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Iron Ore Reserves of the Mesabi Range, Minnesota

Minnesota Univ -Duluth Dept of Geology

Prepared for

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MESABI RANGE IRON ORE RESERVES EVALUATED IN MINES BUREAU REPORT

Although "natural" iron ores in Minnesota's Mesabi Range are nearly depleted, the Range still holds an estimated 47.5 billion metric tons of lower-grade iron ore reserves--more than 200 times the crude iron ore produced in the U.S. last year.

The estimate is from a new assessment released by the Interior Department's Bureau of Mines. It was prepared for government and industry planners concerned with stable sources of iron ore for the U.S. iron and steel industry.

The Mesabi Range, extending 100 miles through northeastern Minnesota, has historically been the major source of iron ore for the United States. Until recently, most ore produced was "natural" ore--called that because the concentration of iron in the ore was produced by natural processes, and the ore could be sent to ironmaking furnaces in virtually its natural state. With the depletion of the "natural" ore reserves, magnetite taconite ore--which requires much more upgrading before use--has become more important and is now the major domestic source of iron ore. According to the Bureau of Mines, domestic sources provided approximately 71 percent of U.S. iron ore needs during 1978, and imports accounted for 29 percent.

The 47.5 billion metric tons of ore in the Mesabi Range reserve include 27.1 billion metric tons of magnetite taconite ore reserves, but only 160 million metric tons of "natural" ore. Also included are 11.6 billion metric tons of material called "oxidized banded iron-formation" (which may be commercially concentrated in the future), and relatively small amounts of still lower grade taconite.

The study, which was prepared by Dr. Ralph Marsden of the University of Minnesota under a $40,000 Bureau contract, is part of the Bureau's computerized Minerals Availability System (MAS). The system is designed to provide government and industry planners and interested segments of the public with current, comprehensive data on the availability of a wide range of minerals.

(more)

According to the Bureau, the study differs from earlier ore assessments in its interpretation of "reserves," which are defined as "economically recoverable material in identified deposits" -- distinct from "resources," which include uneconomic deposits, as well as reserves. Although previous studies have interpreted "economically recoverable" to mean the minerals must be minable at a profit, the current study does not attempt to determine profitability. Instead, it includes as "reserves" all iron ore that can be produced without financial loss. The study notes that the total reserve amount could increase as new technology makes more deposits economic to mine.

The assessment of the reserves is given in a report, "Iron Ore Reserves of the Mesabi Range, Minnesota," which has been placed on open file by the Bureau of Mines (OFR 58-79). It is available for public inspection at the Department of the Interior Library, 18th and C Sts., NW., Washington, D.C.; and at the following Bureau of Mines Field Operations Centers: 4800 Forbes Ave., Pittsburgh, Pa.; Building 20, Denver Federal Center, Denver, Colo.; and East 315 Montgomery Ave., Spokane, Wash.

The report can be purchased from the Commerce Department's National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161, for $5.25 per copy on paper and $3.00 on microfiche. Orders should specify the title and PB 297 162/AS. Copies are not sold by the Bureau of Mines.

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PB 297162

IRON ORE RESERVES OF THE MESABI RANGE, MINNESOTA

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

University of Minnesota-Duluth
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The iron ore reserves estimated to occur on the Mesabi Range are tabulated by ore class and by range unit on Table X. This listing of reserve tonnages does not give the grades of the material in the various classes or the probabilistic grade matrix but shows the general distribution of materials considered to be ore in this study. The estimated tonnages of taconite ores are based on an estimate of the 1974 production costs and represents ores available in 1975. As described in the report, the reserve estimate is designed to include all taconite materials that can be produced to a no-loss situation. The tabulated reserves should include material that does not have sufficient profitability to be economic at this time.

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FOREWORD

This report was prepared by University of Minnesota-Duluth, Department of Geology, Duluth, Minnesota 55812 under USBM Contract Number G0155058. The contract was initiated under the Minerals Availability System. It was administered under the technical direction of IFOC with Mr. R. Craig Smith acting as the Technical Project Officer. Mr. Doyne W. Teets was the contract administrator for the Bureau of Mines.

This report is a summary of the work completed as part of this contract during the period 10/15/74 to 6/30/77. This report was submitted by the author on 10/10/77.

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IRON ORE RESERVES OF THE MESABI RANGE, MINNESOTA

by

Ralph W. Marsden

The Mesabi Range in Minnesota contains one of the major iron ore reserves of the United States. When the Mesabi Range is viewed as a mineral resource, it becomes evident that the Biwabik iron-formation constitutes a single iron deposit (see Figure 1). The deposit contains different types and grades of iron ores and has a complex mineral ownership but geologically and economically it is one continuous body. From 1893 to 1956 only natural iron ore was of economic value. Since 1956 taconite pellets have had an increasing importance. Today in 1977, we near the end of natural ore production as an important source of the iron ore. The available natural ore reserves are insignificant to future iron ore production. Taconite is now the dominant source of iron ore with the better quality taconite materials being mined. The major reserve is magnetite taconite with the oxidized, banded, iron-formation or oxidized taconite or OXIBIF of this report, as a potential reserve for future production. This study of the iron ore reserves of the Mesabi Range for the Minerals Availability System has developed a tonnage reserve of potentially mineable iron ore materials to an estimated no-profit, no-loss economic cutoff. Of necessity, the limits of ore are somewhat arbitrarily drawn as the cutoff on ore and non-ore is not based on grade or physical limits of the Biwabik iron-formation but on an evaluation of the economic limit to a no-loss production cost. The actual ore limit is based on the evaluator's concept of cost related factors such as the grade of the ore, production problems and costs, value of the iron ore, and geological conditions of the ore occurrence at any particular location. Informa-

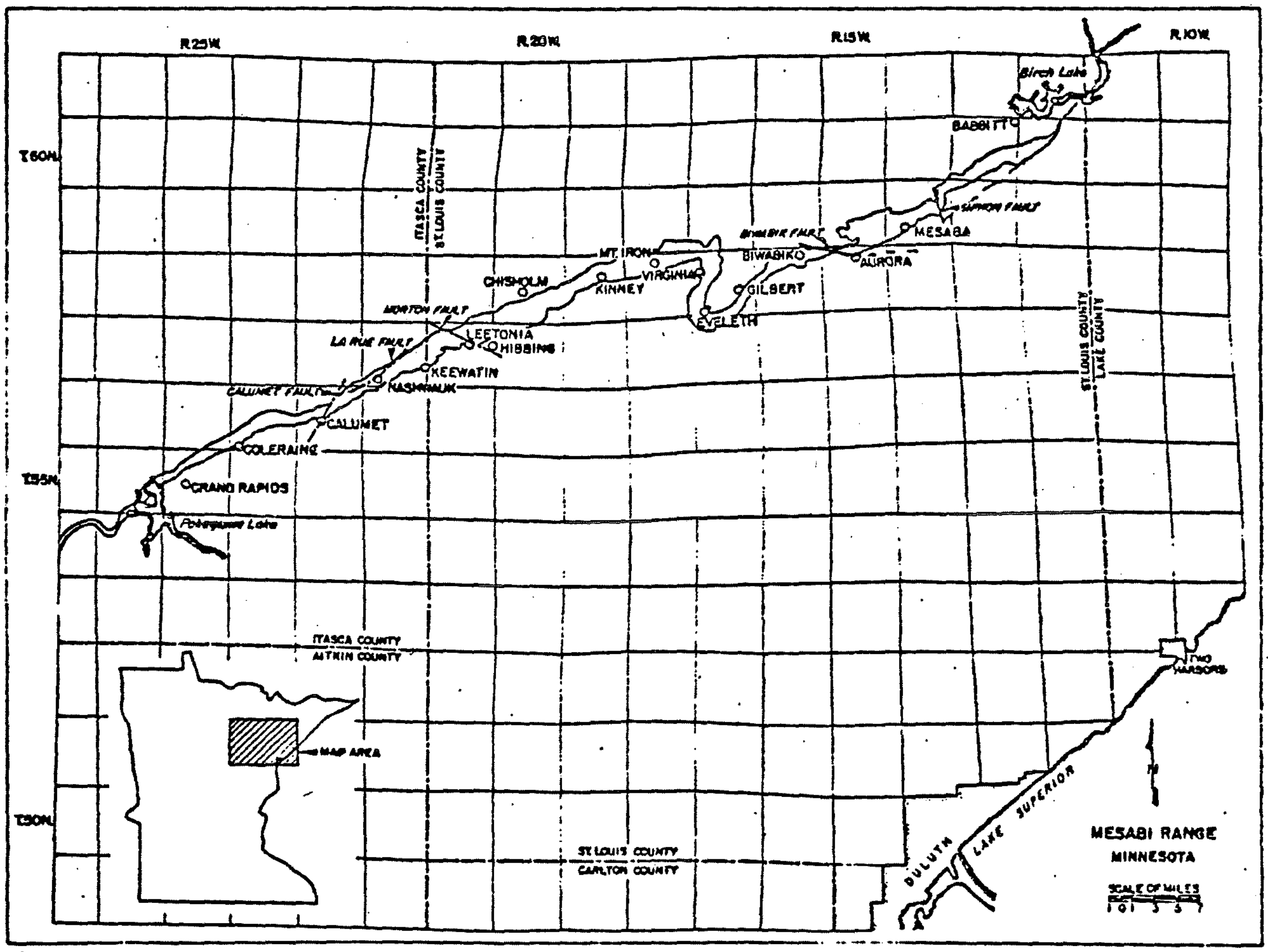

Figure 1. Map showing the Mesabi Iron Range and Range Units

tion concerning any of the above factors is always incomplete, particularly at the ultimate pit limit where a separation between ore and non-ore must be made. It is important that the Minerals Availability System estimate be accepted with a recognition of the definitions and the limitations necessary to accomplish the objective of the study which is a realistic view of the iron ore reserves of the Mesabi Range. A somewhat different reserve tonnage would be obtained using other definitions and by using other limiting factors. The following report covers the concepts, definitions, and limits set for this study as well as the nature of the Mesabi Range iron ore reserves.

Acknowledgements

This study was supported by a grant from the United States Bureau of Mines. Gary Kingston and Jerry Lewis have given valuable assistance and encouragement during the study. I also acknowledge the assistance of the following graduate student assistants: during the 1975-76 school year, Robert Bond, Dennis Laybourn and Mark Severson; during the 1976-1977 school year, Mark Severson and George Lehman, and during the fall quarter, 1976, William Feirn. The graduate students assisted in the tabulation of data, plotting information, preparing maps and cross sections and calculation of reserve tonnages.

I gratefully acknowledge the cooperation of the mining companies on the Mesabi Range. Essential information was received regarding the distribution of types and grades of taconite materials. The Company staffs assisted materially with helpful discussions on numerous problems. I am indebted to the Office of Ore Estimation and the Taxation Department of the State of Minnesota for information on natural ore reserves. The Office of Ore Estimation made a special effort to assemble natural ore reserve data in an easily useable form.

DEFINITION OF AN IRON ORE RESERVE

The definition of an iron ore reserve vs an iron ore resource is important to an understanding of the tonnage estimates reported. The nature of mineral resources and mineral reserves is discussed by V. E. McKelvey in the United States Geological Survey Professional Paper 820[(1)]. In this U.S.G.S. report a mineral reserve is defined very simply as "economically recoverable material in identified deposits", and mineral resources are defined to include, in addition, deposits not yet discovered as well as identified resources that include economically recoverable reserves and uneconomic deposits that may be mined at a future date as technological advances are made or the cost-price relationship changes. The usual mineral resource estimate probably includes only small tonnages as potential sources of minerals that are as yet undiscovered ("Hypothetical Resources" or "Speculative Resources") that may be expected to occur in "broad geological terranes" that are favorable for mineral deposits. It is evident that a wide range of potential mineral availability should be recognized in a study of mineral resources. The evaluation should include deposits that are fully known and thoroughly explored at existing mines to potential deposits in geologically favorable areas. Such a broad coverage in mineral resource studies is necessary for an adequate recognition of future sources of mineral materials so policies regarding mineral supply can be evaluated and made for the long future.

The study of Mineral Reserves is different. Mineral reserves must be limited to known deposits. The definition of a mineral reserve as an "economically recoverable material in an identified deposit" also requires that

(1) The quotation marks indicate wording used in Professional Paper 820.

a mineral deposit must have a favorable cost-price ratio. Many definitions include the word profitable, indicating the need that some level of profit must result from the mineral production.

In the Minerals Availability System study of iron ore reserves, there is a need to be very specific in using the term "Economically Recoverable". On the Mesabi Range, the iron deposit extends beyond the limit of economic extraction so a line must be drawn between an iron ore reserve and an iron ore resource. It is important that the demarkation line be sharp and clearly defined, hopefully on the same basis by all workers. In the determination of the iron ore reserves on the Mesabi Range in this study all iron ore that can be produced without financial loss is calculated and included in the estimated tonnages. The accompanying reserve tonnages include all material that can be produced at a breakeven or on a profitable basis using cost and mineral value information available to the evaluator for the year 1974. The no loss concept is realistic and workable as it does not require the inclusion of a profitability factor in order to judge the economic viability of a deposit yet it places a very positive, easily understood basis for recognition of materials that should be included as an iron ore reserve. The no loss concept permits the evaluator to recognize materials that are marginally economic based on the available cost information. These materials may, in the view of other mineral experts, be classed as reserves or resources based on special information regarding cost factors or knowledge of production technology. The cost basis is time coded to allow future changes which could require adjustment of reserve tonnages either upwards or downwards.

RELIABILITY OF THE MESABI RANGE IRON ORE RESERVE ESTIMATE

The accuracy and adequacy of an iron ore reserve estimate is dependent upon the reliability of the information used to prepare the estimate. Since the usefulness of a tonnage estimate requires the inclusion of all known iron ore reserves, it will include deposits that have a considerable range of information accuracy from very complete and reliable to scanty. There should be in the presentation of the estimate, a way to show the varying levels of reliability of the input data. The estimator must judge the validity and the adequacy of the information sources used. Recognizing the role of the estimator in the development of the input data, the Minerals Availability System includes a "Probabilistic Grade-Quality Matrix" that can be used as a Reliability Factor for the information concerning each deposit and the various ore types that occur. The following scale from Reliability 1 to Reliability 5 is keyed to the Minerals Availability System "Probabilistic Grade-Quality Matrix" to suggest the competence of the reserve tonnage presented.

Reliability 1 - Probability Rank - 90%

Reserve tonnages included in this class are those that concern explored and tested areas where engineering plans have been made or can be made, or the ores occur as reserves to established operations. Reasonably good information concerning the geology, size, and shape of the ore body, mining, milling, and other production information and estimates are available. The data are sufficient for the estimator to prepare an analysis of reserve potential with a high expectation that the reserve tonnage occurs. A large part of the estimated taconite ore, taconite lean ore, and siliceous taconite ore falls in this class. The taconite ore occurrence has been documented by drilling and the concentration systems are well established.

Reliability 2 - Probability Rank - 75%

In this reliability class the Mesabi Range iron ore reserves are estimated with some reservations regarding the economics of production or the accuracy and completeness of the information concerning the ore occurrence but taconite ores are reasonably known to occur. The information available to the estimator was limited regarding the nature of the ore, or the economic evaluation somewhat uncertain, or the shape and size of the deposit is incompletely known, or the ore quality is questionable. However, the occurrence of taconite or iron-formation is known but in the estimator's opinion, there is a possibility that the tonnages estimated could be in error by possibly as much as 25 percent. Yet based on available information, the estimate is believed to be a good representation of the potential of the deposit. In the Mesabi Range estimate magnetite taconite reserves with greater than a 1 to 1 ratio of crude ore to total stripping are given a 75% rating because of the uncertainties in the economic evaluation. There is a common lack of detailed information regarding materials that occur near the proposed ultimate pit limit.

Reliability 3 - Probability Rank - 50%

Iron ores in this reliability class in Mesabi Range reserve estimate includes materials where limited information is available. The estimate presents "an order of magnitude" evaluation of the taconite occurrence. The reserve tonnages figures, classes of ore, and evaluation of the taconite ore potential includes a strong element of judgement representation of the ore potential but are not based on adequate information to give a higher confidence level. There is a chance that the estimate could be in error possibly by as much as 50 percent in the estimator's judgement.

Reliability 4 - Probability Rank - 25%

All the estimated reserves of OXIBIF (Oxidized Banded Iron-Formation) are in this class. The available information strongly suggests the estimated tonnages occur but grade of the material, its concentratability and its economic viability are questionable. Only limited information is available to the estimator on OXIBIF quality and concentratability. The information used to obtain the estimated tonnages are believed adequate to indicate the order of magnitude of the tonnages of OXIBIF reserves, and their general availability. When adequate data are available, a considerable variation may be expected from the reserve tonnage figures and in the quality of OXIBIF. The reserve tonnages given include cherty taconites that, where unoxidized should be ore or lean ore quality magnetite taconite. A reliable estimation of the OXIBIF reserves will require considerable additional exploration, laboratory testing and engineering planning.

Reliability 5 - Probability Rank - 10%

No potential iron ore on the Mesabi Range is given this probability rank. Sufficient exploration work has been done throughout the entire strike length of the Biwabik formation to show the general characteristics and stratigraphic relationships of potential taconite ore materials. Consideration was given to including taconites that could be minded by underground methods. The principle reasons for not including any underground tonnages of taconite type material are the lack of research on the problems of underground taconite mining and the unfavorable cost picture. Cost information clearly indicates that the underground production of taconite ores are uneconomic at this time and should not be included in an iron ore reserve estimate.

CLASSIFICATION OF MESABI RANGE IRON ORES

Iron-formation on the Mesabi Range is commonly termed "Taconite". This name is often applied to all lithologies of the Biwabik formation whether oxidized or unoxidized. The term does not refer to natural ores but includes magnetite taconite ore and oxidized banded iron-formation ore; the OXIBIF ore of this report. Commercially the term "Taconite" is often used to mean any magnetite-bearing iron-formation that can be economically mined and processed by fine grinding and magnetic separation to yield a saleable iron ore concentrate or pellets. Sometimes the "Taconite ores" are termed "magnetite taconite" or "magnetic taconite". In this report the term "magnetite taconite" is used to include all classes of material that can be processed by magnetic methods and are considered to be iron ore reserves.

Iron ores on the Mesabi Range are classed as:

1. Natural Iron Ore
2. Magnetite Taconite Ore
3. Magnetite Taconite Lean Ore
4. Siliceous Magnetite Taconite Ore
5. Siliceous Magnetite Taconite Lean Ore
6. OXIBIF

Each class of iron ore material is described in the following sections of this report.

Natural Iron Ore - All hematitic and goethitic iron-rich material that can be mined and beneficiated to a saleable product by simple methods not including fine grinding are termed "natural iron ores". Fine grinding commonly means grinding to sizes smaller than 20 mesh (0.0328 inches or

0.841 mm). The processing methods used include washing, jigging, spirals and heavy media. The natural iron ores include ore materials that require only crushing and sizing to yield a commercial product to materials that are compact and relatively low in head iron but can be beneficiated to yield an acceptable grade concentrate. The tonnages estimated as iron ore reserves in this report are given as tonnages of shipping product.

Magnetite Taconite Ores - Taconite ores have important mineralogical and textural differences that are geological in nature that are not specifically recognized in the classification of materials used in the ore reserve estimate. Major factors in a geological classification of magnetite taconite ores are mineral composition and texture which are a result of the metamorphic history of the Biwabik iron formation. Three general geological types of magnetite taconite occur on the Mesabi Range: (1) minnesotaite-stilpnomeland-greenalite taconite, (2) amphibole-bearing taconite and (3) pyroxene-bearing taconite. Minnesotaite-stilpnomeland-greenalite taconites occur in the area west of Mesabi, amphibole taconites east of Mesabi to about Iron Lake, a strike length of 9 miles, and pyroxene taconites east of Iron Lake to the end of the Mesabi Range. The three mineralogical types of taconite have important effects on the grindability, mineral liberation characteristics, concentrate grades and influence production costs. All siliceous taconite ore, and siliceous taconite lean ore occurs in the amphibole-bearing taconite zone. The pyroxene-bearing magnetite taconite generally produces good quality concentrates as does the minnesotaite-stilpnomelane-greenalite taconite. The contact between the three mineralogical taconite classes is gradational generally over several thousands of feet as the several stratigraphic horizons respond somewhat differently to metamorphism.

The magnetite taconite ore classes used in preparing the reserve tonnage estimate are based on weight recovery of magnetite and the Fe content of the ore concentrates. Weight recovery and concentrate grade have a direct bearing on production costs and product value and are factors that can be recognized directly from the laboratory test results. Laboratory testing of drill core is the main source of information used by this study to recognize and to classify ore quality materials. Limitations in the use of the test results should be understood as the accuracy of test data are of primary importance to this study. There are problems inherent in using concentration test information. The data used are the test results obtained from several laboratories using the same general test procedures but with somewhat different detailed test elements. Also the test results were obtained over a long period of time, possibly as much as 25 to 30 years, so details of laboratory test procedure may have changed within a laboratory. The presence of differences in test procedures and their influence on the reported test results is recognized but there does not seem to be a practical way in which results obtained at different test times or from somewhat different test procedures can be recognized and adjustments made. Thus the test results from the several laboratories were used as received. In the estimator's opinion, the laboratory test results are sufficiently reliable to permit the preparation of a valid taconite ore reserve estimate for the Mesabi Range and reasonable groups of taconite ores. Mesabi Range taconite ores are placed into five groups that are defined in the following paragraphs.

Magnetite Taconite Ore, for the purpose of this study includes all material that the laboratory magnetic separation tests yielded a weight recovery of magnetite concentrate of plus 25 percent with a concentrate grade of plus 65 percent iron. This class includes most of the magnetite taconite ore being mined on the Mesabi Range and constitutes the most important reserve tonnage.

Magnetite Taconite Lean Ore includes all material that laboratory magnetic separation tests yielded a weight recovery of magnetite concentrates of between 20 and 25 percent with a plus 65% iron concentrate grade. Materials with less than 20 percent weight recovery are classed as waste. This lean ore material is termed "save rock" by some companies and is used as taconite ore only as it is encountered in the current mine operation. Whether taconite lean is a "save rock" waste or is processed depends on whether it can be tolerated in the ore mix at the time it is encountered in mining. It does not represent material that is considered desirable ore with a satisfactory profit generation.

Bottom Magnetite Taconite Lean Ore includes all magnetite taconite lean ore that occurs below mineable magnetite ore. Bottom lean ore need not be moved when the commercial quality magnetite taconite is mined so can be left in the mine as "bottom rock". This material represents tonnages of magnetite-bearing iron-formation that has a marginal to paramarginal cost to value ratio so companies cannot justify mining at this time. At some time in the future with an increase in ore value and/or the need for iron ore this material should be mineable. It is included in the reserve estimate as a separate group because this estimate includes materials to zero profit based on present costs and values.

Siliceous Magnetite Taconite Ore includes all material that laboratory magnetic separation tests showed to have a plus 25 percent weight recovery of magnetite concentrates with a concentrate grade of between 60 to 65 percent iron. The weight recovery range is the same as for magnetite taconite ore but the concentrate grade is below 65 percent which results in a high silica product. It is likely that additional processing will be needed to give a satisfactory iron ore product. The additional processing could be regrinding and magnetic separation, or include fine screening, or possibly flotation of the concentrates. In order to compensate for the losses that can be expected as a result of the additional processing and to keep the estimate in better balance with expected results, 2 percent weight recovery was deducted from the reported laboratory weight recovery in calculating the siliceous taconite crude ore grade.

Siliceous Magnetite Taconite Lean Ore includes all material that laboratory tests give a 20 to 25 percent weight recovery of magnetite concentrate and a concentrate grade of between 60 to 65 percent. Very little material belongs in this ore class. Whether siliceous taconite lean ore should be included as an ore grade can be questioned as its economic viability even in the future is doubtful. This classification grade is included to indicate that material of this composition was looked for in the study and was segregated. A 2 percent deduction was made in the laboratory weight recovery in calculating the average weight recovery grade. This is to compensate for the weight loss expected in additional processing needed to obtain a higher grade concentrate.

OXIBIF - In this report the acronym "OXIBIF" is used to refer to oxidized banded iron-formation that is considered to be a potentially concentrateable material to yield commercial quality concentrates or pellets. This crude ore material is often termed "oxidized iron-formation or nonmagnetic taconite". The term OXIBIF (oxey-bif) is restricted to materials that are believed to be potential ore in an effort to eliminate the confusion that is common in the usage of the terms oxidized iron-formation or non-magnetic taconite which includes the full range of hematitic or goethitic iron-formation whether concentrateable or not. OXIBIF is defined for this estimate as hematitic and goethitic, cherty iron-formation that was formed by the oxidation of magnetite-rich, cherty, iron-formation that if unoxidized should be taconite ore or taconite lean ore. The correlation of OXIBIF with taconite ores is to recognize that taconite ores have a somewhat granular texture that permits liberation of magnetite by fine grinding. Some very fine-grained magnetite-bearing iron-formation are not taconite ore. This also removes from consideration fine-grained, slaty, and silicate-rich iron-formation (taconite) that yield very refractory hematitic and goethitic materials. Available information on reduction roast testing indicate that favorable concentration results are commonly obtained on cherty materials but tests on slaty materials usually give unacceptable results.

GEOLOGICAL FACTORS IN THE MESABI ESTIMATE

Major ore reserves occur on the Mesabi Range as magnetite taconite with a considerable potential tonnage of oxidized Biwabik iron-formation. The important geological factors in shaping the iron ore reserve potential are (1) the low angle of dip of the iron-formation that permits the development of large open pit mines, (2) the widespread occurrence of mineable thicknesses of magnetite-bearing iron-formation that yield a sufficent quantity and grade of concentrates after fine grinding and magnetic separation to be commercial ores, (3) the occurrence of sizeable areas and thicknesses of oxidized, cherty iron-formation that preliminary tests indicate to be concentrateable when iron ore of this type is economically feasible and is needed. Natural ores that were the major source of iron ore from the Mesabi Range for about 70 years are nearing exhaustion and are a minor factor in the Mesabi Range reserve potential.

Geology - The Mesabi Range is described in a number of publications which indicate the nature of the Biwabik iron-formation, its strike and dip and regional metamorphic pattern so only a brief statement regarding the geological setting is needed. The iron ores of the Mesabi Range occur within the Biwabik iron-formation which is a Middle Precambrian age, metasedimentary rock that extends the entire 100 mile length of the Range. The Biwabik formation is from about 300 to 800 feet in stratigraphic thickness and is subdivided into four members named Lower Cherty, Lower Slaty, Upper Cherty and Upper Slaty. The terms cherty and slaty concern the general composition and appearance of the iron-formation units. Cherty members are characterized by relatively thick and wavy bedding, medium to fine grain size, granule texture, common cherty quartz, magnetite and other iron oxides with lesser amounts of iron-silicates and carbonates. Slaty members are characterized by relatively thin and straight bedding, fine grain size, with common chert, iron carbonate and iron silicates with varying amounts of magnetite, other iron oxides, and locally carbonaceous material. The cherty and slaty members each may contain horizons that are cherty or slaty so there is some overlapping and interbedding of the two general lithologies. An important horizon of cherty iron-formation occurs in the Lower Slaty member in the area from near Gilbert westward to west of Mountain Iron. This cherty material included in the Lower Slaty member has a lithology similar to the Upper Cherty member. West of Hibbing the Lower Slaty member is thin, commonly about 20 to 30 feet thick

Geological factors have an important bearing on the mineability and concentrateability of the Mesabi ores. The amount of reserve tonnages of magnetite taconite and OXIBIF depends in important ways on the dip and thickness of the Biwabik formation, folding and faulting, metamorphism, mineralogy, texture and stratigraphy. Each factor may be of major importance in different parts of the Mesabi Range.

The thickness of the Biwabik iron-formation and its various members are shown on logitudinal sections by Gruner and White. These sections show that the iron-formation is thickest, about 700-800 feet, in the central Mesabi Range and thins at both the east and west ends. Important thinning of the Lower Cherty member is observed east of Mesaba in Range 14. This unit becomes too thin to mine in Range 12 and 13. Farther east the Biwabik formation is truncated by the Duluth Gabbro Complex in Range 12 in the vicinity of Birch Lake. At the western end of the Mesabi Range, west of Coleraine, the Lower Cherty and Upper Cherty members merge and then pinch out in a "slaty" iron-formation. The Biwabik formation also thins and becomes unfavorable as a source of OXIBIF ore west of Grand Rapids, Minnesota.

There are a number of ore availability and grade change problems that influence the magnetite taconite ores in various parts of the Mesabi Range. These changes will be briefly identified by Range location from the east to the west in the following paragraphs.

Range 12 - At the eastern end of the Mesabi Range, the Biwabik iron-formation dips at about 5 degrees at the west line of Range 12 and dips at steeper angles to the east. In the Dunka Pit, east of the Dunka River the dip in the outcrop is about 15 degrees and steepens to 20 degrees or more near the south open pit limit. Also in Range 12 the Biwabik formation is truncated in Section 26, T61N, R12E by the Duluth Gabbro complex. The metamorphic rank changes in the western part of this Range from pyroxene-bearing to amphibole-bearing taconite ore.

Range 14 - In the center part of Range 14 there is a change in the metamorphic grade of the Biwabik formation from amphibole-bearing to minnesotaite-stilpnomelante-greenalite-bearing taconite ore. Also from center of T59N, R14W to the west edge of Range 14, the Upper Cherty member changes from taconite ore to waste rock.

Range 15 - In Range 15, the Lower Cherty member contains essentially all of the commercial quality magnetite taconite ore. There are several faults in this area. The Biwabik fault causes a marked narrowing of the outcrop width of the Biwabik formation. The first important areas of oxidation of the iron-formation and natural iron ore are found in this Range.

Range 16 - The Upper Cherty and Lower Cherty members commonly contain magnetite taconite ore where unoxidized in Range 16. The City of Biwabik is situated on the iron-formation and appears to encumber substantial tonnages of magnetite taconite ore. No drill information is available in the City of Biwabik but the occurrence of taconite ore under the city is probable.

Range 17 - The "Virginia Horn" occurs in Range 17 where the Biwabik iron-formation is folded into a broad anticline near Eveleth and a syncline near Virginia. There are large channel type, natural ore bodies in this area and important areas of oxidation near the natural ores.

Range 18 - An important change in the magnetite taconite ore occurrence is found in Range 18. In the western part of this Range, the Upper Cherty member changes from ore to waste rock and the Lower Cherty member, on average, contains somewhat less magnetite. There are substantial areas of oxidation near Mountain Iron.

Ranges 19, 20 and 21 - There are extensive areas of oxidation and natural ore bodies in Ranges 19, 20 and 21. Magnetite taconite occurs in unoxidized areas of the Lower Cherty member. A very limited area with some potential for Upper Cherty ore is present north of Hibbing and in the western part of Range 21.

Range 22 - A magnetic anomaly belt extending between Keewatin and Nashwauk and two drill holes suggest the possible occurrence of magnetite taconite ore in the Upper Cherty member. A reserve tonnage of Upper Cherty taconite ore is included in the estimate. There are substantial areas of oxidation.

Range 23 and 24 - The Calumet fault crosses the Biwabik formation in the central part of Range 23. East of the fault there are several areas of unoxidized iron-formation but to the west of the fault essentially the entire Biwabik iron-formation is oxidized.

Range 25 - The Biwabik iron-formation is oxidized in Range 25. It begins to become notably thinner westward in this Range. Also, the Lower and Upper Cherty units merge and the Lower Slaty member becomes less than 10 feet thick or is absent. The combined cherty members thin rapidly in the western part of Range 25, so that northwest of Grand Rapids the major lithology of the iron-formation becomes "slaty". OXIBIF ore is estimated to just east of Hale Lake, northwest of Grand Rapids. From near Hale Lake westward only the natural iron ores that are listed on the Minnesota tax rolls are included in the estimated reserves of Mesabi iron ores. In addition to the unfavorable character of the Biwabik iron-formation as a source of potential OXIBIF ore, serious environmental problems exist in this area. Hale Lake extends into the City of Grand Rapids, the Biwabik formation is crossed by the Mississippi River, Pokegama Lake, U. S. Highway 2 and the Burlington Northern Railroad.

DETERMINATION OF NATURAL IRON ORE RESERVES

The reserve tonnages of Natural Iron Ores reported in this study are based on information from the State of Minnesota on taxable iron ore reserves. The State information was averaged and consolidated as required to the reserve tonnage figures included. No production cost information was obtained for natural ores so the reserve tonnages for natural ore are based on an engineered estimate of available tonnages. The tonnages represent 1976-1977 reserves. Only iron deposits reported as mines or mine groups on the tax roll that contained approximately 500,000 long tons of reserves were included in the M.A.S. data system.

DETERMINATION OF TACONITE ORE RESERVES

Tonnages included in the Mesabi Range taconite ore reserve estimate are directly related to the cost of production of iron ore pellets. The major factor in determining the cutoff limit for material that can be economically mined is the quantity of stripping that can be economically removed. In making this ore reserve estimate, all funds available after payment of the costs through pellet production are assumed to be applied to stripping to give a no-profit no-loss cutoff. The taconite production costs used were developed as a range wide average that was, to a large extent, calculated from data presented to the Tax Department of the State of Minnesota for seven taconite plants. The effect of using a Range average is to treat the Mesabi Range as one taconite ore body. Each cost element used is an average of individual production costs. In most cases, there are important differences between the costs experienced by the several mines and plants.

The estimation of the iron ore reserves of the Mesabi Range was started in 1975 so all cost calculations and pellet values relate to 1974. Each cost element was calculated as arithmetic averages without a weighting for plant size. The calculation of the average concentration ratio represents a weighted average figure. The production costs are expected to differ in varying amounts from the actual costs experienced at most taconite plants. It is hoped that the costs will be too high for some plants and too low for others.

The existence of cost variances inherent in using averaged production costs should be recognized in using or in accepting the reserve tonnages estimated by this study. The variations in production costs are also reflected in the calculation of stripping that may be economically removed. The amount of stripping to the ultimate pit limit was calculated using an average stripping cost for rock and surface materials. The use of an average cost will result in variances for specific areas as the character of the stripping ranges considerably. The surface materials can be sand and gravel, silt, clay, muck or glacial till. Each material has its characteristic stability problems and costs. The rock stripping, which is the most important material, can range from gabbro to meta-sedimentary rocks that include amphibole or pyroxene iron-formation, minnesotaite-stilpnomelane iron-formation, argillite and various types of oxidized iron-formation. A satisfactory recognition of the nature of the various classes of stripping so that variable stripping costs could be used would require far more detailed information than was feasible for this study. The use of a uniform stripping cost has the advantage that adjustments can be made in the estimate where detailed information is available. This will allow specific local calculations to be made and the estimate modified. In other words, using a uniform yardstick for stripping and production costs for the determination of taconite ore reserves gives the reader a basis for exercising judgement, where possible, with some confidence on how the ore limits were established.

Taconite Production Cost Estimated for 1974 - The production costs used in the estimation of reserves of Mesabi Range taconite ores were calculated using averaged cost information submitted by companies to the State of Minnesota with company tax returns tempered by some consideration given to information submitted during the Reserve Mining Company lawsuit on tailing disposal in Lake Superior, to discussions with colleagues, and to a review of the 1966 estimate made by J. K. Hammes. The estimated costs are shown in Table #1.

Table 1 - Estimated Magnetite Taconite Production Costs - 1974

(Assumed 3 to 1 crude to concentrate)

	Per ton Crude	Per ton Pellets or Concentrates
Mining	.70	2.10
Concentration and Pelletizing	2.10	6.30
Mine Office, Engineering and Laboratory	.16	.48
Social Security, Pensions, Insurance, etc.	.24	.72
	$3.20	$9.60
Stripping	.25	.75
Total direct production cost	$3.45	$10.35
Royalty		1.00
State Taxes		.60
Depreciation		1.10
Interest @8.7%		1.90
Total Production Cost		$14.95
Minus Stripping		.75
Total Production Cost minus Stripping		$14.20

1974 Average value of pellets at the plant	$16.65
Residual Cash flow with stripping	$ 1.70
Residual Cash flow without stripping	$ 2.45

The costs were calculated with the purpose of obtaining average costs, both direct and indirect, for mining, milling, and production of pellets for all taconite ore mined in 1974 on the Mesabi Range. The direct production costs are estimated to be $3.45 per ton of crude ore processed. The average concentration ratio for the Mesabi Range taconite ores was calculated to be 2.985 to 1 for 1974 and rounded to a 3 to 1 ratio. Assuming a 3 to 1 concentration ratio, the direction production costs would be $10.35 per ton of pellets.

Mining Costs - The average cost for mining taconite was calculated to be $0.95 per ton of crude ore produced on the Mesabi Range in 1974. The breakdown of costs per long ton of crude ore and the cost converted to pellets using a 3 to 1 concentration ratio is as follows:

	Crude Ore	Pellets
Drilling & blasting	.15	.45
Secondary breaking	.02	.06
Loading and hauling, etc.	.37	1.11
Stripping	.25	.75
Drainage, etc.	.01	.03
General mine expense	.15	.45
TOTAL	$0.95	$2.85

In the calculation of reserve tonnages all stripping charges were segregated and the money available to a no-profit, no-loss situation was allocated to stripping. These costs include the rock-in-ore as well as surface and rock stripping. If stripping is separated from other mine costs, the mine costs in 1974 would be $0.70 per ton of crude ore or $2.10 per ton of pellets.

Concentration and Pelletizing Costs - An average cost of $2.10 was calculated for crushing, grinding, concentrating, tailings disposal, and pelletizing per ton of crude taconite ore produced on the Mesabi Range in 1974. At a concentration ratio of 3 to 1, this will give a cost of $6.30 per ton of pellets produced. These costs include the following elements:

	Per Ton Crude Ore	Pellets
Labor	.40	1.20
Supplies	1.10	3.30
Power	.40	1.20
Laboratory	.04	.12
General and Supervision	.16	.48
ORE PROCESSING COSTS - TOTAL	$2.10	$6.30

Mine Office, Engineering and Laboratory - The overall district costs not a part of the operating mine and plant costs are included under this heading on Table 1. This would include some of the laboratory costs, research, purchasing, etc. for a total of 16 cents per ton of crude ore or 48 cents per ton of pellets.

Social Security, Insurance, Pensions - This cost center includes a group of costs that might be included with the mine office expense but it seemed advisable to show these as identifiable items. Also included are costs for vacations, group and general insurance, and other employment costs. These costs are estimated to be 24 cents per ton of crude ore or 72 cents per ton of pellets.

Stripping Costs - Stripping costs are determined by the nature of the rock or surface material, the availability and location of dump areas, lift and haul, drilling and blasting costs, slope stability, etc. These cost elements as averages for the Mesabi Range are difficult to calculate because the conditions vary.

The slope stability for rock stripping is assumed to be good for hanging wall rock and for taconite with an average ultimate pit wall slope of 57°.

Surface stripping is assumed to average 20 feet in thickness across the Range so is a minor factor in the stripping cost calculation at the ultimate pit limit. For purposes of the tonnage estimate, the surface materials were averaged into the overall stripping calculation without special recognition. This may introduce a small but uniform error. However, when the difference between a stable slope for surface material and for rock is considered, the error in determining the ultimate pit wall should be insignificant.

As a generalization, with time the pits will become deeper, lift and haul costs will increase and the quantities of stripping to be moved will increase. The average stripping costs will also increase. This assumption of a cost increase was recognized in the calculation of an average cost per ton of stripping to a no-loss cutoff.

The availability of dump areas may become of increasing importance as the volume of stripping increases. The possibility of dumping waste material in the mined areas of taconite pits should be considered. The possible use of the pits for rock dumps is complicated by the occurrence of Bottom Taconite Lean Ore and Bottom Iron-formation materials that contain about 30 percent iron. These materials may eventually be used as a source of iron ore but are currently uneconomic or not treatable. Developing concentration technology may make these materials into valuable ore. Many billions of tons of iron-bearing materials are in pit bottoms below commercial grade taconite ores. From a viewpoint of resource conservation, "bottom rock" that constitutes a source of iron ore should not be needlessly wasted by burial under rock stripping.

The average cost for the removal of all classes of stripping in 1974 for Mesabi taconite plants was 25 cents per ton of crude ore mined or 75 cents per ton of pellets. This probably represents a minimum cost figure as many of the mines are still in an early stage of development. Since some mines were started in 1956 and others are still mining top level cuts, the cost of stripping per cubic yard of material moved shows a wide range. An average cost of $1.20 per cubic yard of stripping moved was calculated for the 1974 mine operations. Since the reserve estimate being made requires projections of stripping to much greater depths with the strong likelihood of longer hauls, a cost of $1.40 per cubic yard for stripping (rock and surface combined) was used.

Based on the estimated production cost and value of taconite pellets in 1974, $2.45 was calculated to be available for use in stripping to a no-profit, no-loss ultimate pit limit, see Table 1. Since much of the rock to be removed will be iron-formation as rock-in-ore or as overlying iron-formation a factor of eleven cubic feet per metric ton was used in calculations to convert stripping to tons. As stated above, an average cost of $1.40 per cubic yard stripping was used. This was converted to cost per ton. The following calculations show the tons of stripping one ton taconite crude ore with a 3 to 1 concentration ratio can carry to a no-profit, no-loss cutoff:

$2.45 per ton of pellets ÷ 3 = $0.8166 per ton of crude ore

1 cubic yard = 27 cubic feet ÷ 11 cubic feet = 2.4545 tons

$1.40 ÷ 2.4545 = $0.5703 per ton stripping

0.8166 ÷ 5.5703 = 1.432 tons stripping per ton crude ore

Since the amount of stripping a ton of crude taconite ore can carry will vary with its quality, i.e., grade and concentration ratio, this fact must be recognized in the calculations. A study of the production costs indicate that the lowest grade magnetite taconite that is economically viable today must have a minimum 20 percent weight recovery. This material would be at zero profitability. The range in magnetite taconite quality, based on weight recovery, ranges from 20 to 45 percent weight recovery. Thus the range in stripping that can be carried per ton of taconite crude ore will range from 0 at 20 percent weight recovery to a maximum at 45 percent weight recovery. The assumption is made that the rate of change in the stripping factor per ton of crude ore related to weight recovery is constant and will be $1.432 at 33.3% weight recovery. Table II shows the tons of stripping that can be carried per ton of crude magnetite ore for each one percent change in weight recovery. This change is from 0.108 tons at 21 percent weight recovery to 2.70 tons of stripping per ton of crude ore at 45 percent weight recovery.

Siliceous taconite crude ore yields a lower quality pellet unless additional process steps and costs are added to improve the pellet quality such as flotation of the concentrates, regrinding and magnetic separation, fine screening, etc. If the additional steps are not used, a lower quality pellet will be produced which will have a lower value than the pellets produced from magnetite taconite ore. As an example, the value of taconite pellets produced on the Mesabi Range in 1974 shows an average mine value for pellets with about 65.0% Fe and a 5.5% SiO_2 of about $22.50 per long ton whereas pellets with about 62.0% Fe and 9.0% SiO_2 had a mine value of about $21.10 per long ton. In addition, the siliceous taconite is more difficult to drill, blast, grind, and to concentrate so added costs in mining are anticipated. The combination of lower potential value of the pellets and higher production costs require an adjustment in the stripping factor per ton of crude ore. The difference used in this study is 15 percent so one ton of siliceous taconite ore will carry 85 percent as much stripping as a ton of magnetite taconite ore with a comparable weight recovery. The stripping factors for siliceous ore are shown on Table II.

Table II - Rock Stripping Tonnages that can be carried by various grades of Magnetite Taconite Ores and Siliceous Magnetite Taconite Ore.

Taconite Ore and Lean Ore		Siliceous Taconite Ore and Lean Ore
% Weight Recovery	Tons Shipping	Tons Shipping
20	0.00	0.00
21	.108	.091
22	.215	.182
23	.323	.273
24	.431	.364
25	.538	.456
26	.646	.547
27	.754	.638
28	.862	.730
29	.969	.820
30	1.080	.912
31	1.185	1.003
32	1.292	1.094
33	1.400	1.186
33.3	1.432	1.213
34	1.508	1.277
35	1.615	1.366
36	1.723	1.457
37	1.831	1.548
38	1.939	1.640
39	2.046	1.731
40	2.154	1.825
41	2.262	1.919
42	2.376	2.013
43	2.476	2.098
44	2.584	2.189
45	2.700	2.280

The potential for error in the calculation of the amounts of stripping that can be carried per ton of taconite crude ore reserve is recognized. The correlation of stripping volume to weight recovery as a measure of ore quality and value seemed a practical approach. The importance of grindability, distance from processing plants, lift and haul, locations of dump areas, etc., as factors in determining value of crude ore are well known but are too variable to be reasonably included in a generalized study of the scope undertaken.

Indirect Costs - Royalty, State Taxes, Depreciation, and Interest on Invested Capital - The indirect costs include an important part of the costs for taconite production. Each item will be considered and the amount used in the study explained.

The royalty costs are known to be variable. Limited information is available on specific royalty agreements. The one dollar amount used is considered a reasonable average figure but does not represent a calculated average.

An attempt was made to obtain an average cost for state taxes for 1974 and the sixty cents used seemed to be an acceptable average. Tax costs have materially increased since 1974 and could modify the monies available for stripping. This could change the reserve tonnages available as the quantity of stripping limits the mineable tonnages.

Depreciation was calculated using an average capital investment for Mesabi taconite plants of $22.00 per annual ton of capacity and an interest rate of 8.7 percent. This gives a cost of $1.914 which is rounded to $1.90. The average capital cost of $22.00 can be debated and was difficult to determine. The actual capital cost of construction has varied markedly. The Reserve and Erie plants were in part completed in 1956 and expansions completed at later dates. With inflation and a general increase in construction costs and the partial depreciation of plants through time, the average Mesabi Range capital investment costs are difficult to calculate. The annual $1.90 cost per ton of pellets used in the study seems reasonable although a capital investment cost of $50.00 per annual ton of capacity was reported by E. Leach, Vice President of the Bethlehem Steel Corporation in 1975 for new construction. The 8.7 percent interest rate used represents a rate between the cost for AAA bonds and secure industrial loans in 1974.

The taconite pellet production cost of $14.95 per ton shown on Table I, with an average selling price at the plant of $16.65 gives $1.70 per ton of pellets available for stripping. Since the cost of production includes $0.75 for stripping as a normal mining cost item for 1974 pellet production, this cost was deducted to permit all stripping costs to be handled as a single cost element. Thus, $2.45 was applied to stripping to determine the available tonnages of the various classes of taconite ore with a stripping limit drawn at a no-loss cutoff.

DETERMINATION OF OXIBIF RESERVES

The reserve tonnages of OXIBIF ore reported in this study are based on limited laboratory test results on the concentrateability of oxidized Biwabik iron-formation. Available concentration tests on OXIBIF suggest that cherty materials may be concentrateable by a reduction roast followed by magnetic separation or by a selective flocculation-flotation system similar to the one used at the Tilden plant in Michigan. Slaty units of the Biwabik commonly give poor test results. Results from general tests using a magnetizing roast followed by magnetic separation are reported to be encouraging. No detailed results using selective flocculation-flotation are available. The quality of OXIBIF as shown by iron content and texture varies considerably and the limits of potentially useable material are not known. In this study, oxidized, cherty, Biwabik iron-formation that, where unoxidized, would be expected to be magnetite taconite ore or lean ore is included in the estimated OXIBIF reserves. Since oxidized iron-formation similar to the oxidized Biwabik iron-formation is being commercially concentrated in Michigan, it seems reasonable to include a reserve tonnage of OXIBIF in the estimated iron ore reserves of the Mesabi Range.

Ultimate Pit Wall Slope

An average 57° final pit wall slope was used in the calculation of ore reserves for this study. This slope is used as it will permit the consolidation of two 40 foot mine benches into one bench 80 feet high and allow a 40 foot berm. The bench face is not expected to be vertical. Experienced operators on the Mesabi Range agree that the ultimate pit wall for taconite mines will be held at the maximum safe and stable slope. Since the general regional dip is into the pit high wall and the Biwabik and Virginia formations are competent rocks, it is expected that a 57 degree average slope will give a stable pit face. The surface glacial material will have a lower stable slope but with only an assumed average thickness of 20 feet, the surface materials do not materially influence the average pit wall slope.

Environmental Problems

The entire length of the Mesabi Range has long been recognized as a mining area. Open pit mines exist as a semi-continuous series of pits from the Dunka mine in Section 26, T61N, R12W, for about 90 miles along the iron-formation to the Lind-Greenway mine at the Prairie River in Section 3, T55N, R25W. The extension of the range beyond the Lind-Greenway mine for another six miles is well known to the Tioga No. 1 Reserve in Section 34, T55N, R26W. Even though this is an old, well established mining district, many environmental problems will be encountered before all of the estimated iron ore reserves are mined. The ore areas are crossed by streams, roads, power lines and railroads. Lakes are present. People have built homes and towns and villages on potential iron ores that are included in the estimated tonnages. Currently the possibility of moving the City of Biwabik is being discussed. Eventually consideration may be given to mining in the villages of McKinley and Parkville. Ely Lake, Deep Lake and Embarrass Lake all encumber potential taconite ores. Also, there are the usual problems related to mining; the need for dumps, disruption of the surface, noise, blast vibrations, dust and the use of water. However, as a result of the long mining history there are extensive unencumbered areas and a common recognition by the local people of the nature of the mining industry.

Explanation of Mesabi Reserve Calculations

The guidelines for determination of the estimated iron ore reserves of the Mesabi Range were established early in the study so the same criteria would be used during the project. Separate guidelines were used for magnetite taconite ores, OXIBIF and for Natural Ores.

Natural Ores - Natural iron ore reserve tonnages, which includes ores that require beneficiation by rather simple methods such as crushing, screening, washing, heavy media, spirals, etc. were determined from the records of the Ore Estimation Division of the State of Minnesota. Data from the estimates of iron ore reserves, prepared for tax purposes, were assembled to fit the Minerals Availability System. This required averaging and consolidation of ore tonnages and grades, in some cases, but no other calculations were necessary. These data were assembled in 1977 and represent reserve tonnages for the latest review of each iron ore deposit. The 1976 ore production has been removed. The reserve tonnages represent engineered estimates based on available information and are reported for each mine unit containing reserves greater than 500,000 long tons.

Magnetite Taconite - Magnetite taconite reserves were estimated for each of the 14 land survey ranges along the Mesabi which includes ranges 12W through 25W. Early in the evaluation of problems related to the preparation of an estimate of the taconite reserves of the Mesabi Range, it was evident that there should be a division of the area into manageable units. The use of the established land survey, six mile range units seemed reasonable and workable (see Figure 1). This has been found to be a satisfactory segmentation during the study. Only one modification of this range unit system reporting was made. A change was made to include the taconite ore reserves in range 18 near Eveleth that are in the western part of the proposed pit and will be mined with range 17 ores.

As a working procedure, geological cross sections were prepared at three mile intervals. This results in two cross sections in each range unit, one and a half miles from the east and west sides. Additional special sections were made in areas of complex geology and where the geological structure lengthened the strike or changed the strike direction of the iron-formation materially as in ranges 12 and 17. Geological data and taconite character information in the three mile units were averaged to give an average condition cross section for each three miles. Preparing the average condition cross sections required a careful evaluation of available information and a judgement of what the average geological and the character factors are. This often required a considerable projection of information to give the probable conditions near and beyond the ultimate pit limit.

Determination of the ultimate pit limit for each average condition cross section is critical to the total reserve tonnage calculation. The ultimate pit limit was determined as the break-even production situation with all available funds beyond production costs used for stripping. The calculation of the average stripping costs are described in a previous section of the report. The assumption was made that there is an average of 20 feet of glacial surface material along the Mesabi Range and that all rock waste has the same costs for removal whether rock-in-ore, iron-formation or Virginia formation. These general assumptions do not influence the estimate except at the cutoff point which is the ultimate pit limit. At the taconite reserve limit, the quantity of stripping was determined using the thickness and grade of magnetite taconite present and applying the proper stripping factor for each ore unit to find how much material could be removed. This amount was plotted on the cross section and the reserve tonnages for each ore class calculated. A factor of 11 cubic feet per metric ton was used for both taconite ore and for waste rock. This is equivalent to 11.2 cubic feet per long ton. A variable factor could have been used, but when the uncertainties concerning the amount of hanging wall iron-formation vs Virginia formation is introduced in preparing the average condition sections and in the projection of these data for three miles are considered, the use of a conservative tonnage factor for waste rock seemed justified. A large portion of the rock stripping will be Biwabik iron-formation.

Separate taconite ore reserve tonnage estimates were made for each taconite ore class and for various grades of ore within a class where a recognition of grade differences seemed justified. The taconite ores were grouped into probabilistic grade-quantity matrix units as required by the Minerals Availability System. These units are also considered to represent a reliability or probability rating for the estimate. In order to give a uniformity of probabilistic grouping, all taconite ore with a 1 to 1 or smaller ratio of crude ore to waste material was grouped at the 90 percent probabilistic grade. Taconite ores with greater than a 1 to 1 ratio of crude ore to waste was given a 75 percent probabilistic grade except for one area where the available information was very limited and a 50 percent probabilistic grade was used.

As previously mentioned in this report, calculation of the siliceous magnetite taconite ore reserve tonnages recognizes the relatively high silica content of the iron ore concentrates obtained by the laboratory tests. A deduction of 2 percent was made from the averaged weight recovery for siliceous ores. The 2 percent deduction is to allow for losses in weight recovery that should occur as a result (1) of a finer grind before magnetic separation needed to give a better liberation, or (2) from fine screening, or, (3) possibly from flotation of the concentrates to remove some of the silica. This deduction may or may not be adequate but serves to indicate an area of concern regarding the estimate of siliceous taconite reserves.

Deductions from the taconite ore reserve were made for oxidized iron-formation areas and for natural iron ores. As a general procedure, the areas of ore and oxidation were determined and a calculation made of the likely tonnages of these materials included in the taconite ore units. This tonnage was then deducted. In some areas, data are too limited to permit the calculation of tonnages by areas, here a percentage of the estimated taconite tonnage was removed from the taconite ore reserve to recognize the likely amount of oxidized material. In arriving at the percentage to be deducted, all available data were reviewed and the situation discussed with people most knowledgeable regarding the area and a percentage figure selected.

<u>OXIBIF</u> - The oxidized iron-formation in the magnetite taconite ore and lean ore zones and oxidized cherty Biwabik in the western part of the Mesabi Range were included in the estimate as tonnages of OXIBIF. As previously discussed, the assumption is made that where the Biwabik iron-formation classed as taconite ore or lean ore is oxidized the resulting hematitic and goethitic material will be concentrateable by reduction roasting and magnetic separation or by the selective floculation-flotation system. This assumption is supported by reduction roast test work done on Mesabi Range oxidized cherty iron-formation. As previously explained, in order to keep this possible ore quality material separate in a recog-

nizable group, it is termed OXIBIF in this study. The crude OXIBIF ore has a wide range of head iron, mineralogy, texture and, very likely, in the ease of concentration. In order to realistically recognize the uncertainty of the process technology and economics of production, all OXIBIF reserves are given a 25 percent probabilistic grade. In ranges 16 through 22, the OXIBIF tonnages are mainly calculated as a deduction from the magnetite taconite tonnages. West of the Calumet fault in ranges 23, 24 and 25, the OXIBIF is calculated for zones classed as cherty by Gruner and White supplemented by limited company information. In the range 23 to 25 area, the OXIBIF tonnages included in the ore reserve estimate are limited to the outcrop area of the Biwabik formation. No projection of potentially useable material beneath the Virginia formation is made so the stripping to ore ratio will be low. No calculation of a stripping to crude ore ratio was used in determining the ultimate pit limit which from range 23 through 25 coincides with the Virginia-Biwabik contact.

ESTIMATE OF MESABI RANGE IRON ORE RESERVES

Iron ore reserves of the Mesabi Range for all classes, grades and probability ratings are estimated to total 47,524,692,000 metric tons. The production of the estimated iron ore reserves will require mining of a major part of the exposed Biwabik formation and the stripping of adjacent areas underlain by the Virginia formation to the ultimate pit limit proposed. Mining of the total reserves will result in the disruption of the surface of considerable areas along the Mesabi Range and the use of significant areas for mine dumps and tailings basins. However, when the importance of the Mesabi Range iron ores is viewed from a national perspective, the location of a major iron ore reserve in a restricted area could represent a minimum impact situation. The occurrence of Mesabi Range iron ore reserves in a specific belt will permit planning to be done to determine the best configuration of the land surface and the best land use situation at the end of the open pit phase of the mining history.

There is a strong likelihood that important tonnages of the Biwabik formation now considered to be iron resources could become iron ore reserves before the currently estimated iron ore reserves are mined. The proposed mine pits can be expanded beyond the limits set by this study if production economics warrant higher stripping ratios, or if advances in process technology allows the mining of materials not included in the estimate. Mining of the estimated iron ore reserves should not result in the termination of iron ore production on the Mesabi Range for reasons listed above and as the underground mining of taconite ores may become feasible.

The iron ore reserves of the Mesabi Range are grouped, for this study, into seven major classes with magnetite taconites and OXIBIF ores containing the largest tonnages. The following summary tabulation by major classes gives the estimated crude ore reserves reported to the Minerals Availability System.

	Metric Tons
Magnetite Taconite Ore	27,108,329,000
Siliceous Magnetite Taconite Ore	4,385,870,000
Magnetite Taconite Lean Ore	2,064,552,000
Magnetite Taconite Bottom Lean Ore	2,079,795,000
Siliceous Magnetite Taconite Lean Ore	50,075,000
OXIBIF (Oxidized banded iron formation)	11,676,000,000
Natural Iron Ore (Mines with plus 500,000 ton reserves)	160,071,000
	47,524,692,000

Data concerning the estimated iron ore reserve for each ore class is summarized and tabulated in the following sections of the report.

MAGNETITE TACONITE ORE RESERVES

Magnetite taconite ore reserves extend from the east end of the Mesabi Range in Range 21 westward to the Calumet fault in Range 23. There are many structural, stratigraphic, lithologic and metamorphic changes along this approximate 80 mile strike length of the Biwabik formation. Changes in the Biwabik formation determine the character of the magnetite taconite, thickness of potential ore zones and influence its mineability, grindability and concentrateability.

The preparation of the magnetite taconite reserve estimate required an interpretation of the geology, which includes detailed stratigraphy, structure, oxidation patterns, facies and metamorphic changes, to give a basis for the projection of mineable magnetite taconite zones along the Mesabi Range and to depths beyond the indicated open pit limits. The evaluations and judgements made are supported in varying degrees by field and laboratory data.

Commonly two or more ore grades based on the weight recovery yield of laboratory magnetic separations on drill core samples are reported for each 6 mile range unit. Often there are different ore grades within a 3 mile unit that were consolidated into the range unit tonnages reported. Grades indicated as separate tonnages either represent important grade differences or represent separate stratigraphic ore zones. If all observed differences are averaged to give one grade and tonnage for a range unit, the estimate would fail to give a realistic picture of the magnetite taconite ore occurrence. There has been considerable simplification and averaging done to consolidate the test information as reported.

Table III gives the estimated tonnages of magnetite taconite ore for the Mesabi Range presented by range units, weight recovery, and probabilistic grade. This estimate identifies a total of 27,108,329,000 metric tons of magnetite taconite ore. This tonnage includes 18,697,337,000 tons with a 90 percent probabilistic grade, 7,706,992,000 tons with a 75 percent probabilistic grade and 704,000,000 tons with a 50 percent probabilistic grade. All tonnages are considered to be potentially mineable by open pit methods.

TABLE III. ESTIMATED MESABI RANGE MAGNETITE TACONITE RESERVES
(Metric Tons)

Range	Weight Recovery	90% Probability	75% Probability	50% Probability	Total
12	38.0	465,764,000	128,436,000	---	594,200,000
	36.0	76,671,000	55,731,000	---	132,402,000
	Total	542,435,000	184,167,000		726,602,000
13	37.0	1,874,800,000	510,790,000	---	2,385,590,000
14	45.0	16,690,000	49,090,000	---	65,780,000
	40.8	51,630,000	859,155,000	---	910,785,000
	38.0	687,535,000	467,730,000	---	1,155,265,000
	34.5	370,485,000	182,415,000	---	552,900,000
	32.0	863,930,000	---	---	863,930,000
	29.9	79,630,000	4,080,000	---	83,710,000
	Total	2,069,900,000	1,562,470,000		3,632,370,000
15	34.0	126,360,000	190,355,000	---	316,715,000
16	34.2	213,945,000	1,064,590,000	---	1,278,535,000
	31.9	208,140,000	81,795,000	---	289,935,000
	30.0	277,150,000	157,860,000	---	435,010,000
	Total	699,235,000	1,304,245,000		2,003,480,000
17	35.0	762,700,000	428,400,000	---	1,191,100,000
	33.5	1,760,380,000	132,980,000	---	1,893,360,000
	32.0	1,895,555,000	798,870,000	---	2,694,425,000
	30.0	1,144,685,000	414,620,000	---	1,559,305,000
	25.5	210,480,000	28,910,000	---	239,390,000
	Total	5,773,800,000	1,803,780,000		7,577,580,000
18	32.3	2,433,410,000	523,575,000	---	2,956,985,000
	30.0	656,465,000	218,820,000	---	875,285,000
	28.7	503,380,000	167,795,000	---	671,175,000
	27.2	225,335,000	75,110,000	---	300,445,000
	Total	3,818,590,000	985,300,000		4,803,890,000
19	29.0	732,737,000	244,245,000	---	976,982,000
20	29.0	263,170,000	130,000,000	---	393,170,000
	27.5	---	36,000,000	---	36,000,000
	Total	263,170,000	166,000,000		429,170,000
21	29.2	1,079,820,000	183,340,000	---	1,263,160,000
22	29.5	1,278,900,000	426,300,000	---	1,705,200,000
	27.0	---	---	704,000,000	704,000,000
	Total	1,278,900,000	426,300,000	704,000,000	2,409,200,000
23	32.0	437,590,000	146,000,000	---	583,590,000
	TOTAL	18,697,337,000	7,706,992,000	704,000,000	27,108,329,000

MAGNETITE TACONITE LEAN ORE RESERVES

Magnetite taconite lean ore zones are interbedded with the magnetite taconite ores in ranges 16, 17, 18, 19, 20, and 21 with a total of 2,064,552,000 metric tons estimated to occur in these areas as shown on Table IV. About 73 percent, 1,510,065,000 tons of the total quantity of lean ore is estimated to occur in range 18. The lean ore estimated includes about 1,412,090,000 tons with a 90 percent probabilistic grade, 576,307,000 with a 75 percent probabilistic grade and 76,155,000 with a 50 percent probabilistic grade.

MAGNETITE TACONITE BOTTOM LEAN ORE RESERVES

A zone of magnetite taconite lean ore that contains from 20 to 25 percent recoverable magnetite is estimated to occur in the central part of the Mesabi Range in ranges 17, 18, 19, 20 and 21. Since this material occurs in the bottom of the proposed pits below ore grade taconite, the mining and processing of this material will depend on the economics of each mine when this material becomes available. The lean ore could be left in the mine and removed at a later time if a more favorable economic picture develops.

A total of 2,079,795,000 metric tons of bottom lean ore is estimated, see Table V. This tonnage includes 1,829,000,000 tons with a 90 percent probabilistic grade and 250,795,000 tons at a 75 percent probabilistic grade.

TABLE IV. ESTIMATED MESABI RANGE MAGNETITE TACONITE LEAN ORE RESERVES
(Metric Tons)

Range	Weight Recovery	90% Probability	75% Probability	50% Probability	Total
16	21.6	135,115,000	68,360,000	---	203,475,000
17	22.0	225,110,000	34,690,000	---	259,800,000
18	22.5	1,051,865,000	458,200,000	---	1,510,065,000
19	22.0	---	15,057,000	---	15,057,000
20	22.0	---	---	63,200,000	63,200,000
21	22.0	---	---	12,955,000	12,955,000
	TOTAL	1,412,090,000	576,307,000	76,155,000	2,064,552,000

TABLE V. ESTIMATED MESABI RANGE BOTTOM MAGNETITE TACONITE LEAN ORE RESERVES
(Metric Tons)

Range	Weight Recovery	90% Probability	75% Probability	Total
17	22.0	93,260,000	31,090,000	124,350,000
18	22.0	1,193,000,000	95,735,000	1,288,735,000
19	21.0	229,165,000	76,385,000	305,550,000
20	22.0	---	13,500,000	13,500,000
21	21.8	313,575,000	34,085,000	347,660,000
	TOTAL	1,829,000,000	250,795,000	2,079,795,000

SILICEOUS MAGNETITE TACONITE ORE
and
SILICEOUS MAGNETITE TACONITE LEAN ORE RESERVES

Siliceous magnetite taconite ores occur on the eastern end of the Mesabi Range in ranges 12, 13 and 14 where the Biwabik formation has been metamorphosed to the amphibole grade. Large siliceous magnetite taconite ore zones occur with the magnetite taconite ore in this area. Only minor amounts of siliceous magnetite taconite lean ores are present. These siliceous taconite ores yield a high silica concentrate by the usual laboratory tests and will require either the acceptance of a high silica pellet, or mixing with good quality magnetite taconite ore, or additional grinding and processing if or when produced. A total of 4,385,870,000 metric tons of siliceous magnetite taconite ore and 50,075,000 metric tons of siliceous lean ore are estimated to occur as shown on Table VI. The siliceous ores include about 3,354,795,000 metric tons of material with a 90 percent probabilistic grade and 1,031,075,000 tons with a 75 percent probabilistic grade.

Siliceous magnetite taconite lean ore is estimated as a zone 40 feet in thickness interbedded with magnetite taconite and siliceous magnetite taconite ores in range 14. The estimated zone is a tabular body with up-dip and down-dip transitions into siliceous taconite ore. This small tonnage is included in the estimated ore to emphasize the limited occurrence of siliceous magnetite taconite lean ore. All siliceous lean ore is given a 90 percent probabilistic grade.

TABLE VI. ESTIMATED MESABI RANGE SILICEOUS MAGNETITE TACONITE ORE RESERVES
Metric Tons

Range	Weight Recovery	90% Probability	75% Probability	Total
12	34.2	308,670,000	68,800,000	377,470,000
13	35.0	267,020,000	151,680,000	418,700,000
	32.0	901,960,000	158,270,000	1,060,230,000
	Total	1,168,980,000	309,950,000	1,478,930,000
14	38.0	309,220,000	196,950,000	506,170,000
	34.0	311,680,000	110,440,000	422,120,000
	31.5	637,550,000	269,310,000	906,860,000
	30.0	130,540,000	30,250,000	160,790,000
	26.6	488,155,000	45,375,000	533,530,000
	Total	1,877,145,000	652,325,000	2,529,470,000
TOTAL		3,354,795,000	1,031,075,000	4,385,870,000

AVERAGE WEIGHT RECOVERY - 36.0%

ESTIMATED MESABI RANGE SILICEOUS MAGNETITE TACONITE LEAN ORE RESERVES
Metric Tons

Range	Weight Recovery	90% Probability	75% Probability	Total
14	22.0	50,075,000	___	50,075,000

ESTIMATED OXIBIF RESERVES

Potentially important amounts of OXIBIF are present in areas of oxidized Biwabik formation from range 15 westward to range 25 near Grand Rapids, Minnesota. The OXIBIF tonnages are included as a single class of material at a 25 percent probabilistic grade. Because of the common variation in iron content which ranges from 20 to 40 percent Fe and the considerable stratigraphic thickness represented, it is evident that lumping large tonnages of oxidized cherty materials as potential OXIBIF ore requires a full appreciation of the significance of the single grade. The strong possibility exists that considerable tonnages included in the estimate will be shown by testing not to be concentrateable or to be uneconomic and should actually be considered iron resources. The occurrence of the estimated quantities of OXIBIF is not in question but the concentrateability of the material and its economic viability are uncertain. A total of 11,676,000,000 metric tons of OXIBIF are estimated to occur on the Mesabi Range as shown on Table VII. Large amounts occur in ranges 17, 22, 23, 24 and 25.

TABLE VII. ESTIMATED MESABI RANGE OXIBIF RESERVES
Metric Tons

Range	25% Probability
15	65,000,000
16	516,670,000
17	1,646,000,000
18	568,910,000
19	396,730,000
20	378,500,000
21	266,270,000
22	2,064,000,000
23	1,581,000,000
24	2,060,780,000
25	2,132,140,000
TOTAL	11,676,000,000

3,571,810,000

8,104,190,000

3 571 810 000
8 104 190 000

88,757,000 1/3
2,064,000,000 all
527,000,000 2/3
Area I → 2,679,757,000

1,054,000,000
2,060,780,000 all
Area II → 3,114,780,000

III → 1,066,070,000 1/2

Area I 2.68 b MT .2
II 3.11 .75
III 1.07 .5
6.86 bMT Marsden figures modified

167,514,000 2/3 R 21
+ 1,066,070,000 1/2 R 25
1,233,584,000
+ 6.86
8.09
≅ 8.1 BMT check R. 21→25 Total

427-9721 Ext. 48

ESTIMATED NATURAL IRON ORE RESERVES OF THE MESABI RANGE, 1977

The natural iron ores of the Mesabi Range that are recognized by the Office of Ore Estimation of the State of Minnesota as identified reserves in January, 1977, have been tabulated for the Minerals Availability System for mines or mine groups with reserves of plus 475,000 long tons. Data from the Office of Ore Estimation has been adapted to the Minerals Availability System to show the estimated average grade of the material included as ore reserves. There is a considerable range in availability of these ores for production and in the processing required to obtain the ore. A substantial tonnage is not easily available and there is a strong likelihood that they cannot be mined economically by open pit methods as the reserves are under thick overburden or are in pit walls and pit bottoms in situations that give a very large stripping ratio. Table VIII gives a tabulation of the natural ore reserves in plus 475,000 long tons deposits showing ore grades and tonnages grouped by range unit. A total of 160,071,000 long tons of Natural Iron Ore are estimated to occur in the 80 deposits listed. Table IX shows a summary tabulation of the reserves listed in Table VIII for each range unit.

TABLE VIII. ESTIMATED RESERVES OF MESABI RANGE NATURAL ORE IN DEPOSITS WITH PLUS 475,000 TONS BY MINES AND RANGE UNIT[1]

Range	Mine	Ore Grade	Reserves
15	Donora	51.33	10,409,000
	Embarrass #2	52.01	1,762,000
	Meadow Reserve	51.92	1,134,000
	0-47 Reserve	52.34	1,297,000
	Stephens, Perkins, Perkins Annex	51.16	1,855,000
	U.S.S. Reserve #40	50.74	1,866,000
Total			18,323,000
16	Bangor, 043 Reserve, Ray	52.91	5,006,000
	Corsica	53.45	485,000
	J&L #45 (Welton)	54.26	1,038,000
	J&L #47 Reserve	50.27	1,714,000
	McKinley	54.74	2,470,000
Total			10,713,000
17	Auburn, Great Western	54.02	3,945,000
	Cloquet & Annex	49.40	1,346,000
	Rouchleau & Annex	54.15	1,073,000
	Security	58.07	581,000
Total			6,945,000
18	Brunt	51.12	1,725,000
Total			1,725,000
19	Budd Reserve	47.10	1,430,000
	Dean, Itasca	51.62	751,000
	Iron Chief Reserve	53.85	910,000
	Midway #2	53.72	1,855,000
	Sharon	53.20	477,000
	Wabigon 1 & 2	52.29	885,000
Total			6,308,000

TABLE VIII. (continued)

Range	Mine	Ore Grade	Reserves
29	Agnew #3	52.82	10,038,000
	Albany	52.59	520,000
	Billings	52.06	2,224,000
	Bruce & Annex	59.86	3,692,000
	Chester	52.31	2,672,000
	Day Reserve	53.46	1,145,000
	Douglas	48.89	580,000
	Dunwoody	51.68	754,000
	East Fraser-Burt	52.38	1,666,000
	Forester-Burt, Forester	52.70	2,299,000
	Fraser	52.54	1,282,000
	Godfrey, Leonard	52.01	5,635,000
	Hartley-Burt	49.93	822,000
	Lenont Reserve	47.17	1,188,000
	Nassau	49.85	862,000
	Niles	--	4,971,000
	Neville & N. Reserve	49.81	751,000
	0-90 Reserve	50.58	1,830,000
	St. Anthony #2	46.46	535,000
	Shenango & S. Reserve	52.88	1,866,000
	Sherman	52.52	2,657,000
	S. Myers, N. & S. Twin Cities	54.10	2,579,000
	S. Tenor	52.79	677,000
	Webb	54.50	621,000
	Whitney	50.52	7,492,000
Total			59,358,000
21	Carlz #1	49.99	1,325,000
	Campbell A & B Reserve	51.86	4,041,000
	Carmi	50.90	840,000
	Carson Lake Reserve	51.56	1,309,000
	Gray Reserve	48.13	837,000
	Niagara #1	54.00	748,000
	N. Eddy, Agnew, S. Agnew	51.13	723,000
	Pierce Group	51.93	1,721,000
Total			11,544,000
22	Carol	51.27	1,510,000
	Gordon & Perry	52.44	554,000
	Harrison	54.28	545,000
	Larue, Shada	52.47	1,991,000
	Mississippi #2	56.64	1,384,000
	Sargent	52.63	665,000
Total			6,649,000

TABLE VIII. (continued)

Range	Mine	Ore Grade	Reserves
23	Arcturus	54.64	4,945,000
	Deleware #2	54.43	2,346,000
	Hill Annex	54.91	2,261,000
	Patrick & P. Annex	54.66	627,000
Total			10,179,000
24	Brown 1, 2, N. Star, Holman Cliffs	55.87	762,000
	Canisteo, Danube	55.16	2,539,000
	Homestead	51.44	1,784,000
	Lorain	50.36	724,000
	Orwell	55.17	606,000
	West Diamond	54.46	2,488,000
Total			8,903,000
25	Bovey-DeLaittre	53.74	1,048,000
	Fargo Reserve	53.36	2,334,000
	Jennison & Buckeye	52.29	2,086,000
	Lind-Greenway	54.95	3,213,000
Total			8,681,000
26	Jordan Reserve	51.98	1,377,000
	Marr Reserve	54.00	844,000
	Pokegama Reserve	52.21	1,124,000
	Tioga #1	56.83	6,037,000
	Tioga #2	55.04	1,353,000
Total			10,735,000
Total mines with plus 475,000 long tons of reserves			160,063,000

(1) Data from the Office of Ore Estimation, State of Minnesota

TABLE IX. SUMMARY OF ESTIMATED NATURAL IRON ORE RESERVES IN PLUS 475,000 LONG TON DEPOSITS BY RANGE UNITS(1)

Range Unit	Reserves
12	---
13	---
14	---
15	18,323,000
16	10,713,000
17	6,945,000
18	1,725,000
19	6,308,000
20	59,358,000
21	11,544,000
22	6,649,000
23	10,179,000
24	8,903,000
25	8,681,000
26	10,743,000
TOTAL	160,071,000

(1) Data from Office of Ore Estimation, State of Minnesota

SUMMARY TABULATION OF THE IRON ORE RESERVES OF THE MESABI RANGE

The iron ore reserves estimated to occur on the Mesabi Range are tabulated by ore class and by range unit on Table X. This listing of reserve tonnages does not give the grades of the material in the various classes or the probabilistic grade matrix but shows the general distribution of materials considered to be ore in this study. The estimated tonnages of taconite ores are based on an estimate of the 1974 production costs and represents ores available in 1975. As described in the report, the reserve estimate is designed to include all taconite materials that can be produced to a no-loss stiuation. The tabulated reserves should include material that does not have sufficient profitability to be economic at this time.

There are marked differences in the amounts of potential ore material in the range units along the Mesabi Range with relatively small reserves in ranges 15 and 20 and large reserves in ranges 14, 17, 18 and 22. The siliceous magnetite taconite ores are restricted to ranges 12, 13 and 14 and the lean magnetite taconite ores are found in the Central Mesabi in ranges 16, 17, 18, 19, 20 and 21. The largest tonnage group, magnetite taconite ore is also the group with the greatest economic potential based on current mining practice on the Mesabi Range.

Range	Taconite Ore	Taconite Lean Ore	Taconite Bottom Lean Ore	Siliceous Taconite Ore	Siliceous Taconite Lean Ore	OXIBIF	Natural Ore Mines Plus 475,000 Tons	Total
12	726,602,000			377,470,000				1,104,072,000
13	2,385,590,000			1,478,930,000				3,864,520,000
14	3,632,370,000			2,529,470,000	50,075,000			6,211,915,000
15	316,715,000					65,000,000	18,323,000	400,038,000
16	2,003,480,000	203,475,000				516,670,000	10,713,000	2,734,338,000
17	7,577,580,000	259,800,000	124,350,000			1,646,000,000	6,945,000	9,614,675,000
18	4,803,890,000	1,510,065,000	1,288,735,000			568,910,000	1,725,000	8,173,325,000
19	976,982,000	15,057,000	305,550,000			396,730,000	6,308,000	1,700,627,000
20	429,170,000	63,200,000	13,500,000			378,500,000	59,358,000	943,728,000
21	1,263,160,000	12,955,000	347,660,000			266,270,000	11,544,000	1,901,589,000
22	2,409,200,000					2,064,000,000	6,649,000	4,479,849,000
23	583,590,000					1,581,000,000	10,179,000	2,174,769,000
24						2,060,780,000	8,903,000	2,069,683,000
25						2,132,140,000	8,681,000	2,140,821,000
26							10,743,000	10,743,000
TOTAL	27,108,329,000	2,064,552,000	2,079,795,000	4,385,870,000	50,075,000	11,676,000,000	160,071,000	47,524,692,000

TABLE X. SUMMARY OF MESABI RANGE IRON ORE RESERVES SHOWN BY ORE CLASS AND RANGE UNIT