DEVELOPMENT OF A COPPER-NICKEL INDUSTRY IN NORTHEASTERN MINNESOTA

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ABSTRACT

Many factors and problems must be considered in the developing of a copper-nickel operation in the Duluth Complex of Northeastern Minnesota. Exploration studies in the Complex reveal large volumes of low-grade copper-nickel sulfides (65 billion tons) and relatively small quantities of high-grade material (in excess of one percent). The Duluth Complex has not been extensively explored and large areas of the Complex remain to be studied for their mineral potential. The known copper-nickel deposits are in a favorable geographic location with respect to labor, transportation, electrical power, water resources, and needed ancillary operations. The known deposits are found along the base of the Duluth Gabbro, and it is believed that most of the mineralized material will be found along the base. The deposits are found on Federal, state, and private lands, and therefore, the acquisition of these lands to prospect and permit to mine is different in each case. Federal and state mineral rights are leased, but private mineral interests may be bought or sold. Mineral land environment must be considered, as exploration and mining will affect the land, water, and air in varying degrees. Exploration can be carried out with no lasting effect on the environment, but actual mining can produce lasting effects. The degree to which the environment will be affected will depend on advanced planning, statutory authority to regulate the impact of mining on the environment, mineland reclamation plans, and the extraction method used or not used. Because
most of the copper-nickel deposits are within the Superior National Forest, prospecting and mining must follow the rules and regulations of the Forest Service and Department of Interior. Part of the Duluth Gabbro is in the Boundary Waters Canoe Area, but a court decision has terminated all attempts to explore the area and prevents future mining in the BWCA. Public opinion is against mining in the BWCA because of the effects that are feared it will have on the wilderness character. Although geological studies could be carried out without having any detrimental effect on the area. At the present, there is an oversupply of copper and nickel on the world market, but a projected demand is expected to substantially exceed supply in the future (10-20 years). Therefore, the United States will become more and more reliant on foreign sources. The prediction clearly indicates that additional U.S. copper-nickel operations will be needed. This report indicates the probability of success of such an operation in Northeastern Minnesota.
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Introduction

Attention continues to be focused on the Duluth Gabbro Complex, in Northeastern Minnesota, as a potential source of copper and nickel ore. Many problems besides the economics of production must be solved before the copper-nickel deposits can be developed into a profitable enterprise. Such as problems and factors concerning the geographic location of the copper-nickel deposits, the geology of the deposits, the acquisition of mineral lands to prospect and permit to mine, the use of prospecting and exploration systems, the economics of the copper-nickel markets and its relationship to the development of a copper-nickel industry in Northeastern Minnesota, the effects created by a copper-nickel industry on the environment, and the political factors involved in exploring or mining in or near the BWCA.

The purpose of this paper is to discuss the geological setting of copper-nickel deposits and to consider the problems involved in a possible development of a copper-nickel industry in Northeastern Minnesota.

HISTORY OF EXPLORATION

Occurrences of copper and nickel are noted before 1900 and again in 1919 (Sims, 1968), but the first significant discovery was made in 1948 by Fred Childers, Senior, near the South Kawiskiwi River in Lake County. Childers noticed
copper stain in weathered gabbro. Later investigators found gossans in the area of Childer's discovery. Studies by the Minnesota Geological Survey indicated widespread copper-nickel mineralization extending from the South Kawishaw River, east of Ely, southward to near Mesaba.

In the summer of 1951 Childers and Whiteside drilled to a depth of 186 feet, penetrating 11 feet of glacial drift and 177 feet of gabbro. The average assay of 104 feet of core was 0.36 percent copper and 0.13 percent nickel, with a 5 foot section from 21 to 26 feet that assayed 1.02 percent copper and 0.21 percent nickel; the sludge from 115 to 124 feet assayed 0.21 percent copper and 0.10 percent nickel; below 124 feet the sulfide content diminished rapidly and no more nickel or copper was found to the bottom of the hole at 188 feet (Schwartz and Davidson, 1952, p. 701).

Schwartz and Davidson (1952) make a study of the mineralized gabbro and concluded that there was an excellent probability of finding a commercial deposit.

Geological knowledge regarding large areas in northeastern Minnesota was almost non-existent until the Minnesota Geological Survey began a program of geologic mapping and sampling in the mineralized area in 1951. In 1953 the Minnesota Geological Survey's investigation consisted of geologic mapping and sampling by putting down three diamond drill holes. Most of the Duluth Gabbro was surveyed with the airborne magnetometer by the United States' Geological Survey.
In 1951 International Nickel Company obtained prospecting permits on a sizeable tract of Federal land within the Superior National Forest. They carried out exploration work that included substantial core-drilling which delineated large reserves of potentially mineable copper-nickel sulfides.

Bear Creek Mining Company began a systematic investigation in the Duluth Gabbro in 1952 on privately owned lands. Their work included geological and geophysical methods of investigations and drilling. No commercial deposits were known to have been discovered. In 1959 exploration work and options were terminated. Active exploration by other companies on the Duluth Complex slowed down until 1966.

In 1966 INCO negotiated mining leases on Federal permits. The passage of the Taconite Amendment, national need for copper and nickel, closing of iron mines at Ely, favorable market prices, and improved technology prompted INCO to proceed with its investigation.

Renewed interest of national scope in the mineral deposits of the Duluth Gabbro was triggered by: INCO's 1966 Federal mining leases, release to open files by the Minnesota Geological Survey in 1965 of a geologic map of the Gabbro Lake quadrangle (covers part of the known mineralized area), and the establishment of rules and regulations covering mining leases for copper, nickel, and associated minerals on state lands by the Minnesota Department of Conservation in 1966.
In 1966 the State set up mining units for competitive bidding along the base of the Duluth Gabbro, but outside the Boundary Waters Canoe Area. These mining units ranged in size from 40 to 640 acres. These state leases are for a 50 year period. Eleven mining firms were awarded 38,000 acres (265 mining units) in the 1966 land sale. Firms awarded substantial acreage included: Amax Exploration Inc., American Smelting and Refining Co., Bear Creek Mining Co., Cleveland Cliffs Iron Co., W.S. Moore of Duluth, Duval Corp., Hanna Mining Co., International Nickel Co., Newmont Exploration Ltd., New Jersey Zinc Co., Phelps Dodge Corp., and U.S. Steel Corp. At the end of 1967, mining leases on state lands totaled more than 86,000 acres and federal prospecting permits covered about 95,000 acres.

1968 was the third successive year that exploration for copper-nickel deposits remained at a high level. INCO had completed a development shaft to a depth of about 1,090 feet, and drifted through the mineralized zone on the 1,000 foot level, sampled and tested mining conditions. The 1968 drilling (Minnesota Geological Survey, 1968, p. 5) indicated large tonnages of low grade copper and nickel bearing deposits near the base of the Gabbro. To aid exploration, gravity, geologic reconnaissance, and aeromagnetic maps of the southern part of the Complex were completed by the Minnesota Survey.

Exploration remained at a high level into 1970. Geologic mapping was carried out in adjacent areas to the west
of the Duluth Complex by the Minnesota Survey. The state of Minnesota held its fourth sale of copper-nickel leases in 1970. Favorable deposits were close-drilled and were being evaluated for possible mining. The Gaburo was tested to depths of at least 6,000 feet (Minnesota Geological Survey Newsletter, 1970). Detailed mapping was continued along the northern margin, adjacent to and within the Boundary Waters Canoe Area.

1971 marked the fifth sale of copper-nickel leases in Minnesota. Exploration and development slowed because of decreasing prices for copper and nickel, surpluses, new finds of high-grade nickel deposits, and an overall slumping economy.

**GEOGRAPHIC LOCATION**

The Duluth Complex extends in an accurate outcrop pattern from Duluth northeastward for a distance of 150 miles and covers an area of about 4,500 square miles. It is located in St. Louis, Lake, and Cook Counties. Most of the Complex is situated in the Superior National Forest and partially in the Boundary Waters Canoe Area. The southern part of the Gaburo Complex is outside of the Superior National Forest. See Figure 1.

The known sulfide occurrences are in a narrow belt about 35 miles long and a mile wide between Hoyt Lakes and the vicinity of Ely. These sulfide deposits are accessible to transportation, population, utilities, and ancillary operations. State Highway 1 crosses the known occur-
Figure 1. The geographic location of the Duluth Complex with respect Superior National Forest, Boundary Waters Canoe Area, and Counties.
rences and connects with U.S. Highway 61 to Two Harbors and Duluth. The Duluth, Missabe, and Iron Range Railway run within five miles of the known deposits. See Figure 2.

Lake Superior is about 45 miles from the prospects and would serve as an excellent waterway for the transport of the ore. The deposits are within reasonable distance of rail, road, and water transportation. The towns of Ely, Babbit, and other towns are within 8 miles of the sulfide deposits and could serve as a source for labor. It would appear that no new towns will be required, but existing towns may have to be expanded. These towns may have to provide expanded public services, which are usually paid for by the mining companies.

Electrical energy can be supplied by the existing utilities. No new power plants will be required for initial operation of the Gabbro Complex. Although, if and when a smelter and a refinery is considered in Minnesota, a power plant may be needed (Inter-Agency Task Force on Base Metals).

The South Kawishiwi River is in the area of the known sulfide deposits and would probably serve as a source for water.

Based on the above information, the known sulfide deposits of the Duluth Complex appear to be in a geographically favorable location.
Figure 2. Geographic location of known copper-nickel deposits with respect to highways, towns, railways, power lines, and water resources (compiled from various sources).
GENERAL GEOLOGY OF THE DULUTH COMPLEX

The Duluth Complex is a large composite basic igneous intrusive of Upper Precambrian age. It is bounded on the southeast by the Upper Precambrian North Shore volcanic group and on the northwest by older Precambrian rocks. At Duluth, the Complex is overlain and underlain by Keweenawan flows. The Duluth Complex intruded along an unconformity between the overlying volcanics and the underlying older Precambrian rocks. See the Geologic Map of the Duluth Complex area, Figure 3.

The Gabbro Complex is composed of multiple intrusions, as indicated by geologic mapping and related studies of it over the past decade (Schwartz and Davidson, 1952; Taylor, 1964; Green, Phinney and Weiblen, 1966; Phinney, 1969). It dips southeastward toward Lake Superior at angles ranging from 5 to 50 degrees. The composite intrusive consists primarily of gabbroic anorthosite and troctolite (olivine-rich gabbro) rock types with lesser amounts of intermediate composition rocks and granophyre. The gabbroic anorthosite is intruded and is older than the troctolite (Green, Phinney, and Weiblen, 1966). Sims (1968) estimates that the gabbroic anorthosite makes up about 60 percent of the complex. So far as known, the troctolite occurs primarily near the base of the Complex.

**Occurrences of copper-nickel sulfides**

All potentially mineable copper-nickel-bearing sulfides that have been found are in troctolitic gabbro and near the
Figure 3. Generalized geologic map of the Duluth Complex
(Weiblen, Davidson, Morey, and Mudrey, 1972)
base of the particular intrusion. Geologic mapping and drilling indicate that the lower part (the base) of the Complex is the most favorable to look for copper-nickel deposits (Sims, Morey, and Green, 1969). See Figure 4 for the known occurrences of copper-nickel sulfides. These occurrences extend discontinuously for about 25 miles from the vicinity of the South Kawishiwi River, east of Ely, southward to near Mesaba.

The area adjacent to the South Kawishiwi River is the best known geologically and has been extensively explored. Two bodies of troctolite intrude anorthosite gabbro in this area (Green, Phinney, and Weiblen, 1966). The copper-nickel deposits are associated with these troctolite intrusions (Sims, 1967). The copper-nickel sulfides show two contrasting occurrences. Northeast of State Highway 1 the sulfides are irregularly distributed in the lower part of the troctolite as discontinuous lenses and southwest of the highway the sulfides have a more uniform distribution in a possible tabular body that lies just above the base of the gabbro.

In summary, available data indicated that all potentially mineable copper-nickel bearing sulfides are found in troctolite gabbro that occurs near the base of the Complex. Drilling indicates that the deposits are mainly disseminated copper and nickel sulfides which are widely dispersed in the lower part of the gabbro (Sims, Morey, and Green, 1969).
Figure 4. Known occurrences of copper-nickel sulfides in the Duluth Complex (Sims, 1969).
The northeastern part of the Duluth Complex does not seem to be favorable for the occurrences of sulfide bodies, but sufficient studies have not been done to prove this.

**Mineralogy of copper-nickel sulfides**

The sulfides present are chalcopyrite \((\text{CuFeS}_2)\), cubanite \((\text{CuFe}_2\text{S}_3)\), pyrrhotite \((\text{FeS})\), pentlandite \((\text{NiFeS})\), pyrite \((\text{FeS}_2)\), and locally bornite \((\text{Cu}_5\text{FeS}_4)\) (Sims, 1967). The copper occurs mostly in chalcopyrite, which is typically intergrown with pyrite. Most of the nickel is restricted to pentlandite. Magnetite \((\text{Fe}_3\text{O}_4)\) and ilmenite \((\text{FeTiO}_3)\) occur as intergrowths and are commonly associated with the sulfides. Biotite and hornblende nearly always occur with the sulfide minerals. The sulfide minerals commonly occur as: interstitial grains (associated with or enclosed within pyroxene or plagioclase), myrmekitic intergrowths with late-stage pyroxene and plagioclase, and as fine grained inclusions in silicates (Sims, 1968). Massive podform bodies of sulfide minerals (up to several feet in width) and tiny irregular discontinuous veinlets of sulfide minerals have been noted.

The sulfide minerals constitute 3 to 5 percent of the material in the ore zones. INCO reported that the material they were developing contained about one percent combined nickel and copper in the ratio of about 3 parts copper to 1 part nickel (Sims, 1967, p. 61)

**Origin of sulfides**

Sims (1967) interprets the ore minerals to be of mag-
matic origin, because of the texture of the sulfide minerals and their paragenetic relations to the silicate minerals that indicate the ore formed contemporaneously with the silicates (Sims, 1969, p. 62). The sulfides were probably formed by the accumulation of sulfide droplets during the early part of the crystallization of the troctolite. The copper and nickel incorporated in the sulfides was concentrated from the magma that created the troctolitic rocks (Bonnichsen, 1969).

ACQUISITION OF MINERAL LANDS TO PROSPECT AND PERMIT TO MINE.

The copper-nickel deposits are on federal, state, and private lands. Regulations and rules that govern the acquisition of these lands are different. It is important to understand the nature of leases used in the three types of ownership. Moore (1969, p. 105-109) and Wayland, Bailey, and Gazdik (1967, p. 65-67) summarize the acquisition of the various types of lands in the mineralized areas.

Federal lands

The Secretary of Interior is in charge of leasing Federal lands. The first step is to acquire a prospecting permit from the Bureau of Land Management for a fee of 10 dollars plus 25 cents per acre of land acquired. The permit is limited to 2,560 acres and is issued for two years. It may be extended for an additional two years, if the owner can show that he has actively prospected for the first two years. The second step is to acquire a lease for the
property. Proof of commercial value of the deposit, nature of deposit, and extent of it must be disclosed for a lease of Federal property.

The lease may be granted for a ten or twenty year period and may be renewed for three successive ten year periods by the Secretary of Interior. He prescribes the terms by which the leases may be renewed. A Federal lease may last a total of 50 years if it is renewed to the full extent.

The Department of Agriculture in conjunction with the Department of Interior controls surfaceland. If the land is in a national park, the supervisor of the park is in control of the land surface. The Supervisor of the Superior National Forest is in control of the land surface in the mineralized area. A plan of development of the mining operation must be submitted to the authorized official. The plan of the mining operation on the Federal land must disclose: location and extent of area used, method of mining, type of equipment used, size of all surface structures, area where vegetation destroyed, means to prevent soil erosion and water pollution, and program to restore disturbed land.

The exact terms of a Federal lease are negotiated. A typical Federal lease (Moore, 1969, p. 106) has an annual rental rate of 1 dollar per acre, until production begins, and a royalty rate of 4 percent of the gross value of minerals mined and shipped to concentration mills for the first
10 year period and \( 4\frac{1}{2} \) percent during the second 10 year period. The rental rate for the second ten year period is raised to a minimum of 5 dollars per acre and to a minimum of 10 dollars per acre for successive renewals. The Secretary of Interior, may in his discretion, increase the royalty rate to 5 percent during the first ten year period, to 6 percent during the second period, and to 7 percent during the third period. Underground operations' royalty rates in successive periods are usually .5 to 1 percent of the total base less than for royalty rates for open pit operations.

Royalty rates are determined by the percentage of gross value of minerals mined and shipped to the concentration mill. The gross value of the minerals mined and shipped to the concentrate mill is equal to \( \frac{1}{3} \) of the market price of the fully refined copper and nickel. Market prices of copper and nickel, F.O.B., are taken from the Engineering and Mining Journal.

State Lands

The rules and regulations that govern the leasing of state lands for copper and nickel are patterned after Minnesota's rules and regulations for the leasing lands for mining of iron and taconite. Mining units include lands that the state is willing to lease for mineral exploration and development. Mining units, where in the state owns an interest in the mineral rights of a section, range in size from 40 to 640 acres.
State mineral interests are granted by the Commissioner of Conservation after competitive bidding at a public sale. The Commissioner may issue a state lease to any qualified buyer, without a public sale, if it is in the best interest of the state. Final approval of awarding any leases as well as the adoption of rules and regulation authorizing prospecting, leasing, and mining is vested with the Executive Council of the Department of Natural Resources. Normally, where there is a general interest, leases are obtained by competitive bidding. The successful bidder is the one offering the highest royalty above the minimum rate of 2 percent of the value of the minerals in the mill concentrate. The form of the lease is set under the rules and regulations. The royalty rate is the only provision left open.

The state leases are for a fifty year term. The first two years of the lease are considered the prospecting period. There is an annual rental rate on each acre that escalates after each five year period, as follows: 1 dollar per acre per year for the first five year period, 5 dollars per acre per year for the second five year period, and 25 dollars per acre per year thereafter until mining begins.

Minimum royalty rate is 2 percent of the value of the metals and mineral products recovered in the mill concentrate and an additional 2 percent of the portion of the value of the metal and mineral products, recovered in the mill concentrate, that exceed 17 dollars per ton of dried
crude ore. Minimum royalty rates escalate to 2\(^1/4\) percent said value for the second ten year period, to 2\(^1/2\) percent for the third ten year period, to 2\(^3/4\) percent for the fourth ten year period, and to 3 percent for the fifth ten year period. During the first ten year period royalty rate is the same for both open pit and underground mining, but after the first ten year period open pit royalty is increased 33\(^1/3\) percent more than for underground royalty.

**Private Lands**

Private leases are a person-to-person legal transaction and the terms of the sale are determined by the seller and buyer. Royalty rates may follow the state form, the "boiler plate method", or follow some other method. Obtaining leases for private mineral rights is sometimes a problem because of unknown ownership.

Moore and Rahn (1969) discuss some of the problems involved with the different types of leases:

The problem of determining ownership of mineral rights in private leases can be a difficult problem. Records of ownership have not been kept in many cases and quite often surface and mineral ownership are separate. Development of some mineral deposits may be hindered for many years because of the lack of knowledge of ownership. A bill to identify and clarify ownership is much needed. The Minnesota State Legislature has before it a bill to eliminate the problem of ownership of severed mineral interests. It
advises that the state confiscate the unclaimed mineral interests. The problem is extremely complicated; some mineral property has undivided ownership in the millions as reported by the Land Exchange Review Board. I feel the above bill is an effective method to eliminate problems of ownership of some private mineral rights and open these mineral properties for exploration.

Establishment of a fair royalty rate is another important problem. What should royalty rates be based on? The Federal leases give some thought to smelting costs; royalty rates are based on the refined metals. State leases give no consideration to smelting; royalty rates are based on recovered minerals in the mill concentrate. I agree with Moore and Rahn (1969) that a royalty rate based on net smelting or leaching returns would be the best choice.

Is competitive bidding the fairest way of obtaining mineral interests on state owned land? Moore argues that bidding denies the small-scale prospector the gains of original discovery and open it up to anyone with enough money. For competitive bidding, Rahn points out that much of the mineral rights bought in Minnesota were held only for speculative purposes, and the purchaser was not a prospector or potential mine operator. Thus, the Department of Conservation is not dealing with the prospective operator, but with people whose main objective is an overriding royalty. I feel that competitive bidding for state leases
favors the large operator and gives little incentive to the small operator. The state lease system should consider both the original prospector and the potential mine operator.

PROSPECTING AND EXPLORATION SYSTEM

Prospecting is the search for ore occurrences and exploration also includes the work involved in gaining knowledge of the shape, size, position, and value of an ore body. Private companies and the Minnesota Geological Survey have made some extensive studies of the Duluth Complex, but there still are many problem areas and unexplored tracts of land to be prospected and explored.

Except for detailed maps of the South Kawishiwi Intrusion (Green, Phinney, and Weiblen, 1966), Duluth Area (Taylor, 1964, and Davidson's current work on the Complex, geologic maps that show separate intrusive bodies and structural data within the Duluth Gabbro are not available (Sims, 1969). Therefore, a much more detailed study of the Complex must be completed before a clear picture can be drawn. Geologic mapping and geophysical surveying are useful to delineate exploration targets in the unmapped areas.

Private companies have conducted extensive exploration studies of mining units in the Duluth Gabbro. Much of the recent work has been directed by the need to evaluate lands in a relatively small specific areas. Consequently, many of the gross structural and genetic problems of
the Duluth Complex are not understood (Lindgren, 1967, p. 64). Lindgren emphasizes the need for statistical three-dimensional data to accurately describe size, shape, and grade of mineralized zones and studies to determine whether structural controls have localized the sulfide occurrences. More studies are also needed to determine the extent of associated minor amounts of cobalt, precious and noble metals, because such recoverable elements could be a major factor in the final evaluation of the deposit.

The Minnesota Geological Survey is helping exploration work by geologic mapping and gravity surveys.

Figure 5 illustrates an integrated exploration program that could be used in the developing of the Duluth Complex. As one goes from left to right in the diagram

Figure 5. A typical exploration system (Warc, 1972).

the cost per square kilometer increases. The modules used in this exploration venture are optional. After each stage of a program, and an appraisal must be made to determine
whether it is economic to continue work.

After the decision is made to go ahead with exploration, geologists must decide what methods of explorations are needed to obtain knowledge of tonnage and grade of ore in the deposit. This may require detailed geologic and geophysical studies, drilling, trenching, and driving of adits and shafts.

Many geophysical methods have been used, but all of them have not been successful. Aeromagnetic data is insufficient to show separate rock bodies of the Complex, but gives some clues to the shape and lithology of the body. Because of the density difference between anorthosite gabbro and troctolite, gravity data is useful to help distinguish the different rock types. Magnetic and gravity data used together are particularly helpful where the bedrock is largely covered by glacial and swamp deposits. Many companies have used airborne electromagnetic methods to find exploration targets, but graphite and magnetite near the base of the Complex and electromagnetic responses from swamps have complicated interpretations (Sims, 1967).

Other methods include diamond drilling and geochemical methods. Diamond drill tests have been done to depths of 6,000 feet (Minnesota Geological Survey Newsletter, 1969). Glacial till cover has hampered the use of geochemistry.

After a possible ore body has been located, a decision of whether development should be undertaken must be made. The decision must consider: is the ore body large
enough to be desirable, what shape is it and does it qualify for open-pit or underground mining, and what are the physical characteristics of the ore (Park, 1967)?

Present data (Sims, 1968) indicates that the copper-nickel sulfide deposits of the gabbro are of two types: (1) estimate of hundreds of millions of tons of relatively low-grade sulfide material (less than 1 percent) and (2) relatively small deposits of copper-nickel sulfides in excess of 1 percent. The Minnesota Geological Survey (1973) has estimated that the Duluth Complex contains at least 6.5 billion tons of mineralized material that has an average grade of 0.35 percent combined copper and nickel. The Minnesota Survey estimates the gross value of these metals at 55 billion dollars. Most deposits are not found at shallow depths (INCO, 1968) and therefore, do not qualify for open-pit mining. It is believed that most of the ore exists in type (1) deposits in the ratio of about three parts copper to one part nickel.

With the above information, a feasibility study should include an investigation of available transportation, mining methods, grinding and concentrating, metallurgy, and disposal of wastes.

Results of the investigation reveal: Rail, road, electrical power, water, labor and most ancillary operations are all within reasonable distance to known occurrences. Tests completed by the Mine's Experiment Section, University of Minnesota, and the United States Bureau of Mines on bulk sulfide samples indicated that most of the sulfide
minerals are liberated at 100-mesh (Sims, 1968). While, a grind of about 270-mesh is required to free the copper-iron sulfides from the nickel-iron sulfides. The tests also revealed that the amount of copper recovered from the bulk sulfide circuit was over 90 percent but nickel recovery ranged only 50 to 85 percent. The amount of nickel and noble metals recoverable will be a major factor in the final economic evaluation. Carriere (AIME, 1972) designed a roasting process for extracting copper and nickel from the Duluth Complex material.

With careful planning tailings may be disposed of in a manner which is agreeable with mine operators and environmentalists.

MINERAL LAND ENVIRONMENT

There has been a growing concern for the environment in the United States and especially in the Northern states. Northeastern Minnesota is an area of natural beauty, one of the last areas of the United States to be considered a wilderness area. The people of the State of Minnesota and especially of Northeastern Minnesota are very concerned over the effects of developing a copper-nickel mining industry in their part of the State. The local and national concern for mineral land environment can not be ignored.

The public and the mining industry must assume their full responsibility in the pollution problem. The United States Bureau of Mines feels that the mining industry must pay the bill for pollution, within their bounds to pay (Hayes, 1970), but one must remember that it is the public
who pays in the long run.

Mineral land environment is a serious problem facing the potential copper-nickel mining industry of northeastern Minnesota. It is not only a financial problem but a public relations problem, and must be dealt with before production begins. By dealing with the problem before production, the public and the mining industry can help to prevent costly and impossible future reclamation projects. The public must keep in mind that they should make it as attractive venture as possible, if they do not want to frighten off the mineral industry with impossible requirements. The mining industries' side of the problem should be openly revealed and recognized if there is a genuine interest in developing a copper-nickel industry in Minnesota.

The copper-nickel mining industry could have an effect on air, land surface, and water. Careful planning of the mineral land environment should control the extent to which air, land surface, and water are affected. Let us examine the problems that a copper-nickel development could cause to the environment and their possible solution.

**Land Surface**

Because the potential deposits will probably be mined by underground methods, the actual surface area required for the underground mine would be very small (10 to 20 acres). Although, the land required for tailings and waste rock would be considerable (about 1,900 to 5,100 acres). Therefore, the total land required for the entire mine operation
would be somewhere between 2,600 and 5,800 acres (Inter-Agency Task Force on Base Metals, 1973, p. 6-15). The total land surface affected by the direct extraction of the ores and the operation equipment is minor and is not a major problem. The White Pine Mine, Michigan supports the above statement.

Only a small fraction of the sulfide ore of the Complex is recoverable as copper and nickel. For example, some of the lower-grade materials of the gabbro contains only 0.3 percent combined copper and nickel and the rest is mine waste and tailings disposal. This results in a great volume of waste material. The waste material is not usually a physical danger but a problem of aesthetics. There is little danger in living with mine dumps, as they usually revert to vegetation-covered detritus piles in time. Although, metallurgical tailing that are finely ground may present dust problem if not covered by vegetation. There is also the problem of where to put the mine waste and tailings, because of the large area required (2,000 to 5,000 acres) and the permanence of the dumps.

Mine waste and tailings disposal is a problem, but it is not a problem without a feasible solution. A method called Designed Environment Development is the cresting of land forms from mine waste to accommodate uses such as skiing, hiking, and other types of recreation as a part of the mining operation. This process is designed to make the mining operation compatible with the surrounding area and the surrounding area compatible with the mining
operations (Schellie, 1970). Thus, creating a more aesthetically pleasing and useful land surface from the mine waste and mined areas. The United States Bureau of Mines and Kennecott Copper have been making successful studies on growing vegetation on tailing piles (Merritt, 1972). Experimental work is being done on waste dumps to make them less harmful to the environment and to reclaim the tailings for other uses, thus eliminating the presence of the tailings. An alternative may be to dump a portion of the tailings (2/3 of total amount) back into the underground mine and leave the rest of the tailings (1/3) at the surface. Careful planning and technology are the keys to solving the land surface problems. The current 1969 statutory authority dealing with mineland reclamation is inadequate in effectively reclaiming and restoring disturbed minelands, but a bill is being prepared by the Department of Natural Resources for the 1973 Legislative Session to solve the above problems.

Water

The copper-nickel extractive industry is not a major contributor to water pollution (Spedden, Research Director of the Metal Mining Division Denneecott Copper Corporation, 1970). Individual operations may have their own unique problems, most of which are not without a solution. The copper and nickel industries have good records for the conservation of water (Spedden, 1970). Most operation have facilities for the effective recycling of tailings' water and means for water clarification and purification. The
Minnesota Pollution Control Agency has the authority to effectively control environmental impacts on water resources.

**Air**

If smelting is carried out in Minnesota, air pollution must be considered. Air pollution is the major pollution problem involved in the extraction of copper and nickel from sulfide ores. The production of copper and nickel from sulfide minerals is a series of smelting steps in which sulfur is burned off forming gaseous sulfur oxides. These gases are hazardous to humans and vegetation, depending on concentrations.

Primary and secondary smelting account for 12 percent of the total sulfur fumes emitted into the atmosphere by man-made sources. See Table 1.

Table 1. World emissions of sulfur into the atmosphere by man-made sources (after Habashi, 1969, p.59)

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal and oil combustion for electricity</td>
<td>50%</td>
</tr>
<tr>
<td>Other combustion of coal</td>
<td>16%</td>
</tr>
<tr>
<td>Other combustion of oil</td>
<td>9%</td>
</tr>
<tr>
<td>Primary and secondary smelting</td>
<td>12%</td>
</tr>
<tr>
<td>Petroleum refining</td>
<td>7%</td>
</tr>
<tr>
<td>Miscellaneous sources</td>
<td>6%</td>
</tr>
</tbody>
</table>

The smelter is a source of trouble for the copper-nickel industry because of the readily visible and highly localized smelter plume and a public concern for clean air. Because of the public's concern for smelter gases, the mining industry has taken several steps to alleviate the problem. A gas with a high sulfur content (at least 46 percent
$SiO_2$, Merritt, 1972) can be converted to sulfuric acid. In some steps of the smelting process, the sulfur dioxide content is too low to be converted to acid. The National Academy of Engineering has concluded that, "Contrary to the widely held belief, commercially proven technology to control sulfur oxides from combustion processes does not exist" (Merritt, 1972). Thus, indicating that smelting also needs some new developments to effectively control sulfur fumes. Although, alternatives such as hydrometallurgy can be used if the economics and chemistry of the operation permit its success.

The control of sulfur during the treatment of the copper-nickel sulfide concentrates lies in three approaches or alternatives: (1) develop more efficient methods of removing sulfur oxides from gases produced by the burning of sulfur in air, (2) develop new smelting methods that eliminate the emission of low-strength sulfur dioxide gases, and (3) develop an alternate process that does not require the burning of sulfur.

Progress has been made in all three alternatives, but the third approach, "chemical smelting", has become increasingly more attractive. Chemical smelters promise to be competitive, if not better than pyro-smelters (Robb, Lawrence Radiation Laboratory, 1972). Chemical processes would eliminate the sulfur dioxide problem, but could create effluent streams of impure water. There is no competitive, universal hydrometallurgical process for the extraction
of metals from sulfide ores at the present. Though, there are such processes in use today as the Sherritt Gordon Process that is acceptable for special situations.

Steps have been taken by government agencies to control the amount of sulfur gases emitted by smelters: restrictions for the removal of 90 percent or more sulfur from nonferrous smelters by 1975 (Environmental Protection Agency), tax proposals on sulfur dioxide emissions, and proposed property tax exemptions on pollution control facilities.

The public and government agencies should remind themselves that unobtainable restrictions will hamper the development of the copper-nickel sulfide deposits of the Complex and elsewhere.

Smelting operations face serious opposition. Public opinion is against the present type of smelter; modifications must be made or alternate processes must be found. At the present, smelting serves as the only economical means of metal extraction of most sulfide ores. Various methods are available to reduce the emission of sulfurous gases, but the added costs would force many marginal operations under and prohibit the opening of many new developments.

Proposed laws are going to make it difficult or impossible to use the present types of smelter without sulfur dioxide control. Environmental protection will be a contributing factor to increase metal costs, which will be passed onto the public. The mining industry recognizes its role of having to increase metal production and to do this within
the constraints imposed by the public for a cleaner environment.

An alternate possibility, would be to smelt elsewhere at an established plant, outside of Minnesota. It was indicated at an Inter-Agency Task Force meeting on base metals that concentrates would not be initially smelted in Minnesota but possibly in Canada. Whether smelting takes place in Minnesota would depend on the number of discoveries, size of operations, and economics.

Summary

A 1973 survey carried out by the Inter-Agency Task Force on Base Metals indicated that Northeastern residents of Minnesota are environmentally oriented but do not intend to let extreme environmental regulations inhibit their economic advancement. The Southern residents feel that the long range preservation of natural and wilderness areas are more important than economic advancement. Residents of Southern Minnesota seem to want more regulations to protect the environment and to delay initial mining operations. The majority of residents of Minnesota favored the exploration and mining of copper-nickel in Northeastern Minnesota. The entire state believed that it is possible to have mining industry and environmental protection. The poll indicated to me that the state residents want to develop the copper-nickel deposits but not at the expense of the environment.

A copper-nickel development in Northeastern Minnesota
would affect the water, air, and land surface to varying degrees. There is little danger now of the industry having a detrimental effect on water because of the modern technology available (Kennecott Copper Corporation). Should an industry seek permits for copper-nickel mining, they would have to establish with the Minnesota Pollution Control Agency that they could comply with the new Water Pollution Control Amendments of 1972. Therefore, I believe there is sufficient statutory authority at the present to control environmental impacts on water resources by the mining industry.

Only small areas will be affected by exploration and the actual mining operation (DNR). Although, large areas of land will be affected by mine waste and tailings disposal. The large volumes of waste may be used as mine fill, shaped into useful landforms, or used for fill in other areas. The real problem with the land surface is the aesthetic changes that may take place, but these can be controlled by careful planning. I do not believe present statutory authority for mineland use and reclamation is effective, but the Department of Natural Resources' bill on reclamation and mineland use will eliminate the problem if passed by the 1973 Legislature. The present statutory authority does not provide for a comprehensive program capable of reclaiming and restoring an area disturbed by mining, nor is it compatible with Federal legislation expected for passage in 1973.

Present day smelters without sulfur control devices
will emit harmful, gaseous sulfur oxides into the air. At the present, the smelter is the only universal and economical method for the extracting of metal from sulfide ores. Hydrometallurgy can be used, but costs usually prohibit its use on marginal deposits. There are many control devices that can greatly reduce emission of sulfur gases (up to 90% removal). In smelting steps where the gases emitted exceed 46 percent in sulfur dioxide, sulfuric acid can be produced.

In conclusion, I feel that complete exploration of the Complex should and can be completed without causing harmful effects to the mineral land environment. The effects on the environment produced by mining operations can be controlled by careful planning and use of present day technology. Smelting does not even have to be done in Northern Minnesota, the ore may be shipped to an already established plant outside of Minnesota. Effective regulations should and is being put into law to limit mining's impact on the environment. My own personal observations of the White Pine Mine, Michigan have convinced me that such an operation can exist near a wilderness area without damaging the environment. Mining operations will bring about changes but they do not have to be detrimental to the environment.

POLITICAL FACTORS (BWCA)

Because the copper-nickel sulfide deposits of the Duluth Gabbro are primarily within the Superior National Forest and Boundary Waters Canoe Area, the deposits are subject to many rules and regulations. These rules and reg-
ulations pose some unique problems to the copper-nickel industry. A clear picture of the situation is important to both the public and the mining industry.

The Duluth Gabbro is situated primarily within the Superior National Forest. See Figure 6. The Secretary of Interior is in control of all minerals on Federal land, while the Department of Agriculture, or more particularly, the Supervisor of the Superior National Forest is in charge of the surface land. All exploration and mining operations must follow the rules and regulations set up by the Forest Service. See part on land acquisition for rules and regulations governing mining of Federal lands.

The ownership of minerals in the BWCA is divided into:
three groups: (1) the State of Minnesota owns mineral rights on 103,000 acres, (2) the Federal Government owns land and minerals on 401,000 acres, and (3) private parties (618 individuals and companies) own mineral rights on 284,596 acres. Plus, there are 270,000 acres in the BWCA whose ownership of mineral rights is complicated and presently unknown. (Report to the Secretary of Agriculture, 1964).

The northern 40 miles of the basal contact of the Duluth Complex is within the BWCA, which has been incorporated into the national wilderness preservation system under the Wilderness Act of September 3, 1964. This act established a National Wilderness System to consist of federally owned areas designated by Congress as Wilderness Areas. These areas are to be administered for the use and enjoyment of the American people in such a manner as will leave them unimpaired for future use and enjoyment as a Wilderness. The Wilderness Act, Section 4, also provides a nineteen year period for exploration in the lands set aside as wilderness areas. Section 4, subsection d, paragraph 2 and 3, explicitly specify the regulations under which the mining industry may carry on its operations.

In 1965 the Secretary of Interior, who controls all minerals on Federal lands, and the Secretary of Agriculture made a special agreement that there would be no mining or mineral exploration, or leasing permitted on Federal lands within the BWCA except under extreme national emergency. To prevent the threat from mining interests, the Superior
National forest has asked the State of Minnesota to exchange its Duluth Complex lands and mineral rights within the BWCA for Federal Lands outside of the BWCA. The State of Minnesota has been reluctant to exchange these lands but has stopped all mineral leasing and selling of its lands in the BWCA.

There are two main types of national forest lands within the BWCA. The first type is land which has been reserved from the public domain for national forest purposes or lands which have been acquired in exchange for public domain lands. The second type is acquired lands, obtained for the national forest purposes by purchase, exchange or donation. The Act of June 30, 1950 (64, Statute 317; 16 U.S.C. 508b), provides for the mining on lands reserved from the public domain for national forests in Minnesota. Federal leases and permits are issued by the Department of Interior and must be consented by the Secretary of Agriculture. But the 1965 agreement between the Secretary of Interior and Secretary of Agriculture has terminated the issuing of permits and leases on Federal lands in the BWCA.

Approximately 1/3 of the national forest lands within the BWCA are without mineral title. The largest portion of these lands are within a triangular area which lies north of Township 63 North and is bounded on the east by the Lake-Cook Counties line and on the north and west by the International Boundary. Most of these lands were in private ownership, and almost without exception, the mineral rights
have been separated from the surface title at the time of federal acquisition of these lands. These privately owned mineral rights beneath the lands of the BWCA are considered the greatest immediate "threat" to the BWCA by the Northern Environmental Council. The potential for ultimate mining development within the BWCA does exist.

It is on a part of the privately owned mineral rights that the late George St. Clair proposed to enter and explore with drilling equipment. The Izaak Walton League of America has brought a court suit against St. Clair and Thomas Yawkey, both from New York, to prevent them from prospecting and exploring in the BWCA. Yawkey contends that he has no mineral interest in the mineral rights of the BWCA. The League is also challenging the existence of private mineral rights and for the rights that exist, the ability of private holders to exploit their holdings (Way, 1970). The League contends that the Secretary of Agriculture, United States Forest Service Chief, and Superior National Forest Supervisor must prevent continuation of mineral explorations in accordance with the responsibilities of their offices (Duluth Newstribune, January 15, 1970). The State of Minnesota has offered to join the Izaak Walton League in its legal request to prevent mineral exploration in the BWCA. Judge Philip Neville handed down an injunction early in 1973 preventing copper-nickel exploration and mining in the BWCA in response to the Izaak Walton League Suit. William P. O'Brien, attorney for some owners of mineral rights in the wilderness area, has made a motion to
amend Judge Neville's order to ban mineral exploration in the BWCA. The motion has been taken under advisement by Judge Neville.

State Senator Perpich has proposed that the Minnesota Department of Conservation give an inventory of state-owned copper-nickel lands to exchange with St. Clairs outside of the BWCA. According to the late St. Clair, the mineral rights in the BWCA could be worth $1^{1/2}$ million dollars per acre with ore containing 1 percent copper and $7$ million dollars per acre if the ore contains $1^{1/4}$ percent copper metal. Evaluation of the mineral values in the BWCA is a problem; there are those who feel it is possible to determine the value of the minerals without drilling and those who feel it is impossible to do it without drilling. I feel it is impossible to adequately determine the value of a deposit without drilling, because you do not know what is down there until you can sample it.

The Northern Environmental Council and concerned legislators contend that the status of both the state lands and private sub-surface mineral rights must be resolved if the BWCA is to be freed of so called exploitative pressures (mineral exploration and development). The Council has issued a report (1970) calling for the acquisition of privately owned mineral rights in the BWCA by condemnation through use of eminent domain, authority invested in the Federal government. To accomplish this, three measures were proposed: (1) acquire all mineral rights and establish value without drilling, (2) annual registration of all
separately held mineral rights; failure to do so would result in reversion of mineral rights to surface owner, and (3) equitable exchange of state lands within the BWCA for Federal lands outside the BWCA or direct sale to the United States.

There are both pros and cons for the exploration and development of minerals in the BWCA:

Cons:

Many who are against mineral exploration argue that mineral exploration will spoil the wilderness character of the area. They point to International's Nickel's exploration development outside of the BWCA to verify this (Northern Environmental Council, 1970). They insist that the discovery of commercial ore would bring roads, railroads, smelters, and water and air pollution. The White Pine Mine, Michigan has not added any environmental problems yet, and is proven fact that mining operations do not always bring environmental pollution. These people believe that preservation of a wilderness is impossible with the development of a mineral deposit.

Most of the present heirs to the mineral rights that were reserved are conceivably second, third, or fourth generation, though the family might not have owned the surface rights since the first family. The owners of the mineral rights have not paid a cent of property tax in all that time which is levied against all other owners of real property to support schools and county governments. Therefore, why should the present owner's of the mineral rights
be given the right to develop the minerals.

In many cases, these mineral rights are divided among many non-resident of Minnesota heirs (registered and unregistered). If a major discovery is made in the BWCA, the people of Northeastern Minnesota would not be the principal beneficiaries. Northeastern Minnesota would benefit little because of the Taconite Amendment, tax exemptions, and the non-residency of mineral development corporate owners. The non-resident stockholders and mineral right owners would gain the most by exploration and development. The above statements do not take into consideration that vast number of jobs that would be created and the amount in payrolls. The Department of Natural Resources estimates that a development in the Duluth Gabbro would create over 2 thousand jobs and payrolls in excess of 4 million dollars.

Pros

Despite the adverse comments that have been made regarding mineral exploration and mining in the BWCA, the importance of and the need for all types of minerals must be recognized. The importance of minerals in our industrial civilization is given in the following statement (Report to the Committee on Natural Resources, National Research Council), "Mineral and metals are woven into every pattern of man's past and present industrial effort. It is safe to predict that they will be no less important in the future" The success and prosperity of the United States and its people depend on locating and obtaining these minerals. Therefore, it is to our advantage to know as much as possible.
about our resource potential.

If the Federal Government is to compensate the state and individuals for lawful surrender of their mineral rights, a true evaluation must be made of the mineral interests. A spokesman for the Bureau of Mines, Merrill, said "Short of actual test drilling it is almost impossible to evaluate the grade and magnitude of these metals in terms of their value for the national economy and defense requirements" (Duluth News-Tribune, May 19, 1970). State Senator Higgins has been assured by competent mining authorities that a diamond drill can be moved in, carefully used and moved out leaving little or no trace to its use. As a geologist, I have seen by personal observation that exploration can be carried through without causing adverse environmental problems.

The owners of mineral rights claim that they sold their land in the BWCA with the understanding that their mineral rights be preserved. The owners would not have sold their land if they thought they would be unable to exercise their mineral rights in the future. The owners are still the legal heirs to the mineral rights.

One of the main reasons why many feel that exploration and mining should be carried out in Northeastern Minnesota is to create employment and to increase the economy. A spokesman for the State Department of Natural Resources said at a hearing held in Bemidji that some 3,000 new jobs would be generated by nickel-copper development in Northeastern Minnesota. Surveys by the Inter-Agency Task Force
on Base Metals' mining in Minnesota and the Minerals Subcommittee of the Natural Resource Advisory Council cited that payrolls in excess of 4 million dollars annually and the annual possible purchase of 3 million dollars in goods and services could be the result of mining operations in Northeastern Minnesota. These possibilities are too important to overlook. A majority of citizens in Northern Minnesota are in favor of additional exploration and mining activities because of the above possibilities. Because of their interest in increase mining activities, hearings were held on the feasibility of developing a copper-nickel industry in Northeastern Minnesota.

Summary

The BWCA is in the Wilderness Preservation System; administers "wilderness area" for the use and enjoyment of the American people in such a manner as will leave these areas unimpaired for future use and enjoyment. The Wilderness Act provides that the land be left open to claim until the end of 1983, and to be surveyed for mineral potential by the Geological Survey and Bureau of Mines, but a special agreement between the Secretary of Interior and Secretary of Agriculture in 1965 terminated all exploration and possible mining operations on Federal lands in the BWCA. This still left open the possibility of exploration and mining on land with state and private mineral rights. Since then, the State has agreed not to give out any permits or leases for exploration and mining in the BWCA. People with private mineral rights in the BWCA still
had the right to explore, but a law suit brought against them by the Izaak Walton League has terminated all exploration on land with privately held mineral rights. They challenged the right of the owners of private mineral interests to exploit their holdings. To prevent future exploration and mining operations, the Northern Environmental Council has recommended the condemnation of private mineral rights in the BWCA through eminent domain. There are both pros and cons for the exploration and mining in the BWCA, but public opinion is clearly against mining in the wilderness area (Inter-Agency Task Force on Base Metals).

Conclusion and comments:

I am in favor of the BWCA being in the Wilderness Preservation System, where it can be protected for the future use and enjoyment of all. I do feel if the Wilderness System can not legally promote exploration and surveying, it should be more selective in choosing wilderness areas; areas that have mineral potential should not be included. The Wilderness Act should promote exploration by permitting the use of essential equipment and reconsider regulations regarding access. The BWCA should be completely explored for mineral potential by the United States Geological Survey and the Bureau of Mines, and the results of the survey should be made available to the public.

Private mineral rights with known and unknown owners should be acquired by the BWCA and administered by the Secretary of Interior. The owners of the mineral interests of the BWCA should be compensated for their loss. The
compensation must be determined by the State of Minnesota. I am in complete agreement with the policy that the BWCA should only be developed for its mineral deposits if a national emergency exists.

I feel the rules and regulations under which exploration and mining operations in the Superior National Forest must be carried out are effectively administered by the Forest Service.

**ECONOMICS OF THE COPPER AND NICKEL MARKETS**

The copper and nickel markets (the supply and demand of copper and nickel) of the United States and the World are one of the factors that will determine whether the copper-nickel sulfide deposits of the Complex will be mined and when. A careful look at the present and the proposed economic situation of the copper and nickel markets may reveal if and when the deposits will be mined.

The Duluth Gabbro Complex holds great potential for mineable copper-nickel ore and great volumes of low-grade material. Sims, Morey, and Green (1969) feel that it is a question of when will the copper-nickel sulfide deposits be mineable. Sims (1969) suggests that development will start within the next ten years. The need for very large deposits and the marginal grade of the material are two contributing factors that have accounted for the delay in mining operations.

Explorations have delineated reserves of several hundred million tons of low-grade copper-nickel sulfides in the Duluth Complex that are marginal at today's prices.
(Sims, 1969). The area of favorable ground remaining to be explored far exceeds that of the known deposits and may result in additional reserves of higher grade ore. Sims, Morey, and Green (1969) point out that even if deposits of higher grade material are not found, three factors favor the development of the existing deposits: (1) the estimates for increased consumption of copper and nickel in the future, (2) the proximity of the deposits to major markets, and (3) the anticipated improvements of mining technology and treatment of ores.

It has been established that the Duluth Complex holds great potential for the copper-nickel industry. What is the present outlook for the copper and nickel markets? Does the copper and nickel markets warrant immediate development of the Complex's sulfide deposits or must it wait another twenty or thirty years? To answer these questions, let us look at the copper and nickel markets.

Copper

Copper prices have averaged about 52 cents per pound for this year (Engineering and Mining Journal). Free copper market prices edged up slightly in 1971, following United State's producer's price cut. The price has fluctuated slightly since then. It has been slipping slightly since the peak price of 86 cents per pound in 1966, except for periodic rises. See Figure 7. Sharply rising costs now require a copper price well over 50 cents per pound to justify investment in a typical North American open-pit mine, let alone an underground mine (Mining Congress Journal,
1970, marked the first time in six years that the supply of copper exceeded demand and this has brought a marked reduction in the price of copper. The slight edging upward of copper prices at the beginning of 1973 probably does indicate an increase in demand (up 7 percent from 1972), but supply continues to exceed demand. The demand for copper is quite good as the economic recovery goes into full swing.

At the present time, there is an oversupply of copper in the world market, but the long term outlook for the copper market is much brighter, consumption is expected to increase considerably. The projected demand is expected to substantially exceed supply. See Table 2.

Charles Brinchenhoff, retired Chairman of the Anaconda Company, sited some of the reasons for copper demand to
Table 2. Summary of projected United States Supply-Demand relationships. (Inter-Agency Task Force on Base Metals, 1973 p.3-35)

<table>
<thead>
<tr>
<th>Year</th>
<th>U.S. Primary Demand</th>
<th>U.S. Primary Production$^2$</th>
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<tr>
<td></td>
<td>(Million Short Tons)</td>
<td>(Million Short Tons)</td>
</tr>
<tr>
<td>1970</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td>COPPER 1985</td>
<td>2.9</td>
<td>N.A.</td>
</tr>
<tr>
<td>2000</td>
<td>5.4</td>
<td>2.4</td>
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<table>
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<th>Year</th>
<th>U.S. Primary Demand</th>
<th>U.S. Primary Production</th>
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<tr>
<td></td>
<td>(Million Pounds)</td>
<td>(Million Pounds)</td>
</tr>
<tr>
<td>1970</td>
<td>311.4</td>
<td>30.6</td>
</tr>
<tr>
<td>NICKEL 1985</td>
<td>492.2</td>
<td>60.0</td>
</tr>
<tr>
<td>2000</td>
<td>770.0</td>
<td>84.9</td>
</tr>
</tbody>
</table>

$^1$ U.S. Primary Demand refers to the projected requirement for the metal as derived solely from domestic mine production.

$^2$ U.S. Primary Production refers to the projected supply of the metal that can be derived strictly from mine production based on historical trends.
rise (Mining Engineering, March, 1972): Consumption of copper per inhabitant per year in 1969 for North America was 19.7 pounds, Japan 13.6 pounds, Western Europe 12.6 pounds, Oceania 11.3 pounds, and U.S.S.R. 7.1 pounds. The Far East, India, China, Middle East, Africa, and South and Central America use less than one pound of copper per inhabitant per year. What would happen if the latter group should use 1 pound of copper more per inhabitant per year? This would mean an increase of at least two and a half billion pounds of copper! Which is quite unlikely to happen suddenly, but these countries are developing and their need for copper is increasing. Desalinization plants are today's answer for potable water, and if constructed worldwide would result in a large new use for copper. Transportation, electrical and building construction, and other users of copper will continue to grow simply because of the population growth. Brincherhoff believes the copper surplus to be short lived.

What material is considered ore for present copper mining? Much of today's copper deposits are ore because of the copper price increases and to a lesser degree to changes in the mining and treatment methods since 1945. Prior to that time, today's copper ore was not even classed as ore. Fifty years ago, operating cutoffs for copper ore was 0.7 percent copper, and today it is as low as 0.25 percent copper. Today's economic cutoff for copper ore is about 0.3 percent or slightly lower. There is reason to believe that this cutoff may slip lower as copper prices
increase and operating properties age (Brinckerhoff, 1973, p. 42). Such a lowering for the cutoff of copper ores would make the copper-nickel deposits of the Duluth Complex seem that much more attractive as a source for copper ore.

The steadily increasing availability of scrap copper and the expectancy of large increments to supply of scrap will continue to hamper the market. The copper industry must look, in part, to the world economic recovery to absorb the expected increments to supply of scrap copper and to avoid an further erosion of prices. An increase of copper uses and a speed-up of United States economy would result in tight supply of copper. The future outlook of copper appears to have turned somewhat more optimistic than last year. The present surpluses of copper will be used up if the present trend in increased copper consumption continues.

**Nickel**

International Nickel estimates that world primary nickel consumption fell to 825 million pounds in 1971, about 15 percent or 150 million pounds lower than the 1970 record of 975 million pounds (Engineering and Mining Journal, March, 1972, p. 184). Gannebin, President of International Nickel, blamed the drop on three factors: (1) the simultaneous decline of all the major economies of the world, (2) high inventories, and (3) higher nickel-scrap utilization brought on by the lower scrap prices. While 1,414 million pounds of nickel were produced in 1971, resulting in an estimated 589 million pound nickel surplus. Inter-
national Nickel Company (producer of 40 percent of the world's nickel) cut its Canadian nickel production substantially because of the high surplus of nickel, disastrous earning reports, and a slumping nickel market. Other producers also eased off slightly, but this did not prevent the increasing surpluses of nickel to continue. Horace Reno of the United States Bureau of Mines thinks the supply-demand imbalance should end within two years, assuming that the worldwide industrial depression is over and considering the announced shutdown of operating mines.

International Nickel Company is going ahead with a 15 million pound per year nickel-operation in New Caledonia which should begin immediately and start production in 1974. The New Caledonia Project could add greatly to an already over supplied nickel market. The Australian nickel industry has been developing so rapidly that a comprehensive evaluation of its status would be difficult. Its potential has captured the interests of the giants of the nonferrous metal industry and drawn the attention away from smaller and lower-grade deposits.

The nickel market has some promising developments in the field of new uses. Increase demand for nickel is expected to result from a surge in nuclear power plant construction, sophisticated low-pollution energy systems, heat and corrosion resistant steels in the automotive industry, and in low carbon, age-hardenable nickel steels for use in large tonnages in pipelines, offshore platforms, and ship components. International Nickel has estimated that
the increase demand for nickel should place consumption in 1980 near the 2,000 million pound mark, twice the 1970 record.

At the present, the nickel supply is ample to meet demands. Prices are stable and high enough to enable profitable exploitation of low-grade sulfide deposits (Reno, 1972, p. 10-11). The present 1.53 dollar price per pound for nickel is a 20 cent price increase over the 1972 price. Future predictions are that demand will develop to balance production capacity in the next decade. See Table 2. The forecast is based on the assumption of nickel's growing use in several new fields, ending of the world industrial depression, and expanding of present markets. Reno (1972) is of the firm belief that other materials will not replace nickel in most markets

Summary

Based on the economic situation of the copper and nickel markets:

The copper industry has been hampered by surpluses, declining growth demand, and a worldwide depression. A renewal of world economic expansion and greater use of the metal are the answer to the presently conservative market. It is not known when the demand for copper will be high again (greater than supply), but developing economies and increasing populations should result in a greater demand. The long term outlook for the copper market is optimistic, consumption is expected to increase considerably and supply will tighten.
The nickel industry is also plagued by high surpluses, but these are expected to end within two years (Reno, 1972). New finds of nickel in Australia have taken away some of the interest in the smaller and/or lower-grade deposits. Because of the oversupply of nickel, many producers have declined to open mines to new capacities. The long term outlook for nickel is optimistic because of increasing prices and because of the economic recovery.

I feel that the present economic situation of both the copper and nickel industries would not warrant the immediate development of the large reserves of low-grade copper-nickel sulfides of the Duluth Complex. I think it would unwise to bring a marginal copper-nickel development into an already oversupplied market. I can not estimate when the economy would permit the successful development of these deposits, but it must be when a resumption in world economic expansion has begun and the oversupply of copper and nickel has been eliminated (thus increasing prices); 1972 has seen progress in both of these areas.

At the present, exploration and plans for mineral development should be encouraged to meet a future copper-nickel market where supply is predicted to lag substantially behind demand.
SUMMARY OF TOPICS

1. The Duluth Complex has great potential as a source of copper and nickel. There are large deposits of low-grade copper-nickel sulfides and relatively small deposits of high-grade copper-nickel sulfides that exceed one percent in copper and nickel.

2. The known occurrences of copper-nickel sulfides are in a favorable geographic location with respect to roads, rails, water, electrical power, labor and other ancillary operations.

3. The lower part of the Complex (the base) in the troctolitic gabbro and near the base of the particular intrusion is the most favorable place to look for copper-nickel sulfides. There is a great possibility that unexplored areas of the gabbro are also mineralized.

4. The copper-nickel deposits are on Federal, state, and private lands. Leasing of Federal lands for copper-nickel exploration is handled by the Secretary of Interior and granted if the prospector can show proof of commercial value of the deposit and extent of it. The royalty rate is set and controlled by the Secretary of Interior. Leasing of State land is granted by competitive bidding at a public sale. The commissioner of conservation issues a state lease to the highest qualified bidder of royalty. Private leases for mineral rights are a person-to-person legal transaction and the terms of the sale are determined by the seller and buyer.
5. Mineral land environment has been added to the problems that a mining industry would face in developing the deposits of northeastern Minnesota. A copper-nickel industry would do little if any harm to water quality because of present technology and sufficient statutory authority to regulate and control the environmental impacts of mining on water. Exploration and mining operations can be carried out with a minimum disturbance to land surface, and careful planning will eliminate the possibility of having future land disturbances. Although, more strict regulation must be passed to insure that land surface has adequate environmental protection. Air pollution is the major problem involved in the extraction of copper and nickel from sulfide ores, but there are control devises to reduce the emission of sulfur gases into the atmosphere and alternate methods to help prevent pollution. An alternative to smelting problems is to export the ore to an already established smelting plant. The placing of too stringent restrictions on copper-nickel mining operations will discourage mine developments.

6. The BWCA poses as a stumbling block in the attempt of the State and private concerns to completely explore the Duluth Complex for copper-nickel deposits. A 1973 Federal order bans mineral exploration in the BWCA and prevents future development of Duluth Complex in BWCA for mining. Public opinion is against mining in the BWCA, because the public feels that exploration and mining would spoil the wilderness area. Mining officials state that the BWCA
could be explored without impairment to the wilderness area.

7. At the present, there is an oversupply of copper and nickel on the world market. Projected demand is expected to substantially exceed supply over the long term. To help meet the predicted shortage of nickel and copper, exploration and plans for development should be encouraged. Although, the present nickel and copper markets do not dictate such a move.
PERSONAL OPINIONS BASED ON REPORT AND HEARINGS

1. The entire Duluth Complex should be explored for mineral deposits, including the BWCA. The BWCA should be explored only by the United States Geological Survey, to eliminate problems that may arise from private concerns that may do exploration work. Private mineral interests of the BWCA should be acquired by the BWCA and owners compensated for their losses, if any. Such acquisition should help eliminate any future threat of mining in the BWCA. Modern mineral exploration techniques involve virtually no lasting environmental effects. Therefore, I see no logical reason why the BWCA's geology should not be explored and appraised. I believe mining in the wilderness area should only be permitted under an extreme national emergency.

2. I am in favor of developing a copper-nickel mining operation in Northeastern Minnesota for several reasons: (1) its indicated success by reliable reports (Department of Natural Resource, 1973) that estimate the Duluth Complex to contain at least 6.5 billion tons of mineralized material (copper-nickel sulfides) valued at 55 billion dollars; favorable geographic location with respect to transportation, electrical energy, and ancillary operations; and predicted increase of demand over supply for copper and nickel; (2) to help economic conditions in Northeastern Minnesota by creating jobs (estimated 2 to 3 thousand) and the possible addition of 4 million dollars into the economy annually; (3) assurance by mining companies and invest-
igating groups (Inter-Agency Task Force on Base Metals and Minerals' Subcommittee) that mining may take place without causing environmental damage. In general, with the exception of land use and mineland reclamation, sufficient statutory authority exists to control environmental impacts of mining on water resources and air. The DNR currently has a bill before the 1973 Legislative Session to effectively regulate land use and mineland reclamation; (4) to make United States less reliant on foreign sources of nickel and copper.

3. I believe plans for development should be encouraged as soon as possible: (1) it may take between 5 to 10 years to get an operation producing; (2) relieve unemployment of Northeastern Minnesota (some towns such as Ely it is over 9 percent); (3) prediction that by the time facility is completed supply of copper and nickel in United States will be lagging behind demand, thus to help relieve a predicted shortage of copper and nickel; (4) advanced planning will help eliminate future pollution problems.

4. Efforts should be aimed at having smelting operations carried out at an already established plant, outside of Minnesota. Smelting should be permitted only when it has been proven that it is totally uneconomic to have the operations outside of the state. I believe there is no reason to endanger the environment just to increase the profit margin. If smelting operations are permitted in the State of Minnesota, operators must prove they can effectively meet air quality standards. Alternate extraction methods
should be seriously considered, such as hydrometallurgical methods. No matter what process is used for the extraction of metal from the ore, the process that is used must be able to prove that it will not harm the environment.

5. I believe the copper-nickel developments should be carried out under strict regulation and continually monitored by a government environmental agency. All companies should be held accountable for their operations. In order to: (1) to protect the environment (land, water, and air) from mining impacts; (2) to prevent future irreversible land plights; (3) to make possible land reclamation (some mining impacts, such as tailing dumps, are irreversible and if proper advance planning is not carried out a lasting problem will result.
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