Volume 2-Chapter 1

EXPLORATION

Minnesota Environmental Quality Board
Regional Copper-Nickel Study
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1.1 INTRODUCTION AND SUMMARY OF FINDINGS

Exploration, as it pertains to the discovery of new mineral deposits, can be defined as all the activities and evaluations necessary before an informed decision can be made establishing the optimum size, initial flowsheet, and annual output of new extractive operations. The purpose of mineral exploration is the discovery and acquisition of new mineral deposits amenable to economic extractive operations now or in the future. A prime objective of mineral exploration is to find and acquire a maximum number of such mineral deposits at a minimum cost and within a minimum time.

The importance of exploration in the mineral industry today is highlighted in a recent report published by the National Academy of Sciences (1978). The report states that "although the mineral industry relies on technology to a large degree in converting resources to usable energy and mineral forms, it does not base its competitive position on technology but rather on control and access to the best available deposits." The required technology is generally available to any company at relatively little or no cost. Correspondingly, a company which purchases the development rights on a proven deposit will pay highly for the security this offers. The real competitive edge goes to the company which succeeds in exploration, whether the company subsequently develops the deposit itself or leases its rights to another. A corrollary of this fact is that exploration information typically is highly proprietary, especially in the early and intermediate stages prior to the acquisition of land ownership or lease rights by the company.

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Exploration is undertaken by a company at great expense in order to obtain relatively simple information on the composition of subsurface rocks. Once this information becomes public knowledge, the company loses any advantage it had in possessing the information, unless it has already acted to secure its position. As a result of this situation, detailed exploration data is often difficult to obtain, which is unfortunate from the point of view of a systematic advancement in an understanding of the geology of the state, as well as other environmental conditions such as water quality which may be strongly influenced by geology. Under present laws, all copper-nickel exploration information gathered in the state by private interests remains confidential, at the discretion of each company, unless the information pertains to state or federal mineral lands on which the company relinquishes its lease or permit rights. It must be noted that several companies involved in exploration in the Study Area have departed from normal practice in voluntarily providing considerable information requested during the course of the Regional Copper-Nickel Study. Company cooperation with study staff was exceptional, both on the part of companies engaged solely in copper-nickel exploration, and those also active in iron mining in the region. The information thus provided is central to much of the work presented throughout this entire report, and reveals the potential value of exploration data to the understanding and prevention of possible environmental impacts.

Under today's regulations, most environmental impact analysis for new operations is conducted prior to facility construction. As a result, much of the information used to determine whether or not various impacts will occur (such as trace metal pollution) must be collected as part of the exploration process. Thus, studies designed to collect this information, clearly beyond the immediate interest of the economic or exploration geologist, must be conducted and coordinated with the studies under his direction.

The lack of early access to exploration data, the absence of proper notification that exploration is occurring in a particular area, and the lack of input by scientific disciplines other than economic geology could result in the loss of needed data for subsequent environmental impact assessment and the corresponding feasibility studies. This lack of data could also lead to regulatory delays and increased data acquisition costs, as previously completed studies would have to be repeated (in part) in order to secure the necessary information.

The above considerations should be recognized by the exploration geologist when implementing exploration activities.

The high cost of exploration data must be noted, since it represents considerable financial risk to a company. This is particularly emphasized by the low success rate experienced in the search for viable mineral deposits. For example, available information (USGS 1975) indicates that a hypothetical mine requires the expenditure of approximately $2.2 million (based on 1975 information) simply to find and define the areas of mineral resources. This does not include the costs of defining the tonnage, grade, and economic feasibility of the deposit. Further data indicates that the average cost to discover a mineable porphyry copper deposit in the U.S. is $25 million. These two figures clearly indicate that fewer than one prospect in ten actually proves out as a mineable deposit. It is reasonable to assume that a similar success rate is applicable to deposits in Minnesota, clearly emphasizing the financial risks involved in exploration.

Northeastern Minnesota has a considerable history of exploration for copper and nickel. It is appropriate to briefly review that history here, to motivate the discussion of exploration technology and procedures which follows. The progression of Cu-Ni exploration in the state is, in turn, best understood in the context of the applicable legal framework. The region within the Study Area most affected by past work, as well as most likely to be affected by present and future mineral exploration activities associated with the Duluth Complex has been designated the "Resource Zone" and is shown in Figure 1. The mineral resources within this 88,600 acre Resource Zone are owned and/or managed by private and public interests as follows:

24% Federal Government

15% State Government

32% Private Individuals and Corporations

29% Unknown and/or Conflicting Ownership

Figure 1

Private exploration of public resources is governed by various federal and state laws, rules, and regulations (see Volume 5-Chapter 4 on mineral leases and permits for more information) controlling access; information exchange; environmental impact mitigation and reclamation; and rents and payments. Exploration of privately controlled resources (32 to 51% of the Cu-Ni Resource Zone) is not under the direct perview of government and is controlled by means of private leases, contracts, or sales. Environmental impact mitigation requirements are usually not specified in such agreements and Minnesota has no specific authority requiring that the state be notified of exploration activities on private mineral lands. No environmental regulations covering such activities on private lands have been promulgated and it is uncertain whether authority to promulgate such regulations exists.

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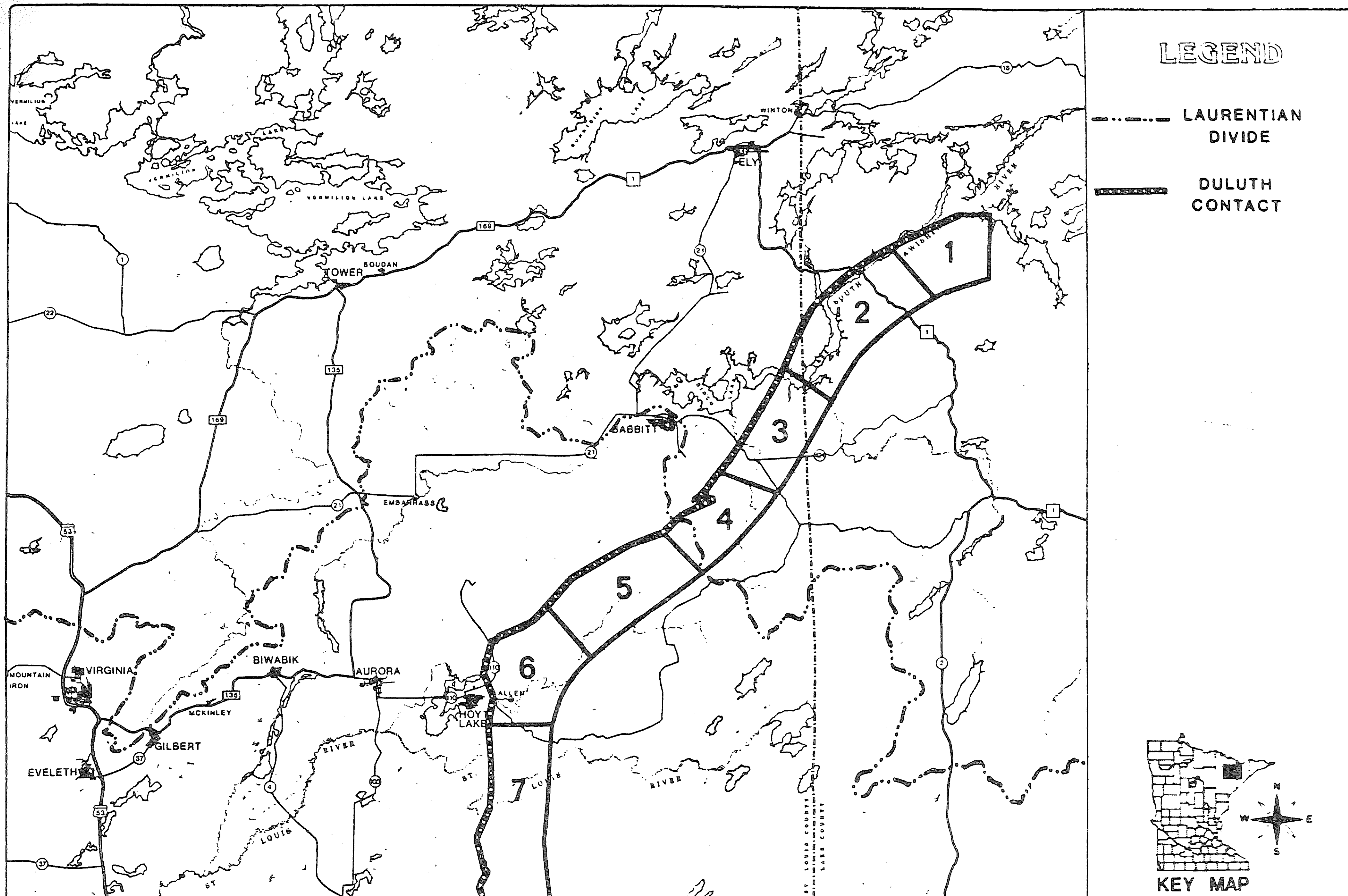

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FIGURE 1

RESOURCE ZONES

The procedures followed in Minnesota by a private interest in order to secure control of and/or access authorization to federal hard rock mineral resources is unique as compared to western states because patent claims are not allowed and a prospecting permit and/or mineral lease must be secured from the U.S. Bureau of Land Management with approval from the Forest Supervisor if National Forest Lands are involved. Prior to the granting of mineral leases, prospecting permits are usually issued with or without exclusive or preference rights depending upon whether the federal lands in question are acquired or public domain lands. In Minnesota, the Secretary of Agriculture or his delegate can write into any prospecting permit or mineral lease for hard rock minerals any stipulations pertaining to environmental protection and reclamation, but specific regulations for this purpose have not been promulgated. The Superior National Forest has adopted minimum guidelines pertaining to environmental mitigation of general exploration (exclusive of bulk sampling) activities for copper-nickel resources in the region between Hoyt Lakes and the BWCA within the Superior National Forest (see section 1.5). The results of exploration activities and processing tests on federal mineral resources are submitted to the federal government on a proprietory basis and the information is reviewed and managed by the U.S. Geological Survey as agent for the federal government. This information can only be released to the public or to other agencies of the federal government upon authorization of the permit or lease holder or upon termination of permits and leases, at which time the information is placed on open-file.

For state copper-nickel minerals, exploration permits or mineral leases are granted by the MDNR pursuant to Minnesota Regulations NR 94. The MDNR administers the leasing of state minerals, but the State Executive Council makes the final authorizations and determines if and when specific tracts of state minerals are to be made available for private leasing and exploration. Results of copper-nickel exploration and testing activities are submitted on a proprietory basis to the Minerals Division of the MDNR. This information remains proprietory to the lease holder and the Minerals Division until the information is released by the lease holder or when the lease terminates; at which time the MDNR places the information in open file. In this legal context, the state's exploration history will now be discussed.

As early as 1854, rumors indicated the presence of copper in northeastern Minnesota, with nickel findings reported in 1893 (USBM 1976). In the first half of the twentieth century, some exploration work was done in the region, notably by the U.S. Geological Survey and the Minnesota Geological Survey. Activity was low, however, until 1948 when road work on Spruce Road in the Superior National Forest revealed traces of copper. This was followed by the granting of the first prospecting permit to Roger V. Whiteside and Fred S. Childers, Sr. in the Superior National Forest in 1951, and the sinking of the first diamond drill hole searching specifically for copper-nickel in the same year. By 1954, forty-one prospecting permits had been issued in the Study Area, and several diamond drill holes had been put down. The International Nickel Company (INCO) began extensive drilling in 1954, working under a mineral lease agreement with the U.S. Bureau of Land Management and the U.S. Forest Service arranged the previous year. The Bear Creek Mining Company, a subsidiary of Kennecott Copper Corporation, was also engaged in surface exploration in the Gunflint area during the early 1950s. In 1966, INCO signed a mining lease with the U.S. Department of the Interior, giving INCO mining rights on 4,945 acres of mineral land in the Superior National Forest.

The State of Minnesota became active in the area of copper-nickel mineral leases in 1966, with the awarding of 50-year leases to 11 companies covering a total of 86,605 acres of state-owned mineral lands. Major lease holders included the Phelps Dodge Corporation, AMAX Exploration, Inc., Bear Creek Mining Company, U.S. Steel Corporation, Cleveland Cliffs Iron Company, Warren S. Moore, and Duval Corporation. Subsequent state lease sales, held in 1968, 1970, and 1971 added other companies, such as Exxon Company, U.S.A. and American Shield Corporation to the list of those active in the state.

As a result of these prospecting permits and mining leases granted along the Duluth Gabbro contact, the Study Area has experienced a great deal of exploration activity over the past two decades. In addition to aerial and surface work, an estimated 1,000 to 1,500 holes have been drilled. Several sites have been explored in considerable detail, including extensive drilling and bulk sampling. Consequently, the types of exploration techniques applicable in the Study Area are well known, and there has been opportunity to directly study the environmental impacts from these activities. This contrasts strongly to the situation in mining, processing, and smelting/refining where no actual industry is currently operating in Minnesota and the potential impacts must be inferred from the study of other operations around the world. In fact, since many aspects of an exploration program simulate a full scale operation, several excellent opportunities have been afforded to understand possible mining impacts through studies of these activities. This is particularly true of the later exploration stages which involve activities such as surface storage of rock, and site water management. The findings from these studies will be presented throughout subsequent volumes of this Regional Study report. Similarly, the following discussion of the exploration process focuses on techniques applicable to Minnesota and highlights those of particular concern for potential environmental impacts.

1.2 MINERAL EXPLORATION ACTIVITIES

A general line diagram of mining activities is shown in Figure 2. The exploration program is primarily involved with the "finding" and "proving" activities shown at the top of the figure. Subsequent activities generally associated with an operation are also shown in this figure to emphasize the fact that exploration, although important, is a very small portion of the total picture where time and money are concerned. Another point to be emphasized is that all phases of the exploration program must consider all subsequent stages of a viable operation, including environmental controls and subsequent long-term reclamation. Each stage must, in fact, constantly be concerned with stages preceding and following it in the sequence.

Figure 2

The finding and proving activities in any mineral venture follow a logical sequence of stages, going from the general exploration of large areas using indicator techniques to specific areas in which results of more detailed investigations indicate greater possibilities of economical mineral deposits. These exploration stages as shown in Figure 3 are:

Stage 1. Regional Appraisal

Stage 2. Detailed Reconnaissance of Favorable Area

Stage 3. Detailed surface Appraisal of Target Area

Stage 4. Detailed 3-Dimensional Sampling and Preliminary Evaluation

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Figure 3

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FIGURE 2

SCHEMATIC DIAGRAM DEPICTING THE SCOPE OF MINING ACTIVITIES FROM EXPLORATION TO FINAL MARKETING OF THE OUTPUT

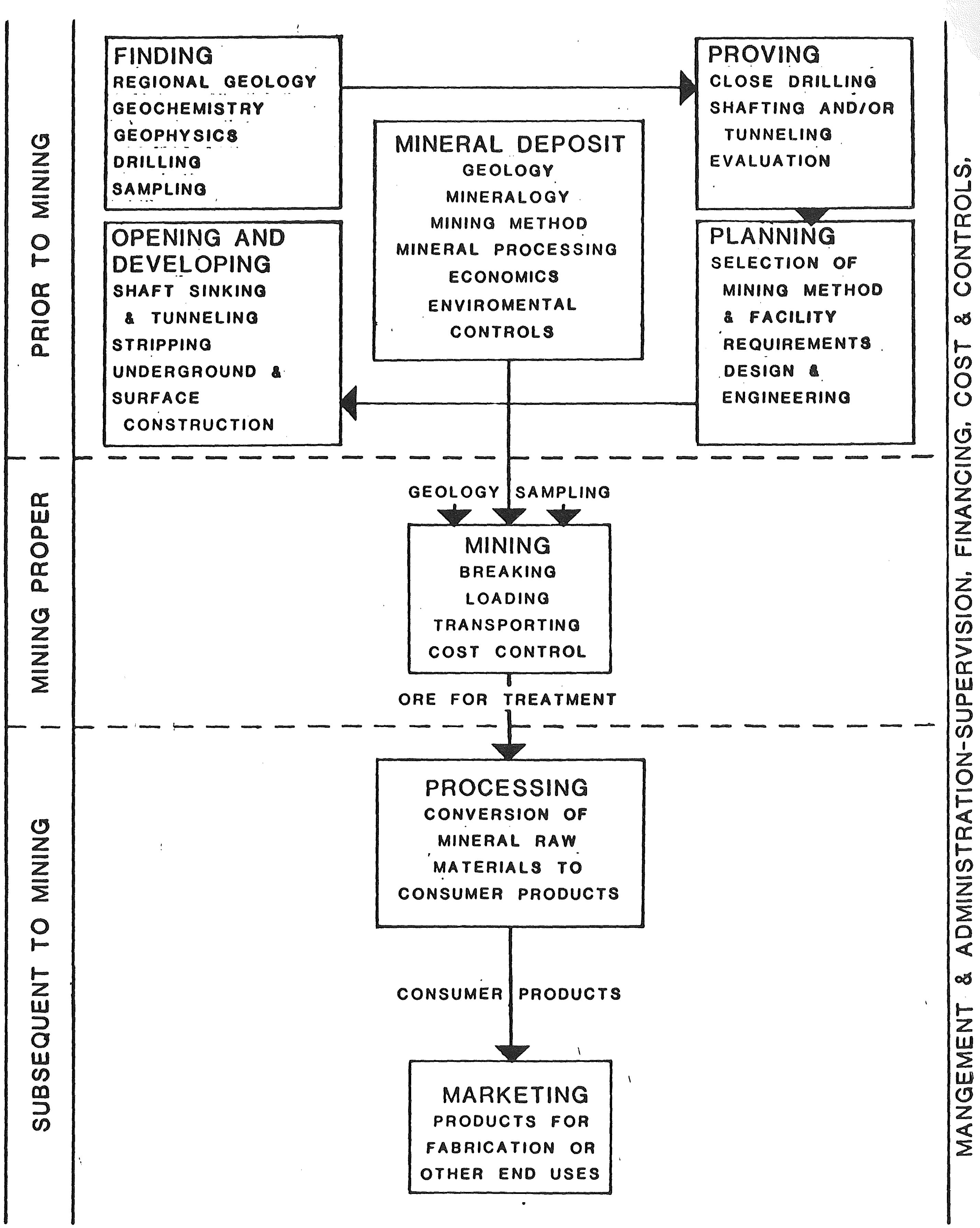

FIGURE 3

STAGES IN AN EXPLORATION PROGRAM

FINDING PHASE (3-5 YEARS)			PROVING PHASE (3-5 YEARS)
STAGE 1	STAGE 2	STAGE 3	STAGE 4
REGIONAL APPRAISAL	DETAILED RECONNAISSANCE OF FAVORABLE AREAS	DETAILED SURFACE APPRAISAL OF TARGET AREA	DETAILED 3-DIMENSIONAL SAMPLING AND PRELIMARY INVESTIGATION
STAFF 1-10	STAFF 5-20	STAFF 5-20	STAFF 20-50
COST $\$10\text{-}50X10^3$	COST $\$50\text{-}200X10^3$	COST $\$50\text{-}200X10^3$	COST $\$3\text{-}15X10^6$
TIME SPAN 0-1 YEAR	TIME SPAN 1-2 YEARS	TIME SPAN 1-2 YEARS	TIME SPAN 3-5 YEARS

Each of these steps will be briefly discussed later.

The definition of exploration used here, that of all activities required prior to the decision to actually develop a producing mine, is quite broad. It is useful to subdivide this into the two activities of "finding" and "proving," as shown in Figure 3. "Finding" includes all of the activities listed in stages 1 to 3, and some of the activities of stage 4, notably some preliminary drilling. As noted earlier, this phase typically might cost $2 million, with less than one prospect in ten resulting in the development of an actual mine. The "proving" phase then proceeds on promising finds, with extensive drilling, bulk sampling, pilot plant testing, and feasibility evaluations. This phase, with highly variable costs typically ranging from $3 million to $15 million, is only undertaken on those relatively few finds which show a high degree of promise for development in the near or medium term future, typically 5 to 15 years. The finding phase itself may require 3 to 5 years, with another 3 to 5-year proving period. No data has been found on the success rate of projects once they enter the proving phase. However, it is fair to say that if the preliminary drilling of the finding phase shows promise, and the program progresses completely through the proving phase with its attendent high costs, the most appropriate question is not <u>whether</u> the deposit is worth developing, but <u>when</u>. With a substantial investment in the site, even though the results may not indicate a profitable operation at current metal prices, the company is not likely to totally abandon control of the site. Unless restricted by lease terms or prohibitive royalty payments, the company is likely to retain its interest in the property in hopes that market conditions will justify development in the future. Actual development may be by the company which conducted the exploration, or by another company under appropriate development agreements.

In the Regional Study Area, the work done by INCO in Resource zones 1 and 2 (see map, Figure 4), by AMAX in zone 4, and by U.S. Steel in zone 5 qualifies these areas as being in the "proving" phase. The rest of the Duluth Complex, to the north and east of zone 1, in zone 3, 6, and 7 as well as the area south to Duluth must be considered to be in the finding phase. In the Study Area, zone 3 is unique in that extensive drilling has occurred in this area as compared to zones 6 and 7, but a find that warrants increasing activities to the "proving" phase has not been identified. For a more detailed discussion of copper-nickel resources in the Study Area, refer to Volume 3-Chapter 2 of this report. As will be apparent in the following discussion, the potential for environmental impacts is much greater during the "proving" phase than during the "finding" phase. Principally, this is due to the drilling and bulk sampling operations, with their attendent access, surface area, water, and storage requirements.

Figure 4

1.3 DEFINITION AND PROCEDURE OF A PROGRAM

As mentioned earlier, an overall exploration program can be divided into the "finding" and "proving" phases. These in turn can be further subdivided into stages. Each stage is distinguished by the techniques employed. This is a useful basis on which to discuss the overall program since environmental impacts, if they result, are caused by the use of particular exploration techniques. The stages used in the "finding" and "proving" phases are:

"Finding" Phase

Stage 1 - regional appraisal to identify a favorable area

Stage 2 - detailed reconnaissance of favorable area to identify a target area

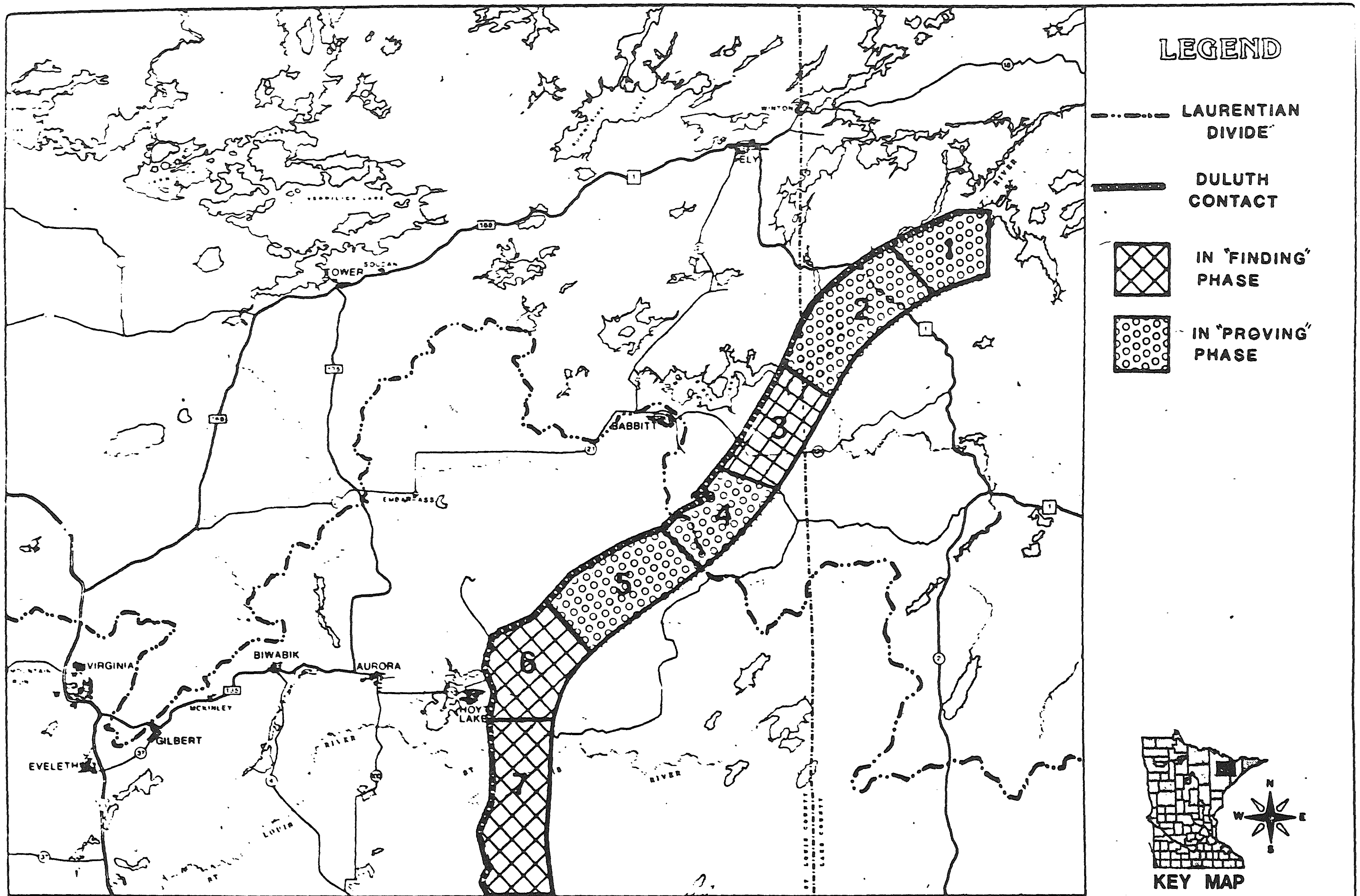

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FIGURE 4

EXPLORATION PHASE OF RESOURCE ZONES

Stage 3 - detailed surface appraisal of target area

Stage 4 - initial aspects of stage 4, involving preliminary drilling

"Proving" Phase

Stage 4 - balance of stage 4 not undertaken during the "finding" phase, involving detailed 3-dimensional sampling, preliminary evaluation, and initial engineering and cost studies

Each of these stages is discussed below.

1.3.1 Stage 1, Regional Appraisal

This first stage consists of collecting geologic maps of the area, aerial photos, and 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 and topography, and to provide an exploration geologist's first hand appraisal of an area.

The staff necessary to complete Stage 1 may be as few as one person working for a month or as large as 10 people working a full summer. The number of personnel is dependent on the size of the area investigated, the detail required, and the complexity of the geology. The area investigated can be as large as 400 square miles or as small as 50 square miles. The costs for such a study could range from $10,000 to $50,000. There do not appear to be any significant environmental impacts associated with this stage.

1.3.2 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 used in conducting such aerial surveys monitor parameters such as magnetic fields, gravity, and radiation. If anomalies are indicated by airborne investigations, ground level geophysical and geochemical tests are used to better locate them. At this time there is no need for detailed examinations of the anomalies, as this will follow in Stage 3 investigations. This stage requires a staff of 5 to 20, generally not much longer than a summer field working season at a cost of $50,000 to $200,000. The area has now been reduced to 10 to 50 square miles, depending on the number of anomalies indicated. Again, Stage 2 should not result in any significant environmental impacts.

1.3.3 Stage 3, Detailed Surface Appraisal of Target Area

Stage 2 has been used to generally locate anomalous conditions in an area. In Stage 3 these conditions are investigated by detailed geochemical and geophysical testing to spacially 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 along with additional testing methods such as induced polarization. The data from all the tests would show whether an anomaly exists, its extent, and if copper-nickel mineralization is the reason for the anomaly. At this point, the area remains about the same size as outlined in Stage 2, as will the costs. The manpower requirement may be somewhat higher but for a shorter period of time. Again, no significant environmental impacts are expected.

1.3.4 Stage 4, Detailed 3-Dimensional Sampling and Preliminary Evaluation

This final and most expensive stage of an exploration program is not started unless there is every preliminary indication that a present or future economic ore body exists. The environmental impacts resulting from this stage are particularly important to consider. Drilling is the method universally used to prove out the existence of such an ore body, and is a major part of the Stage 4 program. The drilling will also provide geologic information needed in planning a mining operation, such as the deposit's shape, size, grade, depth, and type of mineralization. In addition, a drilling program can provide important environmental impact assessment information such as the type, distribution, and extent of trace metals and fibrous minerals, and the quality and quantity of water present in bedrock aquifers. If the drilling results warrant, bulk samples are also taken during this stage and subjected to bench scale and pilot plant tests to determine concentrating characteristics. Once again, special studies could be conducted at this stage pertaining to environmental matters. In total, Stage 4 of an exploration program may involve 20 to 50 full-time employees for several years depending on the intensity and depth of the drilling requirements and bulk sampling activities. Costs will vary greatly, so that a range of $3 to $15 million is reasonable.

1.3.5 Decision Points

As the program continues from the first stage to the fourth, decisions to go on or to stop are made at the completion of each stage. If the program proceeds, the area that is being investigated is being reduced in size and the favorability is being increased. If at the end of the first stage the region is not attractive, for reasons such as unfavorable geology, taxes, political situation, or internal economics, there are two options the company can follow. If the geology is unfavorable, the area may be completely rejected. On the other hand, if taxes, politics, etc. are the reasons for rejection, and the company feels the geology indicates the area may have mineralization, then the project could be put into a hold status. This means the region would not be attractive at this time, but with changes in the unfavorable situation it could be of interest at some later date.

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 potentially economic mineralization is found. The hold decision would be made if mineralization or anomalies are indicated, but not of a grade or size the company deems necessary to continue exploration. The go ahead decision leads to Stage 3.

When Stage 3 has been reached and completed the same three options are available again. The property would be rejected if, under closer scrutiny, the anomalous conditions indicated in Stage 2 proved not to be due to potentially 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 hold option could be used.

At Stage 4, land control 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 they are exploring, they will not go into the 3-dimensional exploration of Stage 4. If in the future the area does become available, the project could then go from hold into Stage 4, and drilling would commence.

The decision to continue may also be made at other times particularly following preliminary drilling in Stage 4. This corresponds to the end of the "finding" phase. At this point, the resulting information is used to determine whether to proceed to the "proving" phase, and if so how much more drilling is needed. If mineralization is found but determined uneconomical at the time, the area is put on hold. This may, for example, be due to grade, recovery, or other processing problems. Also, the deposit could be either too small or too large. If the deposit is too small for a particular company, a company with lesser demands may be encouraged to take over the property. In the case of a deposit being too large, two or more companies could pool capital and technology for a joint venture.

1.4 GEOLOGIC EXPLORATION TECHNIQUES

The exploration geologist has access to hundreds of exploration techniques. Table 1 is a summary of the general techniques available for each stage of an exploration program. The general nature of most of these activities are apparent from the comments shown in the table.

Table 1

Most of the techniques do not have significant environmental impact potential and so need not be discussed further. However, two of the Stage 4 activities, drilling and bulk sampling, could result in significant impacts. Therefore, these rather complex activities are discussed in more detail in the following section.

1.4.1 Drilling

Drilling is the operation of sinking deep holes for prospecting, exploration, or valuation. Two general methods of drilling are common: 1) percussion systems,

Table 1. Geologic exploration techniques.

EXPLORATION STAGES	ACTIVITY OR METHOD USED TO COMPLETE THE STAGE[a]	DESCRIPTION OF ACTIVITY OR METHOD
Regional Appraisal (Stage 1)	O - Geologic compilation	These techniques are all performed through the use of airplanes, helicopters, and motorized vehicles. The choice will depend on the terrain and accessibility of an area.
	O - Photogeologic study (rock units, contacts and structures)	
	O - Structural analysis	
	F - Field inspection of area	
Detailed Reconnaissance (Stage 2)	F - Reconnaissance geologic mapping of outcrops	A field camp is required if accommodations are not readily available
	F - Stream sediment geochemical surveys	Small motorboats would be used to transport personnel in collecting samples
	F - Airborne electromagnetic survey	A plane or helicopter is flown over the area on a predetermined grid
	F - Gravity survey in gravel-covered area	This is performed on the ground. There will be very little site clearing associated with this
	F - Reconnaissance induced polarization survey of covered area	This will require clearing a path
	F - Field inspection of anomalous areas	The use of a plane, helicopter, or motorized vehicle will be required
Detailed Surface Investigation of Target Area (Stage 3)	F - Detailed geologic structural-alteration mapping of outcrops	A field camp is required if accommodations are not readily available
	L - Petrographic-mineralogy-trace element study of rock samples	A building would be required to store samples and perform the lab work
	F - Detailed induced polarization survey of anomalous covered areas	Four-foot-wide paths would be cleared on a grid over the anomalous areas

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Table 1. (contd.)

EXPLORATION STAGES	ACTIVITY OR METHOD USED TO COMPLETE THE STAGE[a]	DESCRIPTION OF ACTIVITY OR METHOD
Stage 3 (contd)	F - Detailed stream sediment and/or soil geochemical survey	The stream sediments would be sampled using small motorboats. The soil samples will be taken along the same grid used for the induced polari- survey
Detailed Three-Dimensional Physical Sampling of Target Area (Stage 4)	F - Drilling	Drilling will be carried out by the use of one of three drilling types hammer drills, rotary drills, or diamond core drills
	L - Mineralogical and chemical analysis, and physical tests on samples, cores and cuttings	These tests will give needed information for the reserve estimate and preliminary valuation
	O - Reserves computation	Mineable tons would be estimated
	O - Preliminary valuation	Estimations of profitability are made
	F - Investigation of water problems and water availability for plants	This would include estimates of water that would flow into a pit or underground mine or other conditions that will pose problems to a mining operation
	F - Down-hole geophysical surveys	Drill holes are surveyed to confirm location and deviation, and geophysical tests for indications of mineralization are done
	F - Investigation of suitability of ground for plant, waste disposal, and town sites	This would include overburden testing for depth variability and favorability for construction
	F - Shaft sinking, tunneling or surface bulk sampling	Samples of a few tons to thousands of tons are taken for testing
	L - Ore dressing tests on bulk samples	Lab work that in most cases will be performed off-site

[a]O - Office study
F - Field investigation
L - Laboratory test

which consist of breaking up the ground by means of repeated impacts using a sharp-pointed instrument; and 2) rotary systems, which employ abrasive grinding and may aim at the extraction of an intact core or permit all the disintegrated material to be washed away.

Drilling is typically directed toward determining the grade, volume, and shape of a mineralized zone that has been generally located by prior detailed surface investigations. Information provided by such a program may include:

1) Geologic framework of the deposit
2) Variations in grade of potential ore and waste materials
3) Distribution and mineralogy of the minerals of economic and environmental concern, with samples for laboratory testwork
4) Shape of the ore zone
5) Physical properties of the ore and host rock
6) Occurrence of mineralization and its dependence on structure, weathering cycles, rock types, alteration, etc.
7) Structural occurrence and quality of groundwater
8) Depth and nature of overburden

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 amount and type of drilling, and the geology of the area under investigation.

1.4.1.1 <u>Drilling Systems</u>--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 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 an intact core that can be brought to the surface for study. In competent rock, core recovery approaches 100% and will show orientation and 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 $39/meter or $12/foot), and if a core is not required, the other two methods, which are less expensive, can be used to produce drill cuttings for sampling.

In poorly consolidated or highly fractured material, core recovery may approach zero, and what is recovered provides a poor indication of the type of material being drilled. Under these conditions another type of drilling should be used to provide a more representative sample of the formation.

Percussion Drilling--This drilling procedure incorporates a reciprocating hammer, usually driven by compressed air, 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 itself is located at the bottom of the hole, the term "down-the-hole-hammer drill" is used. This method produces chips of rocks which

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are blown from the hole by the hammer exhaust air and 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 solid core for geological study. Advantages are cost savings (of \$3-\$6/meter or \$1-\$2/foot), and faster drilling rates. Also, unlike diamond or rotary drilling, there is little or no deviation from vertical of the drilled hole, which eliminates the need for surveying the hole.

Rotary Drilling--This drilling method consists of rotating a column of drill pipe, at the bottom of which is attached a drilling bit. Unlike diamond drilling, no solid core is produced, but rather a flow of rock chips, or cuttings. During the operation, mud-laden fluid is circulated down through the drill pipe under pressure by means of special slush pumps. The drilling mud and cuttings from the bit are forced up the outside of the drill pipe to the surface where the cuttings are collected for examination. With both the rotary and percussion methods, 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.

1.4.1.2 Bulk Sampling--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 near the surface.

The bulk sample is taken to provide sufficient material for metallurgical analysis and for verification of drilling program results. This information will enable mill and smelter design work to proceed in the most 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, for example, six bulk samples have been taken; three by INCO, one by U.S. Steel, and two by AMAX. To show how sample size can vary, to date AMAX has utilized approximately 3,000 st of some 20,000 st of mineralized material removed from the underground drifts at Minnamax. Of this 3,000 st used for concentration and smelting tests, sub-samples of 1,000 st and 300 st were sent to governmental agencies. The remainder is being held in reserve for possible future testwork. In addition, AMAX has taken an open pit bulk sample of some 1,100 st for testwork. The U.S. Steel bulk sample was 300 st and INCO's samples were, respectively, 50 st from a surface site, followed by 10,000 st each from an underground site and another surface site.

1.5 POLLUTION CONTROL TECHNOLOGY

Table 2 lists potential pollution areas, mitigation measures, and effectiveness of such measures for each exploration stage. Such a comparison is highly qualitative; however, it is useful in pointing out generally the distinction between sources of pollution for which effective controls exist and those for which controls are only partly effective or non-existent.

<u>Table 2</u>

Exploration has very few significant environmental impacts associated with it in the first three stages. The fourth stage involves several activities, notably

Table 2. (continued)

EXPLORATION STAGES	OPERATION	POTENTIAL IMPACTS	MITIGATION	EFFECTIVENESS OF MITIGATION MEASURES[a]
Stage 4 (contd)	Surface pit and bulk sampling (contd.)	Pit site (water contamination)	Fill with overburden and revegetate	2
		Waste rock (visual)	Cover with dirt and revegetate	1
		Lean ore (visual)	" " "	1
		Lean ore/waste rock (water contamination)	Place on inert pad, cover with dirt, and revegetate	Unknown

1: Good-proven effective control technology exists and is known to operate reliably in many installations.
2: Fair-proven effective control technology exists or is in the demonstration stage at one or more installations.
3: Poor-proven effective control technology has not been developed or is not yet ready for full-scale operation.

Table 2. (continued)

EXPLORATION STAGES	OPERATION	POTENTIAL IMPACTS	MITIGATION	EFFECTIVENESS OF MITIGATION MEASURES[a]
Stage 4 (contd.)	Drilling	Drill noise	Enclose drill	2
		Dust generation	Wet drilling	1
		Water discharge	Use holding pit and recycling	1
		Access road (visual)	Reclaim on termination	2
		Water holding pit	On termination, filled in	1
		Drill site (visual)	Reclaim on termination	2
		Clearing drill site and access road (vegetation)	Clear minimally and reclaim on termination	2
		Groundwater contamination by seepage into hole	Seal hole on termination	1
	Shaft sinking for bulk sample	Clearing shaft site Construction of headframe Buildings Blasting	Contractor attempts to minimize disturbed areas, enclose noise sources	2
		Water	Holding pond	2
		Access road (visual)	Design road to be unobtrusive	2
		Access road (dust)	Use water truck	1
		Buildings and headframe (visual)	Good visual design Remove when work is completed	2 1
		Shaft site (visual)	Revegetate	2
		Shaft safety on termination	Cap shaft	1
		Waste rock (visual)	Cover with dirt and revegetate	1
		Lean ore (visual)	" " "	1
		Lean ore/waste rock (water) contamination	Place on inert pads, cover and revegetate	Unknown
	Surface pit for bulk sampling	Clearing pit site (noise)	Clear minimum area	2
		Blastings	Keep blasts small	2
		Access road (visual)	Design to be unobtrusive	2
		Access road (dust)	Use water truck	1
		Buildings (visual)	Remove building on termination	2
		Pit site (visual)	Contour and revegetate	2

Table 2. (continued)

EXPLORATION STAGES	OPERATION	POTENTIAL IMPACTS	MITIGATION	EFFECTIVENESS OF MITIGATION MEASURES[a]
Stage 4 (contd)	Surface pit and bulk sampling (contd.)	Pit site (water contamination)	Fill with overburden and revegetate	2
		Waste rock (visual)	Cover with dirt and revegetate	1
		Lean ore (visual)	" " "	1
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1: Good-proven effective control technology exists and is known to operate reliably in many installations.
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drilling and bulk sampling, which necessitate precautionary measures on the part of both the exploration companies and equipment operators whom they employ. For example, problems may result from the fact that drilling rigs require road access to each site. Existing roads must invariably be augmented, usually by clearing or bulldozing access roads 10 to 14 feet wide along which the drill rig is skidded. In addition, each drill site may occupy a plot 50 feet on a side. As a result, a detailed drilling program of 150 to 200 holes in an area of 2 to 3 square miles may involve the direct disturbance of 25 to 30 acres. Much of this may be temporary, with natural vegetation returning relatively rapidly. However, the recovery of certain areas, particularly drill sites, may take decades if the use of lubricants and management of drill cooling systems are not carefully controlled, with proper cleanup following site abandonment.

Drilling can produce water that has oil, drilling mud, and high levels of dissolved solids. The common procedure with rotary and diamond drills is to dig two small holding pits (e.g. 3 m X 3 m), called mud sumps. The water from drilling is pumped into the first pit which functions as a settling pond. The overflow runs into the second pit and is then recycled. In instances where a down-the-hole-hammer drill is used, water is not required to cool the drill or remove cuttings. However, if conate water (water trapped in bedrock) is encountered, large quantities (1100 liters/min or 300 gal/min) of water can be blown from the hole along with hammer exhaust air. These waters have been observed to have dissolved solids three orders of magnitude higher than background well water. This may be due, for example, to elevated levels of calcium carbonate, sodium, and chloride. There is little chance of controlling this water when down-the-hole-hammer drilling is used, due to the nature of this type of drilling. However, impacts can be prevented if the operator shuts the rig down when water is encountered, and finishes drilling with a rotary or diamond core drill which will minimize the discharge.

Access road and drill site reclamation, as already noted, is best served by intelligent planning and operation during drilling. The length of roads contructioned can be minimized, and minimum widths used. Where possible, bulldozers should minimize removal of topsoil, in order to shorten natural revegetation time. Sites should be kept as small as possible, with the avoidance of discharges of oil, groundwater, and other materials not native to the area. Following operation, all foreign material should be removed, and the drill hole should be carefully sealed to prevent seepage of water either into or out of the hole (should it be artesian). Any sumps should be filled, and topsoil replaced. Both sites and roads will recover more rapidly if some artificial revegetation is used to speed up the return of natural plant communities.

As a specific example, an Environmental Analysis Review conducted by the U.S. Forest Service on proposed mineral exploration work in the Duluth Gabbro Complex in the Ely-Hoyt Lakes area (Behling and Sweet 1975) contains a list of guidelines which must be considered when approving operating plans for mineral exploration. The guidelines are minimal, and are intended to be used along with all other factors that will help to eliminate or mitigate adverse environmental impacts. These guidelines include:

1) Roads to be used for access to exploration sites shall be constructed or reconstructed to a standard commensurate with the period of planned use. Adequate cross drainage, spot surfacing and turnouts will be provided to insure control of erosion and protection of water resources and provide user safety.

2) Access points into state, county, or forest roads will require a side entrance permit.

3) The crossing of navigable streams will require the permittee to obtain a water crossing permit issued by the State of Minnesota.

4) Access routes will be on locations approved in advance by the authorized forest officer or his representative.

5) Adequate sump and catchment basins will be provided at each drill site to control runoff from drilling operations and will be located a sufficient distance from lakes, streams, and water sources to prevent contamination.

6) All operations will be conducted so as to minimize the adverse impacts on streams, lakes, ponds, waterholes, seeps, marshes, and fish and wildlife resources. Occupancy of the surface in deep marshes, shallow marshes, and sedge meadows will be prohibited.

7) Access points from main roads will require a minimum of 200 ft, 6 in. deep of gravel from the point of intersection unless access is to be wholly on frozen, snow-covered ground.

8) Operations under the permit will require and provide for adequate fire protection.

9) Restoration of drill sites will include complete cleanup, debris removal, landscaping, and revegetation of disturbed areas including access roads. Acceptance of restoration will be delayed until the disturbed area is revegetated to acceptable grasses, legumes, or natural shrubs and trees. In areas of high erosion potential, the restoration and revegetation will be accomplished

concurrently with the operation but in no case will it be delayed beyond the next full growing season.

10) Exploration drilling may be permitted within 400 ft of streams, lakes, reservoirs, and wetlands, if seasonal operations will mitigate the impacts on the environment and other forest uses; and/or, if drill sites are located and constructed so as to prevent drilling solutions from entering surface runoff.

11) If casing is left in the drill hole, it will be firmly set in the bedrock and tightly capped to avoid transfer of water between aquifers and between surface and ground waters. Capped drill holes will not extend more than 6 in. above the surface of the local ground surface.

12) A brief description of all drilling fluid additives and their possible environmental effects will be submitted in advance to the Forest Officer in Charge or his authorized representative for approval.

13) No drilling will be permitted within 10 chains (660 ft) of an active eagle or osprey nest.

14) Before specific areas are to be occupied, or otherwise disturbed, a reconnaissance check will be made by the Forest Service to determine whether the areas are suspect of having archeological significance. If such is the case, suspect areas will either be avoided or further evaluated by a professional archeologist to determine whether disturbance could be permitted.

Bulk sampling is also conducted during the fourth stage. With either surface or underground bulk sampling, typically 5 to 10 acres of surface land would be disturbed, at least temporarily. Surface samples may be taken by digging a pit which can be refilled and contoured. Minor amounts of water may have to be pumped from the pit during the sample taking to maintain good working conditions. If the bulk sample is taken at depths of more than a few hundred feet, a shaft will have to be sunk. Waste rock from this shaft will have to be stored above ground. Water that is pumped from the shaft will have to be disposed of or at least stored in ponds. This shaft water may be high in constituents such as chlorides, which may necessitate treatment before discharge if associated impacts are to be avoided. Runoff water from the rock piles may also be stored in the ponds if this water is of poor quality as a result of the leaching of heavy metals and sulfate from the piles. The conditions affecting the nature and rate of this leaching are not yet well understood. Therefore, it is not now possible to specify with assurance the mitigation measures which will result in the elimination of possible leaching and resultant environmental impacts.

Many of the long-term reclamation practices mentioned with respect to drilling also apply to the bulk sample sites. In addition, buildings, parking lots, headframes, and other artificial structures should be removed and natural topsoil returned to the affected areas prior to revegetation. Waste rock piles should receive special attention to be sure they are isolated from leaching into surface or groundwaters. This might be accomplished in certain cases (in which only a small amount of waste rock is produced, for example) by returning wastes to an underground shaft prior to securely capping it. Piles might be placed on inert pads isolated from ground water, and be sealed with a relatively impervious layer of material such as clay, to prevent surface water infiltration. The protected piles could then be revegetated to protect the seal. However, the successfulness of such measures are not well known. For ultimate elimination of possible impacts, all waste rock might simply be removed from particularly environmentally sensitive areas along with the bulk sample itself. Clearly, with proper planning and execution, it appears to be technically feasible to greatly reduce, if not eliminate any significant long-term environmental impacts associated with exploration.

1.6 EXPLORATION CHAPTER REFERENCES

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