be $8,000.

Stage 4: Three-dimensional investigation would cost \$2 to \$7 million. This large range is due to the differing number and lengths of drill holes needed in looking at deposits that are mineable by underground or open pit means. For a near-surface ore deposit, 180 holes would be drilled to a depth of 1,000 feet at a cost of \$11,000 per hole. The \$7.2 million project is for an underground operation where 300 holes would be drilled an average of 2,000 feet deep at a cost of \$24,000 per hole. The cost of obtaining a bulk sample would also have a very large range, with \$100,000 at the low end for a surface sample to \$4,000,000 for a shaft 1,700 feet deep.

In summary, it can be said that the costs for exploration will range from \$2.2 million to \$11.4 million, depending on the size and depth of the ore deposit.

THE EXPLORATION MODELS

Open Pit

The first model describes the exploration needs and costs which precede the development of an open pit mine producing 11,330,000 metric tons of ore per year. An area 30 miles long and 5 miles wide would be surveyed by aerial geophysical exploration techniques to locate a target area that would be one mile long and one half mile wide. This program would take three to five years from the time a company started exploration until the decision to start a mining operation is reached. The exploration program would be conducted in four stages as previously described. Stage 1 would be a regional appraisal at a cost of $21,000. Stage 2 would be a reconnaissance of the area narrowing down the 150 square mile area into a 4 or 5 square mile area would cost $100,000. Stage 3, surface investigation, would be the geochemical and geophysical techniques, reducing the area down to a 2 square mile area which would then be drilled at a total cost of $66,000. The fourth stage, three-dimensional physical sampling, would entail drilling 180 to 300 holes and would outline the ore deposit to its one mile length and one half mile width with an associated cost of $2.0 to $3.3 million. A bulk sample is taken and sent to a pilot plant for testing at a cost of $400,000 (pilot plant testing cost of $300,000). The total cost for exploration would be about $4,000,000.

Surface disturbances and water quality are not affected until stages 3 and 4 where traverse lines are cleared for geochemical and geophysical work and drilling is started.

Bulk sampling, which is part of stage 4, affects the largest contiguous area of any of the exploration procedures, and if not properly managed after the sample is removed, water quality could be affected. The number of personnel working on the exploration program over the 3 to 5 year life of the project varies between 5 and 20, with 13 for an average.

Underground

The second model describes the exploration needs and costs which proceed the development of an underground mine producing 7,940,000 metric tons of ore per year. The total area explored for this model would also be 150 square miles. Exploration would take 3 to 5 years from the time the first stage was started until the decision to develop a mine is reached. This program also follows the four-stage sequence. The first stage, regional appraisal, would be conducted in the same manner as in the first model and at the same cost ($21,000). Stage 2 would also be the same in that the area being explored would be narrowed down and indications would be that mineralization is at depths greater than 1,000 feet. The cost would be $100,000. Due to the high cost of deep drilling, the surface investigation stage would use more geophysical testing than in the first model to reduce the area size and help insure better definition of the target area. The increased use of geophysical testing and inherent interpretive problems associated with low grade ore deposits at depth would then increase the cost of stage 3 to $80,000. The fourth stage, three-dimensional physical sampling would entail drilling 200 to 300 holes at a cost of $4,000,000 to $7,000,000. The cost of taking a bulk sample would be ten times the cost of the open pit bulk sampling, or about $4,000,000 which includes the shaft and drifting required for the bulk sample. The cost for pilot plant testing of the bulk sample would be $300,000.

Surface disturbances and water quality are again not affected until stages 3 and 4 with traverse line clearing, road building, and drill site clearing.

Because of the methods used in shaft sinking, this stage would involve the building of holding ponds for water produced from the shaft. Waste rock and, in some cases, mineralized rock is taken from the shaft or drifts and has to be stored permanently or until it is processed. The number of personnel for this project would vary between 5 and 40 with 33 for an average over a life of 3 to 5 years.

Table 2 shows a summary chart of the model data

SUMMARY

This report has not dealt with mineral ownership, leasing of surface and mineral rights or the environmental studies that would be carried out by an exploration company. These subjects have not been included because they were beyond the scope of this report but will be dealt with in subsequent reports by the Copper-Nickel Study. It is hoped that this report gives some insight into how an exploration program moves from one stage to the next and some of the operations performed in each stage.

TABLE 2

SUMMARY OF EXPLORATION MODELS

Exploration Model	Exploration Stage	Cost, 1977 $s	Stage Duration Years	Manpower Requirements No.	Area Disturbed Acres
Open Pit Mine	1	21,000	1	5	--
	2	100,000	1	10	--
	3	66,000	1	15	--
	4	3,700,000	2	20	40
Underground Mine	1	21,000	1	5	--
	2	100,000	1	10	--
	3	80,000	1	20	--
	4	11,300,000	2	40	40

GLOSSARY

Erode - The classification of an ore reflecting the quality, according to the amount of desired material contained.

Grid - The imaginary lines by means of which the surface of an area is divided into squares when a checkerboard placement of boreholes is followed.

Dip - The angle of a slope, vein, rock stratum, or borehole as measured from the horizontal plane downward and is the true to steepest incline.

Anomaly - Any deviation from uniformity. A distinctive local feature in a geophysical or a geochemical survey over a larger area. An area or a restricted portion of a geophysical survey, such as a magnetic survey or a gravity survey, that differs from the rest of the survey in general. The anomaly might be associated with petroleum, natural gas, or mineral deposits, or provide a key to interpreting the underlying geologic structure. Drilling for economic mineral deposits might be conducted in the area of a geophysical anomaly.

Mineralization - The processes taking place in the earth's crust resulting in the formation of valuable minerals or ore bodies.

Milling - The crushing and grinding of ore. The term also includes the removing of valueless constituents and preparation for market.

Ore - A metalliferous mineral, or an aggregate of metalliferous minerals, more or less mixed with gangue, which, from the standpoint of the miner, can be won at a profit or, from the standpoint of a metallurgist, can be treated at a profit. The test of yielding a metal or metals at a profit seems, in the last analysis, to be the only feasible one to employ.

Connate Water - Water that was deposited simultaneously with the solid sediments and which has not, since its deposition, existed as surface water or as atmospheric moisture.

Drift - A horizontal underground opening in or near an ore body and parallel to the course of the vein or the long dimension of the ore body.

Beneficiation - To improve the grade by removing gangue material.

Processing - The methods employed to clean, process, and prepare metallic ores into the final marketable product.